REPORT

DOUBLING THE PACE OF DEPLOYMENT OF RENEWABLE ENERGY CAPACITY IN INDIA

A POLICY REVIEW TO MEET THE 2030 GOAL OF 500 GW OF CLEAN CAPACITY

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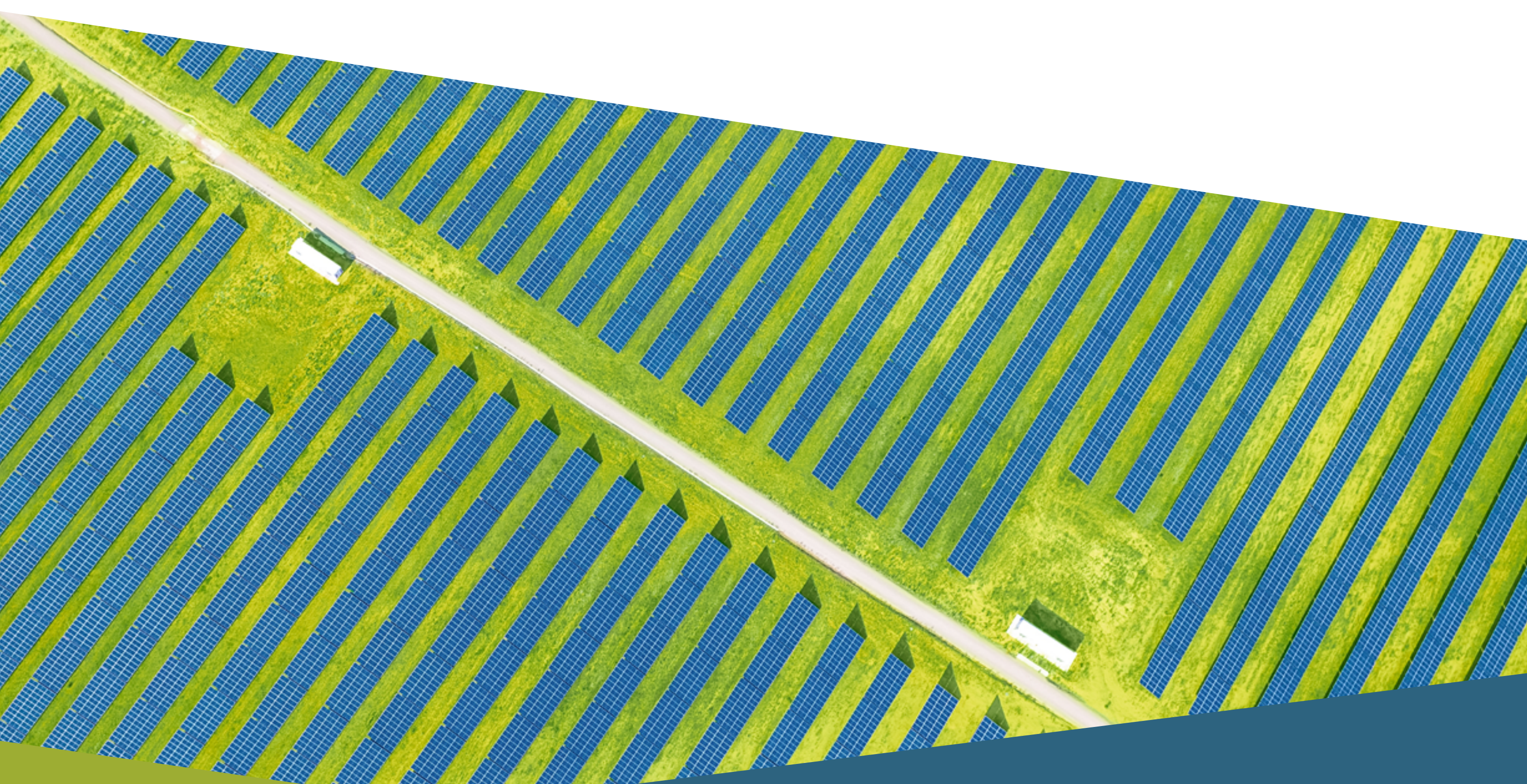

EXECUTIVE SUMMARY

Due to rapid economic growth, urbanization, and industrialization, India's electricity demand is expected to nearly double in the next decade. The electricity demand in the country has grown at an average of 6-7% in the last three years. 250 GW peak demand was met in May 2024, up from 240 GW in September 2023, and is projected to touch 270 GW in summer 2025. At the same time, India has announced an ambitious target of deploying 500 GW of non-fossil or clean capacity by 2030. The Government of India has undertaken several policy measures and regulatory reforms to enable progress towards this target, and 212 GW cumulative renewable energy (RE) capacity, including 46 GW large hydro, was installed by 31st January 2025. With 8 GW of nuclear capacity installed, 280 GW is remaining to achieve the 2030 clean capacity target.

Most of this new clean capacity is expected to come from solar and wind energy sources, which are cost-effective and can be installed rapidly. However, several implementation and ecosystem challenges have restricted the pace of deployment to less than 20 GW per year, with the exception of 2024, which saw 28 GW of new solar+wind capacity installed. Therefore, to deploy 500 GW of clean capacity, of which about 80 GW is projected to come from large hydro and nuclear[1], the next 6 years must achieve a deployment rate of ~45 GW per year of renewable capacity[2], double the average pace over the last three years. If the country is unable to deploy renewable capacity along with grid-scale storage at the required pace, peak power shortages can be expected.

Both the central and state governments have taken several measures to shorten implementation cycles and enable procurement of RE power. In March 2023, the Ministry of New and Renewable Energy (MNRE) announced a goal of tendering 50 GW/year to be implemented by four renewable energy implementing agencies (REIAs) responsible for tendering of RE capacity. The RE tendered capacity (across REIAs, Discoms and C&I) has tripled from 27 GW in 2022 to 84 GW in 2024. However, the conversion to completed auctions and thereafter signed offtake agreements continues to be a challenge. Data shows that about half of announced tenders result in auctions and about half of those convert to power purchase agreements (PPAs).

This challenge is compounded by the huge variance among states in installing and procuring renewable capacity. We examine trends in the top six states by energy consumption, accounting for 70% of total RE capacity. While some states such as Rajasthan and Gujarat have doubled their installed RE capacity since FY 2021-22, Karnataka has slowed down considerably over the last three years and Uttar Pradesh has much smaller installed base at only about 3 GW.

1 As per Optimum Generation Capacity Mix for 2029-30 by the Central Electricity Authority

2 In this report, 'renewable capacity' refers to solar, wind, small hydro and biomass, unless otherwise indicated

These states would need to scale the installed RE capacity ~2.5 times to meet the 2030 requirement (Figure ES-1)[3].

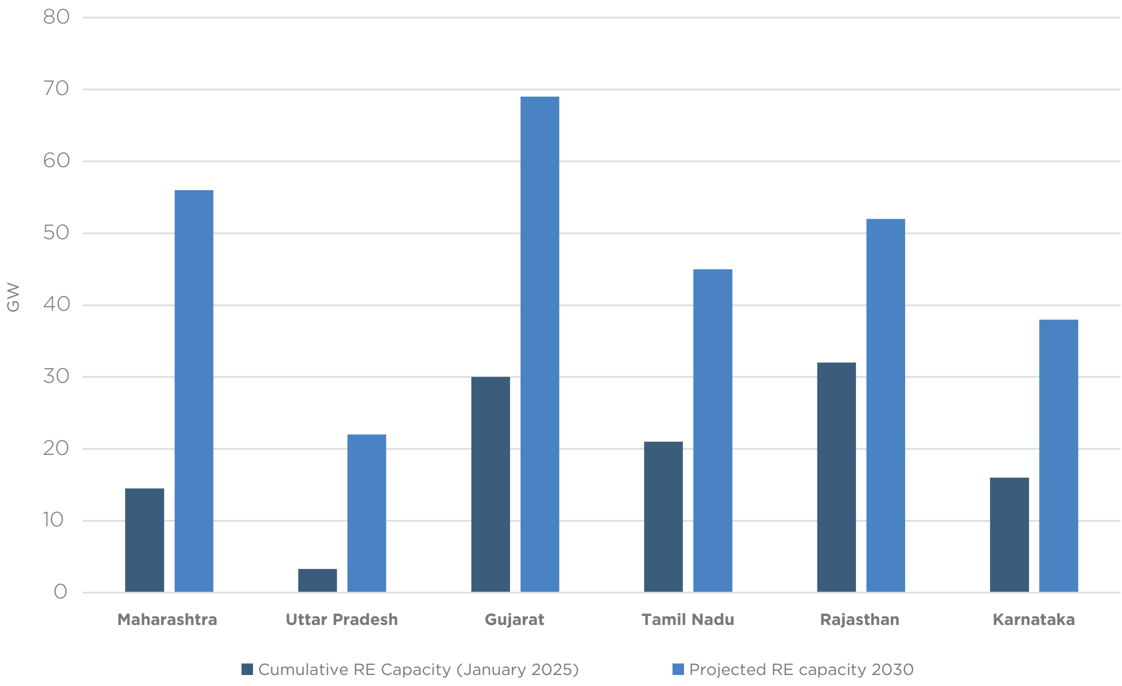

FIGURE ES-1: State-wise installed RE capacity Vs Projected 2030 capacity

This report aims to distill the key barriers that are thwarting the pace of deployment of large-scale renewables and energy storage, with the objective that addressing these key challenges would move the needle significantly. The barriers have been broadly divided into project implementation challenges and slow evolution of ecosystem enablers.

Implementation challenges continue to be dominated by land acquisition/leasing and availability of transmission connectivity aligned with project timelines. While on paper, plenty of wasteland seems available, ground-truthing, unsuitable terrain along with aggregation and acquisition challenges prolong project cycles. New transmission buildout timelines combined with availability of connectivity is a major obstacle. High demand for evacuation infrastructure in resource-rich states such as Rajasthan while the RE projects enjoyed the inter-state transmission system (ISTS) waiver has also resulted in geographical bottlenecks.

Ecosystem enablers include improved resource planning and procurement by the states, in the absence of which states continue to plan for traditional resources such as coal to meet the peak demand, while RE is mainly considered for meeting the renewable purchase obligation (RPO). Grid-scale battery storage is needed to store solar energy generated during the day to discharge and meet peak demand in the morning and evening hours.

3 State-wise RE capacity projections for 2030 are taken from forthcoming report Abhyankar et al 2025b

Slow deployment of grid-scale storage reduces the value of additional RE on the grid. Taking an integrated resource procurement approach is critical for determining the value of RE+storage to meet the load. Lastly, India has made concerted effort to enable domestic manufacturing in the sector, however domestic cell/module production continues to lag annual capacity addition targets of 50 GW.

Both these types of barriers need coordinated action by the centre and states to resolve in the short to medium term. The table bellow summarizes key challenges and potential solutions, based on our research and conversations with stakeholders.

TABLE ES-1: Summary of key challenges and potential solutions

Factor	Challenges	Potential solutions
Land acquisition	Varying land availability and land-use type conversion policies among states; unorganized processes of land records, aggregation and acquisition	Streamline classification of wasteland for use in RE projects; proactive role of state nodal agency in land aggregation and leasing/acquisition; innovative land leasing models; aggregation of land through solar park schemes; coordination and capacity building at state agencies
Transmission planning and connectivity	Mismatch between planning and RE installation cycles & geographical distribution	Using advanced conductors to double line capacity for evacuating power from RE rich zones; siting local solar close to expensive coal plants to use existing transmission network; accounting for energy storage systems in transmission planning
Supply chains and domestic manufacturing	Domestic manufacturing lagging to meet domestic demand of solar & batteries, along with a price premium	Long term policy certainty; strategic cooperation with friendly nations for upstream component manufacturing, exploration and ownership of critical mineral mines; improved implementation of green energy open access rules to reduce cost of power for domestic manufacturing units
Resource planning & procurement at the state level	Outdated processes prevent states to determine the cost-effective resource mix needed to meet their evolving demand	Integrated resource procurement by the states along with rigorous implementation of Resource Adequacy (RA) reforms; state-level venue for RA planning; technology-neutral RPO; streamlined PSA process combined with direct procurement by states
Deployment of energy storage systems	States do not know how much storage capacity is required, and if it is cost-effective, due to gaps in resource portfolio assessment approach	Incentives for battery storage co-located with existing/new solar projects; deployment of battery storage at substations; stack value streams provided by storage; integrated resource planning and procurement at the state level

Addressing these barriers would require overhauling the resource planning and procurement through a mix of policy & regulatory changes, fine-tuning the role of and improved coordination between central and state agencies, building capacity in new technologies such as advanced conductors and creating an ecosystem for upstream manufacturing, etc. Collaboration with friendly countries would be key in developing strategic supply chains and technology expertise, in addition to creation of bilateral markets for products of domestic manufacturing. Improved capacity of power sector officials and the industry would be the foundation on which this new grid of the future can be built.

INTRODUCTION

Now the third largest renewable energy market in the world, India has ramped up deployment of renewable energy in order to enhance energy security and in line with climate commitments. At COP 26, India committed to meeting 50% of cumulative installed power capacity from non-fossil sources by 2030, among other commitments. In accordance, an internal target to deploy 500 GW of non-fossil or clean capacity by 2030 was announced by the Prime Minister. As of January 2025, renewable energy, including large hydro, accounts for 45% (212 GW) of the total installed electricity capacity (466 GW) in the country[4] (CEA Dashboard). Several studies have shown that ~420-450 GW of renewable capacity[5] (excluding large hydro) would be cost-effective for meeting India's load in 2030. Central Electricity Authority (CEA) has projected renewable sources would account for more than 50% of the total electricity capacity (422 GW of 777 GW) by 2030 (CEA 2023a). Forthcoming study from UC Berkeley estimates that 456 GW of renewable capacity with 61 GW/218 GWh of energy storage, would be needed to meet India's 2030 demand at a least cost (Abhyankar et al 2025a).

Over the last few years, India has witnessed unprecedented growth in power demand, over 9-10% (PIB 2024a); as a result of industrial growth, new electricity connections, increasing per-capita consumption and increasing air-conditioner (AC) penetration. The peak demand touched 250 GW in May 2024 (The Hindu 2024). With the increasing number of electric vehicles, industrial growth, rising AC ownership and demand from data centers, electricity demand is forecasted to grow at an average 6.3% annually over the next three years (IEA 2025). The Ministry of Power (MoP), Government of India (GoI), has undertaken several measures in recent years to meet the soaring power demand. This includes an increase in blending of imported coal with domestic coal, plans to build new coal capacity (in addition to the 27 GW under construction), no retirement of thermal power plants till 2030 (PIB 2023a), and operationalisation of gas power plants. Currently, coal power plants account for 74% of total power generation in the country (NITI Aayog ICED).

In addition to keeping fossil fuel-based power generation online, GoI has announced several policy measures to support the deployment and integration of renewable energy in the country. The Ministry of New and Renewable Energy (MNRE) announced an annual bidding trajectory of 50 GW of renewables (with 10 GW allocated for wind capacity) starting FY 2023-24 until FY 2027-28. Other notable policy measures include transmission plan for integrating 500 GW RE capacity by 2030, wind repowering policy, production linked incentive (PLI) scheme for solar PV modules and batteries to support domestic

4 With nuclear capacity of 8 GW, India already has 46% of power capacity from non-fossil sources.

5 In this report, we exclude large hydro from renewable capacity, and focus on the pace of deployment of solar & wind capacity. Planned large hydro capacity under construction is ~11 GW until 2030.

manufacturing, Resource Adequacy regulatory reforms etc. The new regulatory framework would enable the States and Discoms to develop resource adequacy plans to enable reliable system operation at least cost (Ministry of Power 2023b, CERC 2023a).

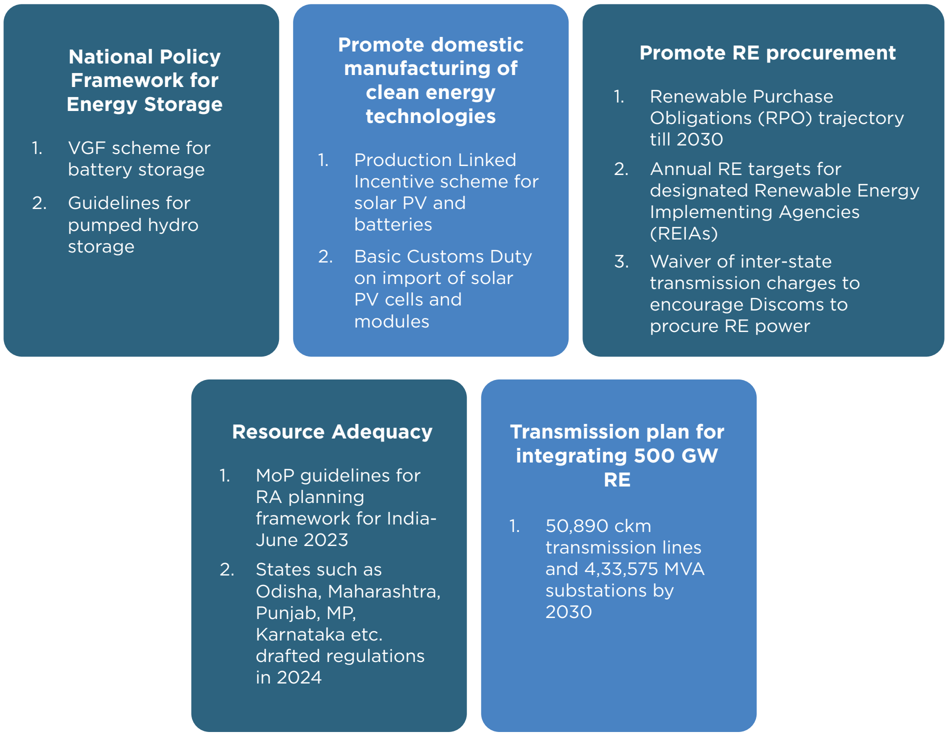

FIGURE 1: Notable policies to promote RE deployment in India

Increasingly, RE plus storage projects are becoming competitive with coal power- solar plus battery storage projects in particular can be built much faster than new coal capacity. With increasing grid integration of renewables, grid-scale energy storage is critical for shifting solar energy to peak hours, grid balancing, improved transmission utilization, etc. CEA's National Electricity Plan (Generation) estimates that the grid would need 74 GW of energy storage (pumped hydro and battery storage) by 2031-32, however India has installed 110 MW battery energy storage systems (BESS) and 4.75 GW of operational pumped hydro storage (PHS) capacity as of March 2024 (CEA 2025). To expedite the development of energy storage, GoI has introduced several policy measures, such as the national policy framework for promotion of energy storage, guidelines for development of pumped hydro storage projects and viability gap funding (VGF) scheme with an outlay of INR 9400 crores to develop 4000 MWh of BESS projects by 2030-31 (PIB 2023b). RE hybrid and energy storage integrated tenders have been announced to support Discoms with round the clock firm and dispatchable power- though uptake of these tenders has been low. In 2024, SECI introduced solar plus storage tenders to meet evening peak demand; the tender of 600MW/1200MWh discovered the lowest tariff of INR 3.41/kWh, and the tender of 2 GW solar with 1 GW/4 GWh of storage capacity discovered a tariff of INR 3.52/kWh (SolarQuarter 2024).

TRENDS IN PACE OF RE DEPLOYMENT

With all the policy measures in place, renewable energy capacity (excluding large hydro) increased from 95 GW in March 2021 to 166 GW in January 2025. The annual addition of RE has been in the range of 14 to 18 GW in this period, except in 2024, which saw a jump in capacity addition of 28 GW (PIB 2024b). This is primarily on account of significant evacuation infrastructure going live in 2024, which enabled projects in the pipeline to get connected. However, to achieve 500 GW of clean capacity by 2030, of which ~80GW is projected to be nuclear and large hydro (CEA 2023a), the sector needs to install an additional ~254 GW of renewable capacity by 2030. This implies that we need a pace of **installing ~40-45 GW/year, or double the ongoing pace of deployment**.

Currently, solar and wind contribute over 90% of the total RE capacity (MNRE) and this trend is expected to continue. While PM Surya Ghar Muft Bijli Yojana has accelerated adoption of solar PV rooftop systems, it amounted to an addition of 4.6 GW in 2024 (PIB 2025). Bulk of the 2030 target capacity is expected to be at commercial/utility scale. Accordingly, our analysis in this report focuses on the challenges and opportunities for deployment of utility scale solar and wind projects.

Several states have ramped up solar and wind deployment, though the momentum vastly differs from state to state. An overview of solar and wind capacity addition in top 6 states as per total energy consumption from FY 2021-22 to FY 2024-25 is presented in figure 2. By January 2025, these states have about 115 GW of solar and wind capacity combined, representing more than 70% of the total installed capacity (MNRE).

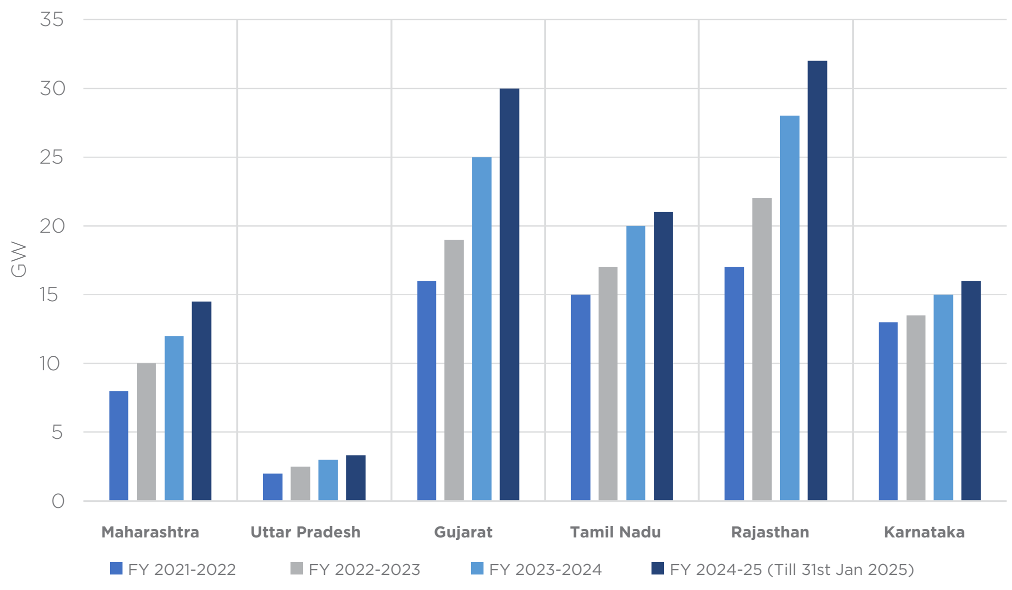

FIGURE 2: State-wise cumulative installed capacity of Solar and Wind from FY 2022 to FY 2025

Source: MNRE year wise achievements

To meet the 2030 target, RE capacity combined in these states is projected to more than double from current 2025 levels, except for Maharashtra and Uttar Pradesh where capacity is set to more than quadruple, as enlisted in Table 1 (Abhyankar et al 2025b). In Maharashtra, Gujarat and Rajasthan, project pipeline through FY 2027 is an average of 10 GW/year (RE Navigator Dashboard). However, for Karnataka and Uttar Pradesh, the RE project pipeline is about 2.7GW and 72 MW respectively (India RE Navigator Dashboard), therefore lagging the pace of capacity addition needed to achieve 2030 goals.

TABLE 1: State-wise cumulative solar & wind capacity in 2025 and projected capacity in 2030

State	Cumulative RE Capacity (January 2025) (Wind and Solar) GW	Projected RE capacity 2030 (Wind and Solar) GW
Maharashtra	14.5	56
Uttar Pradesh	3.3	22
Gujarat	30	69
Tamil Nadu	21	45
Rajasthan	32	52
Karnataka	16	38
Total	116.8	282

Source: MNRE and Abhyankar et al 2025b

STATUS OF RE TENDERS

In 2024, MNRE announced a scheme with an annual trajectory of 50 GW RE capacity to be tendered from FY 2023-24 to FY 2027-28. This scheme is expected to announce tenders of 250 GW capacity RE over these 5 years, with 50 GW dedicated for wind projects. The scheme identifies four renewable energy implementing agencies (REIAs) namely; NTPC, SECI, SJVN and NHPC, directed to announce tenders, organise auctions and facilitate the process of power purchase agreement (PPA) and power sale agreement (PSA). This initiative provides a long-term vision to the industry and hence is expected to help manage developer risk premium.

However, under-subscription of tenders and slow PPA signing continues to be a risk. For example, in the first year of MNRE's scheme (in FY 2023-24), the REIAs announced solar tenders totalling 42 GW capacity, but only 50% of this announced capacity was auctioned in FY 2023-24 (Mercom India 2024b). Though the tendered capacity almost tripled from year 2022 to 2024, the auctioned capacity has not kept pace with the tenders issued.

Figure 3 provides an overview of the mismatch in tender issuance and auctioned capacity for different RE technologies. In 2023, for example, 9.6 GW of solar PV-wind hybrid tenders were issued out of which only 14% of the capacity was auctioned. Similarly, 9.8 GW of wind tenders were issued, of which only 13% of the capacity was auctioned (India RE Navigator Dashboard).

The data on PPA/PSA signing is scarcely available to understand the trends in tender conversion. There is about 50-65% conversion from auctioned capacity to PPAs/PSAs, based on discussions with stakeholders and available data (ET Energy World 2024). The time lag between award of projects to PPA signing is about 6-8 months, down from up to 10 months in 2023. As a result, at the time of writing this report, about 20 GW of auctioned capacity by SECI has no signed PPAs. We examine potential reasons in a later section of this report.

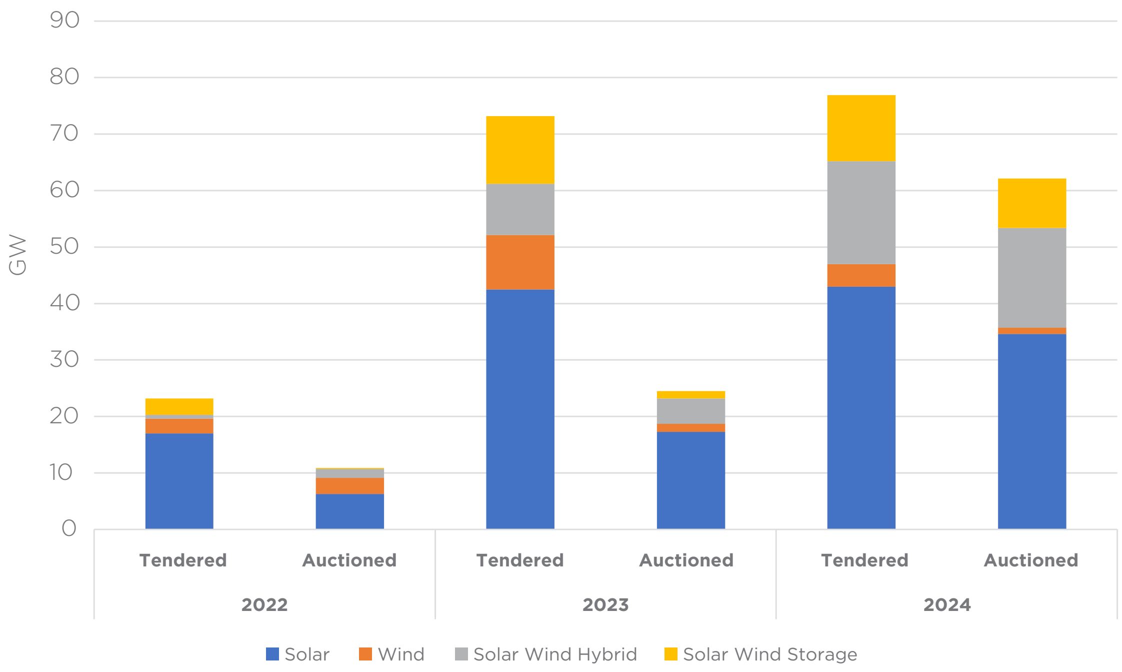

FIGURE 3: Year wise tenders issued and auctioned capacity for key technologies

Source: India RE Navigator Dashboard

OBJECTIVE AND SCOPE

The objective of this paper is to identify key barriers slowing down the pace of RE deployment in India and provide potential solutions and/or recommendations that could unlock these barriers. In addition to secondary research, the process of identifying these ecosystem barriers and opportunities included interactions with 20 experts/stakeholders across central government agencies, private sector, industry associations, state government officials, civil society, etc. The consultations were conducted in Q2 2024, and the list of organisations consulted is enclosed in the Annexure.

The stakeholders acknowledged the supportive policies and regulations in place to drive the growth of renewables in the country. While there are several factors that hinder renewables deployment, we select a few major challenges which if addressed could move the needle on the ground significantly. The need for holistic planning, coordination and convergence across centre and state level agencies has emerged to be an underlying theme across all the factors, and needs an intentional ecosystem enabler improvement effort.

The following factors and related issues, current policy landscape and potential solutions are discussed in this paper:

1. **Land acquisition**
2. **Transmission planning and availability**
3. **Supply chains and domestic manufacturing**
4. **Resource planning and procurement at the state level**
5. **Deployment of energy storage**

Of these, addressing the first two will have a direct impact on project implementation timelines in the short run, whereas the latter three are ecosystem enablers, which would take some time to address, and thereafter unlock the pace of deployment in the medium-term.

LAND ACQUISITION

Utility scale RE projects are land intensive- on average, about 3.5 acres (1.4 hectare) of land is required to set up 1 MW capacity of solar PV and about 1 acre (0.4 hectare) per MW turbine is the land footprint for wind projects (turbine only). For India to achieve 254 GW of additional RE by 2030, about 3 lakh hectares of land would be required.

Prior analysis on land requirement for RE demonstrated that as higher amounts of RE capacity are installed, projects will be developed in areas of higher population density, thereby increasing the land price per MW installed as well as running into land conflicts (Mallya et al 2024). Additionally, it was found that while several states have provisions for deemed land conversion, most RE policies did not include provisions for 'wastelands'

The land cover atlas of India classifies land into categories such as cropland, built-up land, woodland, water bodies, etc. across all Indian States (National Remote Sensing Centre. 2024). Wasteland is defined as degraded land that can be brought under vegetative cover with reasonable efforts and which is currently underutilized. It includes rocky areas, scrub lands, mining dumps, gullied lands, sand dunes etc. In table 2, we estimate the amount of land needed for select states to achieve the 2030 projected RE capacity. Thereafter, % of wasteland that could meet this land requirement is assessed based on the state-wise wasteland cover for 2021-22. This analysis provides an approximation of the land requirement. However, challenges of land acquisition remain and ground truthing is needed.

TABLE 2: State-wise percentage of wasteland required to meet the goals of 2030

State	Projected solar and wind capacity by 2030	Total Land (required for solar and wind capacity 2030-hectares)	% of wasteland (for RE by 2030)
Maharashtra	58	81,727	4
Uttar Pradesh	22	44,830	4
Gujarat	63	82,773	2
Tamil Nadu	45	52,244	10
Rajasthan	50	80,279	1
Karnataka	39	56,266	6

Source: National Remote Sensing Centre, 2024 and author's analysis

For 4 of the top 6 states, less than 5% of wasteland is on-paper sufficient to install the required RE capacity by 2030. However, concerns have been raised over the definition of "wasteland" particularly when open natural ecosystems (ONEs)[6] overlap with 70% of wastelands classified by Government of India (The Times of India 2023). States of Gujarat, Maharashtra and Rajasthan have the largest number of ONEs in India and have the highest potential of RE, therefore the impacts on ecological/biodiversity could continue to be a concern for the deployment of renewable energy projects on this land category.

Land being a state subject, state governments have a big role to facilitate acquisition or leasing of land through enabling policies. Some states such as Maharashtra, with the Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) scheme, have provided farmers an option to lease their farmland, which might be drought-prone and/or unirrigated with low agricultural yield. This provides an opportunity to enhance annual income for the farmer families.

Land acquisition challenges stem from a combination of factors, including lack of digital records, divergence between the record and current use, wide range of state-specific processes on land transfer, unorganized nature of land aggregators, etc. In 2016, the department of land resources launched a scheme on "Digital India Land Records Modernization Programme (DILRMP)" with an objective to develop a modern, comprehensive and transparent land record management system. By the end of 2023, about 95% Record of Right (RoR) under the computerization of land records has been completed, and several RE rich States have achieved more than 95% of digitisation of land records (PIB 2023h). This would provide the foundation for streamlined land acquisition or leasing.

It was envisaged that a solar park scheme could potentially help project developers to overcome challenges to acquire land and obtain necessary permits and clearances. The Government introduced the scheme on "Development of Solar Parks and Ultra-Mega Solar Power Projects" in 2014 with a target of 20 GW capacity by 2025-26, which was further enhanced to 40 GW in 2017. The projects were developed in collaboration with State Governments and CPSUs. As on 30th June 2023, about 50 Solar Parks of cumulative capacity 38 GW were sanctioned, against which 11 Solar Parks with aggregate capacity of 8.5 GW have been completed and 7 Solar Parks with aggregate capacity of 4 GW have been partially completed (PIB 2023c). About 1.70 lakh acres of land have been acquired and development thereof is in progress.

Details of solar parks at the state level are presented in table 3. The data indicates slow progress in states of Gujarat, Rajasthan, Madhya Pradesh and Uttar Pradesh- in these states a total of 5 GW capacity is installed against the 28 GW of sanctioned capacity. The ambitious target of 38 GW of solar parks has not been met, and several social, economic and ecological factors may have contributed to this outcome.

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6 Wastelands encompass diverse ecosystems such as grasslands, shrublands, and deserts. These ecosystems are often referred to as open natural ecosystems or ONEs and have ecological and social value.

Key issues include low compensation to land owners (Venugopal 2024), biodiversity and ecological constraints, unclear land acquisition policies (Rai 2023), increase in costs because of inhospitable terrain & lack of supporting infrastructure.

TABLE 3: State-wise solar park capacity installed vs sanctioned

States	Number of Parks	Sanctioned Capacity (MW)	Projects Installed (MW)
Rajasthan	9	8276	2901
Madhya Pradesh	8	4680	1000
Gujarat	7	12150	900
Uttar Pradesh	7	3730	266
Karnataka	2	2500	2000
Maharashtra	2	750	0

Source: PIB 2023c

Leasing of state government land for a period of 30 to 40 years has been the primary modality for setting up solar/RE parks but states have now expanded to other solar-wind hybrid and storage projects. Leasing of private land has also picked up as a model wherein the project developers reach out to the title holders for a lease. In some cases, developers continue to work with aggregators for acquiring the land.

Several states have announced favourable land acquisition policies for setting up RE parks/projects. In addition to the leasing models, these policies provide support for conversion of agricultural land to non-agricultural land, aggregation of land etc. Some of the key features of selected state-level land policies are listed in figure 4:

Uttar Pradesh

UP Revenue Code (Amendment) Bill, 2019:

1. Streamlined the process of converting agricultural land to non-agricultural land and could be leased out to solar power developers for 30 years.

Solar Policy 2022:

1. Directs for land banks to be created by UPNEDA in consultation with District Collector

Maharashtra

Mukhyamantri Saur Krushi Vahini Yojana (MSKVY) 2.0:

1. Provides for identification, procurement of revenue land and private land around the identified substations by MSAPL (within 10 km radius of the selected substations)
2. Land aggregation portal is established to provide Government and Private land information

Rajasthan

Rajasthan Integrated Clean Energy Policy (2024):

1. Private agricultural land can be acquired without conversion. Govt. land can be leased to RE developers.
2. Developers can establish RE Parks with approval. Rajasthan permits public-private partnerships, allowing developers to invest up to 50% equity.
3. Online approval portal planned for RE projects & SKAY portal for farmer-developer land leasing.

Andhra Pradesh

Andhra Pradesh Integrated Clean Energy Policy (2024):

1. NREDCAP aggregates and leases govt. & private land to developers for 30 years.
2. RE project land automatically gets non-agri status, removing extra approvals; dedicated portal for fast-tracked RE approvals.
3. State to develop REZs with plug-and-play infrastructure.
4. 50% exemption on wheeling/transmission charges for wind-solar hybrid projects (5 years).

Telangana

Telengana State Electricity Regulatory Commision (2025):

1. RE land gets automatic non-agri status & is exempt from ceiling limits.
2. Nodal agency to enable fast approvals via TG-iPASS or govt. portals.
3. Financial Incentives:
4. 100% stamp duty reimbursement for RE land.
5. No NOC required from Telangana Pollution Control Board.
6. Full water charge reimbursement for solar projects.
7. 100% electricity duty exemption for MSMEs (8 years)

FIGURE 4: Land policies of key states for renewable energy projects

Source: Author's compilation from State RE and land act policies

There is lack of uniformity across states for land acquisition policies for RE projects and significant differences can be observed in provisions of agriculture land conversion policies, statutory approvals, land lease charges, stamp duty exemptions for purchasing land and the nodal agency appointed for facilitating government/private land, etc. (Mallya et al 2024). As per interactions with industry stakeholders, other practical issues with land acquisition include complexities in aggregating land parcels due to issues of urbanisation and rising land costs, right of way, administrative clearances, encroachments, terrain etc.

POTENTIAL SOLUTIONS TO ADDRESS LAND ACQUISITION CHALLENGES

1. The **classification of wasteland in India needs to be streamlined**, potentially identifying land that is degraded or with low yield and doesn't directly overlap with ecological areas. Better coordination between the Ministry of Rural Development, Ministry of Environment and Forests and Ministry of New and Renewable Energy to assess and classify such land to enable utilisation for clean energy projects could simplify the process.

2. The **State Government's role, in particular that of the State Nodal Agencies (SNAs), in facilitating land availability and acquisition is crucial**. This can be observed in the best practices from Andhra Pradesh, Rajasthan and Uttar Pradesh in Figure 2 above. Many of the states have broader land policies, which need to be integrated with the state's RE policies. The approach for leasing of government land, private land and necessary charges and exemptions should be clearly outlined in the RE policies of the states with reference to land acts/policies of the state. Capacity building of and empowering the SNAs to be the one-stop-shop for land aggregation and leasing for RE projects could significantly reduce the friction in the process.

3. **Better coordination among different state departments**- coordination among state renewable energy development agency, revenue department, district collector and Discoms could streamline the process for developers. Clear responsibilities delineated for each state agency can expedite the clearance, allocation and aggregation of land. Identification of land banks and making this information available for developers/investors through an online portal could reduce delays in project implementation, e.g. PM-KUSUM in Maharashtra. The web-based database "Energy Maps of India" by NITI Aayog and ISRO, could map and integrate state-wise land use cover data, for example.

4. **Leasing of private land** has been a successful model for developers to acquire land. However, fair compensation/rent closely tied to market rates are needed to ensure wider and sustainable use. Land parcels that are unirrigated with low agricultural yields can be identified, and farmers educated on long-term leases to enhance family incomes, especially in regions with high farmer distress.

5. The Central and State Governments are promoting **other technologies to avoid the burden on land use**. Technologies such as floating solar PV, off-shore wind, agrivoltaics, solar PV rooftop would relieve the pressure on land for deployment of RE. For example, the estimated potential of floating solar power is 280-300 GW (Surbhi Goyal 2024), with a current sanctioned capacity of 2.1 GW. Madhya Pradesh is leading the development of floating solar PV projects. Agrivoltaic projects have also been demonstrated successfully across several states such as Maharashtra, Gujarat, Rajasthan and Telangana (Agrivoltaics Map of India). While these first few projects are relatively small-scale, a concerted effort to incentivize agrivoltaic projects could have the double benefit of increasing farmer incomes while deploying more solar capacity.

TRANSMISSION PLANNING AND CONNECTIVITY

Addressing the need for transmission infrastructure for evacuation of RE power, the Government of India initiated the **Green Energy Corridor (GEC) project** in 2015, that comprised of developing Inter-State Transmission System (ISTS) and Intra State Transmission System (InSTS) along with the setting up of Renewable Energy Management Centres (REMC). About 12,000 ckm of transmission lines have been constructed under the GEC-I for evacuating 14 GW ISTS and 19 GW intra-state RE capacity (Ministry of Power). About 10,750 ckm of transmission lines is under construction under GEC-II for evacuating 20 GW intra-state RE capacity. Given fast growing electricity load and emergence of new load centers across the country, there would be a need for additional investment in transmission capacity with or without RE capacity expansion (Abhyankar et al 2021).

While India has one of the shorter lead times for construction of transmission lines (about 3-4 years) as compared to advanced economies (IEA 2023a), to match the pace of renewable energy deployment, India needs to plan and build new transmission as quickly as possible. This is because the gestation period of building high-voltage transmission lines is much higher than that of building solar and wind projects. In view of this, **CEA has prepared a transmission plan for integrating 500 GW RE by 2030** which subsumes the transmission network developed under the GEC-I and II. The plan outlines the ISTS development required to integrate the additional solar and wind capacity of 236 GW by 2030, identified based on RE potential zones. The length of the transmission lines and substation capacity planned under ISTS has been estimated as 50,890 ckm and 4,33,575 MVA respectively, which is about 6 times the total transmission lines already built under the GEC-I (ISTS and InSTS) scheme over the last 8 years (CEA 2022). Discussions with stakeholders have revealed that HVDC lines which are more economical for long distance transmission (beyond 900-1000 kms) take about 4 to 6 years to build. Considering the majority of the equipment and material for HVDC systems is imported by India, supply chain constraints have and continue to cause delay in building these transmission lines.

In addition to the gestation time of building transmission systems, siting of transmission is equally important to ensure evacuation and grid integration of renewable energy in a cost-effective manner. As per CEA's transmission plan, there is about 33 GW of margin available at ISTS network in States of Uttar Pradesh, Odisha, Chhattisgarh, Bihar etc. but there is low deployment of RE projects in these States. Major reasons cited by stakeholders are the relatively high RE generation costs in these States (as compared with states of Rajasthan or Gujarat), and the waiver of transmission charges at the inter-state level.

Evacuation infrastructure from Rajasthan is fully utilized, as per industry consultations. Another reason for delay has been the ban by the Supreme Court on building overhead power transmission lines in the RE potential zone that coincided with the Great Indian Bustard (GIB) zone. Lifting of this ban in March 2024 (Economic Times 2024a) is expected to ease construction of transmission lines in Rajasthan.

Moreover, CERC introduced general network access (GNA) regulations in 2022 to facilitate connectivity and network access to the inter-State transmission system for generating companies or consumers. Several amendments in these regulations have been introduced to streamline the process to make these regulations suitable for RE developers connecting to the ISTS network.

Besides transmission planning, a major policy boost introduced by GoI in 2016 was the **waiver of ISTS charges to promote development of renewables** and encourage inter-state procurement of clean power. Several orders by MoP extended the ISTS waiver deadline and the waiver is expected to expire in June 2025. Since the off-taker did not pay any transmission charges for projects connected to the ISTS, the waiver led to a concentration of projects in a few RE-rich states such as Rajasthan and Gujarat. Such concentration has led to grid congestion, specifically for evacuation of power from these states, as well as under-utilization of planned transmission networks in other states. Building transmission systems across geographies and regions far from load centers has complications of right of way (RoW) and adds cost to the system too. Since the waived charges were socialized amongst states based on total drawl, it also resulted in disproportionate burden on states that had a higher share of thermal power vs RE. Moreover, in the presence of the ISTS waiver, projects connected to the ISTS network have taken precedence over those connected to the intra-state grid. While this strategy worked well to kick-start connection and management of large RE plants on the grid, with increasing share of clean energy in the resource mix, states would need to procure and manage new RE capacity on the state grid.

However, in 2023, the **first amendment in the CERC regulations for sharing of inter-state transmission charges and losses**, notified that the yearly transmission charges would be shared by the drawee designated ISTS customers (DIC) of the receiving region in proportion to their quantum of GNA and GNA_{RE}[7] (CERC, 2023). That is, irrespective of the type of electricity, transmission charges would be primarily based on total drawal by the offtaker. About 80% of transmission charges are based on GNA, while the remaining 20% or so are based on usage. This would simplify the calculation and allocation of transmission costs going forward, especially as the network is enhanced to meet the growing electricity demand. Therefore, the role of ISTS waiver as a subsidy to RE has been significantly scaled down.

7 GNA- General Network Access is the open access to ISTS granted under the Connectivity and General Network Access to the inter-State Transmission System Regulations, 2022

GNA_{RE}- General Network Access for RE- Open access to the ISTS granted for drawal of power exclusively from the renewable sources

CERC has also proposed a provision for 'Grant of Solar hours Connectivity and Non-Solar hours Connectivity through the same Transmission system' in the staff paper on GNA Regulations (CERC 2024). This is intended to address the low utilization of dedicated transmission lines to RE plants, by sharing the transmission capacity with another plant during non-solar hours. Appropriate utilisation of existing transmission assets and distributing future RE deployment across states would be important for keeping transmission costs low.

POTENTIAL SOLUTIONS TO TACKLE TRANSMISSION CHALLENGES

1. **Planning for BESS**- It is important that transmission planning accounts for energy storage systems that would store and discharge solar energy during peak hours. Optimal placement of storage systems could reduce the overall requirement for new transmission by reducing network congestion. A recent analysis shows it would be cost-effective to build the majority of 2030 BESS capacity in states such as Rajasthan, Uttar Pradesh and Maharashtra (Abhyankar et al 2025a). Co-locating storage with existing RE projects would also improve utilisation of the transmission assets.

2. **Coal-to-Solar generation swap**- Swapping coal generation with locally sited solar would facilitate use of the existing interconnections, ramp up RE deployment and keep coal plants online (which is critical to support the grid during the non-solar hours). During afternoon hours when solar is generating electricity, coal plant can be ramped down. As per initial assessment, there is 500 GW of solar potential near coal plants in India, with 97% of the coal plants having enough local solar capacity to replace all the coal generation (Paliwal et al 2024). Further, about 142 GW of coal capacity has a higher variable cost than locally sited solar LCOE. The interactive GIS tool identifies available land parcels near the coal units, and recommends optimum placement of solar plants. For NTPC plants, grid-reliability analysis concludes that up to 30% of generation can be swapped cost-effectively. Similar analysis needs to be repeated for select state-owned plants. State-level swaps need no regulatory intervention, while CERC has indicated a 50-50 sharing of cost-savings with the off-taker in case NTPC adds solar capacity to existing coal plants (Neelima Jain 2025).

3. **Reconductoring with advanced conductors**- Technology solutions are available that could increase the transmission capacity of the current grid, thereby enabling more RE capacity to be installed close to the existing network. Reconductoring with advanced ACCC conductors can double line capacities within existing RoW and such projects typically cost less than half the price of new lines for similar increase in capacity (2035 The Reconductoring Report). CEA introduced a draft paper on reconductoring of transmission lines in ISTS that specifies the planning and mode of implementation (CEA 2023c).

The paper highlights the factors to be considered for reconductoring (new conductor capacities/tower healthiness etc.), suggests a regulatory tariff mechanism (RTM) for reconductoring within the useful life of the transmission system and competitive bidding for reconductoring after 35 years. However, this paper does not include ACCC conductors, which have significant efficiency and cost benefits over other options. There have been a few projects undertaken by Tata Power on low-voltage lines in urban areas as well as a 400 kV project in Bangladesh (Wirecable 2024). A case for reconductoring high traffic lines and for using advanced conductors for new lines needs to be made. One of the leading manufacturers of ACCC conductors has opened a production facility in Pune, Maharashtra (Businesswire 2024).

SUPPLY CHAINS AND DOMESTIC MANUFACTURING

SOLAR PV CELLS AND MODULES

In 2019, India imported close to 90% of solar PV modules and cells, of which 80% were from China (PIB 2023d). However, the Indian Government has taken protective measures to reduce dependence on other countries for supply of solar PV modules and cells, through the introduction of safeguard duties (in 2018) and basic custom duties (in 2022).

1. GoI announced imposition of **basic customs duty (BCD)** of 40% and 25% on import of solar PV modules and solar PV cells respectively from 1st April, 2022 (MNRE 2022).

2. The **Approved List of Module Manufacturers (ALMM)** was initiated in 2019 (MNRE 2019) and includes the models and manufacturers of solar modules complying with the Bureau of Indian Standards (BIS). ALMM requires solar power developers to source modules from domestic manufacturers registered under ALMM and applies to all procurement done by the government and its agencies. The ALMM order of 2019 has been amended to include solar PV cells to be effective from June 2026 (MNRE 2024).

With these measures the module imports have seen a reduction of about 35% from 2019 levels (PIB 2023d).

In order to catalyze the domestic manufacturing ecosystem, GoI introduced the **Production Linked Incentive (PLI) scheme**. The PLI scheme was announced for high efficiency solar PV modules in April 2021 and aims to develop local manufacturing, employment generation and technological self-sufficiency. With an outlay of INR 24,000 crore, this scheme supports post commissioning manufacture and sale of solar PV modules for selected solar PV manufacturers for 5 years. The scheme is divided into two tranches;

a. tranche-I with an outlay of INR 4500 crore announced in April 2021 selected three bidders for setting up of 8.7 GW capacity of fully integrated solar PV module manufacturing units in December 2021 (PIB 2023e), and

b. tranche-II with an outlay of INR 19500 crore selected 11 bidders for setting up of 39.6 GW capacity of fully/partially integrated solar PV module manufacturing units in April 2023 (PIB 2023f).

While the domestic **manufacturing capacity for solar PV modules crossed 60 GW by December 2024** (PV-magazine 2024), operational capacity is estimated to be 50-60% for most manufacturers (IEEFA 2024a). The operational capacity of solar PV module manufacturing lags the annual demand for solar PV deployment, especially as the country aims to deploy close to 50 GW/year. India imported 16.2 GW solar modules and 15.6 GW of solar cells, while 24 GW of solar capacity was installed in 2024 (Mercom India 2024c). Further, exports of solar PV modules to other countries have increased significantly over the last couple of years, with about USD 1 billion worth of solar PV modules exported to the United States in FY 2022-23 (PIB 2024c). While this is good news for India's balance-of-trade, it might result in restricted supply for domestic projects, especially as the policies enforce domestic content requirements for all government projects.

As per the global solar market outlook, with support from current policy measures, the PV module manufacturing capacity in India is expected to grow from 60 GW in 2024 to 100 GW in 2026 and solar cell capacity is expected to grow from 23 GW in 2024 to 65 GW in 2026 (Solar Power Europe 2024).

Module prices in India: Even with BCD, the imported modules are typically cheaper than the domestic modules. Prices of domestic mono-crystalline modules were in the range of 38 to 31 USD cent/W during FY 2022-23 , while in the same period, prices of imported mono-crystalline modules were in the range of 30 to 21 USD cent/W, inclusive of BCD (India RE Navigator Dashboard). Hence, there is a difference of about 8 to 10 USD cent/W between the domestic and imported modules, or ~25-45% domestic premium.

Examining solar EPC cost for projects in India, modules and taxes account for about 70% of the total cost (India RE Navigator). Changes in the module costs or taxes ultimately have an impact on the overall solar tariffs. For example, it was projected that solar tariffs could see about 21% increase for projects that sourced duty free imported modules by Q1 2022 and those sourced in Q1 2023 after imposition of 40% BCD on modules. (IEEFA 2022). Solar tenders saw winning tariff jump from 2.17 INR/unit to 2.61 INR/unit from Q1 2022 to Q1 2023 (India RE Navigator).

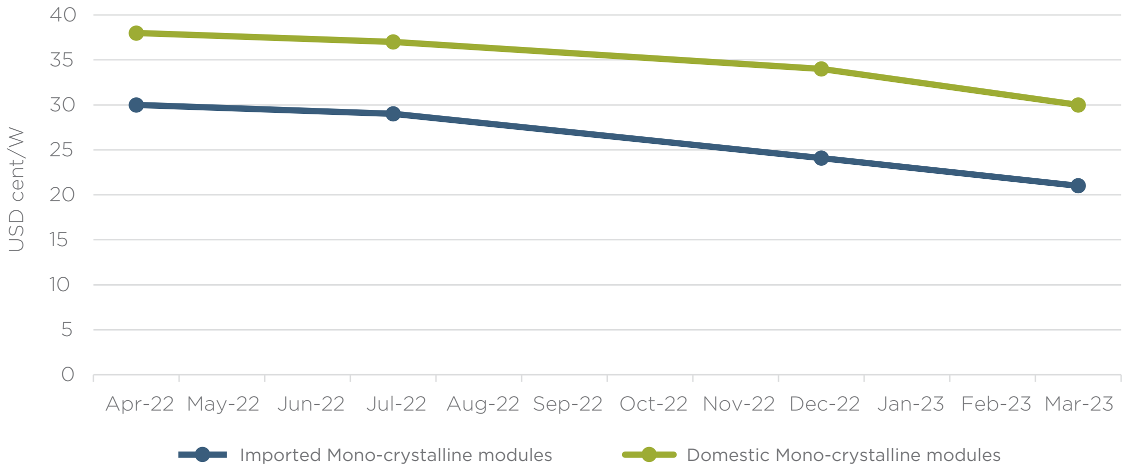

FIGURE 5: Price trends of imported and domestic mono-crystalline modules

Source: India RE Navigator Dashboard

Gujarat is the leading state for solar PV module manufacturing followed by Rajasthan and Tamil Nadu. The tariffs for high tension industry consumers in these states are in the range of INR 5.6/unit to INR 9.5/unit, with a cross subsidy component of >80% of the average cost of supply (ACOS) (REC India 2022)- this could have an impact on the competitiveness of manufacturing units.

Additionally, upstream components such as polysilicon, ingots and wafers are still imported heavily from China, thereby promoting calls for vertical integration. The Adani Group has set up a manufacturing facility for ingots and wafers, a first in India (Reuters 2024). Investment in manufacturing of products such as wafers as well as grid and transmission components to diversify supply chains has been a key point of discussion under the U.S.-India Strategic Clean Energy Partnership (White House 2024).

While the PLI scheme, ALMM and BCD could potentially promote the ecosystem for domestic manufacturing capacity, continued import of wafers and ingots, machinery for production of cells and modules, and other raw materials in conjunction with shortage of skilled manpower and low operational capacity are some of the challenges in front of industry.

BATTERY STORAGE TECHNOLOGIES

In December 2021, GoI announced technology neutral "**Advanced Chemistry Cell (ACC) Battery Storage PLI scheme**" with an outlay of INR 18,000 crore to incentivize domestic manufacturing capacity of 50 GWh of energy storage. The scheme is expected to strengthen the ecosystem for Electric Mobility and Battery Storage, reduce import dependence and foster innovation. As per the scheme guidelines, the beneficiary has to ensure achieving a domestic value addition of at-least 25% and incur the mandatory investment of ₹ 225 crore /GWh within 2 Years (at the Mother Unit Level) and raise it to 60% domestic value addition within 5 Years (Ministry of Heavy Industries- MHI). Three beneficiary firms have been selected and awarded a total of 30 GWh of capacity and for an additional 10 GWh of capacity, MHI has awarded the entire capacity to Reliance Industries Limited under the PLI scheme (PIB 2024d).

As per NITI Aayog's accelerated scenario, battery demand of 260 GWh is estimated by 2030, and therefore India would need to rapidly build 26 gigafactories with an average battery production capacity of 10 GWh per year (Mohanty et al 2023). While the PLI scheme aims to activate domestic capacity of battery manufacturing, the issues on supply chains need to be addressed. Currently, China dominates production at every stage of the upstream battery components and has 85% of global cell manufacturing capacity (IEA 2024a). Further, the mining of critical minerals for batteries is highly concentrated in a few geographies such as China, Indonesia and Democratic Republic of Congo (DRC). In order to address some of the supply chain issues and ensure self-reliance in raw materials for clean technologies, the GoI has announced the National Critical Minerals Mission in the Union Budget 2024-25. The mission aims to enable domestic exploration and production of critical minerals, overseas acquisition of critical minerals assets, PLI for critical minerals recycling and develop ecosystem for R&D and skilling requirements (PIB 2024e).

With recent cost reductions and performance improvements, lithium-ion batteries currently dominate battery use and contribute to 80% market share for new battery storage capacity in 2023 (IEA 2024a). Argentina, Chile and Bolivia, known as the Lithium Triangle, account for half of the world's known reserves of Lithium. India's Ministry of Mines has signed an agreement with state-owned enterprise of Argentina for exploration and production rights to lithium blocks (PIB 2024f). Additionally, India recently discovered ~6 million metric tons of lithium in the Indian state of Jammu & Kashmir and Karnataka (PIB 2023g).

However, the high degree of geographical concentration of minerals and processing technologies, geopolitical risks, limited production capacities, supply shortages and price volatility all together could impact the supply chain for batteries and India's ambitious targets to ramp up BESS in the power sector.

POTENTIAL SOLUTIONS TO ADDRESS SUPPLY CHAIN BARRIERS

1. **Long term policy certainty-** There is a need for long term visibility and stable policy to enable domestic manufacturing of solar PV modules, cells and other components. Policy certainty taking into account the impact of increased cost of projects due to BCD and ALMM is needed. Further, as capacities and capabilities of manufacturers develop, the ALMM list for solar cells is being reconsidered by MNRE and draft guidelines have been issued to make the scheme effective from June 2026.

2. **Support domestic manufacturing environment-** while the PLI scheme is a great tool to kick start domestic manufacturing, a sustained ecosystem effort is required to accelerate the momentum. In addition to incentives, focused skilling initiatives and subsidizing R&D programs could result in a virtuous cycle of innovation, employment generation, and high quality production for both domestic and export markets. Cost of power for these industrial units can be reduced via enhancing share of renewable energy, which can be facilitated through improved execution of Green Energy Open Access (GEOA) Rules. GEOA Rules have propelled growth in C&I open access, though implementation and coordination challenges remain (IEEFA, 2024b). Resolving process issues around GEOA as well as streamlining the registry would enable industry to procure cheaper power, that would indirectly support their competitiveness.

3. **Increased international cooperation-** Indian industry needs to build capacity on certain fronts such as developing process and machinery for ingots and wafers, advancing research and development of new battery technologies, training and capacity building, extraction and recycling capabilities for critical minerals, etc. This would require increased international cooperation with countries pioneering the technology, process, and machinery for such systems. For example, California-India cooperation on lithium could enable exchange of learnings from CA's Lithium Valley Corporation on discovery, extraction and production of lithium. The Salton Sea region has a huge deposit of Li, making California a leading global producer of this critical mineral for batteries (California Energy Commission 2024).

RESOURCE PLANNING AND PROCUREMENT BY THE STATES

REIAs, including SECI, have been conducting auctions, signing PPAs with developers, and thereafter re-selling the power to states/Discoms (through PSAs). This has resulted in competitive pricing of RE contracts, by keeping developer risk low. This worked well to kickstart the industry and ramp it up to 25+ GW annual deployment, nevertheless, more and more states want to structure and time procurement based on internal requirements. To achieve the goal of tendering 50 GW/year, the majority of announced projects by REIAs do not have an explicit buy-in from a particular state. Given lack of upfront commitment, there is typically a lag of ~6+ months between signing of PPA and PSA, which has also resulted in a huge stockpile of unsold inventory at SECI, for example.

As renewable energy penetration on the grid increases, the planning and procurement processes at the state level also need to be revised to prepare, manage and optimize for various resource types on the grid. While several policy and regulatory measures have been introduced towards this objective, it is an ongoing process and needs focused effort by the state agencies with support from the central government.

Renewable Purchase Obligations (RPO) was one of the earliest policy interventions adopted to activate renewable energy procurement by Discoms and other obligated entities (Shrimali et al 2020). The RPO trajectory has seen several amendments since 2016. In the recently announced amendment to the Energy Conservation Act, the Ministry of Power has specified the minimum share of consumption of renewable energy by the electricity distribution licensees as a percentage of total share of energy consumption for different types of non-fossil fuel resources. Thus the RPO trajectory announced till 2030 has widened the scope to include PHS (as part of other RE) and distributed solar PV (Ministry of Power, 2023). RPO targets for DISCOMs are notified by State Electricity Regulatory Commissions, and several states have adopted the new RPO trajectory. However, some of the states continue to follow the categories of solar and non-solar RPO and define their targets accordingly. There is a mismatch in the RPO targets between the trajectory prescribed by MoP and several states. For example, Uttar Pradesh, Maharashtra, Gujarat and Rajasthan have kept relatively lower RPO targets and have not met their own targets in the last 2-3 years (see Table 4 below). While Karnataka has the highest penetration of RE by % and has met the RPO targets, installation of RE capacity has stagnated over the last three years, in addition to states such as Maharashtra, UP and Tamil Nadu.

TABLE 4: Total RPO target and actual from FY 2022 to FY 2024 for key Indian States

State/Centre	Total RPO target and actual (in %)[8]					
	FY 2021-22		FY 2022-23		FY 2023-2024	
	Target	Actual	Target	Actual	Target	Actual
Gujarat	17	14.7	17	17.1	18.7	17.9
Uttar Pradesh	13	10.97	14	14.8	15	12
Maharashtra	17.5	13.95	19.5	16.49	22	14.99
Rajasthan	18.48	22	19.6	27	21.6	-
Tamil Nadu	21	10	24.60	26.14	27.07	18.7
Karnataka	22.5	27	23.75	26	27.07	-
MoP Target	**21.18**		**24.61**		**27.07**	

In the past, Discom finances have been cited as one of the reasons for not meeting RPO. Over the years, Discom efficiencies have improved with measures from the government through enabling policies such as the Electricity (Late Payment Surcharge and Related Matters) Rules 2022. There has been a substantial reduction of outstanding dues of state generating companies. Dues of INR 1.4 lakh crores in June 2022 have dropped to INR 70,000 crores by July 2024 (PRAAPTI Dashboard). Further improvement in AT&C losses, billing and collection efficiency have helped Discoms to improve their finances. As per the 12th annual integrated rating report by Power Finance Corporation, 42 state government power utilities have been rated, of which 9 utilities belonging to Gujarat, Haryana, Karnataka, Madhya Pradesh and Andhra Pradesh have earned a rating of either A+ or A (PIB 2024g).

States are meeting the rapidly growing electricity demand at high costs. During Jan 2023-June 2024, peak demand met stood >=99.5% for 17 out of 18 months while the energy requirement met was =>99.5% for 16 of those months (CEA Dashboard). India Energy Exchange (IEX) Green Market, comprising the Green Day-Ahead and Green Term-Ahead Market segments, achieved 989.6 MU volume during July 2024 as compared to 275.4 MU in July 2023, registering an increase of 259% YoY. Wholesale electricity prices have been on increase and have almost doubled from 2019 to 2023. Weighted market clearing price for the Day-Ahead-Market (DAM) was above Rs. 5/kWh for 59% of the peak hours (7pm-12 midnight) and above Rs. 10/kWh for 40% of the peak hours between May and October 2024 (author analysis using IEX data). Thus, states are willing to pay high prices for meeting the demand during peak hours, with blackouts no longer politically viable. However, Discoms can save on their costs by procuring electricity from solar+storage systems, as we elaborate in the sections below.

8 Data for Gujarat, Uttar Pradesh and Maharashtra compiled from regulatory orders and SNA websites. Data for Tamil Nadu, Rajasthan and Karnataka compiled from NITI Aayog's ICED dashboard (Solar+Wind procurement data), Prayas' RPO Portal, and other publicly available sources

RESOURCE ADEQUACY

While the demand is increasing at a faster-than-projected rate, procurement of thermal capacity to meet peak load without taking into account renewables or other flexible resources on the grid can result in an oversized system and inflated costs. Mechanisms that enable sharing of resources among states to maximize diversity benefits would help create a more cost-effective and robust system. Additionally, solar energy produced during the day must be shifted to evening hours to meet peak demand through energy storage. Therefore, planning and procurement practices need to account for renewables, flexible resources and sharing of resources to enable the states to meet their demand in a least cost manner. Project-level procurement cost is no longer an accurate indicator of the system-wide costs, that must be determined at the portfolio level. For example, if the peak demand (for a few hours in the day) grows faster than the base load, it would be cheaper to add solar+storage instead of adding new thermal base load supply which is then run at a 40% capacity factor. Therefore, portfolio-level optimization becomes key for a grid which has a diverse resource set with varying characteristics in addition to an evolving load curve.

To plan for an efficient and cost-effective grid, the Central government has laid out a vision for Resource Adequacy reforms. Resource adequacy simply means ensuring sufficient firm capacity on the grid to meet a reliability target for projected demand, that includes all supply and demand side options. **Guidelines for resource adequacy (RA) framework** were issued by the Ministry of Power in June 2023 to guide power system planning and procurement by Discoms to ensure reliable operation of the power system across all timeframes at minimum cost. With an overarching objective of ensuring reliable 24x7 supply, the guidelines cover determination of "optimal capacity mix required to meet the projected demand at minimum cost" and "a mix of long/medium- and short-term contracts to ensure security of supply to consumers at least cost". 75% of required capacity is purported to come from long-term contracts, 15-20% from medium-term contracts, while the remaining can come from short-term or power markets. CEA has completed state-level studies for Discoms up to 2031-32, and is in the process of revising them until 2034-35 (Powerline 2024).

Subsequent to the issuance of the guidelines, and the Model Regulations for RA Framework by the Forum of Regulators in June 2023 (FOR 2023), the State regulatory commissions of Madhya Pradesh, Maharashtra, Punjab, Jharkhand, Odisha and Karnataka have published draft RA regulations. Implementation of RA frameworks and compliance by DISCOMs would be a key step in preparing the ecosystem for a growing penetration of variable renewable energy with fast evolving economics on the grid. Accurate and agile demand forecasting combined with capacity building of state agencies to move to the new process would be needed to ensure success of these reforms.

POTENTIAL SOLUTIONS TO STREAMLINE PLANNING & PROCUREMENT

1. **Technology neutral RPO trajectory:** The Central Government has utilized RPO effectively since its inception in 2003, catalyzing growth of industry and renewable capacity deployment. This was critical in the early years, given renewable energy was more expensive than thermal. However, given the fast-changing economics of various technologies and the specific geographical distribution of renewable resources such as wind and hydro, moving to a technology-neutral RPO would have several advantages.

   First, it would leave the choice to the states to meet the total RPO with locally optimum resources. For example, wind in Tamil Nadu, solar in Rajasthan and hydro in Himachal Pradesh. The latest yearly trajectory from MoP might be too detailed for the states, given the diversity of resources. It is noteworthy that several categories are fungible, such as hydro with wind, thereby beating the purpose of technology-specific numbers. At the same time, the cost of maintaining and reporting on categories with targets of 1-3.5% by 2030 might be disproportionately high. The objective of maintaining a diverse portfolio of grid resources by encouraging deployment of specific technologies can be achieved with production incentives or subsidies instead of mandates. For example, the budgetary support for enabling infrastructure for hydropower plants, as announced by MoP in September 2024 (Ministry of Power 2024b).

   Second, a technology-neutral RPO would bring down the total cost of meeting the targets which would enable higher buy-in from the Discoms (and other obligated entities) and thereby result in higher likelihood of RPO compliance. As the penetration of renewable energy on the grid increases from current level of ~15% to ~43% by 2030 (as per the MoP notification), total cost of integration can be minimized by letting the market decide the cheapest portfolio of clean resources to meet the given demand in a state

   Additionally, it is critical to have accurate data for improved monitoring. A monitoring mechanism for RPO compliance that aggregates data at the state level and transmits to a central agency/dashboard could bring about ease of monitoring and transparency. Currently, the mismatch between state level and central level RPO trajectories and categories adds to the challenge of monitoring for compliance. Simplifying the framework would have this added benefit of improved and efficient monitoring and compliance.

2. **State-level venue for RA planning**: State-level RA frameworks would ensure grid reliability by establishing a regular process of planning for firm capacity needed. Nevertheless, this would need to be closely coordinated with resource assessment and procurement to support cohesive implementation. The Model Regulations for Resource Adequacy Framework outline the different roles and responsibilities of the state Discoms, transmission utility, load despatch center, etc. The onus for determining the capacity requirement and the resource mix has been put on the Discom. This might work well for states with one or two Discoms, but could be suboptimal for states who have several Discoms including smaller ones for urban areas, such as Karnataka. A state level procurement agency (such as GUVNL for Gujarat) or a planning agency (such as STU) might be the right venue for this exercise. This would enable optimization of resources on a larger geographical area.

   As procurement moves from a mix of coal and hydro to a diverse portfolio of thermal, renewable and energy storage resources, new capabilities would be required at the state level. It is imperative that the sector invests in building capacity at the state level through training on RA framework implementation.

   Several recommendations on various components of the RA planning exercise including methodologies for RA credits, duration based capacity credits, seasonal and regional adjustments, performance based and probabilistic adjustments, etc. can be found in a forthcoming report by the IECC team (Abhyankar et al 2025a).

3. **Streamlining process for PSA with REIAs**: REIAs need to take into account state-level RE procurement tenders, as well as RA plans to align with state procurement cycles. Seeking upfront interest/buy-in from a state could significantly reduce process time between PPA and PSA, as well as discover cheaper price points by containing risk premiums for specific states. While more states are interested in conducting auctions for projects to connect with the intra-state grid, a combination of capacity, intra-state transmission planning, state Discom financial health and resource requirement would determine success. From a developer perspective, balance between offtake risk and longer project cycles is required. This is possible if states with high-rated Discoms conduct auctions at the state level, while others continue to procure via SECI and other REIAs.

DEPLOYMENT OF ENERGY STORAGE SYSTEMS

Grid-scale energy storage would be critical to integrating large amounts of renewable energy into the grid. Primary role of energy storage would be to shift the solar energy generated during daytime to peak hours in the evening. Without energy storage, renewable energy would not be able to meet the demand during the evening hours, necessitating addition of new base load capacity, which would then be run at low capacity factors (Abhyankar et al 2025a). Additionally, it can provide benefits such as higher utilization of transmission assets, ancillary services, capacity value on the grid, etc.

Li-ion battery prices have dropped by over 90% over the last decade, and have beaten all forecasts. In China, LFP pack prices are now lower than $75/kWh, and manufacturing capacity is 5000 GWh/year, which is more than double the current global demand (BNEF 2024).

In India, SECI and a few states have conducted reverse auctions for battery storage in a variety of formats over the last three years. As of December 2024, about 110 MW of Battery Energy Storage Systems (BESS) and 4.75 GW of PHS projects are operational in the country (CEA 2025), while 10 GW of BESS (RE plus battery and standalone projects) and 18 GW of PHS projects are under various stages of development (RE Navigator Dashboard).

The pipeline of projects has grown with increased policy support for energy storage. In July 2022, MoP notified an RPO and Energy Storage Obligation (ESO) trajectory, establishing a roadmap through 2029-30 (Ministry of Power 2022). This trajectory mandated a gradual increase in grid-scale energy storage from 1% of total electricity consumption in FY 2023-24 to 4% by 2029-30, with annual increments of 0.5%. This would be equivalent to ~250 GWh of energy storage by 2030, based on CEA's load forecasts. However, the subsequent RPO notification under the Energy Conservation Act did not include ESO as a category (Ministry of Power 2023a). Hence, it is unclear if the ESO trajectory is being continued or/ and enforced.

MoP issued a National Policy Framework for Promoting Energy Storage Systems in August 2023 (Ministry of Power 2023c). This framework incorporated several incentives such as waiver of inter-state transmission charges for BESS, introduction of a high-price Day-Ahead Market, etc. The Viability Gap Funding (VGF) scheme, notified in December 2023, provides an outlay of INR 9400 crores to develop 4000 MWh of BESS projects by 2025-26 (PIB 2023b). As per the guidelines, VGF of up to 40% of capital cost for BESS shall be provided by the Central Government.

The BESS Implementing agency (such as SECI) would be responsible for charging power of BESS and discharge of power from BESS during the pre-declared high-demand and stress hours (Ministry of Power 2024a). Waiver of inter-state transmission charges is also available to BESS projects commissioned by June 2025.

Central Electricity Regulatory Commission (CERC) Ancillary Services Regulations notified in January 2022 allow ESS to participate in the Ancillary Services market (by providing Secondary and Tertiary Reserves), creating additional revenue streams for ESS operators. In May 2024, CERC also issued an order under Petition No. 249/MP/2023, setting a procedural framework for the scheduling, metering, accounting, and settlement of a pilot BESS project. These frameworks are building the regulatory foundation for a novel type of asset on the grid.

Discoms have increasingly demanded innovations in RE tender design to suit their demand profiles and easier grid integration. Consequently, the REIAs introduced hybrid tenders with relatively higher CUF requirements, Round the clock (RTC) and firm and dispatchable renewable energy (FDRE) tenders to enable power procurement on a “demand-following” basis, incorporating assured peak power and/or RTC power (as per specified capacity factors). Since the guidelines of FDRE projects with ESS were introduced in June 2023, FDRE and PHS tenders accounted for 91% of the entire ESS tender issuance in 2023 (JMK Research and Analytics 2024). The price discovery of FDRE tenders remains in the range of INR 4-5/unit, marginally higher than RTC tenders. However, states have been unwilling to sign PPAs at those price points. While in some cases 80% annual CUF (e.g. in an RTC tender) might not guarantee supply during peak demand hours, in other cases, strict load following requirements can add a significant cost premium.

On the other hand, co-locating storage with solar can be a cost-effective solution for shifting daytime solar power to evening peak hours. Sharing of BoS and the interconnection can result in savings of up to 20%. In 2024 SECI concluded two auctions of 2 GW of solar with 1 GW/4 GWh of storage capacity and 1,200 MW of solar PV combined with 600MW/1,200MWh of BESS, both resulting in record low prices discovered of INR 3.52/unit and INR 3.41/unit respectively (Mercom 2024e). REIAs such as SJVN and NHPC have since announced tenders of 1.2 GW of solar capacity with 600MW/2400MWh and 600MW/1200MWh of BESS respectively. Additionally, CEA has also published an advisory on co-locating 2-hour storage equivalent to 10% of installed solar capacity in future tenders (CEA 2025). However, this amounts to 4% of storage capacity by MWh of solar energy produced, and might not be sufficient to propel the development of BESS.

The pace of deployment of energy storage would need to take a step up to ensure renewable energy can meet load requirements. A total of 61 GW/218 GWh of energy storage is projected to be required by 2030, with BESS capacity of 51 GW and PHS of 9 GW (Abhyankar et al 2025a). States such as Rajasthan, Uttar Pradesh, Maharashtra and Telangana are expected to be the leading states for battery storage installations by 2030.

Given the high capex needed for PHS, and long gestation period combined with construction delays in projects underway, significant additional capacity (beyond 9 GW or so by the end of the decade) is unlikely to be added. Recent IECC analysis also suggests that peak power shortages to the tune of 20-40 GW are expected by 2027 even if all the thermal & hydro capacity currently under construction comes online as planned (Abhyankar et al 2024). It is estimated that 100-120 GW of new solar, of which about 50-100 GW is co-located with 16-30 GW x 4-6 hours of storage, could potentially avoid evening power shortages.

Current barriers to BESS procurement include missing regulatory incentives and gaps in integrated planning and procurement process at the Discom/state level. This results in confusion around how much storage capacity is needed, how solar+storage can avoid new expensive coal, and how those storage assets should be operated. The Resource Adequacy reforms are a positive step in this direction.

POTENTIAL SOLUTIONS FOR RAPID DEPLOYMENT OF BESS

Given the rapidly growing electricity demand, it is critical that installation of battery storage keeps pace to avoid peak shortages over the next few years. Co-locating 2-4 hours of BESS with solar would result in cost savings due to shared infrastructure and make such projects competitive. While the Resource Adequacy framework will take time to operationalize procurement at the state level, in the short to medium term, co-located battery storage could be supported via a mandate or VGF. Mandating/incentivizing 2-hour storage of 50% solar capacity for a subset of upcoming GW scale solar projects would address this gap, without new transmission build-out. Adding BESS to installed or under construction RE projects would also enhance the utilization of transmission infrastructure. Alternatively, the existing VGF policy could be expanded in scope to include BESS co-located with solar plants, implemented by REIAs, which simplifies the project by eliminating the requirement for contracting of charging power.

IECC team's forthcoming study assesses optimal locations, duration, technologies and economics of energy storage for India's grid through 2032 (Abhyankar et al 2025a). The regulatory framework might need to explicitly enable BESS to stack revenue-streams for improved margins and reduce developer risk. This requires assessment of value streams such as load shifting, peak demand support, meeting RA capacity requirement, frequency regulation and other ancillary services, and improved transmission utilization. Adding battery storage at substations procured and operated by grid operators could help avoid transmission investments. Integrated resource planning and procurement at the state level would be the foundation, enabled by capacity building of state agencies.

CONCLUSION

The global renewable power capacity is expected to triple by 2030 and for India this capacity is expected to more than double from 2024 levels to achieve the target of 500 GW of non-fossil capacity by 2030. India has made strides towards the 2030 goal, by achieving 166 GW of RE and 220 GW of clean capacity by January 2025 with the support of robust policy and regulatory framework. However, to meet the 500 GW goal, India needs to double the pace of deploying RE capacity, from ~20-22 GW/year (average over the last three years) to ~40-45 GW/year.

Key barriers that have slowed the pace of RE deployment in India include aggregation and acquisition of wasteland/suitable land parcels, mismatch in transmission planning with RE deployment, delayed build-out of domestic manufacturing and supply chain of clean energy technologies, lack of integrated resource planning and procurement at the state level, and lagging installation of battery storage systems. Institutional capacity at the state/Discom level and inadequate coordination among various central/state agencies is a broader challenge underpinning the above. However, a mix of policy, regulatory and technological solutions could help address these challenges.

Digitisation of land records, innovative land leasing models and simplified land policies are key steps towards streamlining land availability for renewables. A more empowered and skilled SNA to facilitate land aggregation for RE projects could streamline land acquisition, and enable best practices exchange among the states. While transmission planning has been key to enabling renewable energy integration, advanced reconductoring technologies and swapping coal generation with locally sited solar could further optimize the use of existing transmission infrastructure. Long-term policy certainty along with international cooperation could foster innovation, boost domestic manufacturing, and help build resilient supply chains for clean energy technologies. As the states manage evolving demand patterns (intra-day, seasonal, etc.) and cater to new power loads such as EV charging, air conditioners/cooling demand, data centres, domestic manufacturing etc., it is critical to lay the foundation of integrated resource planning and procurement, streamlined with the current rollout of resource adequacy reforms. This will enable states to assess their least-cost portfolio and plan resource buildout to meet the growing demand. Battery storage co-located with solar plants would help meet the peak power demand in off-solar hours. Incentives along with regulatory and market reforms would bring BESS deployment to the required pace. Capacity building at various state agencies and Discoms would be essential. Addressing these key barriers can significantly accelerate the overall pace of RE deployment to meet the 2030 targets.

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APPENDIX

LIST OF STAKEHOLDERS INTERVIEWED

Organization	Contact	Designation
Ministry of Power	Hemant Pandey	Chief Engineer (R&R)
Ministry of New and Renewable Energy	Dinesh Jagdale	Joint Secretary
Central Electricity Authority (CEA)	Ammi Toppo	Chief Engineer
Central Transmission Unit (CTU)	Kashish Bhambhani	General Manager
Central Electricity Regulatory Commission (CERC)	Dr. S.K.Chatterjee	Chief (Regulatory Affairs)
CERC	Shilpa Agarwal	Joint Chief (Engineering)
India Energy and Climate Center (IECC)	P. K. Pujari	Advisor ex- Chairman CERC
Solar Energy Corporation of India (SECI)	R.P.Gupta	Chairman & Managing Director
SECI	Pratik Prasun	Senior Manager
National Solar Energy Federation of India (NSEFI)	Subrahmanyam Pulipaka	CEO
Tata Power	Dr. Praveer Sinha	Managing Director
Adani Green	Manish Karna	Head- Business Development
Avaada Group	Praveen Golash	Assistant Vice President (Chairman's Office)
JSW Energy Ltd	Rakesh Rathore	Business Development
EY Parthenon	Abhishek Ranjan	Partner - New Energies
GUVNL	Jai Prakash Shivhare	Managing Director
Government of Tamil Nadu	Vikram Kapur	Former Additional Chief Secretary
Maharashtra Energy Department	Prashant Badgeri	Deputy Secretary
Lawrence Berkeley Lab	Dr Jiang Lin	Scientist
Prayas Energy Group	Ashwin Gambhir	Fellow
Idam Infrastructure Private Ltd	Balawant Joshi	Managing Director