Battery storage is now cheap enough to unleash India's full solar potential

Ember's analysis shows how solar and battery storage can meet as much as 90% of India's electricity demand at lower LCOE than the average power purchase costs in most states.

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About

This report builds on Ember's previous analysis showing that rapid advances in battery technologies have made round-the-clock solar electricity increasingly viable in the world's sunniest regions. It explores India's vast solar potential and assesses how far solar power, when paired with battery storage, could supply electricity reliably throughout the year. Using hourly electricity demand and solar radiation data, the analysis examines how solar-plus-battery storage systems can meet demand as it varies across hours, days and seasons. The report evaluates both the technical potential of solar and batteries to supply a large share of India's electricity demand and the cost implications across major states.

Key highlights

90%

Solar and batteries could supply 90% of India's electricity demand at a competitive LCOE of around INR 5.06/kWh ($56/MWh).

4.9 GW

of solar and 13.5 GWh of battery capacity for every 1 GW average demand load is enough to meet 83-92% of annual electricity demand in the ten largest states.

7

of India's largest states by electricity demand can meet 90-92% of their demand with solar and batteries at an LCOE between INR 4.96–5.09/kWh ($55–56/MWh).

Executive summary

Unleashing India's solar potential with battery storage

Battery economics have improved sharply in the last two years. Our thought experiment shows that solar and batteries can already meet 90% of India's electricity demand at a competitive levelised cost of electricity (LCOE) of INR 5.06/kWh ($56/MWh).

This thought experiment shows that national solar with battery storage could have met 90% of India's 2024 electricity demand with 930 gigawatts (GW) of solar capacity, a fraction of the country's enormous solar potential, and 2,560 gigawatt-hours (GWh) of battery storage capacity. Battery storage turns daytime solar into reliable electricity after sunset. The main challenge is extended periods of low solar output, especially during the monsoon and not a lack of battery capacity.

The economics are already very attractive. Solar has become "the cheapest form of electricity in history", according to the International Energy Agency (IEA), since 2020. More recently, battery economics have improved dramatically in just the last two years. Following a sharp 40% fall in turnkey battery costs in 2024, 2025 saw another big fall of 31%. Previous Ember analysis has shown that falling battery costs and improving storage technologies are making round-the-clock solar electricity increasingly viable, enabling it to meet 90% of electricity demand efficiently in solar-rich countries like Mexico, and helping them become global solar superpowers. India is also one of these solar-rich countries. With access to solar and battery technologies at globally competitive prices, it can unleash this potential to meet large shares of its demand.

The LCOE at which solar-plus-battery storage could meet 90% of India's electricity stands at a competitive INR 5.06/kWh ($56/MWh). The ten largest states by electricity

demand are similarly well-positioned to take advantage of India's enormous solar potential, owing to favourable demand patterns where high demand coincides with seasonally higher solar radiation and eases during the low solar-output period of the monsoon.

01 Solar with battery storage could supply 90% of India's electricity demand at INR 5.06/kWh LCOE and just 5% of solar generation curtailed

Ember's modelling shows that solar and batteries could supply 90% of India's electricity demand at an LCOE of INR 5.06/kWh ($56/MWh). Achieving this would require around 930 GW of solar capacity and 2,560 GWh of battery storage – equivalent to 4.9 GW of solar and 13.5 GWh of battery capacity for every 1 GW of average demand. Only 5% of the annual solar generation would need to be curtailed where it exceeds demand and battery storage capacity. The main challenge is not shifting solar generation from day to night with batteries but maintaining supply during extended periods of weak solar output, especially during the monsoon.

02 The ten largest Indian states could meet between 83% and 92% of electricity demand with national solar

Using the same capacity configuration as in the national analysis and the same blended solar resource from India's highest-potential states, solar and batteries could supply 83–92% of electricity demand across the ten largest states by electricity demand. Seven states reach 90% or more, led by Andhra Pradesh (92%), with Uttar Pradesh the lowest at 83%. States with higher demand in the sunniest months achieve the highest shares, while states with stronger monsoon-season demand, like Uttar Pradesh and West Bengal, perform less well.

03 Six of the ten largest Indian states could procure over 90% of electricity from solar and batteries at LCOE cheaper than current power purchasing costs

Of the seven states that achieve 90% or more loads met, the LCOE of the modelled electricity from solar-plus-battery is cheaper than the current average power purchase cost in the state. Across these states, the modelled LCOE is on average around 15% lower than current procurement costs. For example, in Gujarat, it is 7% lower at INR 5.05/kWh ($56/MWh) to meet 90% of demand, compared with an average power purchase cost of INR 5.45/kWh ($60/MWh). On the other hand, in Karnataka, it is 21% lower at INR 5.04/kWh ($55/MWh) to meet 91% of demand compared with an average power purchase cost of INR 6.37/kWh ($70/MWh).

Solar already plays a large and growing role in India's power system. It accounted for 9.4% of electricity generation in 2025, nearly doubling from 5.3% in 2022. Solar plays an important role during the day, meeting up to a quarter of demand during the sunniest hours of the day but none at night. Installed solar capacity reached 143 GW in FY2025-26, up from less than 5 GW in FY2014-15, contributing to India's broader goal of 500 GW of non-fossil capacity by 2030. Solar could play an even larger role in India's electricity system over the longer term – especially with the help of cheap batteries.

The dramatic improvement in battery economics over the past two years has delivered the missing piece that turns sunshine into reliable electricity day and night. For solar-rich countries like India, this makes the case for becoming a global solar superpower. The question is no longer whether solar can power India's electricity system, but how quickly it can scale.

Kostantsa Rangelova
Global Electricity Analyst, Ember

Solar and batteries are already delivering power below the prevailing power purchase costs in many states, while rivalling coal in terms of reliability. From here, the economics only becomes more compelling.

Duttatreya Das
Asia Energy Analyst, Ember

Chapter 1

Batteries can fully unlock India's vast solar potential

Batteries can enable solar power to meet 90% of India's electricity demand day and night, using just a fraction of its feasible solar potential.

India has 143 gigawatts (GW) of solar as of February 2026, around 4% of its estimated feasible 3,343 GW ground-mounted potential. This potential capacity alone can produce enough electricity to meet around three times India's 2024 demand. In 2025, solar produced 9.4% of all electricity in India. This share is likely to continue rising as India further develops its national solar potential. Already, solar meets around a quarter of the national electricity demand in the sunniest hours, but none at night. Fully unlocking India's solar potential means delivering solar at night. With the recent fall in battery storage prices, it is now economically feasible to supply solar at night.

To explore how solar-plus-battery storage could translate India's vast solar potential into a reliable electricity supply, Ember modelled how solar generation from India's highest-potential states could meet hourly electricity demand, assuming no grid constraints. Ember used solar irradiation data from 15 locations across Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh. This provides a broad geographical coverage while still reflecting that large-scale solar deployment is likely to take place primarily in high-resource states with high land availability.

The model uses national hourly demand data from 2024. We selected solar irradiation data from 2023 as a representative year with slightly below-average output. Year-to-year variations in solar output are relatively small, meaning results are not highly sensitive to the choice of year.

1.1 India has enormous solar potential across its territory

India has an immense, well-distributed solar potential. Around 9% of India's land area has no possible land restrictions and excellent practical solar potential above 4.4 kWh/kWp (the daily amount of electricity generated by 1 kW peak PV capacity of a typical utility-scale system, taking into account factors like temperature and soiling), based on data from the Global Solar Atlas. Nearly every state has significant solar potential.

A government assessment estimates 3,343 GW of feasible ground-mounted solar potential, using just 6.7% of suitable wasteland with high irradiance. This portion of the wasteland area constitutes less than 1% of India's total land area. The estimate excludes key additional solar potential from rooftops (with over 600 GW technical potential on residential buildings alone), as well as the possibility for developing floating solar (up to 300 GW estimated potential) or agrivoltaics. The ground-mounted potential of 3,343 GW alone is more than 23 times India's current installed solar capacity of 143 GW, and more than 17 times the average demand load in 2024 of 190 GW.

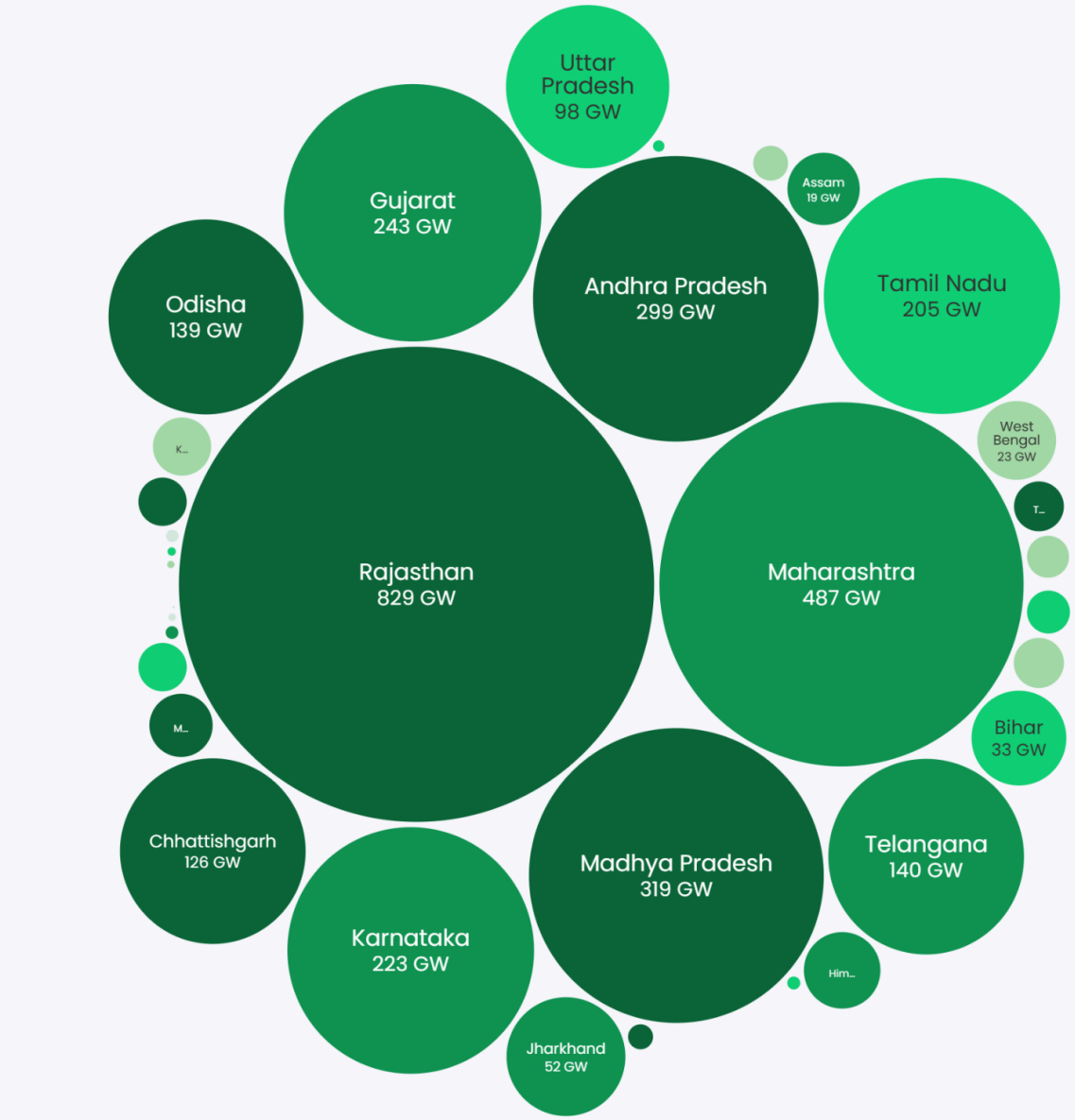
Many of India's largest electricity demand centres also have substantial solar resources. Among the ten largest states by electricity demand, only two, Uttar Pradesh and West Bengal, fall outside the top ten states by solar potential, ranking 11th and 14th, respectively.

Meanwhile, states such as Rajasthan and Madhya Pradesh have far more potential than their own electricity demand.

India has vast utility solar potential across its territory

Bubble size= ground-mounted solar PV potential (GW)

Colour represents solar potential as a multiple of average demand load in 2024



Source: MNRE (state-level ground-mounted solar PV potential in GW when no more than 10% of wasteland in the state is utilized for solar power), excludes rooftop, 2024 average demand load based on hourly data from India Climate and Energy Dashboard (Niti Aayog)

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1.2 Solar plus battery could supply 90% of national electricity demand economically

In India, solar has the potential to become a dominant source of electricity. Ember's modelling shows that solar plus batteries could supply 90% of India's electricity demand at a levelised cost of electricity (LCOE) of INR 5.06/kWh ($56/MWh). While higher shares, including 100%, are technically possible, moving closer to 100% would be costlier. Each additional percentage point from 90% requires increasingly more solar and storage, leading to higher system costs. Moreover, with other existing and planned clean sources such as wind, hydro and nuclear, the country would not need 100% solar.

In 2024, electricity demand was just over 2,000 terawatt-hours (TWh). Meeting 90% of this requires 930 GW of solar capacity – less than one-third of India's 3,343 GW of estimated feasible ground-mounted solar potential. It also requires around 2,560 gigawatt-hours (GWh) of battery storage. In other words, 4.9 GW solar capacity and 13.5 GWh battery capacity for every 1 GW annual average demand load.

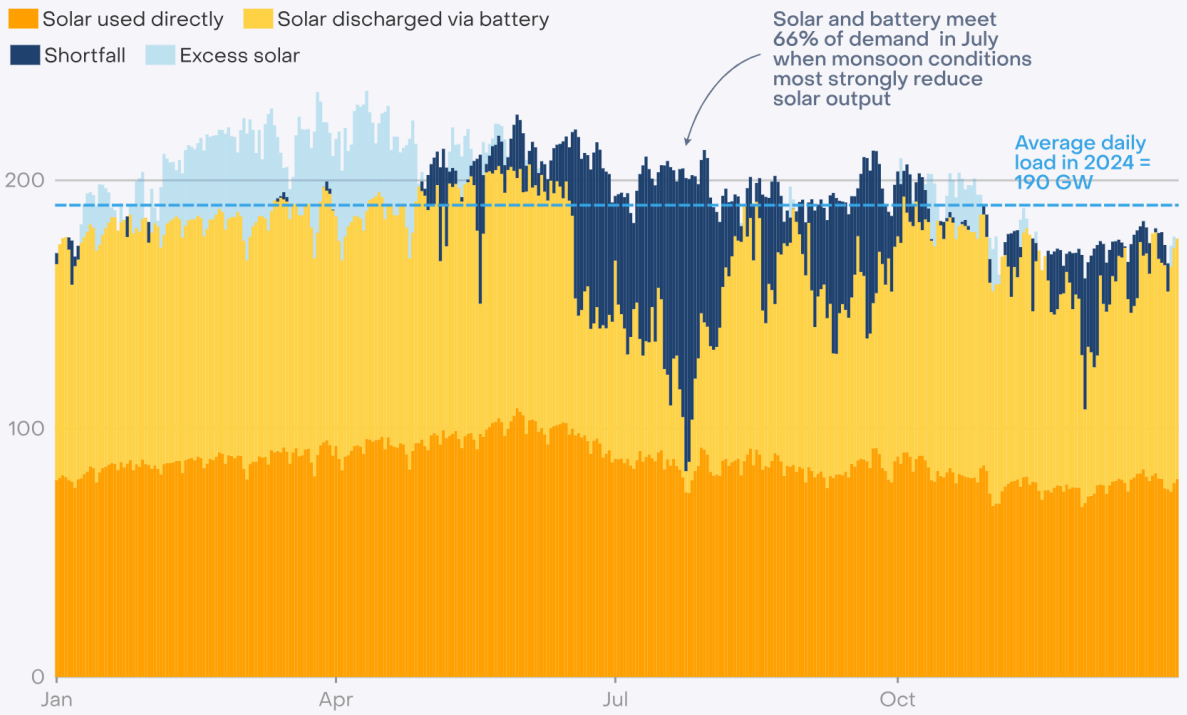
During January-April, when solar radiation is typically above the annual average, batteries can shift abundant daytime solar into the evening and night so that solar and storage meet 100% of demand almost every day. During peak summer (May–June), when demand is around 10% above average, they still meet about 88% of demand.

The biggest challenge comes during periods when solar output is weak for several consecutive days. Batteries can move solar generation from daytime to after sunset, but they cannot carry large amounts of solar output across extended cloudy spells. This is why the main constraint is not battery capacity itself, but lower solar generation during the monsoon months. In July, when cloudy monsoon conditions severely reduce solar output, solar and batteries meet 66% of demand.

In practice, India's power system would rely on a broader mix of resources, with solar able to play a central role. Tapping into India's wind resources is key as wind generation typically strengthens during the monsoon, partly offsetting lower solar output. Determining the optimal pathway requires a deeper system modelling exercise than the scope of this report.

A thought experiment: how India could meet 90% of its electricity demand with solar and battery at INR 5.06/kWh LCOE

Modelled electricity supply from 4.9 GW solar (DC) and 13.5 GWh battery storage (usable) capacity for each 1 GW annual average demand load (GW)



Source: Ember analysis of hourly data • Demand data is for 2024 from India Climate and Energy Dashboard (Niti Aayog); Solar power data is from JRC for 2023 as a representative year and is a blended average of data for Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh (3 locations per state)
Key assumptions: 4% PV to grid loss, 10% PV to grid via battery loss; Installation costs (2025): solar - 435 $/kW; battery - 126 $/kWh; 20 year project lifetime, 7% discount rate

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Chapter 2

Solar and batteries can already meet most electricity demand in major Indian states economically

Solar and batteries are already cheap enough to provide around 90% of electricity in many of India's largest states at lower LCOE than their current average power purchase costs.

The feasibility and cost of such solar-plus-battery systems depend not only on solar irradiation but also on electricity consumption patterns across regions. Demand patterns, including when electricity is used during the day and especially how it varies across seasons, strongly influence how easily solar generation can match electricity demand.

This chapter examines how these dynamics influence the performance and cost of solar-plus-battery systems across India's largest electricity-consuming states, assuming that solar generation from high-potential states can be transmitted across the country's interconnected power system. This approach reflects the current development pattern of renewable energy in India. Typically, India deploys large-scale solar concentrated in a limited number of resource-rich states with strong irradiation, available wasteland and lower execution risk due to fast land acquisition. Simultaneously, it is building transmission infrastructure to move power from these solar-rich zones across state borders.

2.1 National solar generation strongly overlaps monthly demand variations in most of the largest Indian states

Seasonal alignment between electricity demand and solar generation is a key driver of state-level results. States with the highest demand in the sunniest months need less solar overbuild to reach high annual solar shares.

In the high-resource states used for the modelling, solar capacity factors peak in March and April, at around 20% above the annual average. In July, the monsoon month, it dips 28% below the annual average. In many of India's largest states by electricity demand, peak solar months are also months of above-average demand. This overlap is particularly strong in Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu and Telangana, where demand in the high-solar months is around 10–29% above the annual average. Except for Tamil Nadu, demand also dips below average in July in these states by between 6% (Andhra Pradesh) and 18% (Karnataka).

Gujarat, Rajasthan and Madhya Pradesh also show broadly favourable seasonal profiles. In these states, demand varies less across the year, which helps because electricity use does not rise sharply during the weakest solar months.

Uttar Pradesh and West Bengal stand out as less favourable cases. In these states, demand load in July, when solar output is weakest, is 38% and 24% higher than the annual average, respectively.

These differences help explain why the same solar-plus-battery system using the same hourly irradiation performs better in some states than in others, as explored in the next section of this report. States with demand concentration in the sunniest months are more likely to achieve high shares of electricity from solar plus batteries.

In most of the largest Indian states monthly demand overlaps strongly with national solar

Monthly demand by state vs solar capacity factor in high-resource states (annual average = 1)

Source: Demand based on 2024 hourly data from India Climate and Energy Dashboard (Niti Aayog); Solar power data is from JRC hourly data for 2023 as a representative year and is a blended average of data for Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh (3 locations per state)

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2.2 Ten of the largest Indian states could meet between 83% and 92% of their electricity demand with national solar

The differences in seasonal and daily demand patterns translate directly into system performance. Using 4.9 GW of solar and 13.5 GWh of battery storage for each GW of average demand (the configuration that achieved 90% in the national analysis), solar-plus-battery systems could supply between 83% and 92% of demand in the ten largest states.

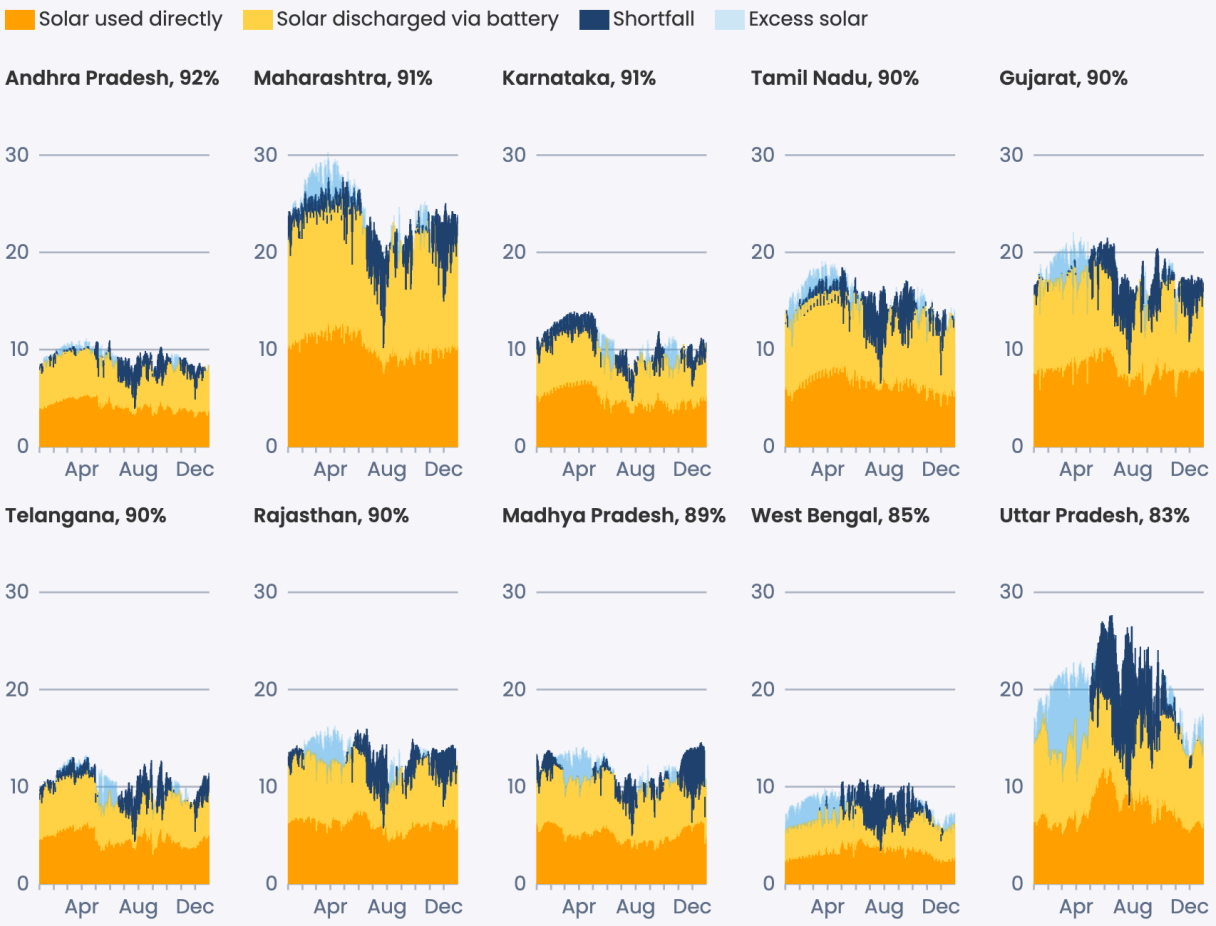
Seven states reach 90% or more, led by Andhra Pradesh (92%). Uttar Pradesh shows the weakest result but remains at a high level of 83%.

The monthly results show that the weakest period is, generally, the monsoon. This is despite demand being below average in most states during this period. July is the lowest-performing month in nine of the ten largest states, with only Madhya Pradesh having the largest shortfall in December, owing to higher winter demand. By contrast, the highest-performing months cluster in January–April, when solar output is stronger, and demand is either lower or better aligned with solar generation. Karnataka is a key exception due to 22% above average demand over January–April, although in our experiment, solar plus batteries still met 90% load on average in these months.

Uttar Pradesh and West Bengal show the largest difference between the highest and lowest-performing months, swinging from 100% in the best months (January-April) to 56–57% in July. The spread is the narrowest in Karnataka, ranging from 83% (July) to 100% (October). This reinforces the national finding that the main challenge is not shifting solar across the day, but maintaining supply through extended periods of weak solar output.

Load profiles of the largest Indian states allow them to meet between 83% to 92% of electricity demand using national solar

Modelled electricity supply from 4.9 GW solar (DC) and 13.5 GWh battery storage (usable) capacity for each 1 GW annual average demand load (GW)



Source: Ember analysis of hourly data • State-level hourly demand data from India Climate and Energy Dashboard (Niti Aayog) for 2024; Solar power data is from JRC hourly data for 2023 as a representative year and is a blended average of data for Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh (3 locations per state)
Key assumptions: 4% PV to grid loss, 10% PV to grid via battery loss

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Sensitivity testing using only local solar resources shows limited divergence in results. Even in states with lower ground-mounted solar potential, local solar-plus-battery systems could supply a similar share of demand, reaching 80% in Uttar Pradesh and 79% in West Bengal with the same configuration. However, land availability can become a constraint. West Bengal would require around 40 GW solar capacity to meet 79% of 2024 demand - around 70% more than the estimated ground-mounted solar potential of 23 GW.

2.2.1 Seven of the largest Indian states could procure at least 83% of their electricity from solar-plus-battery at a lower LCOE than current power costs

Solar and batteries are already cost-competitive. For the solar-plus-battery storage configuration used in the state-level analysis earlier, the modelled LCOE for states ranges from INR 4.96/kWh ($55/MWh) in Andhra Pradesh to INR 5.48/kWh ($60/MWh) in Uttar Pradesh.

In six of the ten largest states, where this configuration can meet 90% or more of electricity demand, the LCOE is below current average power purchase costs. Across these states, the modelled LCOE is on average around 15% lower. For example, the modelled LCOE is 7% lower in Gujarat at INR 5.05/kWh ($56/MWh) to meet 90% of demand, compared with an average power purchase cost of INR 5.45/kWh ($60/MWh). In Karnataka, the LCOE is 21% lower at INR 5.04/kWh ($55/MWh) for meeting 91% of demand compared with an average power purchase cost of INR 6.37/kWh ($70/MWh).

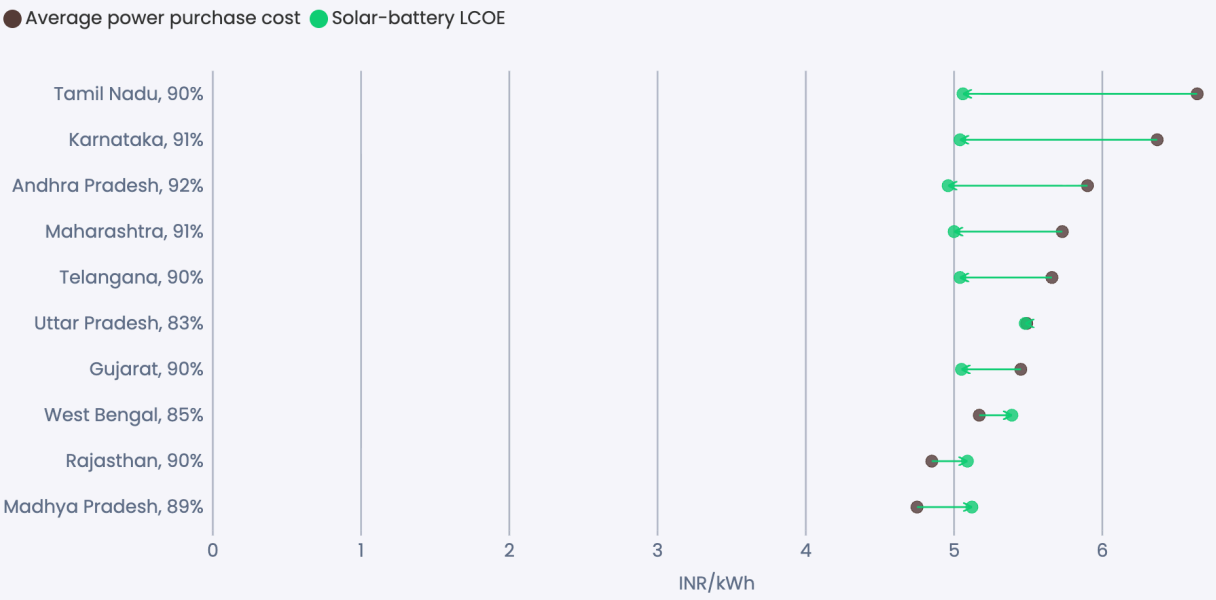
These results reflect the cost of meeting demand with solar and batteries using generation from high-resource states, rather than the full delivered cost to each state. In practice, states would balance lower generation costs in resource-rich regions against additional transmission charges, losses and state-level network costs.

Transmission costs are shared across states in proportion to their demand, irrespective of where the power lines are built. Estimates suggest that average transmission charges are in the range of INR 0.7–0.9/kWh ($8–10/MWh) under typical conditions. Even when sourcing renewable energy from distant states, the total landed cost for states may effectively increase by around INR 1.2–1.5/kWh ($13–17/MWh), assuming typical costs for state-level transmission charges and losses.

From a policy perspective, the government currently provides waivers on transmission charges to facilitate the signing of renewable power purchase agreements. This creates a strong incentive for states to procure solar from resource-rich regions. It translates into lower effective transmission costs in their power procurement mix.

Seven of the largest Indian states could procure at least 83% of their electricity from solar and battery at a lower LCOE than current power costs

Modelled LCOE at the indicated share of demand met with solar and battery and FY2024-25 average power purchase cost, INR/kWh



Source: Average power purchase costs: FY 2024-25 tariff order of individual distribution utilities, Ember analysis hourly data • Modelled electricity supply and LCOE using 4.9 GW (DC) of solar and 13.5 GWh of battery storage (usable) capacity for every 1 GW of annual average demand load
State-level hourly demand data is from India Climate and Energy Dashboard (Niti Aayog) for 2024; Solar power data is from JRC hourly data for 2023 as a representative year and is a blended average of data for Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh (3 locations per state); Key assumptions: 4% PV to grid loss, 10% PV to grid via battery loss; Installation costs: solar - 435 $/kW; battery - 126 $/kWh; 20 year project lifetime, 7% discount rate

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2.2.2 All the largest states can procure at least 75% of electricity from solar plus battery at an LCOE cheaper than current power purchase costs

Ember tested a range of solar-plus-battery system sizes for each state. It found that all ten of India's largest states could procure at least 75% and up to 99% of their electricity from solar with battery storage at an LCOE lower than today's power procurement costs of these states' distribution companies.

In Madhya Pradesh, which has the cheapest average power purchase costs of the ten states (INR 4.75/kWh or $52/MWh), solar with batteries could meet up to 76% of electricity demand before the LCOE exceeds that cost.

In six of the ten largest electricity-consuming states, solar and batteries could meet 90% or more of demand without exceeding today's power procurement costs. In these states, the modelled LCOE for systems meeting between 95% (Gujarat) and over 99% (Karnataka and Tamil Nadu) of demand falls broadly within a range of INR 5.5–6.6/kWh ($61–73/MWh).

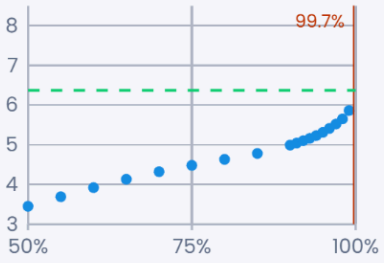
The opportunity is not limited to very large solar-plus-battery systems. States do not need to aim for a perfect or near-100% solar-plus-battery system to benefit. Even smaller configurations can already deliver well over 50% of electricity at an LCOE that is significantly below current procurement costs.

All ten of the largest states can procure at least 75% of electricity from solar with battery at cheaper LCOE than current power purchase costs

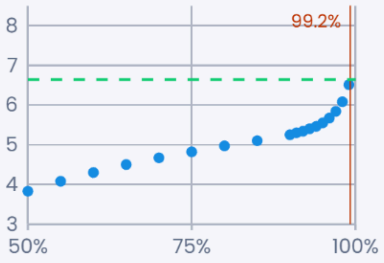
Modelled load met (x axis, %) and LCOE (y axis, INR/kWh) from different solar and battery configurations

Average power purchase cost FY2024-25 ---- Orange lines show maximum load that can be met at an LCOE equal to average power purchase costs |

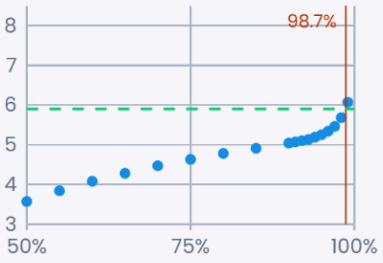
Karnataka



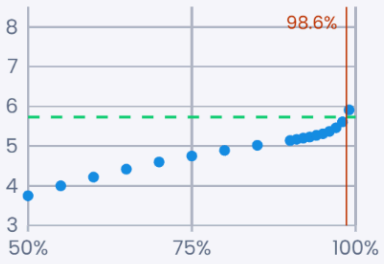
Tamil Nadu



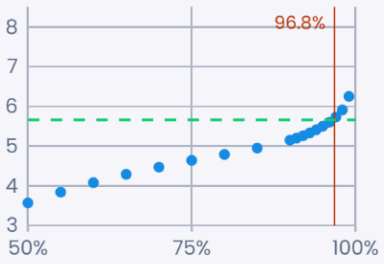
Andhra Pradesh



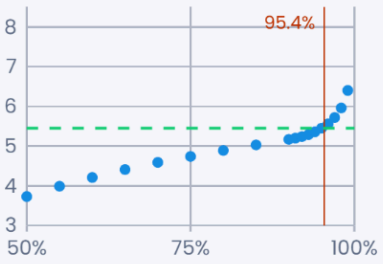
Maharashtra



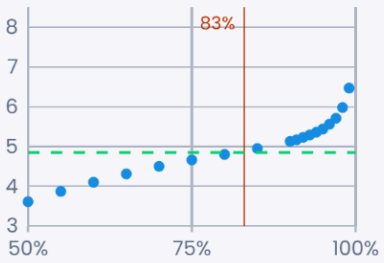
Telangana



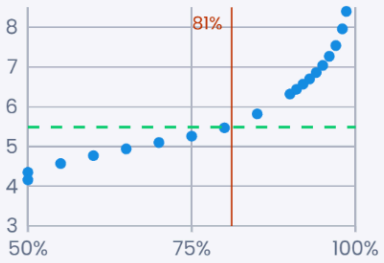
Gujarat



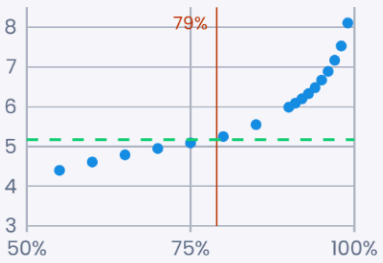
Rajasthan



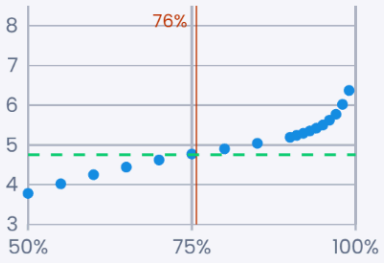
Uttar Pradesh



West Bengal



Madhya Pradesh



Source: Average power purchase costs: FY 2024-25 tariff order of individual distribution utilities, Ember analysis hourly data • State-level hourly demand data is from India Climate and Energy Dashboard (Niti Aayog) for 2024; Solar power data is from JRC hourly data for 2023 as a representative year and is a blended average of data for Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh (3 locations per state); Key assumptions: 4% PV to grid loss, 10% PV to grid via battery loss; Installation costs: solar - 435 $/kW; battery - 126 $/kWh; 20 year project lifetime, 7% discount rate; Key assumptions: 4% PV to grid loss, 10% PV to grid via battery loss; Installation costs: solar - 435 $/kW; battery - 126 $/kWh; 20 year project lifetime, 7% discount rate

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Ember's modelling is based on the current battery and solar costs, which are more conservative than the costs implied by the tariffs discovered in the most recent auctions for solar and storage.

Solar-plus-storage auctions in 2025 cleared at INR 2.9-3.5/kWh ($32-39/MWh) for projects with a 4-hour battery. More recently, India's first solar and 6-hour BESS auction in early 2026 discovered a tariff of INR 3.12/kWh ($34/MWh). These auctions typically require developers to deliver solar generation at specified capacity-factor thresholds and supply evening peak demand through storage with about 70% monthly reliability.

Some of these projects are likely to be commissioned over the next 2–3 years. Therefore, they already factor in anticipated declines in battery costs.

2.3 Coal power costs are rising while solar and batteries offer a reliable and cheaper alternative

While solar and batteries are getting cheaper every year, coal power is becoming more expensive.

Recent coal power auctions have seen tariffs rising across new projects. Recent auctions for coal plants across different parts of India have discovered tariffs in the range of INR 5/kWh ($55/MWh) and INR 6.3/kWh ($69/MWh).

Several factors are contributing to these higher tariffs. These include higher capital costs due to stricter mandates for pollution-control equipment, declining coal quality, and poorer station heat rates resulting from plants operating at lower loads. In addition, coal plants are increasingly expected to ramp more deeply to balance variable renewable electricity sources, which raises repair and maintenance costs.

Moreover, solar-plus-battery tariffs are typically fixed for the entire contract duration, whereas coal power tariffs are linked to inflation through fuel costs and other escalation clauses. Reflecting this cost risk, some states have already begun moving away from long-term 25-year power purchase agreements, instead preferring shorter-duration contracts.

Ember's analysis shows that solar paired with battery storage is already competitive with new coal in several states when supplying high shares of electricity demand. In seven of the ten largest states, solar with batteries can provide 90% of electricity at a comparable LCOE to the low-end new coal tariff of INR 5/kWh ($55/MWh). The cost advantage could strengthen further in the coming years.

Given these differences, solar and batteries offer a compelling alternative, providing low-cost, dispatchable and inflation-proof power while reducing exposure to fuel price volatility and long-term utilisation risks associated with new coal capacity.

The economics of solar-plus-battery electricity supply are already attractive and likely to improve over the coming years. As India's electricity demand continues to grow, solar can play a major role in meeting this demand economically and reliably with the help of battery storage. A total of 930 GW of solar is enough to meet 90% of 2024's national electricity demand, and the 3,343 GW estimated feasible ground-mounted potential alone is more than three times larger. With the additional potential of building solar from other options, like rooftops, India has more than enough to become a global solar superpower and strengthen its energy independence and security with local, inflation-proof resources.

Supporting materials

Methodology

This report uses a simplified modelling approach to assess how far solar power, paired with battery storage, could meet India's electricity demand and at what cost. The analysis is designed as a thought experiment, illustrating the potential of solar with battery storage rather than optimising a full power system.

Data sources

- Demand: The analysis uses hourly electricity demand data for 2024 from the India Climate and Energy Dashboard (NITI Aayog). The year 2024 is used as a representative baseline, as electricity demand in 2025 was lower due to reduced cooling demand. Demand is analysed at both the national level and across the ten largest states by electricity demand, allowing comparison of how different demand profiles affect system performance.
- Solar: Hourly solar generation data is sourced from the European Commission's JRC PVGIS tool. Simulations use:
    - Solar generation is modelled using vertical-axis PV systems (crystalline silicon) with optimised tilt by location, based on a blended average of five high-resource states: Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh. These states were selected to provide broad geographic coverage and reflect where large-scale solar deployment is most likely. Using a blended average approximates generation from multiple sites, smoothing local variability in solar output and enabling the model to match national and state-level demand, which a single-site project would not be large enough to do.
    - Solar generation is based on data from 2023, used as a representative year with slightly below-average solar radiation. Year-to-year variations in solar output are relatively small, meaning results are not highly sensitive to the choice of year.

Modelling approach

Battery storage is used to shift solar generation from periods of high output to periods of low output, particularly from daytime to evening and night hours.

The model operates on an hourly basis, matching solar generation with demand, with the same hourly energy flow logic used in a previous Ember study, with the following key parameters:

- Excess solar generation is stored in batteries, subject to storage capacity limits
- Stored electricity is discharged when solar output is insufficient
- Remaining unmet demand is recorded as a shortfall
- Excess generation beyond storage capacity is recorded as surplus

Efficiency losses:

- PV to grid loss: 3.76%
- PV to battery loss: 4.5%
- Battery to grid loss: 5.5%

Battery depth of discharge: Battery capacity in GWh represents usable capacity, assuming it includes enough overbuild (typically around 10-20%) to guarantee 0-100% depth of discharge on the usable capacity.

Cost and Financial Assumptions

Capital expenditures:

- Solar: $435/kW (total installed cost)
- Battery: $126/kWh usable capacity (total installed cost, including augmentation costs - see battery degradation -also accounting for cost savings from hybridisation with solar, such as shared inverter, other installation cost sharing)

Operational expenditures:

- Solar: 2% of capital expenditures per year
- Battery: 2.5% of capital expenditures per year
- Escalation rate: 2.5% per year

Project lifetime: 20 years

Degradation Rates

- PV degradation: 0.5% per year
- Battery degradation: 2% per year, included in the battery capital expenditure as the present value of capacity augmentation costs

Discount rate: 7%, applied annually to both costs and energy output

LCOE Calculation

The LCOE is calculated as:
LCOE [$/MWh] = Total Discounted Costs / Total Discounted Energy Supplied

Where:

- Total Costs include CAPEX, discounted OPEX
- Total Energy Supplied includes discounted energy from PV and battery

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Contributors

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Cover image

An aerial perspective showing rows of solar panels installed across a vast outdoor site in Maharashtra, India, for renewable energy production.

Credit: Paulose N Kuriakose / Getty Images Plus

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