Redirecting wind energy in India

Accelerating the wind capacity deployment is a crucial element of India's energy transition story.

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About

This report discusses the role of wind in India's energy landscape in 2030 and beyond. It highlights key development in the wind sector and their implications for the sector's growth. The report examines the complementarity of wind and solar in India, demonstrating how their diurnal and seasonal patterns can work together to create a more balanced and reliable renewable energy grid. It also addresses how overcoming current challenges in wind energy could unlock further potential for India's energy transition. Additionally, this report provides data-driven insights on how increasing wind capacity can help reduce reliance on costlier energy storage solutions or thermal generation, ensuring non-fossil fuel electricity supply during non-solar hours.

Highlights

80%

India's non-solar electricity demand being met by thermal power

14.5%

Highest share on wind in India's power grid in non-solar hours, if 2022 wind targets were met

100 GW

Projected contracted wind capacity of 21 Indian states by 2030

Executive Summary

Catching the wind: boosting capacity benefits India on multiple fronts

Ramping up year-on-year wind installations by 22%, will not only help India meet NEP14 targets, but also help leverage its complementarity with solar to supply the demand during non-solar hours, potentially reducing the balancing needs through storage.

India's power sector is witnessing a significant transformation, driven largely by the rapid expansion of solar power installations. Between 2014 and 2024, solar capacity grew multifold and is increasingly catering to daytime electricity demand. However, during non-solar hours, the supply of green electricity drops significantly and thermal resources continue to fill the gap.

While India is pushing for energy storage capacity deployments to address this issue, finding alternatives is critical to maintain the momentum of India's energy transition. In this context, ramping up wind offers strategic advantages especially because of its diurnal, seasonal and spatial complementarity with solar power. In recent years, the impact of this complementarity is also being observed in the number of wind-solar hybrid tenders and the tariff discoveries.

01 Solar spree boosted India's daytime grid share, but thermal still caters to 80% of demand in non-solar hours

In 2023, the share of wind and solar in India's power grid on average was 19% during daytime whereas the share of thermal power stood at 71%. However, outside of solar hours, India continues to rely heavily on thermal power, meeting about 80% of total electricity demand on average. Wind contributed about 6% of demand during non-solar hours on an average.

02 Indian states plan to contract over 100 GW of wind capacity by 2030

By 2030, 21 out of 27 Indian states plan to contract more than 100 GW of wind. Even states with little or no wind potential, such as Odisha, Jharkhand, Punjab, and Bihar, are planning to include wind in their energy supply mix. This presents a unique opportunity for wind-rich states to export surplus generation to these states.

03 Meeting 2022 wind target could have fulfilled up to 14.5% of non-solar hour demand

While solar capacity grew rapidly in recent years and is expected to accelerate further, meeting the electricity demand during non-solar hours with clean energy remains a challenge. If India had met its 2022 wind target of 60 GW, up to 14.5% of the non-solar hour demand could have been fulfilled through wind energy.

Wind energy plays a critical role in India's energy transition. Ensuring round-the-clock availability of clean energy is essential for a smooth shift from a fossil-fuel-based economy to one driven by renewable energy. While efforts to deploy energy storage capacities are underway, diversifying the energy resource remains crucial for energy security, and wind energy is rightly placed to do so.

In addition to supporting the energy transition, the wind sector's growth offers broader economic benefits, including creation of green jobs, both in capacity deployment and manufacturing and the opportunity to become an export hub for wind turbines and associated components, further boosting the country's economic development.

Wind energy's complementarity with solar is crucial to addressing India's increasing clean energy needs during non-solar hours. By planning to contract over 100 GW capacity by 2030, Indian states will not only reduce dependence on thermal power but also drive economic growth through job creation and manufacturing opportunities. This approach allows India to build a robust, future-ready energy system that benefits both the environment and the economy.

Ruchita Shah

Electricity Policy Analyst, Ember

Chapter 1 | State of play

Renewables rise in the daytime, thermal still dominates in dark

Despite the recent growth in wind and solar installations, thermal power still caters to about 80% of India's power needs in non-solar hours

India's renewable energy (RE) sector is undergoing a significant transformation, particularly driven by solar power. Ever since the country has revised its RE target to 175 GW in 2015 and later updated it to 500 GW of non-fossil fuel capacity target at COP26, solar capacity installations surged by 180% from 3.8 GW in 2014 to 89.4 GW in August 2024, mainly due to falling costs, favourable policies and technological advancements. This rapid growth has positioned India as a key player in the global solar market. In the same period, however, India added only 7 GW of wind energy capacity. Although wind power had a head start, its growth slowed over the last decade due to land acquisition issues, transmission bottlenecks, and policy hurdles.

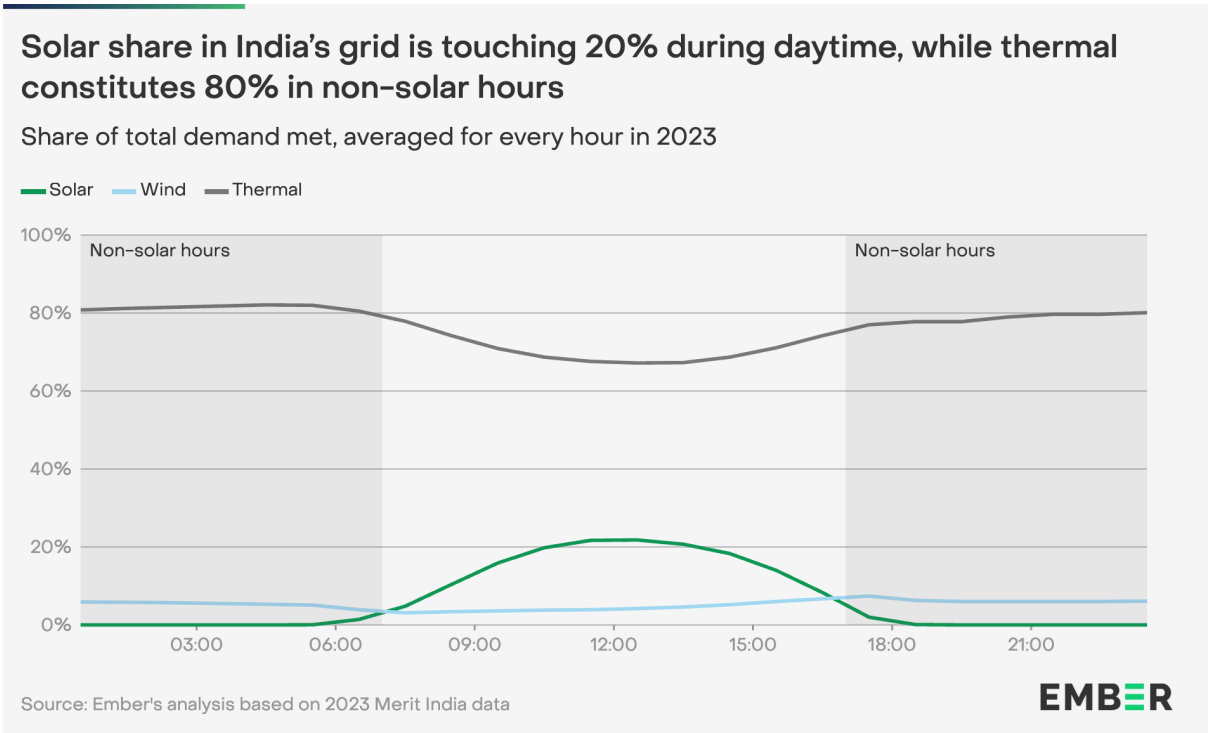
Since 2014, India's non-fossil fuel generation capacity has steadily expanded. By August 2024, it reached 208 GW, accounting for 46% of India's total installed capacity of 451 GW; of which, wind capacity stood at 47.2 GW (10.5% of total installed capacity) and solar capacity at 89.4 GW (20% of total installed capacity). As per the Central Electricity Authority's (CEA) report on under-construction RE projects, as of June 2024, 83.6 GW of RE capacity is under-construction comprising 16.5 GW of wind, 54.3 GW of solar and 12.9 GW of hybrid RE projects.

In terms of electricity generation, wind and solar accounted for 4% and 6% of the overall mix in 2023. This share is expected to become 10% and 25% by March 2032, if India achieves its 14th National Electricity Plan (NEP14) targets.

NEP14 outlines capacity addition targets of 122 GW for wind and 364.6 GW for solar by March 2032, to accommodate rising electricity demand. To realise this target, wind and solar capacity has to grow at 22% and 24% y-o-y, respectively.

Thermal power remains dominant in non-solar hours

On examining India's average daily generation profile, solar power meets up to 17% of demand during daytime (7:00 AM - 5:00 PM). This share increases to 19% when wind generation is included. However, the average share of wind and solar falls significantly during the non-solar hours; meeting only 6% of demand on average, leaving thermal power to cover around 80%.



Ramping up wind could now therefore be of more strategic importance than we realise as it can not only provide enhanced demand-supply balance but also help leverage the complementary nature of wind and solar helping the power sector planners to avoid

locking-in resources into building more thermal capacity to meet the non-solar hour demand growth.

Chapter 2 | Wind is more necessary now than ever

Wind offers strategic advantages in India's energy transition story

Leveraging wind's complementarity with solar is crucial for India's energy transition. Reaching the 2022 target of 60 GW would have increased wind power share in the grid during non-solar hours up to 14.5%.

Wind and solar resources are intermittent by nature, meaning they cannot provide a reliable power supply on their own. However, utilising the complementary nature of these resources can significantly enhance their reliability. This is especially true in India where solar generation is witnessing an accelerated growth and will be increasingly catering the daytime electricity demand, while addressing non-solar hour demand with non-fossil fuel resources remains a challenge.

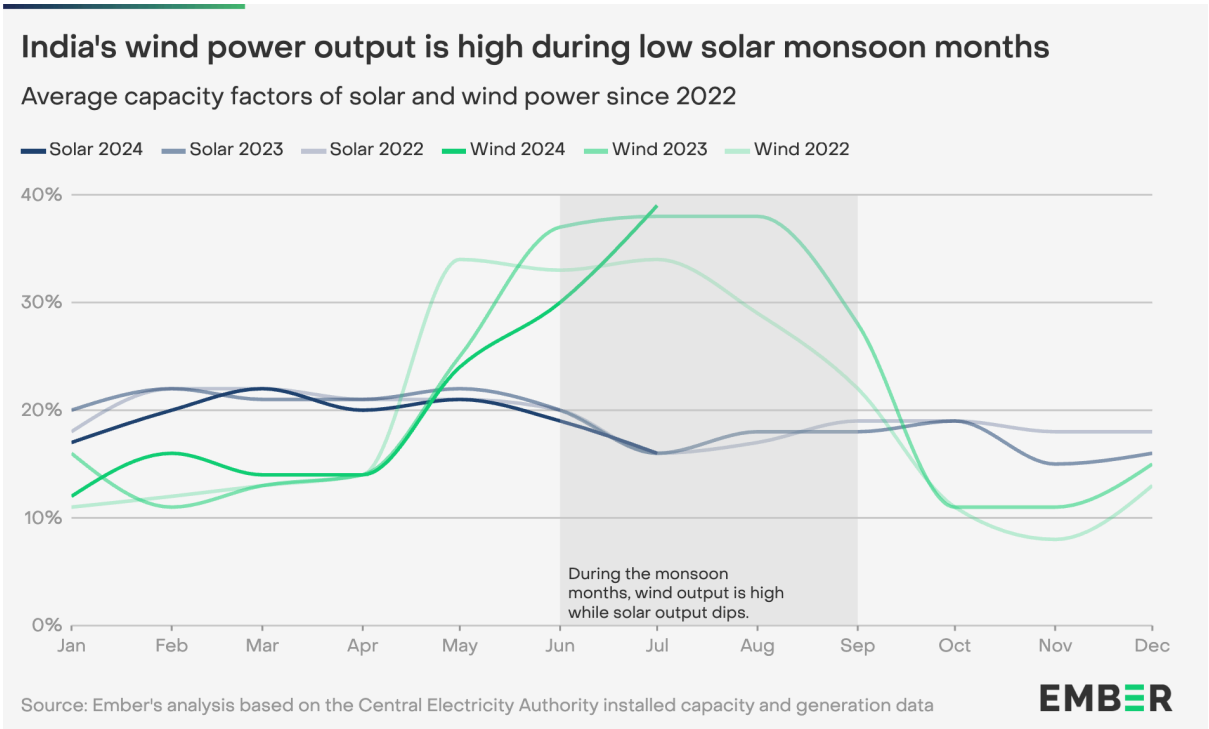
To resolve this issue, multiple alternatives coupled together are being explored and three most prominent clean options are: (a) expanding hydro power capacity, (b) deploying energy storage solutions (batteries and pumped hydro storage) and (c) increasing wind capacity. This chapter focuses on the complementarity of wind and solar resources and the impact of adding more wind to India's overall capacity mix.

Leveraging wind-solar complementarity for reliable supply

Complementarity refers to the ability of two energy resources to balance each other's generation, providing a more stable and reliable power supply. Wind and solar demonstrate both temporal and spatial complementarity. In India, temporal complementarity is evident across seasons (seasonal complementarity) and throughout the day (diurnal complementarity).

Seasonal complementarity:

In India, wind and solar follow a seasonal complementarity. For example, the strong southwest monsoon wind causes an increase in wind generation during the monsoon season (June - September) whereas a decrease in solar generation is observed due to monsoon cloud cover, reflecting higher seasonal synergies.



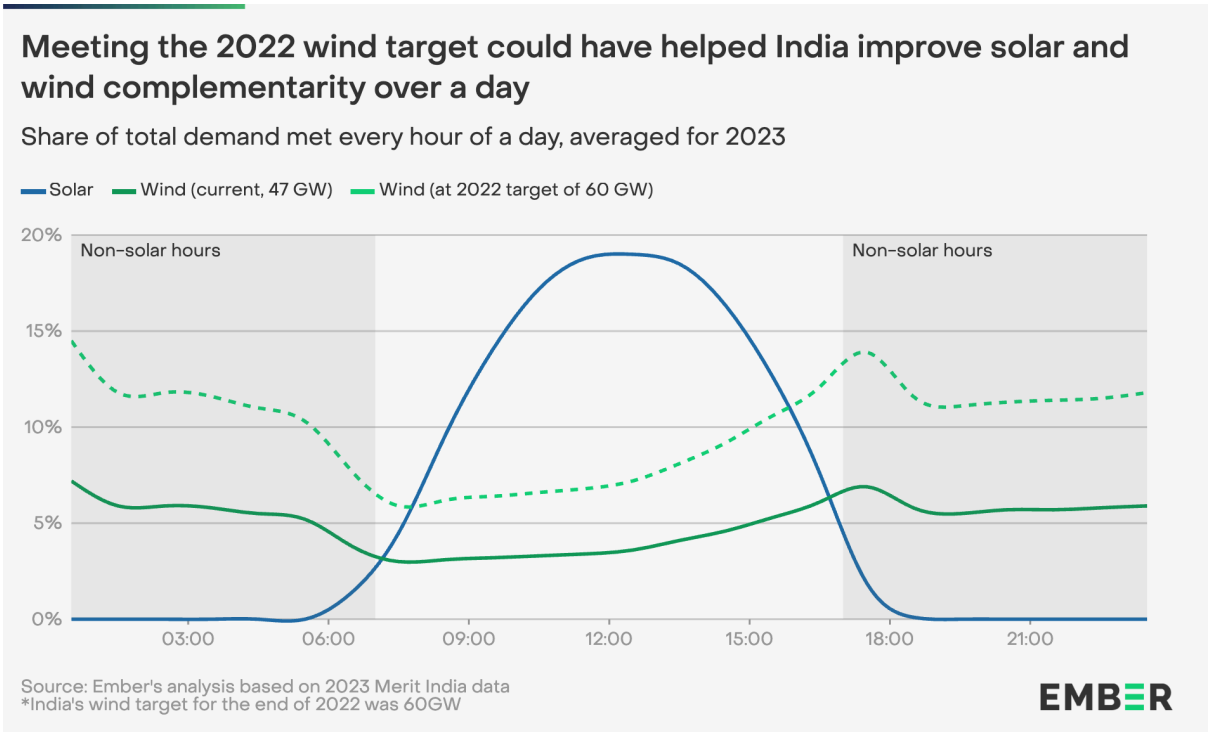
Diurnal complementarity:

In India, wind power often peaks during the night and early morning, while solar power is at its highest during the day. Wind generation often increases during the late afternoon, evening and early morning hours when solar power is not available. By harnessing this complementarity, India can achieve a more reliable and stable RE supply throughout the day, reducing the need for thermal power during non-solar hours.

Data from 2023 suggests that wind's share in the grid ranged from 3% (around 7:30 AM) to 7.2% (around 12:30 AM) and remained below 5% between 6 AM and 4 PM. Solar, on the other hand, gradually increased from sunrise, reaching 19% around noon before declining by sunset.

Had India met its 2022 wind targets, wind capacity by the end of 2022 would have reached around 60 GW and this would have pushed the share of wind in the grid to at least 6% during daytime (from close to 3% currently) and it could have gone up to 14.5% during non-solar hours, up from the current evening time high of around 6.3%. This would have helped reduce reliance on thermal power considerably (~7%-points) to meet non-solar hour demand.

Therefore, while solar capacity continues to expand, achieving the projected wind capacity addition of 122 GW by March 2032 (as defined in the NEP14) is critical.

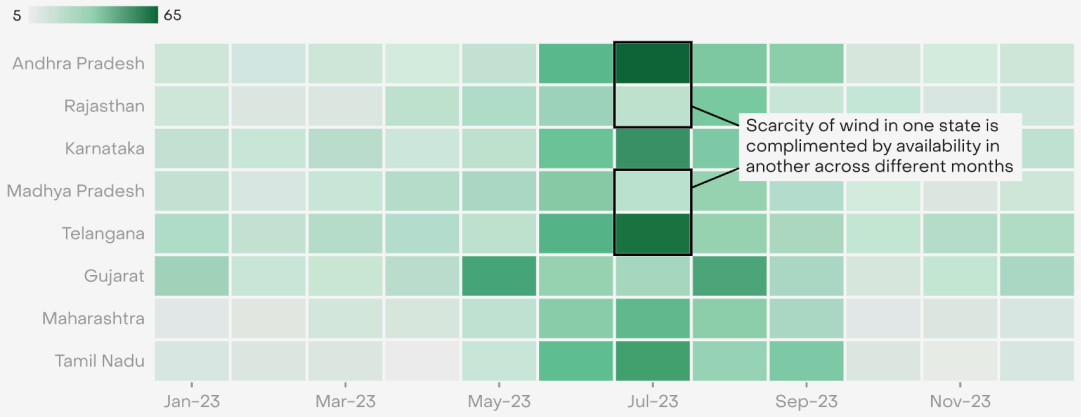


Spatial complementary:

India's wind resources also show spatial complementarity especially across western and southern regions. For instance, scarcity of wind resources in Rajasthan is complemented by its availability in Andhra Pradesh and vice versa across different months of the year. Similar trend could be observed in wind resource availability in Gujarat and Telangana.

Wind power output from different wind-rich states in India generally exhibit geographical complementarity

Average capacity factors (%) for wind power in 2023



Source: Ember's analysis based on the Central Electricity Authority installed capacity and generation data

Wind-solar hybrid projects are realising lower tariffs vs vanilla wind

The reverse auction mechanism for wind capacity allotment was introduced in 2017, replacing the earlier feed-in-tariff mechanism. Since then, wind tariffs have ranged from INR 2.43 (2017) to INR 3.7 (2024) per unit, showing a steady upward trend compared to solar tariffs.

Wind tariff versus solar and wind-solar hybrid configuration

Due to the diurnal complementarity between wind and solar, combining the two technologies results in increased generation on a daily basis compared to standalone solar or wind projects. Consequently, wind-solar hybrid projects have higher capacity utilisation factors (CUF) than standalone wind or solar projects. Moreover, the differing peaking times of the two technologies optimises the transmission infrastructure utilisation and results in reduced capital costs. The enhanced CUF and lower capital costs translates into a lower tariff

discovery. In 2018, the first wind-solar hybrid auction was concluded at a tariff of INR 2.67 per unit.

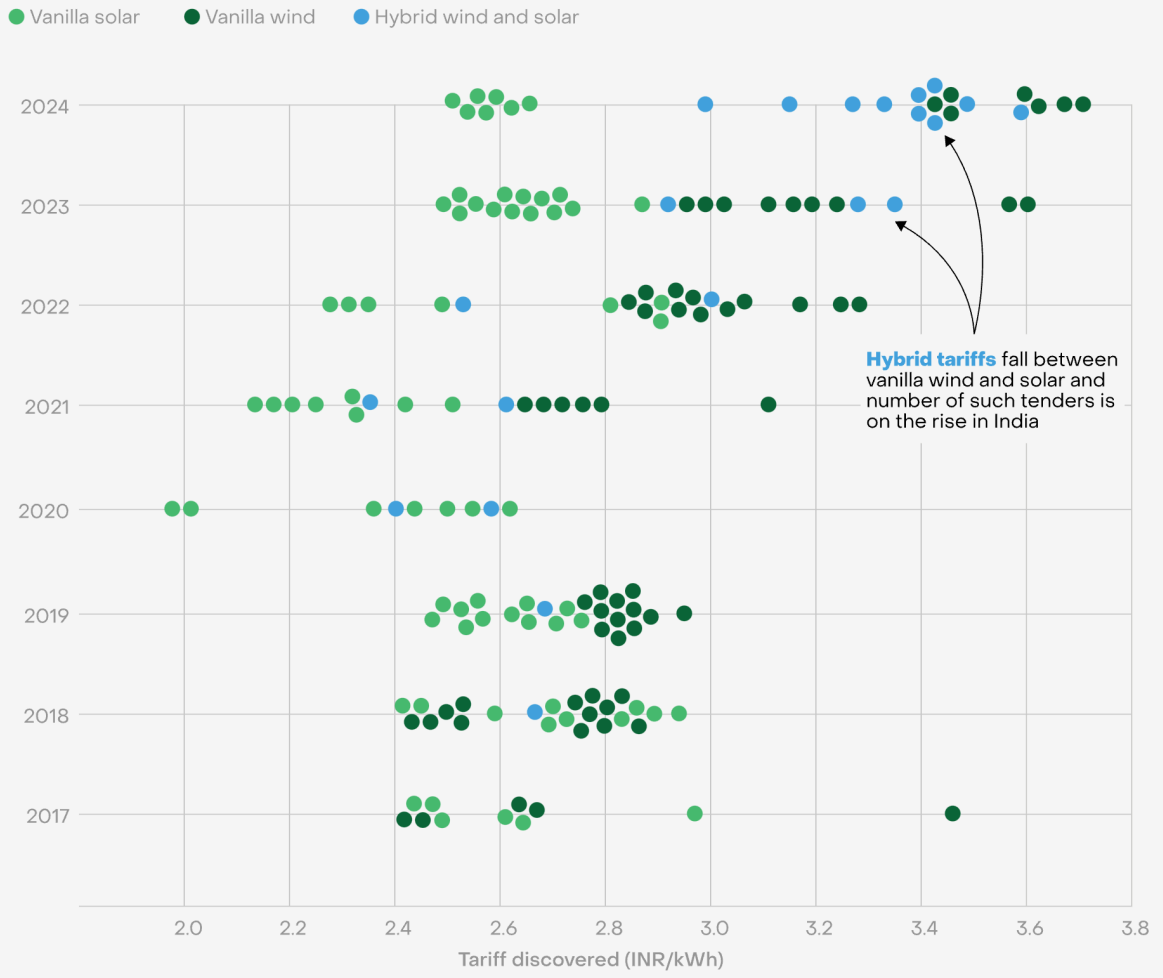
Comparing the latest vanilla wind, vanilla solar and wind-solar hybrid tenders concluded by Solar Energy Corporation of India Limited (SECI) further highlights the impact of complementary nature of wind and solar resources on the CUF and ultimately on tariff discovery.

a. For a 1350 MW auctioned wind capacity (closed bidding), tariffs ranged between INR 3.60-3.70 per unit with a minimum CUF requirement of 22%.
b. For a 1200 MW auctioned wind-solar hybrid capacity, discovered tariff ranged between INR 3.43-3.46 per unit with a minimum CUF requirement of 30%.
c. For a 1200 MW auctioned solar capacity, discovered tariff stood at INR 2.48 per unit with a minimum CUF requirement of 17%.

From 2018 to the first half of 2024, tariffs discovered in wind-solar hybrid auctions consistently ranged between those of vanilla wind and solar tariffs.

Number of wind-solar hybrid tenders are increasing, witnessing lower tariff discovery than vanilla wind

Tariff discovery (INR/kWh) since 2017



Source: Ember's analysis based on India RE Navigator , Mercom India
Vanilla wind and solar tenders refer to standard, non-hybrid projects.

Wind also offers added economic benefits

Beyond providing energy security and resource diversification, the wind sector contributes to India's economic development by creating green jobs and positioning India an export hub of wind turbines.

In terms of employment creation, wind sector jobs are spread across four broad categories: business development, design and pre-construction, construction and commissioning and operations and maintenance. In addition to jobs associated with wind capacity deployment, India also has a substantial wind turbine and associated component manufacturing facilities to provide employment opportunities.

As per International Renewable Energy Agency's (IRENA) estimates the Indian wind sector provided 40,000 jobs in 2022. Additionally, as per another study conducted by Council on Energy, Environment and Water (CEEW), the sector employed a workforce of 25,500 as of March 2021 and the employment opportunities are expected to rise six times by 2030.Further development of offshore wind is expected to generate additional employment across the value chain.

In terms of exporting wind turbines and associated components, India already has an annual domestic manufacturing capabilities of 17.25 GW. As per NITI Aayog's study, India has over 17 domestic manufacturing companies and they export wind turbines and blades to Australia, Brazil, Europe and USA among other countries.

Chapter 3 | Evolving policies

Government's policy interventions to boost wind capacity addition

Wind capacity addition in India slowed down in recent years, but both the central and state governments have introduced a series of interventions to bring the focus back on wind capacity addition.

The growth of any RE technology is closely tied to the policy environment shaped by central and state governments. Since 2014, solar power has dominated India's RE capacity additions due to favourable policies and declining tariffs. However, wind energy was the original frontrunner in India's clean energy transition. Although regulatory changes briefly slowed wind capacity growth, recent policies are designed to reignite momentum in the sector.

To revitalise the wind capacity addition in India, the government has introduced several key policy initiatives focused on three primary areas: (a) expanding onshore wind capacity, (b) repowering and refurbishing the existing (inefficient wind plants) and (c) for a longer-term enabling offshore wind development.

Evolution of wind power policies and regulations post the feed-in-tariff regime

Summary of policies announced in the past decade

October 2015
National Offshore Wind Energy Policy

October 2016
Guidelines for development of onshore wind power projects

August 2016
National repowering policy for wind projects

December 2017
Announcement of competitive bidding guidelines for wind

May 2018
National wind-solar hybrid policy

September 2019
Wind data sharing policy (WDSP)

July 2022
Introduction of wind specific renewable purchase obligation

January 2023
Removal of reverse auction mechanism

April 2023
Announcement of annual bidding trajectory with at least 10 GW of wind capacity

December 2023
Updated policy for repowering and refurbishment of wind power projects

December 2023
Announcement of offshore wind energy lease rules

February 2024
Reintroduction of reverse auction mechanism

February 2024
Amendment to competitive bidding guidelines for wind

June 2024
Viability gap funding (VGF) scheme for implementation of offshore wind projects

Source: Ember's compilation based on PIB, Mercom India

Accelerating onshore wind growth with revised policies and strategic bidding

A major recent development in onshore wind was the introduction of a revised renewable purchase obligation (RPO) trajectory in 2022, which allocated a specific portion to wind energy. In October 2023, the Ministry of Power (MoP) notified the RPO mandates under the Energy Conservation Act, thereby imposing monetary penalties for non-compliance.

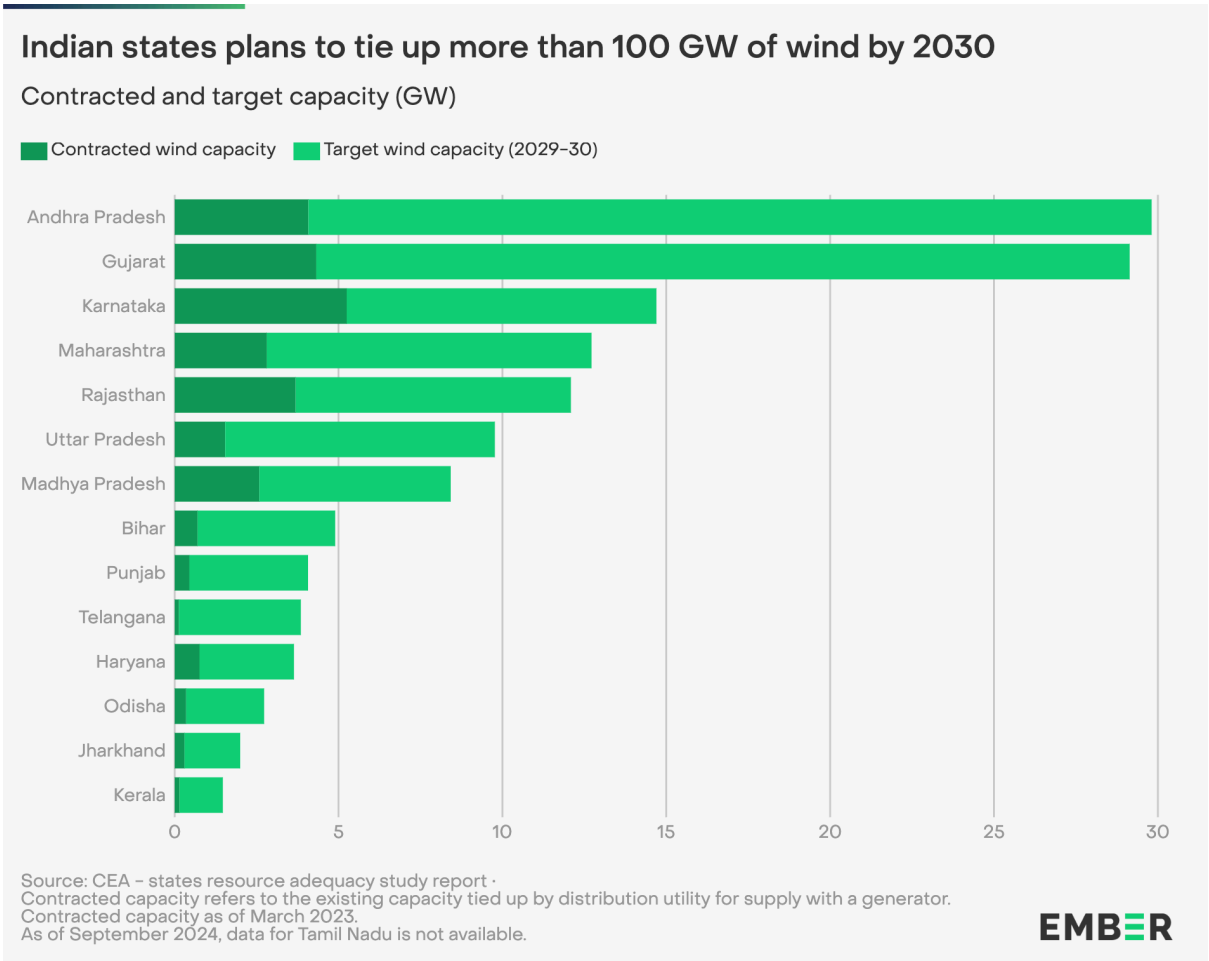
According to this trajectory, the wind RPO starting at 0.67% will gradually reach 3.48% by 2030. To meet this requirement, distribution utilities must contract with new wind capacities installed after March 2022, ensuring continuous wind capacity expansion.

In another key policy shift, the Ministry of New and Renewable Energy (MNRE) replaced the reverse auction mechanism for wind projects allotment with a single-stage, two-envelope closed-bid process. However, the reverse auction mechanism was reintroduced in March 2024 due to rising tariffs. Additionally, MNRE announced a 50 GW annual bidding trajectory, with at least 10 GW capacity reserved for wind projects from FY2024 to 2028.

Further development includes updated micrositing guidelines from MNRE in 2024. Micrositing is a suitable geometric layout of wind turbines in a wind farm to maximise energy production. Updated guidelines now focus on optimising the output from wind turbines rather than strictly adhering to minimum distance requirements between turbines.

Several Indian states plan to contract new wind capacity by 2030

As of September 2024, 21 out of 27 states that have released resource adequacy study reports 2024 published by CEA, have included wind capacity in their plans for 2030 and beyond. These wind capacity projections are not only governed by the mandatory wind specific RPO requirement, but also demonstrate a growing awareness of wind's importance in meeting non-solar hour demand through RE resources, alongside storage capacity.



Harness maximum output by repowering and refurbishing existing wind turbine

Wind repowering - replacing older, less efficient turbines with newer, advanced models - optimises wind and land resources, significantly increasing energy output from the same land parcel.

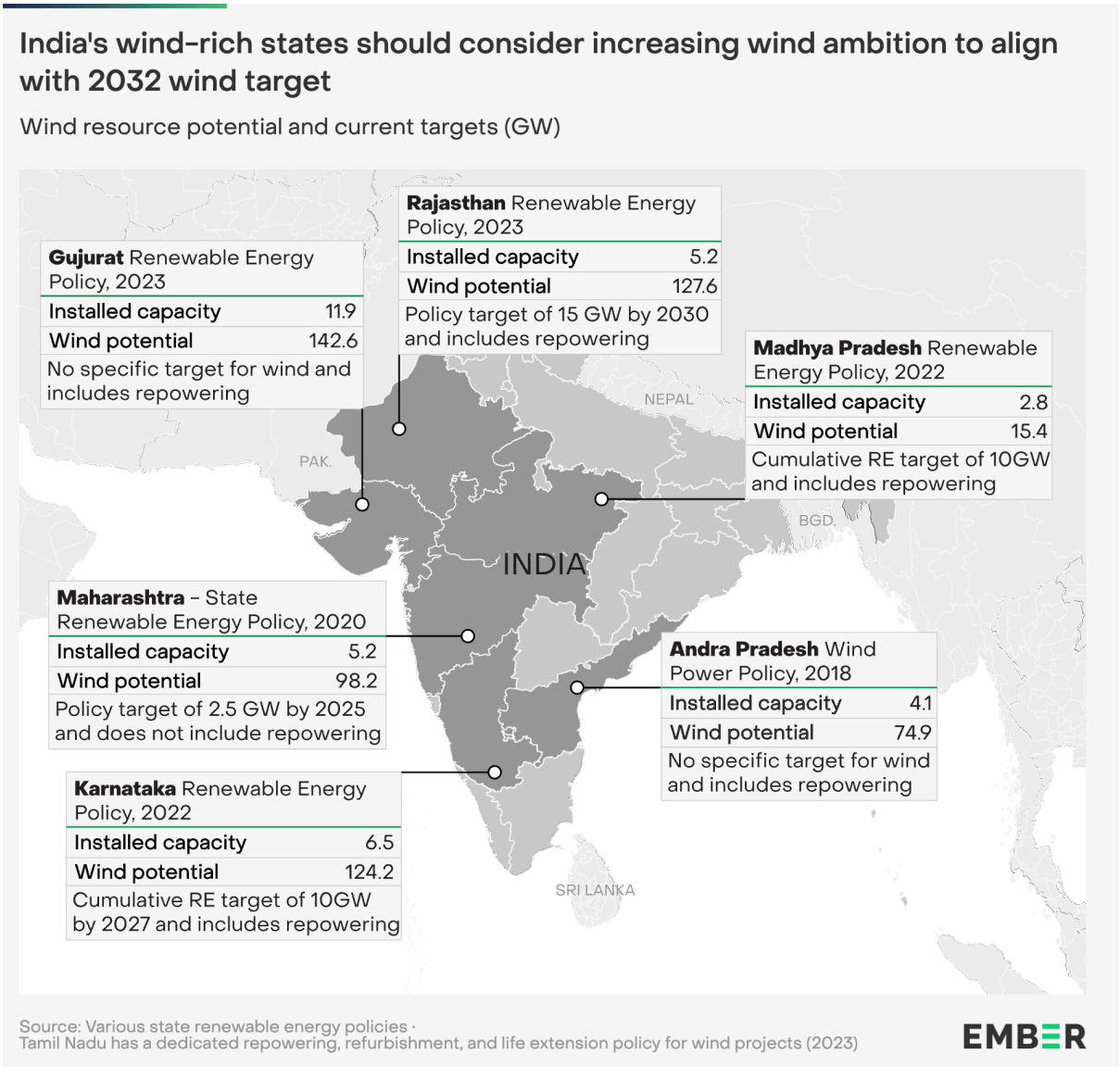
In 2016, MNRE introduced its first policy for repowering wind projects, followed by the National Repowering & Life Extension Policy in 2023, which superseded the earlier policy. This updated policy defines eligibility criteria for repowering and provides incentives for

repowered projects. In the policy, India’s repowering potential is estimated at 25 GW, based on older wind turbines of up to 2 MW capacity.

In 2024, Tamil Nadu became the first state to announce an exclusive policy for wind repowering, refurbishing and life extension of wind projects in the state. Notably, this policy includes relaxed micrositing norms and has modified the energy banking norms specifically for projects opting for repowering, refurbishment or life extension.

Highlights of state-level policies

India's wind energy potential is widely distributed across eight states. To foster growth in the wind sector, state-level initiatives are pivotal, alongside central policies and incentives. Through their RE policy, Maharashtra and Rajasthan have set clear wind capacity addition targets whereas other states like Gujarat, Madhya Pradesh and Karnataka have cumulative RE targets. On the policy front, Telangana and Tamil Nadu are yet to release their updated RE policy. As outlined in Chapter 2, 21 Indian states have included wind in their projected 2030 capacity plans, presenting a strategic opportunity for states rich in wind resources to expand their wind capacity beyond their requirement and supply wind power to states with no or limited wind resources.



Enabling offshore wind capacity addition

To further diversify the electricity mix, in 2015, India announced the National Offshore Wind Energy Policy. Offshore wind offers a significant opportunity for the country to tap into its vast coastal resources. With a long-term planning perspective, India is actively working to deploy offshore wind projects along the coastlines of Gujarat and Tamil Nadu.

In 2024, the Union Cabinet approved a viability gap funding (VGF) scheme for offshore wind energy projects with a total outlay of INR 74.53 billion. This includes an outlay of INR 68.53 billion for installation and commissioning of 1 GW of offshore wind energy projects (500 MW each off the coast of Gujarat and Tamil Nadu), and INR 6 billion for upgrading two ports to meet logistical requirements for offshore wind energy projects. This VGF scheme is a major step towards implementation of the National Offshore Wind Energy Policy, 2015.

Further, in February 2024, SECI announced a tender for allocation of sea-bed lease rights for 4 GW offshore wind power projects in Tamil Nadu. Later in September 2024, another tender to set up 500 MW offshore wind projects in Gujarat was announced.

Chapter 4 | Next steps

India needs to overcome key headwinds to meet wind targets

India needs to triple its wind capacity to align with NEP14 projections, prioritising policy implementation and establishing clear state-level targets.

The complementary nature of wind and solar generation offers strategic advantage for India to achieve a reliable and diversified energy mix. As the country continues to expand its RE capacity, particularly in solar, wind power plays a crucial role in supplying non-solar hour demand and reducing the reliance on thermal generation.

According to NEP14, India needs to build 75 GW of new wind by 2032. Achieving this target will require ramping up y-o-y installations by 22%. For this, improving the pace of auctions and timely commissioning the project would be crucial. Announcement of 50 GW annual bidding trajectory in 2023 was an encouraging step, however ensuring that at least 10 GW of wind is auctioned annually is the essential next step. Further, the government should also ensure that the auction process includes guaranteed and timely grid connectivity and land availability to prevent project delays. Given that states own the land while central agencies manage auctions, coordination between the central government and states is essential. Digitising land records could help streamline the acquisition process and reduce setbacks.

Increasing wind capacity deployment is strategically important for India's power system planners to avoid locking-in resources into building more thermal capacity considering that meeting non-solar hour demand could become a key bottleneck in the country's energy transition by the end of 2020s. More so, in case battery energy storage system (BESS) costs do not fall as expected.

In terms of policy development, significant progress has been made both at central and state level. However, on-ground realisation of these policies still has a long way to go. Ensuring the timely and effective implementation of policies, including ensuring fulfilment of RPO mandates and following the wind-specific bidding trajectory. In 2022 and 2023, only 13 and 4 states have fulfilled RPO mandates (as per MOP trajectory) of 21.18% and 24.60%, respectively. The government needs to explore stronger mechanisms to ensure RPO compliance by states and consider imposing significant penalties against defaulting entities.

Revitalising the wind sector will require a comprehensive approach. In addition to increasing new onshore capacity addition, repowering of old wind projects should be prioritised to maximise output from resource-rich sites. From a long-term perspective, continuous efforts to enable the deployment of offshore wind capacities are essential to diversity the energy mix.

At the state-level, it has been observed that many wind-resource-rich states do not specify a wind capacity addition target in the state policy. Tami Nadu and Telangana, for example, currently lack wind-specific policies. There is an urgent need to establish clear targets at state-level and update the policies to send a positive signal to wind project developers and investors.

By focusing on accelerating auction processes, improving project implementation, enforcing RPO mandates and addressing state-level policy gaps, India can unlock the full potential of its wind energy resources and contribute to a cleaner, more sustainable future.

Supporting Materials

Methodology

This report primarily uses hourly generation data for 2023. The RE share estimates are based on Merit India data which reports wind and solar combined. For this analysis, wind and solar are disaggregated using the following approach. Hourly wind speeds were extracted from ERA5 data at the location and hub height of 4000 wind farms and converted to hourly capacity factors following this approach.

Global Horizontal Radiation was extracted from ERA5 data at the locations of solar installation and converted to capacity factor using this approach. These capacity factors were bias-corrected by state, using Ember's state-level data, and the corrected capacity factors plus installed capacity used to split renewable generation reported by Merit India into wind and solar. As far we are aware, this is the first analysis based on Merit India data disaggregated between wind and solar.

For installed capacity, data is taken from CEA's monthly installed capacity report.

In Chapter 1, a surge in solar capacity addition is calculated using installed capacity between 2014 and August 2024 whereas to arrive at a required growth rate for wind and solar NEP14 targets are considered. The share of wind and solar in the overall generation mix is taken from Ember's Electricity Data Explorer for 2023 and to estimate the share of wind and solar in 2032, NEP14 projections are considered.

To estimate the contribution of wind, solar and thermal generation on hourly basis during solar and non-solar hours, the average of hourly generation data across all months is taken as per disaggregated Merit India data (see above).

Further in Chapter 2, to establish temporal complementarity of wind and solar resources, (a) for seasonal complementarity, average monthly capacity utilisation factors are calculated

using CEA's installed capacity data and total monthly generation and (b) for diurnal complementarity, average hourly generation data across all months is analysed.

To assess the contribution of wind if 2022 wind targets were met, 2023 generation data was modelled with average capacity utilisation factors of 30% and 19% for wind and solar capacities, respectively.

For spatial complementarity, monthly capacity utilisation factor is calculated based on state's wind installed capacity and generation data across eight windy states in India and are compared for geographical complementarity.

To discuss leveraging the diurnal wind-solar complementarity in terms of tariff discovery, tariff data for vanilla wind, vanilla solar and wind-solar hybrid tenders were collected from various publicly available sources.

To highlight the added value of wind in terms of jobs and export opportunity, data is collected through literature review.

In Chapter 3, CEA's state-specific resource adequacy report for 27 states were reviewed and projected wind capacity data for 2029-2030 was collected to estimate the projected contracted capacity.

For detailed data and calculations, the accompanying excel file can be accessed here.

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Header Image

wind farm in the rural area of India

Credit: pradeep subramanian / Alamy Stock Photo