PERSPECTIVES ON CHALLENGES AND EMERGING RISKS IN INDIA'S UTILITY-SCALE SOLAR

2014–2024

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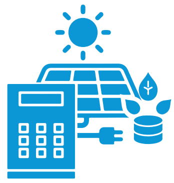
KEY HIGHLIGHTS

15%

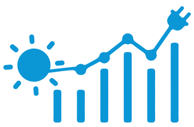
Solar energy is the leading contributor to clean energy in India, with its share of total installed capacity rising from **1% in 2014 to 15% in 2024.**



The reduction in **project capital costs** for solar projects has emerged as a dominant factor in scaling solar. This trend is expected to continue in this decade as well.

3 states

The performance of Renewable Purchase Obligations (RPO) by DISCOMs have been very dismal across states, with only **three states meeting the compliance** in FY 2023.



There is a strong requirement of **capacity adequacy planning exercises** by the DISCOMs based on emerging power demand. Concerns from land-use change from solar energy suggest requirement of land-use impact assessment to integrate further capacity.

88%

There is a concentration of solar projects in few states in India. **Top 10 states** account for **88 per cent** of the total solar energy installed capacity, while only 2 states have met their targeted 2022 capacity, highlighting asymmetric development of solar even within states with comparable potential.

1. Introduction

India has experienced steady growth in renewable energy over the past decade, increasing its cumulative capacity from 36 GW in 2014 to 144 GW in 2024, not including large hydro power.[1] The growth in solar-installed capacity in India has been one of the fastest globally, the solar energy installed capacity in March 2014 was 2.8 GW compared to 84.3 GW in March 2024.[2] The 84.3 GW is further split between utility-scale solar (66.9 GW), rooftop solar (11.9 GW), off-grid solar (3 GW) and solar hybrid (2.7 GW). Currently, India is the fourth largest in renewable energy, fifth largest in solar (84.3 GW)[3] and third in terms of solar generation.[4]

Since 2014, the share of utility-scale solar in the country's total installed capacity has significantly increased. Currently, it is 14.57 per cent of the total installed capacity compared to 1.05 percent in 2014 (*see Table 1: Share of utility-scale solar as a percentage of total installed capacity in India*). The utility-scale solar segment has experienced the most rapid growth in renewable energy (RE) installed capacity. It now constitutes 44.8 per cent of the total RE-installed capacity in the country.

Table 1: Share of utility-scale solar as a percentage of total installed capacity in India

Year	Total installed energy (all sources)	Total utility-scale solar installed	Percentage share of UTS Solar as compared to total installed energy
FY 2014	248.5	2.6	1.05 %
FY 2015	274.9	3.6	1.31 %
FY 2016	305.1	6.3	2.06 %
FY 2017	326.8	11.5	3.52 %
FY 2018	344.0	20.5	5.96 %
FY 2019	356.1	26.3	7.39 %
FY 2020	370.1	32.1	8.76 %
FY 2021	382.7	35.6	9.30 %
FY 2022	399.4	45.7	11.44 %
FY 2023	416.0	53.8	12.93 %
FY 2024	441.9	66.9	15.14 %

Source: Adapted from CEA Installed Capacity, MNRE Physical Progress[5]

THE RISE OF UTILITY-SCALE SOLAR

The utility-scale solar facility mentioned in this report is one which generates power to feed directly to the electricity grid. The solar sector within renewable energy (RE) includes different deployment models, such as utility-scale ground-mounted systems and rooftop installations. In this report, 'utility-scale solar' refers specifically to large-scale, grid-connected solar installations, typically exceeding 5 MW, as opposed to smaller systems like rooftop solar or other minor installations. The terms is also used to refer to hybrid energy systems such as solar with wind, with or without storage options but meeting the central criteria of large-scale electricity generation feeding into the grid.

Table 2: Installed capacity and generation of utility-scale solar as a percentage of electricity generation over the years

Year	Fossil (coal + gas) in percentage	Combined solar in percentage
FY 2014	79.80	0.42
FY 2015	80.33	0.82
FY 2016	81.10	1.46
FY 2017	80.13	1.11
FY 2018	78.11	2.12
FY 2019	74.51	2.84
FY 2020	74.80	3.71
FY 2021	75.14	4.41
FY 2022	75.08	4.96
FY 2023	74.55	6.30
FY 2024	76.54	6.74

Source: Calculated from data in MNRE Physical Progress, Niti-Aayog Climate and Energy Dashboard, EMBER-climate[6]

The share of solar in the renewable energy sector is going to be dominant from this decade. Examining the projected increase in solar from both in capacity and generation mix, and trends such as expected compounded annual growth rates (CAGR) of 32–35 per cent between years 2022–27 in installed capacity, and 18 per cent growth in terms of generation as per the recent National Electricity Plan 2023.[7] Moreover, with solar power costs now matching the tariffs of newly-built coal plants, the energy landscape is poised for a shift towards renewables as the primary energy source. Within the renewable sector, solar energy is expected to emerge as the leading segment.

Various projections for growth of solar energy in the country suggest nearly 300 GW+ additions from this segment by 2030. The estimates are presented in the table below.

Table 3: Capacity addition projections from solar till 2032

Year	Projection for solar (GW)	Source
2026-27	185.5	CEA, National Electricity Plan 13 (2023)
2029-30	292.5	CEA, Report on Optimal Generation Capacity Mix (2029–30)
2031-32	364.5	CEA, National Electricity Plan 13 (2023)

Source: CSE calculations from various sources[8]

Table 4: Trends in solar tariffs based on benchmark capital costs of projects

Year	Solar tariffs (Rs/kWh)	Benchmark capital costs (crores/MW)
FY2014	6.67	6.75-7
FY2017	3.30	5-6
FY2020	2.36	3.5-4.5
FY2024	2.61	2.5-3.25

Source: CSE's Calculation from SECI and CERC data.

Additionally, the solar sector is anticipated to experience consistent capacity growth, driven by the revised 50 GW annual Renewable Energy Bidding Trajectory released by the Ministry of New and Renewable Energy (MNRE) in April, 2023.[9] Furthermore, the solar sector is expected to see steady capacity expansions, supported by the updated 50 GW annual Renewable Energy Bidding Trajectory announced by the Ministry of New and Renewable Energy (MNRE) in April, 2023.[10] Current trends, including the record 18 GW of solar installations in FY2024—the highest since 2014—suggest that solar will see the greatest capacity growth among clean energy technologies. It is projected to reach nearly 300+ GW by FY 2031.[11]

The electricity demand in the country has increased at a CAGR of about five per cent per annum during the 2017–22. During the 2022–27 and 2027–32 electricity demand is projected to increase at a CAGR of about 6.4 per cent per annum and 5.7 per cent respectively as per the National Electricity Plan 2023.[12] Trends in solar energy-based electricity generation show a growing share over the past decade, with data projections from the Central Electricity Authority indicating that it will reach 19–20 per cent by 2030, up from the current six percent. Thus, aligning solar power generation with rising power demand requires essential planning efforts that account for the increasing variability in electricity demand from rapid urbanization, industrial use, clean transportation, and the growth in residential consumption, particularly related to space cooling.

RENEWABLE PURCHASE OBLIGATION

Renewable Purchase Obligation (RPO) is the primary demand creation mechanism applicable on DISCOMs in states. This was done to promote uptake of RE-based energy and create demand in states. The RPOs are mandated by the Electricity Act, 2003. The power procurement entities have to procure power based on certain minimum of energy from distinct RE sources.

In terms of generation and final energy consumption by source, the share of solar energy has been steadily increasing since 2014, surpassing wind energy in 2020. To increase adoption of clean energy technologies and mandate power purchase from solar, the renewable purchase obligations targets mandated 10.5 per cent solar RPO by 2021 (*see Box above on RPOs)*. These targets were not met by nearly all the states except a handful (such as Karnataka, Andhra Pradesh, etc.). The Central Electricity Regulatory Commission (CERC) after 2019-20 constituted a special commission to specify new obligation targets beyond 2021. These have come into force as new RPO regulations applicable from April 2024 onwards. The deficit in meeting targets showcases shortfall in current generation as compared to planned generation in the same years.

IMPACT OF SOLAR UTILITY-SCALE PROJECTS ON INDIA'S 2030 RENEWABLE ENERGY TARGETS

It is pertinent to know that India achieved 125.1 GW against 175 GW in 2022, with solar sector (81.8 GW) driving growth in the RE sector. This sector's strong growth outlook calls for an examination of the risks that may stem from its current trajectory. In the ground-mounted segments, capacity additions from FY 2014 to 2018 were 17.1 GW and from FY 2019 to FY2024, it was 43.9 GW—a 2.5 times increase in five years, with a CAGR of 16.1 per cent, adding nearly 10 GW on an average annually. According to a Central Electricity Authority report[13] on Optimal Generation Mix 2030, India is targeting around 500 GW of renewable energy capacity by 2030, including nearly 300+ GW of solar energy. To meet such targets there has to be a net addition of nearly 50 GW annually. National Electricity Policy, 2023 has also provided intermediate targets for solar power which is 185 GW by 2026–2027 and 364 GW by 2031–2032,[14] highlighting the reliance and significance from ground-based solar energy which is planned to drive capacity additions in renewable energy in this decade.

The Ministry of New and Renewable Energy (MNRE) had set a target of 175 GW by 2022 which included an ambitious plan of 100 GW of solar energy. The 100 GW of solar energy target included 60 GW target from ground-mounted solar[15]. Overall utility-scale solar is projected to account for 34 per cent of total renewable energy installations from 2017–18 to 2022–23. While India fell short of its cumulative target of 175 GW by 2022–23, achieving only 125 GW—of which 56 GW came from solar utility—it underscores the significant reliance on utility-scale solar, accounting for nearly 45 per cent of the total renewable energy installed capacity during this period.

The annual growth rates of ground-mounted solar have shown inconsistent growth as indicated by the available data (*see Table 2: Share of utility-scale solar as a percentage of total installed capacity in India*). Currently, ground-mounted solar contributes nearly 44.8 per cent of the total renewable energy capacity. It is expected that by 2027, solar energy will contribute more than 78 per cent of all installed renewable energy in India. The current annual growth rates of under 20 per cent) (*see Table 10: High solar potential India States with dedicated renewable energy policies*) are inadequate to achieve the targets outlined in the National Electricity Plan 2023, which aims for an additional capacity of 185.6 GW by FY 2027. A lag in capacity addition will affect the growth trajectories till 2030–31. To address the slowdown in year-over-year capacity additions, a growth rate of at least 25 per cent will be necessary.

In 2014, the Indian solar energy market was still in its early stages, with low investor confidence in emerging technologies and concerns about long-term energy generation reliability. The solar market started expanding 2017 onwards with the promulgation of several market-enabling guidelines, schemes and policies that have helped the solar markets gather pace since and significantly reduced capacity addition risks. However, despite various facilitation measures, the overall targets for anticipated solar energy growth were not met in 2022 in several states. Given the planned solar energy additions leading up to 2030, it is crucial to thoroughly understand the challenges and risks associated with deployment.

Table 5: Targets set for the year 2022 and their achievement in 2023

Status from 2017–2022	Installed renewable energy (ex. large hydro)	Installed grid-connected renewable energy	Installed solar energy (on/off grid)	Installed ground-mounted solar	Installed grid connected solar capacity
Target scheduled in 2022	175	--	100	60	--
Targets achieved for FY 2023 (GW)	125.1	110	66.7	56	53.9
Target (2030)	500	--	300+	--	--

Source: Adapted from MNRE Year Wise Achievements, NEP 13, and PIB sources

Table 6: Annual capacity installed and annual percentage change from 2014–24

Year	Renewable energy installed capacity	Year-on-year installed capacity change (%)	Ground-mounted solar installed capacity in GW	Y-o-Y installed capacity change (%)
FY2014–15	39.9 GW		3.38 GW	-
FY2015–16	47	15.11 %	6.23	83.92%
FY2016–17	58.5	19.66 %	11.58	85.85%
FY2017–18	70.6	17.14 %	20.58	77.73%
FY2018–19	79.4	11.08 %	26.38	28.15%
FY2019–20	88.2	9.98 %	32.11	21.71%
FY2020–21	95.8	7.93 %	35.64	11.00%
FY2021–22	109.8	12.75 %	45.79	28.47%
FY2022–23	125.1	12.23 %	53.80	17.49%
FY2023–24	143.6	12.88 %	64.4	16.46%
Percentage growth from FY 2014–24	72.2 %		94.7%	

Source: CSE's calculation from MNRE physical progress

2. States and solar

CAPACITY ADDITION TRAJECTORIES HAVE BEEN CONCENTRATED IN SELECT FEW STATES

The location of solar power plants is dependent on correlational factors such as land availability, solar irradiance, position of power evacuation infrastructure, and enabling policies in respective states. Typically, the states with high integration of solar energy have prioritized their renewable energy policies and solar installation targets. The six leading states listed below account for more than 78 per cent of the total installed capacity of ground-mounted solar energy in the nation, while the top 10 states account for 88 per cent of the total. This highlights the concentration of solar energy distribution in the northwestern and southern regions of India.

Table 7 indicates that Rajasthan has the highest potential for solar utility in the country followed by Maharashtra, Madhya Pradesh and Andhra Pradesh. According to the CEA's transmission planning initiative aimed at integrating 500 GW of renewable energy by 2030, areas with significant renewable energy resource potential have been identified. These are the regions where there is availability of power evacuation under the Green Energy Corridor Scheme. The target setting exercise has to be more elaborative and consider solar potential in other states also. For instance, states like Maharashtra and Madhya Pradesh have harnessed

Table 7: 10 states with highest installed capacity of utility-scale solar

States	Capacity potential solar	Utility-scale solar (March 2024)	Percentage of potential utilized	Targets 2030
Rajasthan	142.3 GW	15 GW	10.5 %	60
Karnataka	24.7 GW	7.8 GW	31 %	9
Gujarat	35.7 GW	7 GW	19.6 %	-
Tamil Nadu	17.6 GW	6.9 GW	11.9 %	5
Telangana	20.4 GW	4.3 GW	8 %	10
Andhra Pradesh	38.4 GW	4.2 GW	7.9 %	33
Maharashtra	64.3 GW	3.7 GW	3 %	5.5
Madhya Pradesh	61.6 GW	3.5 GW	2.8%	6
Uttar Pradesh	22.8 GW	2.4 GW	1.9%	-
Punjab	2.8 GW	0.8 GW	0.6%	-

Source: Calculated from various PIB sources, and MNRE physical progress[16].

only three per cent of their solar potential and have significantly lower targets or exclusions from the current high renewable energy potential zone criteria used in the planning exercise. Nonetheless, there is substantial opportunity for both the central and state governments to set more ambitious targets for integration.

Table 8: Comparison of planned target versus achieved in 2022 goals of solar rich states with commensurate targets

States	2022 targets[17] for utility scale solar	Installed status in 2022 of utility-scale
Rajasthan	5.2 GW	11.4 GW
Karnataka	5.1 GW	7.2 GW
Gujarat	7.8 GW	5.3 GW
Tamil Nadu	8.1 GW	4.6 GW
Telangana	8.9 GW	4.2 GW
Andhra Pradesh		4.1 GW
Haryana	3.7 GW	0.26 GW
Punjab	4.2 GW	0.82 GW
Uttar Pradesh	9.2 GW	1.8 GW
Madhya Pradesh	4.9 GW	2.4 GW
Maharashtra	10.9 GW	1.6 GW
West Bengal	4.8 GW	0.1 GW

Source: Authors compilation from PIB, MNRE, CEA

* Approximations are taken for removing targets related with RTS or off-grid (if any) from the combined target

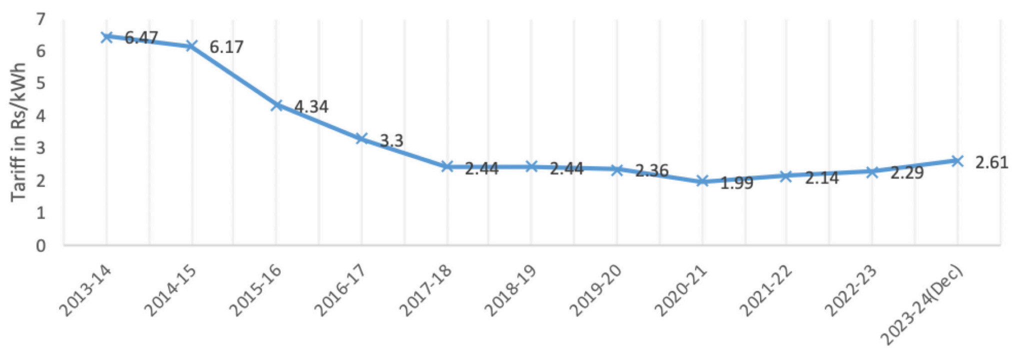
3. Factors driving utility-scale solar growth in the last decade

Continuous reduction in solar power tariffs: The consecutive decline in solar tariffs since 2014 has fundamentally transformed the market, making solar the most cost-competitive power source, even cheaper than conventional thermal power tariffs established through long-term power purchase agreements. For example, the tariff fell from INR 6.47/kWh in FY2014 to INR 2.61/kWh in FY24. This reduction was facilitated by the shift from the feed-in tariff mechanism (used before 2017) to reverse bidding (adopted post-2017), which enabled the identification of the lowest costs for solar power supply. This drop in tariffs is expected to generate savings across the power system, benefiting end-user customers and distribution entities alike. Additionally, these savings should lead to lower electricity tariffs in states with high solar penetration.

Most states in India have not witnessed any significant increase in tariffs especially for the residential and agricultural segments. This stagnation may be attributed to substantial upfront subsidies rather than actual reductions in power procurement tariffs. Furthermore, the levelized cost of electricity from solar is expected to be considerably lower than that of thermal power in the coming decade, which should enhance reliance on solar energy to meet India's base energy demand and facilitate a shift away from thermal sources.

These reductions, driven by market reforms, have established India as the largest solar market, fostering widespread adoption and promoting value chain development within the solar sector.

Graph 1: Trends in solar tariffs



FEED-IN TARIFF vs REVERSE BIDDING

Feed-in tariff measures are electricity pricing policies designed to support the development of renewable energy sources. They offer a guaranteed price above the market rate for producers, providing a minimum price floor. This assurance helps project developers earn viable returns, even when facing uncertainties during project execution.

In contrast, the reverse-bidding mechanism selects the lowest quoted tariff (known as the L1 bid). This approach fosters price competition and enables a robust market development for the technology.

The significant drop in solar power prices (quoted in INR/kWh) is largely due to the reverse-bidding mechanism introduced after 2017.

Falling prices of solar PV modules and reduction in capital costs of solar projects: After 2013, global solar energy deployment accelerated, and India quickly followed suit. Positive market sentiment grew due to advancements in technology, particularly in photovoltaic (PV) module manufacturing, along with drops in the prices of raw materials like poly-silicon and aluminium. These changes led to significant price reductions in the solar PV market and increased its adoption in India.

To put things in perspective, the cost of PV modules fell from INR 35–40 per watt in 2013–14 to Rs 16–22 per Watt in 2024, depending on the technology. This decline has lowered the capital costs per megawatt (MW) for solar PV projects. In 2014, the Central Electricity Regulatory Commission (CERC) set the benchmark cost for solar PV at INR 6–6.9 crores per MW. Thanks to improved project delivery and falling costs, this has now dropped to around INR 2.5-3.5 crores per MW.

Since the cost of PV modules is nearly 60-65 per cent of the project capital costs, there was simultaneous reduction in bid tariffs as well. Additionally, the decrease in capital costs, along with supportive regulatory measures, has increased the internal rate of return (IRR) for large utility-scale PV projects, driving further capacity additions across the country.

Central policies and market responses;The growth in solar capacity has been supported by various schemes and policies aimed at rapidly advancing domestic energy markets. Central agencies, including the Ministry of New and Renewable Energy (MNRE) and the Ministry of Power (MoP), have established a broader policy agenda focused on solarizing and decarbonizing the power sector through initiatives like the National Electricity Policy, the National Tariff Policy, and the National Solar Mission.

Key schemes include the Solar Parks Scheme, designed to achieve economies of scale, along with measures permitting 100 per cent Foreign Direct Investment (FDI). Additional initiatives like Green Energy Corridors (GECs) facilitate long-distance power transmission, while bidding guidelines streamline power procurement processes. (*see Table 6*: Annual capacity installed and annual percentage change from Financial Year (FY) 2014 –24)

Moreover, the Solar Energy Corporation of India (SECI) plays a crucial role in mitigating counter-party risks associated with power off-takers such as DISCOMS, captive power consumers, and open access users. SECI facilitates a payment security mechanism that enhances the credit ratings of various solar

Table 9: Key schemes and guidelines to promote solar energy since 2014, as per launch date

Launch year	Name and mandate of the policy/scheme
2014, MNRE	Scheme for development of solar parks and ultra-mega solar power projects with a target of setting up 40 GW capacity. Facilitates expeditious development of utility-scale projects in India.
2015, MNRE & MoP	Inter-state Transmission System (ISTS) for seamless transmission of RE power and strengthening the grid stability
2017 & 2022, MNRE	Green Energy Corridor (GEC) Phase I &II for developing a resilient inter-state transmission system for RE projects and creating new power evacuation infrastructure in 13 states for evacuation of 44GW of renewable power.
2019, MNRE	CPSU Scheme Phase II (Government Producer Scheme) for setting grid-connected solar PV power projects by central and state PSU's, government organizations etc.
2021, MNRE	Production Linked Incentive (PLI) for National Programme on High Efficiency Solar PV Modules for achieving GW scale domestic manufacturing of high efficiency solar PV panels.
2021, MNRE	Renewable Energy Research and Technology Development (RE-RTD) programme to support new technological development and demonstrations in various emerging renewable energy systems.
2022, MNRE & MoP	Green Open Access Rules to enable power users to demand green power from DISCOMS to help bring down power costs substantially.
2023, MNRE	Standards & Labelling Programme for solar PV modules. For informed and judicious decision making while installing solar PV modules based on the modules' efficiency ratings
2023, MNRE	New bidding trajectory for renewable energy power projects to be issued by REIA's to support 50GW of RE capacity annually.
2023, MNRE & MoP	Revised Renewable Purchase Obligations (RPO) trajectory and targets up to 2030
2023, MNRE	Uniform Renewable Energy Tariff facilitating seamless power procurement between GENCOs and DISCOMS through appointed Intermediary Procurers at uniform tariff

Source: Compiled from MNRE, MoP, etc.

projects. This support provides project developers with assured cash flows and reduces the risk of project defaults. The payment security mechanisms have also reduced the payment default risks from power off-takers such as DISCOMS that were prevalent in the past. This has led to increased risk mitigation from payment defaults or re-negotiation of Power Purchase Agreements, which had been issued in states Andhra Pradesh and Punjab earlier.

Since electricity falls under the concurrent list, state agencies have played a crucial role in implementing the framework, particularly in RE-rich states in West and South India. According to the Electricity Act of 2003, states have the autonomy to secure projects based on their estimated potential and to create regulatory frameworks that encourage investments to meet their anticipated energy demand in alignment with national policy frameworks. As a result, many states have taken the lead in drafting and implementing renewable energy policies tailored to their specific resource potential and power needs.

State-level policies: Nearly all states have released renewable energy policies to meet their renewable energy goals. Table 6 highlights the states that have notified their renewable energy policies, prioritizing solar energy. The main role of state renewable energy agencies—including renewable energy development agencies, renewable energy departments, and power departments—is to foster the generation and co-generation of electricity from renewable sources. They also focus on developing the necessary infrastructure for transmission, distribution, and electricity wheeling to support these initiatives.

The policies focus both on general and specific objectives. Such as market mechanisms (publishing tariff-orders, inviting bids based on upcoming capacity) to promote solar based power with certain timeline targets based on state potential assessments. Based on their respective policies, various states offer procedural details related to land acquisition (leasing/purchase), creation of assets for consumption and sale of power, exemptions for expediting installations etc.

To enhance solar deployment in states, it is essential to address existing gaps in policy implementation by considering factors like current and future renewable energy potential. This should be supported by dedicated mechanisms that facilitate effective deployment. While the MNRE and MoP have set the broader agenda, states and their nodal agencies are responsible for implementation and facilitation. The investment appeal of solar energy for a particular state depends on the facilitative measures outlined in its policies. This includes the prior identification of land, creation of local assets such as inroads, water and basic civil work, single-window clearance etc.

Table 10: India states with high solar potential and dedicated renewable energy policies

State	Year/Type of policy	Target for solar energy
Rajasthan	2023, RE Policy	65 GW by 2030
Gujarat	2023, RE Policy	50 % RE by 2030
Karnataka	2022, RE Policy	---
Tamil Nadu	2019, Solar Energy Policy	9 GW by 2023
Andhra Pradesh	2018, Solar Power Policy, 2020 RE export policy	5 GW by 2024
Telangana	2015, Solar Power Policy	---
Madhya Pradesh	2022, RE Policy	10 GW RE by 2027
Maharashtra	2020 Non-Conventional Energy Generation Policy	10 GW
Uttar Pradesh	2022, Solar Energy Policy	22 GW solar, 14GW Utility-scale projects by 2027.
West Bengal	2012, RE Policy	0.5 GW by 2022
Chattisgarh	2012, Solar Energy Policy	--
Jharkhand	2022, Solar Energy Policy	3 GW by 2027
Bihar	2017, RE Policy	2.9 GW by 2022
Odisha	2022, RE Policy	--
Haryana	2016, Solar Power Policy,	--

Source: CSE's calculation from PIB sources[18]

The states themselves are at varied levels of development to integrate renewable energy into their power sectors and exhibit different levels of preparedness. According to Institute for Energy Economics and Financial Analysis (IEEFA)[19], Gujarat, Karnataka and Andhra Pradesh have taken strong measures for decarbonization, such as integrating higher share of renewable energy in power consumption mix, utilization of existing renewable energy potential and capital expenditure on it. Eastern states such as Bihar, Chhattisgarh and West-Bengal perform low in readiness and performance of the power ecosystem besides lacking in creating effective market enablers such as high capital expenditure on renewable energy, time-bound facilitation mechanisms, frequent release of tariff-orders for capacity expansion etc.

Development of solar parks and ultra-mega solar power projects scheme in 2014: This has been the biggest policy measure that has fast-tracked the development of ground-mounted solar projects in India. The development of ground-mounted solar projects in a scattered manner raises project infrastructure cost on a per MW basis. It also increases the time and costs on mandatory statutory clearances.

In order to fast-track large utility-scale solar power installations in India, and achieve cost-competitiveness from large-scale integration of solar energy, the Ministry of New and Renewable Energy (MNRE) released the Development of Solar Parks and Ultra Mega Solar Power Projects scheme in 2014 with subsequent revisions and guidelines for a cumulative capacity of 40GW (revised in 2017 from 20GW) until FY 2026. This scheme prioritizes solar park development above 0.5 GW to a maximum of 1 GW with provisions for lower and higher capacity based on terrain and state policies. Majority of the ground-mounted capacity additions since 2016 onwards can be ascribed to this scheme.

Under this scheme, 50 solar parks with an aggregate capacity of 38 GW[20] in 12 states have been approved until 2023. This scheme has led to approximately 10.5 GW of capacity development in 20 solar parks, with an additional sanctioned capacity in front-running states. To support the development of solar parks, 69,000 hectares (approximately 170,000 acres) of land have been acquired under the solar parks scheme. In the fiscal year 2022–23, the Ministry of New and Renewable Energy (MNRE) allocated INR 2,722 crores for this initiative.

These solar parks will be managed by Solar Power Project Developers (SPPD) with eight different implementation models with built-in CFA pattern to facilitate bidding, construction, commissioning and transmission of power to the grid. The Ministry has also included Floating Solar PV and Wind-Solar Hybrid power plants under the aegis of the Solar Park Scheme.

Table 11 lists states where the solar parks scheme is being implemented alongside commission status and the land acquired for the same. There have been capacity additions besides the solar parks scheme as well, such as in Tamil Nadu and Telangana. Both of which are leading but not priority states under this scheme.

Table 11: Capacity installed from solar parks scheme

Leading states for solar park projects	Total sanctioned capacity till Dec 23	Projects commissioned till Dec 2023	Land allocated
Rajasthan	8276 MW	3065 MW	40,367 acres excluding 2 sites.
Andhra Pradesh	4200 MW	3050 MW	66,893 Acres
Karnataka	2500 MW	2000 MW	15000 Acres
Madhya Pradesh	4180 MW	1000 MW	19,380 Acres excluding 2 sites.
Gujarat	12150 MW	900 MW	60,034 Acres
Uttar Pradesh	3730 MW	341 MW	16,294 Acres excluding 2 sites.

Source: CSE compilation from MNRE Solar Parks Scheme and PIB

4. Challenges facing solar utility projects

Concentration of solar power in certain states: The deployment of solar energy across states, based on their solar potential, has been inconsistent and primarily concentrated in just six to eight states. Understandably, besides solar potential, the power evacuation flexibilities based on system constraints will determine the trajectories ahead. A high concentration of energy generators in close proximity can lead to system congestion, resulting in inefficient utilization of power during long-distance transmission to load centers (typically cities) due to inherent power losses. This congestion also impacts grid dynamics, including system stability, rapid dispatch capabilities, and the development of ancillary services for load balancing, thereby increasing the risk of grid instabilities from regional imbalances in solar power integration. Regions with excess solar power will need to develop Inter-State Transmission Networks concurrently to facilitate bulk power supply, matching the growth of solar resources in those areas.

Further, the additional RE potential zones identified for development till 2030 are also located solely in these high potential states, thus indicating a greater propensity for not meeting targets based on the current status-quo. As per data available from Ministry of Statistics and Programme Implementation (MoSPI), nearly 32 transmission projects with a combined investment value of INR 44,000 crores are already or likely to be delayed. Delays in transmission make new installations ineffective, as generation from these facilities cannot occur without the necessary infrastructure in place.

Delays in energy generation have occurred due to transmission and grid connectivity issues, particularly because of the large number of projects located in the Great Indian Bustard (GIB) zone. Out of the 60 GW of identified solar energy zones in Rajasthan, nearly 30 GW are situated within the GIB zone (CEA 500 GW CEA TAX plan). The top-performing states in North-Western and Southern India are the ones that have been further prioritized (*see Table 11*: *Capacity installed from solar parks scheme*). Even in the prior planning exercises the same states had been identified to meet 2022 targets of 175 GW. Besides the top six states, the others that were prioritized were Haryana, Uttar Pradesh, Maharashtra and West Bengal, all of which have missed their targets by huge deficits.

Table 12: Potential capacity identified for 2030 in top performing states, as of 2023

State	Potential capacity identified in renewable energy zones, exclusively for solar till 2030
Rajasthan	60 GW
Karnataka	9 GW
Gujarat	-
Tamil Nadu	-
Andhra Pradesh	33 GW
Telangana	10 GW
Madhya Pradesh	6 GW
Maharashtra	5.5

Source: Compiled from CEA report on Transmission System for Integration of Over 500 GW of RE capacity by 2030[21].

Poor implementation of Renewable Purchase Obligations (RPO): RPO is a mechanism that mandates power procurers to obtain a specified minimum amount of electricity from renewable sources. The notional idea behind introduction of RPO targets was to intensively promote power procurement from growing renewable sources, particularly solar. It was first introduced in 2010(CERC RPO Regulations) by Central Electricity Regulatory Commission (CERC) and entailed meeting these annual targets from different RE sources, and in particular from solar to increase solar power injection and encourage solar power procurement. With the implementation of the Renewable Purchase Obligation (RPO) rules, power procurers are required to meet annual targets for purchasing a specified amount of electricity from renewable energy (RE) sources. The solar obligations for solar ranged from 2.75 per cent (FY2016) to 10.50 per cent (FY2022) of the total generation mix.

As solar generation grew rapidly in high solar potential states compared to other states, compliance also reflected the skewed composition. Table 13 shows that only three states—Karnataka, Andhra Pradesh and Uttar Pradesh—had met their targets in 2022–23. Seven states (*see Table 13: Performance of states with published data in reference to their annual targets)* had achieved the target in 2019–20. However, they missed the target in 2022–23, while the others states showcase deficits of more than 60 per cent.[22]

Under RPO guidelines released by Central Electricity Regulatory Commission (CERC), the State Electricity Regulatory Commissions (SERC) were mandated to detail appropriate RPO targets for respective states. Besides targets, they also mandate application of penalties in terms of non-compliance. Currently, nearly all

Table 13: Performance of states with published data in reference to their annual targets*

States**	2015	2016	2017	2018	2019	2020	2021	2022
Rajasthan	-47 %	-49 %	-47 %	0	0	-	-	-78%
Karnataka	140 %	180 %	138 %	149 %	174 %	210 %	237 %	165 %
Gujarat	150 %	117 %	101 %	118 %	100 %	100 %	-	-70 %
Tamil Nadu	-	-	-	-	-	-	-	-84%
Andhra Pradesh	-55 %	-74 %	720 %	270 %	168 %	178 %	215 %	185 %
Telangana	-	-	183%	-	-	-	-	-86%
Madhya Pradesh	-72%	132%	138%	137%	157%	100%	-69%	-46%
Uttar Pradesh	-16%	-30%	-43%	-83%	133%	128%	144%	137%
Punjab	134%	-84%	204%	217%	173%	101%	124%	-83%
Maharashtra	-69%	-87%	-45%	-40%	-66%	-76%	-92%	-88%
Chhattisgarh	-17%	-60%	100%	-77%	-61%	-41%	-32%	-4%
Jharkhand	--	--	--	--	-89%	111%	--	--
Haryana	--	--	--	--	-21%	-25%	-50%	--
Assam	--	100%	--	--	--	--	--	--
Himachal Pradesh	-13%	225%	122%	-85%	-43%	118%	74%	145%
Meghalaya	--	--	-43%	-9%	-18%	--	--	--
Goa	-32%	276%	131%	92%	104%	107%	--	--

Source: CSE analysis based on IndiaREdata.org (PEG, 2024)
* The denoting colour percentage is for excess/shortage in each: Numbers in red indicate percentage shortfall in meeting the annual solar RPO target of that year, green indicates additional target over and above the target for the corresponding year. Blanks indicate lack of data.
** The timeframe selected from 2015 includes published data for the respective SERC's which had mandated RPO compliances.

the states have provisions related to application of annual penalties in case of non-compliance. As per data available from proceedings from Rajya Sabha (Starred Question No. 122, 1st August 2023),[23] only the distribution licensees of UT of Delhi were imposed with penalties amounting to INR 62.57 Crores (between FY2017–2020). This highlights both non-compliance in other states as well as non-application of respective penalties. Previously, the Standing Committee on Energy (2020–21) of the 17th Lok-Sabha also mentions dismal performance by DISCOMs in RPO target compliances and non-enforcement of penalties by respective SERCs.[24]

Inefficient power procurement and management practices by DISCOMs: Most DISCOMs are entangled in inflexible, long duration power procurement agreements, limiting their ability to tap into low-cost power emerging from solar energy. The current operational status of DISCOMs urgently requires resource adequacy planning (from RE power) and advancing market-based economic dispatch.

- In 2021 and 2022, generating companies faced non-payment of charges by DISCOMS due to accumulated losses. However, timely reforms through the implementation of the Electricity (LPS and Related Matters) Rules 2022 significantly reduced outstanding dues in 2023, decreasing from INR 1.39 lakh crore in May 2023 to INR 82,000 crore by December 2023, according to data from the PRAAPTI portal. The current mechanisms have improved the financial health of DISCOMS; however, they also highlight a case of counterparty risk as off-takers of renewable energy. The credit ratings of DISCOMS play a crucial role in signing Power Purchase Agreements (PPAs) with developers. According to the Power Finance Corporation's (PFC) 12th Integrated Rating and Ranking of Power Distribution Utilities, which assigns 75 per cent weight to financial sustainability, 13 DISCOMS are ranked in the B category, 11 in the C category, and 6 in the C- category. The combined integrated score shows 18 of 55 DISCOMS declining in performance, while 17 have more or less shown relative stability. The best performing DISCOMs (12) are equally split between private and state.

- Defaults in payments and the renegotiation of contracts, including Power Purchase Agreements (PPAs) and tender cancellations, increase the capital risks faced by renewable energy developers. Notably, the states with the highest outstanding dues from DISCOMs—Tamil Nadu, Maharashtra, Karnataka, and Rajasthan—are also rich in renewable energy resources. Sectoral reform of DISCOMs to accommodate more RE power and improve operational issues would require short-and long-term solutions to reduce counterparty risks. Besides, DISCOMs also have an active role to play in the anticipated capacity planning exercises based on emerging demand. The inability of DISCOMs to effectively plan their future power procurement leads to missed opportunities in decarbonizing the energy sector.

Table 14: States with highest accumulated debts to GENCOS in January, 2024

States	Existing accumulated debts (INR)	Number of DISCOMS
Maharashtra	4,437	2
Uttar Pradesh	3,697	1 (5 regional)
Tamil Nadu	3,628	1
Gujarat	3,312	1
Karnataka	2,801	5
Madhya Pradesh	2,360	3
Rajasthan	2,265	3

Source: CSE analysis from PRAAPTI portal

Land acquisition for large-scale projects: Development of large-scale solar parks with different land-use changes, such as acquisition of arable lands, grasslands and barren wastelands have led to conflicts over land acquisition for such projects. Typically, around three to five acres per MW is required for ground-mounted solar utility translates to 1,000–1,500 acres for a 500 MW plant. The requirement of a large contiguous land parcel for installations to achieve economies-of-scale in generation directly affects communities living near the projects or those displaced by them. There are instances where few solar parks that are approved now were initially cancelled due to issues such as coastal zone clearance, such as for West Bengal Solar Park and Gujarat's Dolera Ph-II Solar Park. A few solar parks, including the Kaza and Kinnaur Solar Parks in Himachal Pradesh, were initially canceled due to issues related to forest clearance.

The main concerns surrounding solar energy projects are primarily related to land acquisition processes, compensation for leasing or purchasing land, conversion of agriculturally viable lands, loss of grazing rights on community lands, restrictions on sacred sites, and disputes over water extraction and access to common resources like roads. These risks underscore the need for equity considerations in the energy transition and highlight the necessity for impact assessments, from which the solar industry is currently exempt. For example, a 2022 study by The Nature Conservancy[26] found that approximately 84 per cent of solar installations in India were situated on land with potential conflicts over food production and biodiversity. Specifically, about 67.6 per cent of this land was agricultural, while 18.7 per cent comprised natural habitats. As we strive to meet the clean energy goals for 2030, it is crucial to account for environmental and socio-economic risks associated with large-scale solar deployments.

These grievances have surfaced in nearly all states where ground-mounted solar installations are concentrated. Often, the auctioning of solar park projects takes place before fair land acquisition procedures are fully completed. Possession typically occurs only after procedural safeguards are in place, yet these measures often fall short of addressing the concerns of local land-owning or land-using communities. Solar Park developers have reported delays in project installations and sometimes in obtaining physical possession of the land.

Since land falls under state jurisdiction, the acquisition process is complicated by multiple entities involved, including local administrations, state revenue departments, and informal landowners, along with a history of poor land records. This complexity can hinder effective land acquisition for solar projects. The courts in India have taken cognizance of such conflicts. The table below mentions a few regions where disputes from land-use change from solar energy installations were witnessed.

Table 15: Land footprints (acre/MW) of sanctioned solar parks

State	Name of the Solar Park	Installed capacity	Land allocated (acres)	Area in acres/MW
Andhra Pradesh	Ananthapuramu I	1500 MW	11000 Acres	7.3 Acres
	Ananthapuramu II	500 MW	2751 Acres	5.5 Acres
	Kadapa Solar Park	1000 MW	5943 Acres	5.9 Acres
	Kurnool Solar Park	1000 MW	5683 Acres	5.6 Acres
	Ramagiri Solar Park	300 MW	1185. 6 Acres	3.9 Acres
Chhattisgarh	Rajnandgaon	100 MW	466 Acres	4.6 Acres
Gujarat	NTPC Khavda, Bhuj	4750 MW	23750 Acres	5.0 Acres
	GSECL Khavda, Bhuj	3325 MW	16432 Acres	4.9 Acres
	GIPCL RE I Bhuj	600 MW	2965 Acres	4.9 Acres
	GIPCL RE II Bhuj	1200 MW	5930 Acres	4.9 Acres
	GIPCL RE III Bhuj	575 MW	2500 Acres	4.3 Acres
	Radhnesada Solar Park	700 MW	3517 Acres	5.0 Acres
	Dholera Solar Park	1000 MW	4940 Acres	4.9 Acres
Karnataka	Bidar Solar Park	500 MW	2000 Acres	4.0 Acres
	Pavagada Solar Park	2050 MW	13000 Acres	6.3 Acres
Madhya Pradesh	Neemuch Solar Park	500 MW	2471 Acres	4.9 Acres
	Agar Solar Park	550 MW	2718 Acres	4.9 Acres
	Shajapur Solar Park	450 MW	2224 Acres	4.9 Acres
	Chhtarpur Solar Park	950 MW	5238 Acres	5.5 Acres
	Barethi Solar Park	630 MW	2800 Acres	4.4 Acres
	Rewa Solar Park	750 MW	3929 Acres	5.2 Acres
Maharashtra	Dondaicha Solar Park	250 MW	1247.16 Acres	4.9 Acres
Mizoram	Vankal Solar Park	20 MW	194 Acres	9.7 Acres
Odisha	Odisha Solar Park	40 MW	176 Acres	4.4 Acres
Rajasthan	Phalodi-Pokaran	750 MW	3328 Acres	4.4 Acres
	Noakh Solar Park	925 MW	4587 Acres	4.9 Acres
	RVUN Solar Park I	2000 MW	11975 Acres	5.9 Acres
	Bhadla I Solar Park	65 MW	459.6 Acres	7.0 Acres
	Bhadla II Solar Park	680 MW	4440.4 Acres	6.5 Acres
	Bhadla III Solar Park	1000 MW	6103.5 Acres	6.1 Acres
	Bhadla IV	500 MW	3286.6 Acres	6.5 Acres
	Fatehgarh IB	1500 MW	6187 Acres	4.1 Acres
Uttar Pradesh	Jalaun Solar Park	1200 MW	5138 Acres	4.2 Acres
	Lalitpur Solar Park	600 MW	3062 Acres	5.1 Acres
	Jhansi Solar Park	600 MW	3429 Acres	5.7 Acres
	Chitrakoot Solar Park	800 MW	3706 Acres	4.6 Acres
	Mirzapur Solar Park	100 MW	637.3 Acres	6.3 Acres
	Kalpi Solar Park	65 MW	322.2 Acres	4.9 Acres

Source: CSE's calculation from CEA status of UMREPP[25]

Table 16: Land related conflicts observed in various Indian states (categorized by nature of concern)

Concern	Year	Energy source	Region	Observations
Land Acquisition	2021	Solar	Assam - Nagaon	Protests and incidents of violence arising from eviction and land transfer processes. Land in contestations were deemed cultivable lands used by community.
Land Acquisition	2023	Solar	Tamil Nadu – Tirunelveli	Discrepancies in classification of land, used for grazing activities. Region has high livestock dependency for livelihood generation.
Land Acquisition	2022	Solar	Rajasthan-Jaisalmer	Discrepancies observed in classification of land, change in land-use categorization.
Land Acquisition	2022	Solar	Rajasthan-Jaisalmer	Inconsistencies in land allotment, disputes with local community over land-use in pastural/grazing lands.
Land Acquisition	2019	Solar	Maharashtra-Nashik	Acquisition of erstwhile reserve forests, sale of disputed lands. Violence and protests recorded.
Land Acquisition	2019	Solar	Gujarat- Mehsana	Community opposition over acquisition of community grazing lands
Compensation	2016	Solar	Andhra Pradesh-Ananthapur	Local protests over compensation disbursement, land transfer mechanisms. Incidents of disruptions of operations
Compensation	2016	Solar	Andhra Pradesh-Kurnool	Discrepancies in compensation and forcible land transfers
Compensation and Employment	2019	Solar	Gujarat – Charanka, Patan	Discrepancies in compensation payouts, partial to incomplete fulfillment of employment, energy access and infrastructure. Contested land transfers.
Compensation and Employment	2019	Solar	Karnataka-Pavagada	Non-fulfillment of promised jobs to locals, issues raised over mode of compensation
Biodiversity and Ecology	2023	Solar	Rajasthan – Jaisalmer	Site location contests with conservation efforts for Great Indian Bustard, grazing lands for indigenous cattle species, deemed forest lands used for ecosystem services.
Biodiversity and Ecology	2022	Solar	Rajasthan-Sambhar Lake Jaipur	Popular wetland conservation hotspot. Location is an avian migratory route with significant specie level genetic diversity

Source: Compiled from various sources, primarily from Land Conflict Watch, and directory maintained on land-use changes

The highly land-intensive nature of ground-mounted solar suggests inhibitory models towards further large-scale adoption. The land footprint of solar is huge compared with any other renewable technology, land scarcity in solar rich states has affected project sanctioning and has led to delays in deployment. Currently, the solar capacity additions via the solar parks scheme have been fast-tracked with implementation facilitation on on-site development and power evacuation infrastructure leading to reduced timelines from bidding to generation. A closer examination on the land acquisition of the site highlights more than five acres of land requirement per megawatt (MW). Assuming a conservative estimate of 250 GW utility-scale solar addition by 2030 will result in nearly 13,25,000 acres of land (5,362 sq kms) requirement. This raises concerns about the opportunity cost of using land exclusively for energy generation, especially given the declining per-capita land availability. The Economic Survey 2023–24 highlights that per-capita land availability in India is among the lowest in G20 nations. In addition to land needed for generation, there is also a parallel requirement for land use related to long-distance power evacuation, which will contribute to the overall costs of the energy transition.

Moreover, land acquisition is a complex and lengthy process involving extensive negotiations, which poses a significant obstacle to the development of large-scale solar energy infrastructure. This acquisition must be completed before any civil works can commence at the site. Since 2019, 26 land-based solar parks have been sanctioned while only eight have been commissioned as of March 2024 as per CEA Ultra Mega Renewable Energy Power Plants. While eight projects have commenced civil works, the remaining 10 are still in the process of navigating land acquisition and negotiations.

Delays in project progress vary based on site locations and the level of facilitation by local administrations. For instance, almost all sites in Gujarat (specifically in Bhuj or the Rann of Kutch) have advanced significantly, while sites in Western Madhya Pradesh and Eastern Uttar Pradesh have experienced notable delays.

Domestic manufacturing of solar modules and ancillary systems: India's current domestic module manufacturing capacity is 37 GW with optimistic projections to 60 GW by 2025 with cell manufacturing of 6 GW. The module has benefitted from schemes such as Production Linked Incentive (PLI) and curbs on imports via increased custom duties and mandatory use of local modules.

The primary challenges involve enhancing backward integration in sourcing raw materials, such as polysilicon ingots that require significant capital investment and technological upgrades. Domestic production also faces risks due to a reliance on imports for critical minerals, particularly metallurgical grade pure silicon needed for solar modules. Additionally, the market for auxiliary balance-of-systems needs strengthening to meet the increasing domestic demand for modules while also providing an alternative market for solar module exports. The global chip shortage witnessed in 2021 and 2022 can further increase the cost of inverters, sensors and power electronic equipment used in solar power projects. Currently, India is heavily dependent on the import of raw materials and components. In 2023–24, India spent INR 430 crore in procuring solar panels, an exponential increase of 361 per cent (INR 94.3 crore) when compared to 2022–23.

All of these challenges necessitate corrective policy measures that can direct substantial investments into manufacturing to achieve economies of scale. While the manufacturing ecosystem is positively responding to recent incentives, scaling operations will require focused research and development (R&D) in technical expertise, alongside efforts to enhance human skill development for manufacturing and industrial operations.

5. Recommendations

The uneven progress in solar energy deployment impacts national energy transition trajectories. It is essential to address gaps in the implementation of various solar energy initiatives, including the incomplete policy transmission stemming from governance deficits. This optimization should focus on long-term power system planning based on emerging demand assessments, suitable generation sources, and the effects of the transition on interconnected sectors like industry and electric mobility.

The consequences arising from current deployment models can be direct (first order) such as increased cost of capital investment and deficits in meeting peak power demand, as well as indirect (second-order), affecting the development of associated clean energy technologies and carbon emissions. These issues ultimately lead to delays and increased transactional costs in the clean energy transition. This will have further cascading effects on industrial growth, pace of urbanization and infrastructural development, and ultimately human development.

1. **Boosting RPO performance with state improvements and central financial incentives:** With the implementation of new RPO rules from 1 April, 2024, states must carry planning for adequate resources towards meeting RPO targets. Since new obligations on storage and rooftop solar or distributed resources is factored in, enforcements towards these obligations must be met by periodic publishing of RPO compliance data. This will signal parallel markets towards co-developing emerging resources such as rooftop solar and promote energy storage norms that will address solar intermittency.

2. **Devising a phased methodology for DISCOMs to exit old, expensive and polluting thermal PPAs:** This will make DISCOMs readily procure cheaper solar power and enhance the pace of capacity addition. The cost foregone from stranded capacity in old and inefficient thermal plants can be offset from various clean energy funds. As the costs of solar PV module deployment continue to decrease, the competitiveness of thermal PPAs may become less attractive. Prior to reduction of incentive structures such as waiver of inter-state transmission charges, equal offset subsidies may be provided towards early closure of thermal PPAs, facilitation of solar PPAs and spot exchanges.

3. **Addressing land-based conflicts from solar energy by devising a benefit sharing mechanism through:**
    a. Mandating an impact assessment for sites that consider social and economic factors in addition to environmental impacts. Absence of a national framework on impact assessment for the green energy sectors is required to prevent risks to current installed capacities and also to plan better. The Solar Energy Corporation of India (SECI) released draft guidelines mandating that environmental and social impact assessment should be levied on land-based solar projects requiring 10 MW and upwards, or in acquisition of lands beyond 50 acres for energy deployment. Current white-category exemption provided to solar projects prevent local impact assessments. While solar is a non-polluting source the externalities developed from land-use change in terms of long term socio-economic and ecological impacts cannot be ignored. Superimposing social and environmental risks on the projects may bring an additional cost per/MW in the short run but will also improve the credit ratings of the project developers, thereby enabling them to tap into more clean energy funds.
    b. States have an opportunity towards creating inclusivity in their solar energy development. There is a need to devise a resource sharing mechanism between the local community and project developers, which is mindful of the region's ecology and socio-economic characteristics. Provisions such as resource-sharing agreements, for example, water-sharing between communities and project developers, promoting on-site livelihood opportunities, and enabling some profit-sharing with the community towards developmental activities should be included. Apart from this, human resource development for the local community especially for women and marginalized should be prioritized. This has to be included in state renewable energy policies, and location-specific activities have to be emphasised for equitable siting of solar PV projects.
    c. Simultaneously promote alternative segments in the solar energy sector that enables dual land use such as agro-PV, floating solar PV etc. which can reduce the exclusive dependency on land. There is an urgent requirement of dedicated guidelines for these to make them more attractive. Addressing land-related barriers should also adapt towards alternative locations that allow multiple land-use, such as promoting agriculture within energy generation. Since land leasing is now established as an attractive option, solar deployments can promote agriculture/other land-based activities thereby multiplying the land value.

4. **Strengthening the transmission networks** requires compelling capital investments in grid stability and transmission operations. Currently, investments amounting to INR 2.4 lakh crores have been planned to enhance the transmission system for integrating a higher share of renewable energy. Implementation of the Integrated Power Development Scheme (IPDS) and provision of Green Energy Corridors has improved reduction of losses and ensured reliability of power. These can be strategically directed at:
   a. **Incentivizing states with low RE (esp. solar) penetration** to prioritize development of power evacuation infrastructure based on identified demand corridors within the states. The current timelines of transmission infrastructure are 20–30 months, matching the timelines for the solar installations (from bid to generation). There has to be simultaneous competitive bid process undertaken as per the installation trajectories, the development of projects under the Tariff Based Competitive Bidding (TBCB) mechanisms.
   b. **Development of strong ancillary services** (such as voltage and frequency regulation, balancing area regulations, grid codes etc.) at the distribution interface to manage the variability in power generation. This becomes crucial with the increase in RE-based power, and will ensure grid stability. This requires closer functioning of the central and state transmission utilities and improve reliability of the inter-and intra-state transmission systems based on contingencies such as line failure, tower collapse etc. which can lead to power cuts that persist for long durations. This becomes crucial with the increase in RE-based power, and will ensure grid-stability.

Endnotes and references

1 Anon 2024. *Programme/Scheme wise Cumulative Physical Progress as on August, 2024*. Ministry of New and Renewable Energy. Available at https://mnre.gov.in/physical-progress/, as accessed on 10 May, 2024

2 Ibid

3 Anon 2024. *Year End Review 2023 of Ministry of New and Renewable Energy*, Press Information Bureau. Available at https://pib.gov.in/PressReleasePage.aspx?PRID=1992732, as accessed on 8 May, 2024

4 Anon 2024, *India overtakes Japan to become world's third largest solar power generator: report*. Doordarshan News. Available at https://ddnews.gov.in/en/india-becomes-worlds-third-largest-solar-power-generator-overtakes-japan-report/

5 Anon 2024. *Installed capacity dashboard*. Central Electricity Authority. Available at: https://cea.nic.in/dashboard/?lang=en, as accessed on 9 May, 2024

6 Anon 2024, *India overtook Japan to become the third-largest solar power generator in 2023*, EMBER. Accessed at: https://ember-climate.org/countries-and-regions/countries/india/ on 7, October 2024

7 Anon 2023. *National Electricity Plan 2022 (Volume I Generation)*, Central Electricity Authority (CEA). Available at https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf, as accessed on 21 May, 2024

8 Anon 2023, *Report on Optimal Generation Capacity Mix for 2029–30*, Central Electricity Authority (CEA). Available on https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf, as accessed on 19 May, 2024

9 Anon 2024, *Year End Review 2023 of Ministry of New & Renewable Energy*, MNRE Press Release, Press Information Bureau (PIB). Available at https://pib.gov.in/PressReleasePage.aspx?PRID=1992732#:~:text=Annual%20Bidding%20Trajectory&text=Bids%20for%2050%20GW%20per,2023., as accessed on 22 May, 2024

10 Ibid

11 Anon 2022. *Transmission system for integration of over 500 GW RE capacity by 2030*. Central Electricity Authority (CEA). Available https://cea.nic.in/wp-content/uploads/notification/2022/12/CEA_Tx_Plan_for_500GW_Non_fossil_capacity_by_2030.pdf, as accessed on 23 May, 2024

12 Anon 2023, *National Electricity Plan*. Central Electricity Authority (CEA). Available at https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf, as accessed on 9 May, 2024

13 Anon 2023, *Report on Optimal Generation Capacity Mix for 2029–30*, Central Electricity Authority (CEA). Available on https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf, as accessed on 19 May, 2024

14 Anon 2023, *National Electricity Plan*. Central Electricity Authority (CEA). Available at https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf, as accessed on 9 May, 2024

15 Since targets were available for RTS segments for 40 GW, it is assumed the 60 GW was for utility-scale ground mounted solar and of off-grid mini grids

16 Anon 2024. *India's solar energy potential is estimated to be 748 GWp: Union Power and New & Renewable Energy Minister*. MNRE press release, Press Information Bureau Available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2003561, as accessed on 4 April, 2024

17 G. Balachandar 2023, Rajasthan and Andhra Pradesh have commi*ssioned higher capacity under solar park scheme. The Hindu Business ine. Available at* https://www.thehindubusinessline.com/economy/rajasthan-and-andhra-pradesh-have-commissioned-higher-capacity-under-solar-park-scheme/article67662432.ece#:~:text=The%20Scheme%20for%20%E2%80%9CDevelopment%20of,is%20up%20to%202023%2D24, as accessed on 23 May, 2024

18 Anon 2024. *India's solar energy potential is estimated to be 748 GWp: Union Power and New & Renewable Energy Minister*. MNRE press release, Press Information Bureau Available at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2003561, as accessed on 4 April, 2024

19 S. S. Michael, Tanya Rana, Neshwin Rodrigues et al., 2024, *Indian States Electricity Transition (SET):2024*, Institute of Energy Economics and Financial Analysis. Available at https://ieefa.org/sites/default/files/2024-04/Indian%20States%20Electricity%20Transition%20%28SET%29%202024.pdf, as accessed on 23 May, 2024

20 G. Balachandar 2023, *Rajasthan and Andhra Pradesh have commissioned higher capacity under solar park scheme*. The Hindu Businessline. Available at https://www.thehindubusinessline.com/economy/rajasthan-and-andhra-pradesh-have-commissioned-higher-capacity-under-solar-park-scheme/article67662432.ece#:~:text=The%20Scheme%20for%20%E2%80%9CDevelopment%20of,is%20up%20to%202023%2D24, as accessed on 23 May, 2024

21 Anon 2022. *Transmission system for integration of over 500 GW RE capacity by 2030*. Central Electricity Authority (CEA). Available https://cea.nic.in/wp-content/uploads/notification/2022/12/CEA_Tx_Plan_for_500GW_Non_fossil_capacity_by_2030.pdf, as accessed on 23 May, 2024

22 Calculated from Table 13

23 Anon 2023. *Mandatory purchase of Renewable Energy*. Rajya Sabha Proceedings, *Starred question no; 122, answered on 1/8/23*. Ministry of Power, Government of India. Available at https://powermin.gov.in/sites/default/files/uploads/RS0108.2023_Eng.pdf, as accessed on 2 May 2024

24 Anon 2021. *Action plan for achievement of 175 GIGAWATT (GW) renewable energy target*, Standing committee on Energy (2020-2021), Seventeenth Lok Sabha. Available at https://loksabhadocs.nic.in/lsscommittee/Energy/17_Energy_17.pdf, as accessed on 2 May, 2024

25 Anon 2023. *Status report on development of solar parks/UMREPPs in the country*. Central Electricity Authority. Available at https://cea.nic.in/wp-content/uploads/rpm/2023/11/Status_of_UMREPP_Solar_Parks.pdf, as accessed on 11 May, 2024

26 K. N. Shivaprakash 2022, *Degraded lands can aid achieve four times India's 2030 renewable energy targets*. The Nature Conservancy. Available at https://www.tncindia.in/what-we-do/our-insights/stories-in-india/renewableenergy/, as accessed on 15 May, 2024

In the past decade, India's renewable energy capacity surged from 36 GW to 144 GW, with utility-scale solar accounting for 44.8 per cent of this growth. As the solar sector is projected to reach over 300 GW by 2030, challenges have emerged, including uneven project distribution among states, policy gaps hindering Renewable Purchase Obligations (RPOs), and conflicts over land use. Additionally, the infrastructure needed for efficient transmission and distribution presents significant hurdles. This book delves into the complexities of India's solar landscape, emphasizing the urgent need for a holistic framework that prioritizes access, affordability, reliability, sustainability, and inclusiveness in the transition to clean energy.

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