Policy Study on Energy Transition Roadmap 2030

A Technical Summary

December 2024

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Summary

The document summarises a published report, *Policy Study on Energy Transition Roadmap 2030*, for Rajasthan, conducted by the Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC) in collaboration with the Council on Energy, Environment and Water (CEEW) and Indicc Associates, LLP (Indicc).[1]

The report examined Rajasthan's evolving power sector landscape and the challenges and opportunities presented by the clean energy transition. It used modelling tools, analytical approaches, and stakeholder consultations. It identified key outcomes and interventions that the state policymakers must prioritise in the near term to build a clean and resilient power sector. This summary synopsises the key insights from the report to provide crisp recommendations to the policy makers.

India's energy transition journey will be realised in its states and union territories. Rajasthan, bestowed with abundant renewable energy (RE) resources, has the opportunity to leverage the advantage to drive its own clean energy transition and support the nation's transition. The state is already leading RE deployment in India with 23 GW of installed capacity as of June 2023 and aiming to set an ambitious goal: 90 GW of installed RE capacity by 2030.

1 The policy report is available at: https://jankalyanfile.rajasthan.gov.in//Content/UploadFolder/DepartmentMaster/111/2023/Dec/30409/111e915dab0-03a3-4a3b-8f6b-cfec384354bc.pdf.

Achieving this target will require careful planning and concerted efforts because it will involve moving away from a system designed to work with firm and predictable sources of power generation and instead building an ecosystem prepared to manage and integrate high volumes of variable RE with the grid. It will also require a commitment to turn around the state's financially stressed power distribution companies so that they can actively participate in and enable clean energy initiatives. Without such planning and action, the state's clean energy goals may prove elusive.

Key trends, challenges, and opportunities in Rajasthan's power sector transition

- **With 90 GW of RE, Rajasthan will emerge as a major clean energy exporter, helping other Indian states meet their renewable purchase obligations (RPOs).** However, the state will require significant investments in new storage capacities, transmission infrastructure, network upgrades, and coal fleet flexibilisation to enhance system flexibility and enable cost-effective RE integration. By 2030, ~32 GW of storage – nearly half of India's storage needs – and ~8.5 GW of flexible coal capacity – with 40 per cent minimum technical load (MTL) – will likely be situated in the state to minimise RE curtailment.
- **The state-owned coal fleet will play a crucial role in meeting the state's energy and flexibility needs.** However, in FY22, the fleet's on-bar declared capacity ranged from 32 -69 per cent, much lower than the 83 per cent norm, mainly due to technical faults, coal shortages, and limited maintenance. Improving the fleet's availability and ensuring its economically efficient scheduling, which should be guided by robust demand forecasting, would be imperative for cost-effective operations. For instance, the state discoms would have saved ~INR 500 crore if state's coal plants were available as per norms and utilised cost-optimally.
- **To reliably manage the increase in electricity demand while meeting RE purchase obligations, Rajasthan's discoms will need an additional 21 GW of RE and other capacities beyond current plans.** This will double the share of RE in discoms' supply mix and quadruple the ramping needs between 2022 and 2030, underscoring the need for investments in suitable supply- and demand-side flexibility solutions, which need to be guided by robust planning and resource adequacy assessments.
- **In order to invest in additional RE capacity and the requisite infrastructure upgrades, state discoms must strengthen their financial indicators.** Over the past three years, the state discoms have progressively reduced their recurring annual losses – down to 17.5 per cent in FY22. However, they remain heavily indebted and have accumulated financial losses of ~INR 90,000 crore. Improving discoms' credit ratings, dissipating the accumulated unfunded revenue gap (URG), and improving billing efficiency through technological interventions will be instrumental in breaking the vicious cycle of losses and rising debt.

It follows from the above, that in order to take advantage of the state's RE potential and achieve the 2030 goals, all actors in Rajasthan's power sector ecosystem must prioritise interventions and undertake coordinated actions (as presented in Tables 5 and 6 on page 22).

1. Context

Blessed with the enormous renewable energy (RE) potential in the country, Rajasthan could be a natural choice to be the clean energy transition leader. As per the draft Rajasthan Energy Policy 2050, the state aims to "align with the country's ambitions of achieving Net Zero by 2070, harness its huge clean energy potential, and emerge as a global clean energy leader" (Energy Department, Government of Rajasthan 2023). The state is likely to set an ambitious RE target of reaching 90 GW of installed capacity by 2030.[2] Rajasthan had more than 23 GW of installed RE capacity as of June 2023, and was the largest RE producer among the states in FY23 (MNRE 2023; CEA 2023a).

As Rajasthan pursues ambitious energy transition goals, it will be essential to enable cost-effective integration of RE at scale and increase the off-take of clean energy by state discoms. To achieve this, the state must address three key questions:

- How should the state plan to meet its rising power demand reliably and cost-effectively while integrating new RE capacities?

2 Indicative target as per stakeholder engagements and secondary literature (Economic Times 2023).

- How should the state operate, manage, and remunerate its thermal fleet to support reliable and cost-optimal system operations?
- How can the state discoms strengthen their financial position such that they become active participants and enablers of a new energy future?

The Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC) commissioned the Council on Energy, Environment and Water (CEEW) to reflect on these questions and prepare a roadmap for the state's power sector transition.[3] CEEW undertook a study based on an in-depth analysis of the state's power sector landscape and the emerging and potential challenges, using modelling tools, secondary research, and consultations with diverse stakeholders. This document summarises the key insights and recommendations from that study. The recommendations aim to assist all key state actors in undertaking timely and data-informed decisions on policy, regulatory, institutional, and financial reforms to help the state leverage its natural advantages of high clean energy potential.

2. How can Rajasthan integrate renewable energy cost-effectively?

By 2030, the share of RE in Rajasthan's generation mix will rise significantly. This transition will present new and complex challenges for integrating RE with the grid while managing the increase in demand in a reliable and cost-effective manner. Some of these challenges are already visible. For example, inadequate reactive power support – mostly during high-solar hours – has led to increased intra-state transmission losses and instances of grid faults, with resultant loss of RE generation. Increased variability and uncertainty in the state's net load[4] in 2030 is likely to be seen. Notably, the net load also becomes negative during instances of low demand, indicating surplus RE generation (Figure 1). These patterns will lead to operational complexities, such as fast and steep ramping, requiring flexible resources in the system. Thus, it is important to characterise the emerging complexities and challenges so that Rajasthan can develop strategies for cost-effective integration of the rising share of RE in the state.

Box 1 Simulation design and tools

Case 1: An all-India least-cost despatch model using GE MAPS[5] was simulated to understand the system flexibility requirements at the national level, with 500 GW of non-fossil capacity by 2030. This was used to understand the role that the power generation and storage units installed in Rajasthan will play in the operations of the national grid. In this case, each state was modelled as a node and a market-based economic despatch (MBED) was assumed. India, as a whole, acted as a balancing area – that is, power was free to flow between nodes, subject to available transfer capabilities between regions and states. While running a 15-minute despatch, India's annual curtailment of RE and the unmet demand were restricted to be below 5 per cent and 0.5 per cent, respectively.

Case 2: Here, a state-level copper-plate despatch model, using GridPath,[6] examined the feasibility of Rajasthan's discoms achieving their RPOs while meeting the rising demand. This case represented the business-as-usual situation, wherein the state discoms balance the power demand on their own through existing and planned contracted capacities. Unlike Case 1, this case did not model storage capacities unless it was already stated in the state's plans.

Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

3 The policy report is available at: https://jankalyanfile.rajasthan.gov.in//Content/UploadFolder/DepartmentMaster/111/2023/Dec/30409/111e915dab0-03a3-4a3b-8f6b-cfec384354bc.pdf.

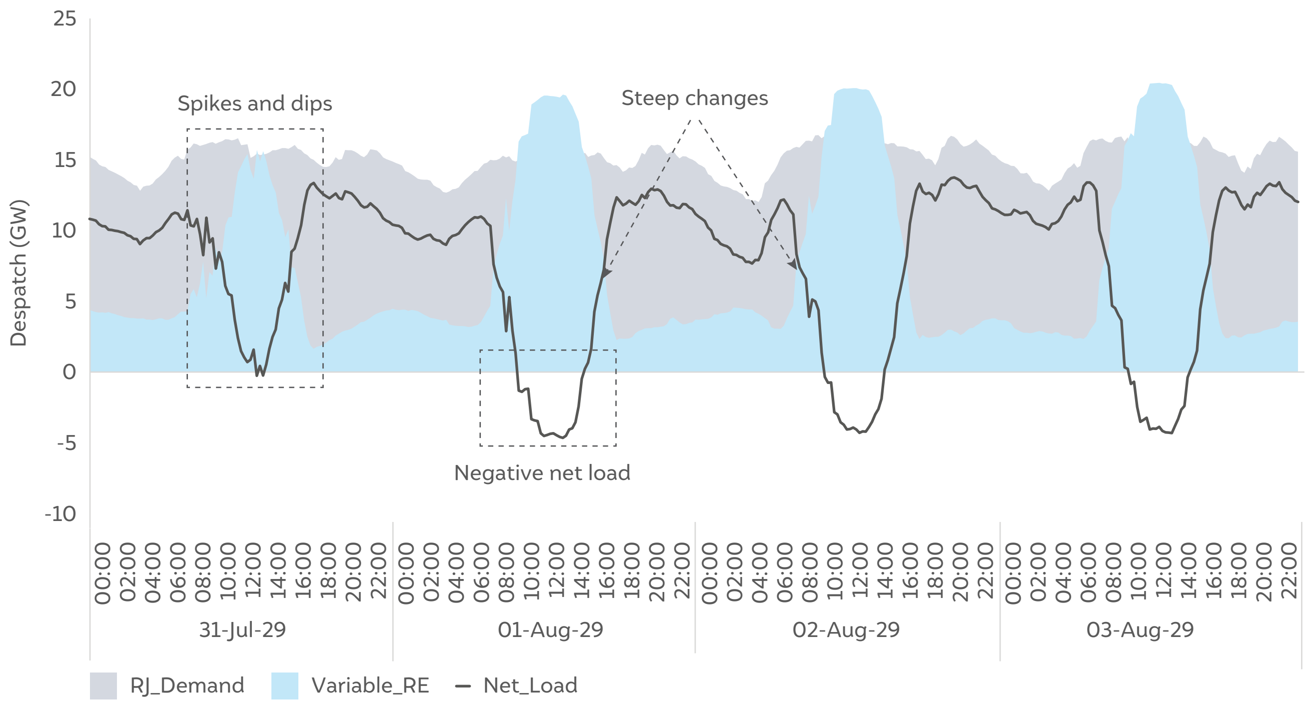
4 Net load is the load to be served using resources other than RE that are considered must-run. RE penetration corresponds to the renewable purchase obligation (RPO) for 2030.

5 GE MAPS is a security-constrained linear optimisation model, which is used to simulate the national power system in 2030, with input data and system constraints as discussed in Annexure I.

6 GridPath is an open-source grid analytics tool developed by Blue Marble Analytics. The tool has been used to conduct a similar study for Maharashtra (Dukkipati et al. 2021).

Two distinct cases were modelled (Box 1) to foresee how the state's power system despatch could look like in 2030. The inputs and assumptions are set out in Annexure I. The two cases helped identify the challenges with integrating RE, evaluate the current system's preparedness to deal with these challenges and suggest strategies that could help the state prepare for a power system of the future.

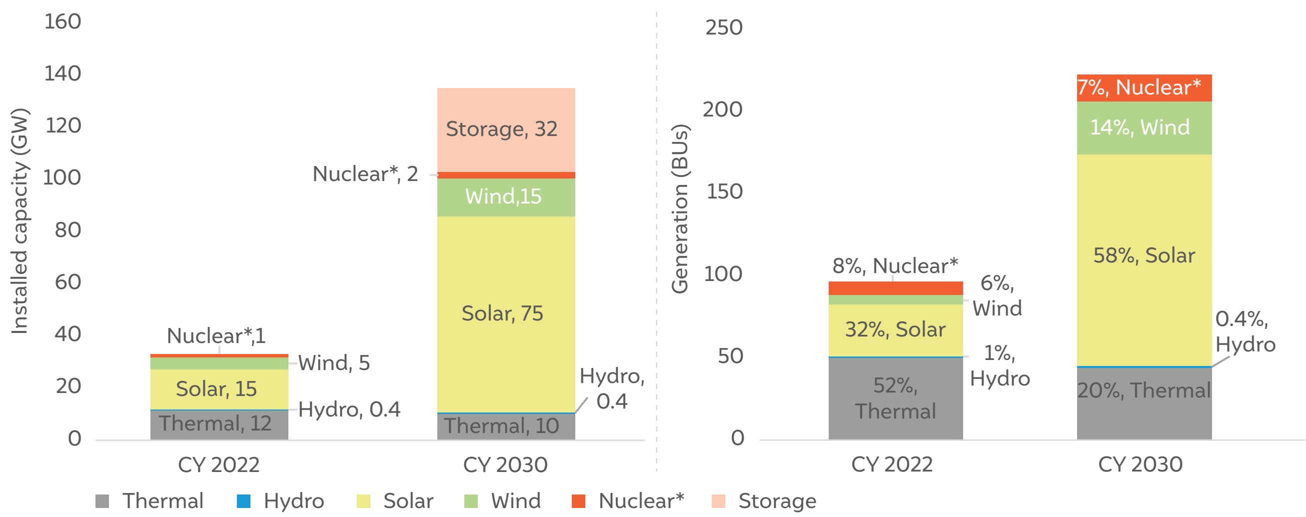
Figure 1 Integrating RE at scale will make the state's system operations complex and challenging



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: Assuming a renewable purchase obligation (RPO) trajectory to meet the state's demand for 2030.

Figure 2 The share of RE in Rajasthan's power generation mix would reach 72 per cent in 2030



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: (1) Capacity and generation mix for Case 1 (all-India despatch). (2) 'Thermal' includes coal- and gas-based plants, and 'Nuclear*' predominantly includes nuclear, along with bio-energy and small hydro projects (SHPs). (3) The base year is considered as the calendar year (CY) 2022.

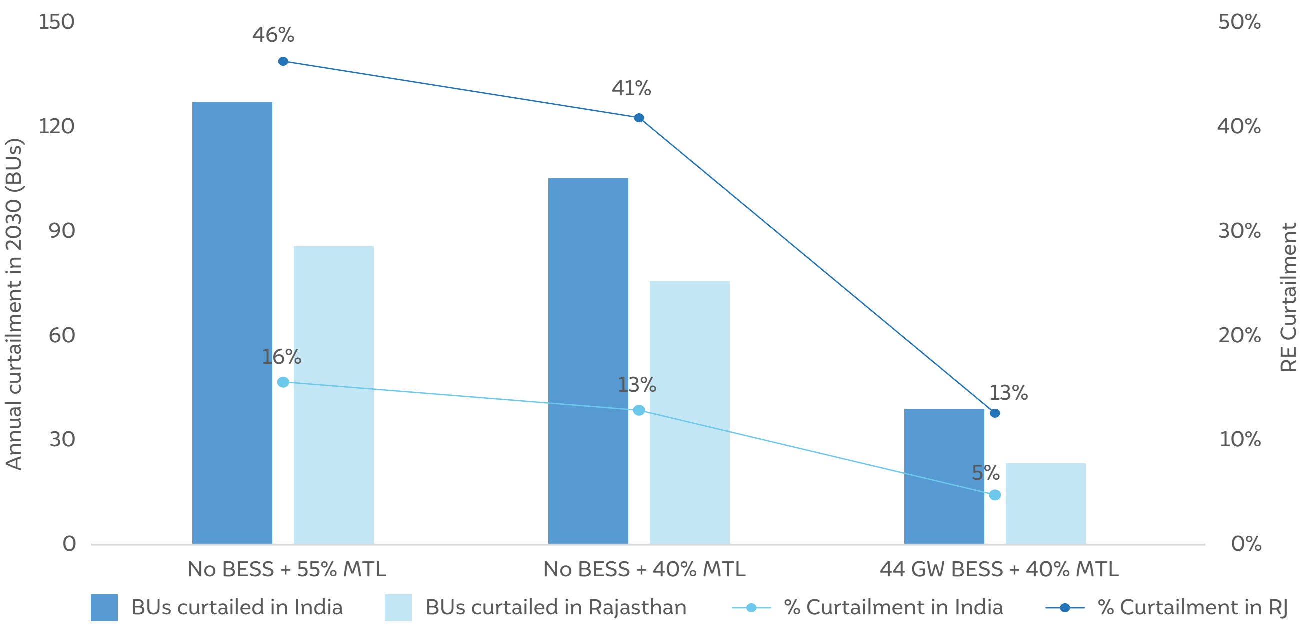
2.1 By 2030, Rajasthan must considerably increase its system flexibility to enable integration of the targeted 90 GW of RE capacity in the state and meet the country's 500 GW target

With 90 GW of RE capacity, Rajasthan will emerge as India's RE export house by 2030. The simulations under Case 1 suggest that by 2030, RE (solar and wind) will comprise 72 per cent of power generation at the state periphery (Figure 2), which is more than double the share of RE generation in the national grid. It is also observed that the state will become a net exporter of electricity. The quantum of net exports could increase by ~12.5 times between now and 2030, indicating the contribution Rajasthan will make to the RPO compliance by other states.[7] However, to realise this, investments in new flexible solutions, transmission capacity, and infrastructure upgrades are essential.

Rajasthan must house a huge share of flexibility resources required by the country to reduce RE curtailment and meet the peak demand. Case 1 results suggest that India will need around 44 GW -4 hours of battery energy storage systems (BESS) along with 22.5 GW of pumped storage hydropower (PSH) capacity. BESS will reduce the curtailment of RE generation in the state substantially. A majority of the national storage capacity (~32 GW) is likely to be located in Rajasthan (Figure 3).[8]

Rajasthan must also enhance the flexibility of its coal fleet. At the national level, ~81 GW of coal-based capacity would be needed to operate much more flexibly at 40 per cent minimum technical loading (MTL), down from 55 per cent, to absorb surplus RE generation. Rajasthan will house more than 10 per cent (~8.5 GW) of this flexible coal capacity (including central, state, and privately owned units). Lowering the MTL from 55 per cent to 40 per cent of rated capacity can help absorb an additional 22 billion units (BUs) of RE at the national level.

Figure 3 Rajasthan's RE curtailment can be reduced substantially by adopting a range of flexibility solutions



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: While these interventions will restrict national RE curtailment to 4.8 per cent in 2030, 13 per cent of RE generation will still be curtailed at the Rajasthan periphery. More RE generation could be absorbed if line transfer capabilities are enhanced or more BESS is deployed. However, additional BESS or transmission capacities may see lower utilisation levels and, therefore, may not be as economically attractive.

7 The state was a net importer until FY22. In FY23, Rajasthan's net exports amounted to 4 billion units (BUs), while it could export a net of 50 BUs of electricity in 2030.

8 Storage is added in states such as Rajasthan, which contributed the highest to India's total RE curtailment. A 32 GW BESS in Rajasthan helps export RE during non-RE hours when the transmission network is also available.

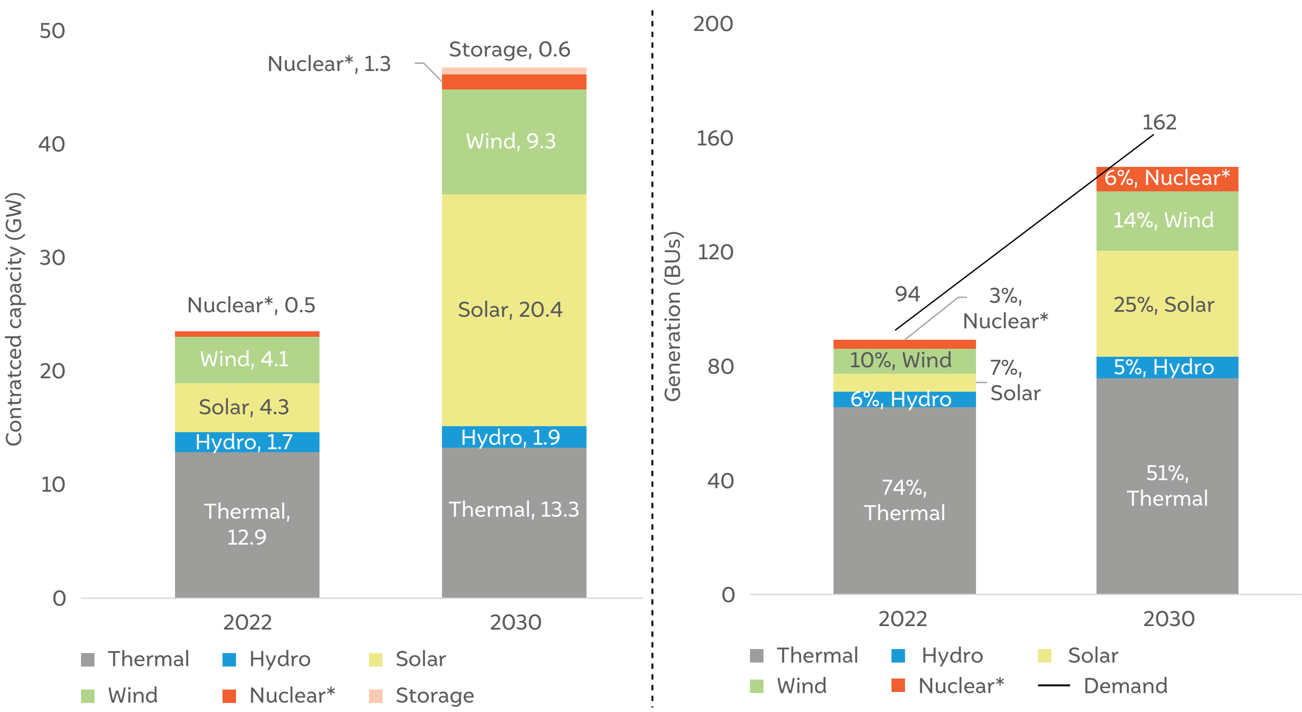
2.2 Rajasthan's discoms will need additional generation capacity and flexible solutions, beyond current plans, to ensure the reliability of supply to their consumers

In Case 2, a state-level copper-plate despatch model was simulated to visualise the requirements of state discoms to meet the RPOs and serve the demand in 2030. All operational norms and demand projections were the same as in Case 1. Findings from case 2 simulations are discussed below.

Rajasthan's discoms will need 30 GW of RE to meet their RPOs in 2030, which will double the share of RE in the state's contracted supply mix between 2022 and 2030. State discoms will need to procure an additional RE capacity of 21 GW to meet their RPOs, which will raise the RE shares in the contracted generation capacity and mix to 64 per cent and 39 per cent, respectively (Figure 4).[9] The share of coal-based generation in the mix will reduce to 51 per cent, down from 74 per cent in 2022. However, the annual utilisation of coal capacity will increase to ~65 per cent, up from 58 per cent in 2022, to meet the increase in electricity demand.

Electricity demand in the system is rising, but planned capacity addition is not commensurate. While RE additions would ensure RPO compliance, 7 per cent of the state's electricity demand in the simulation remains unmet in 2030 (mostly during non-solar hours) despite the current and planned conventional generation capacities.[10,11] As indicated in Figure 5, energy storage solutions could help utilise the curtailed RE to partly meet evening/early morning demand – when RE generation is low. The system will need additional resources that can cost-effectively reduce the unmet demand further.

Figure 4 One-third of Rajasthan's installed RE capacity will help meet its 2030 RPO target



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: (1) Contracted capacity and the corresponding generation under Case 2. (2) 'Nuclear*' predominantly includes nuclear along with bio-based energy and SHPs; 'Thermal' includes coal and gas-based projects. (3) The generation results for 2022 are as reported by the State Load Despatch Centre (SLDC) and the Northern Regional Load Despatch Centre (NRLDC) in daily implemented schedule reports. (4) The July 2021–June 2022 period was considered for 2022 to negate the impact of COVID-19 during the initial months of FY22, and a similar period was used for 2030. (5) Two units of the Giral thermal power plant (TPP) (250 MW) were excluded because they are in permanent outage as per the Central Electricity Authority's (CEA) operational performance monitoring reports on the thermal fleet (CEA 2023c).

9 Aligned with 7 per cent RPO for wind and 29 per cent RPO for solar (MoP 2022).

10 This does not account for procurement from short-term markets. Even if short-term markets are accounted for, the unmet demand is high, and there is a need to augment the capacities to close this gap.

11 As per the simulations, unmet demand will continue to be observed despite adding more firm coal-based capacity, indicating that frequent switching of coal capacity – required for meeting the unmet demand – is uneconomical.

Image: iStock

RE tenders for round-the-clock supply showcase such options.[12] Because of the evolving system needs and market developments, it is important that discoms and all relevant actors conduct regular and robust planning and resource adequacy assessments.

The flexibility level of the state's current power system is not enough to meet the ramping requirement posed by an RPO-compliant system in 2030. The analysis of the fleet operations shows that state-owned coal units exhibit a ramp rate lower than 1 per cent per minute and a much higher MTL than the CEA standard of 55 per cent.[13] Similarly, while considering the normative availability of the state's coal units, the actual availability is lower, as discussed in Chapter 3. Both these factors restrict the current system's flexibility.

It is also estimated that the rising RE penetration will result in discoms' ramping needs quadrupling between 2022 and 2030.[14] Even when planned generation capacities come online, and the CEA's current standards of 55 per cent MTL and 1 per cent per minute ramp rate are met, the system will still not be flexible enough to meet the increased ramping requirements. Thus, coal fleet flexibility must go beyond the current standards. However, doing so will lead to an increase in fixed-cost implications and operating costs. These costs will need to be compensated if coal units are to meet the flexibility needs of the state and the country. Additionally, other supply- and demand-side flexibility solutions need to be scaled to meet the system needs cost-effectively.

2.3 Enabling cost-effective integration of RE will require new initiatives and institutional collaborations

National net-zero goals, technological advancements, and consumer preferences must guide the state's plans for and investments in the desired set of technologies and solutions.

The state power sector institutions must collaborate to conduct robust exercises for resource planning and adequacy. For that, the Rajasthan Electricity Regulatory Commission (RERC) must mandate that the

12 In May 2020, SECI's auction for round-the-clock supply discovered a tariff of INR ~3.6 per kWh for RE projects coupled with energy storage (NetZero Pathfinders 2021). This is cost-effective as compared to the recently announced new coal capacities: for example, Obra D, a supercritical 800-MW coal plant, whose tariff in 2030 is estimated at INR 5.5 (assuming a 2 per cent escalation in the variable cost (VC) component of the auction-discovered tariff of INR 4.79) (The Indian Express 2023).

13 The ramp rate indicates the ability of a generating unit to increase or decrease its output; for example, if a 200-MW coal-based unit can change its generation by ±2 MW in a minute, then its ramp rate is 1 per cent per minute.

14 Ramping needs are assessed as the variation in the net load between two consecutive 15-minute time blocks.

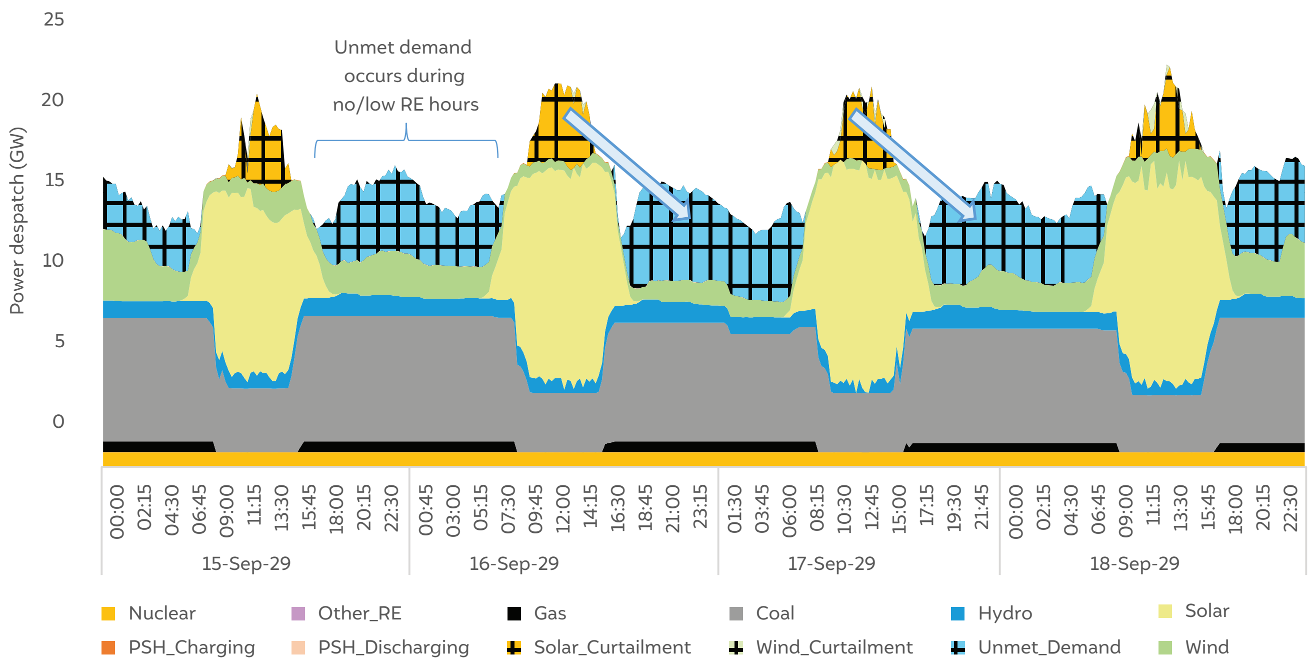
annual revenue requirement submission be developed and approved based on a robust integrated resource planning (IRP) exercise, which must be conducted every three years. Upon institutionalisation of a coordination mechanism, Rajasthan Urja Vikas and IT Services Ltd. (RUVITL) – the state power procurement and holding company of discoms – must develop a detailed IRP for the state in coordination with discoms, SLDC, and the state transmission company, all of whom must be tasked with providing the requisite data and inputs.

Support flexibility solutions such as BESS, PSH, and robust transmission systems to integrate RE at scale. The state energy department must develop a roadmap to achieve the state's energy storage obligation (ESO) targets for 2030. This roadmap, among other objectives, must incentivise and fund demonstration projects for various use cases, ensure robust assessments of grid balancing needs, and encourage the implementation of suitable energy storage procurement models. To enable RE exports, the state must contribute to national evacuation infrastructure and investment planning.

Simultaneously, the RERC must enforce provisions for reactive power support and integration of inverter-based resources through the state grid code. Better demand forecasting with the use of advanced tools and improved visibility of grid conditions will also ensure increased RE absorption in the state network.

Support measures to enhance coal fleet flexibility. As discussed above, flexibilising the state-based coal fleet will support the integration of RE at the country level. Therefore, states and the central government must co-develop a cost–benefit sharing framework to enable flexible operations, such as running at part load or lower MTL. As initial steps, the state generating company must conduct feasibility and cost–benefit analyses for retrofitting coal plants and develop and implement a flexibilisation plan in coordination with other relevant entities. The delivery of the flexibilisation plan must be supported through a procurement schedule in the interim. To initiate action, the state must allocate funds to undertake retrofitting measures in select units as a pilot project.

Figure 5 Unmet demand throughout the year is high and typically observed during non-solar hours



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

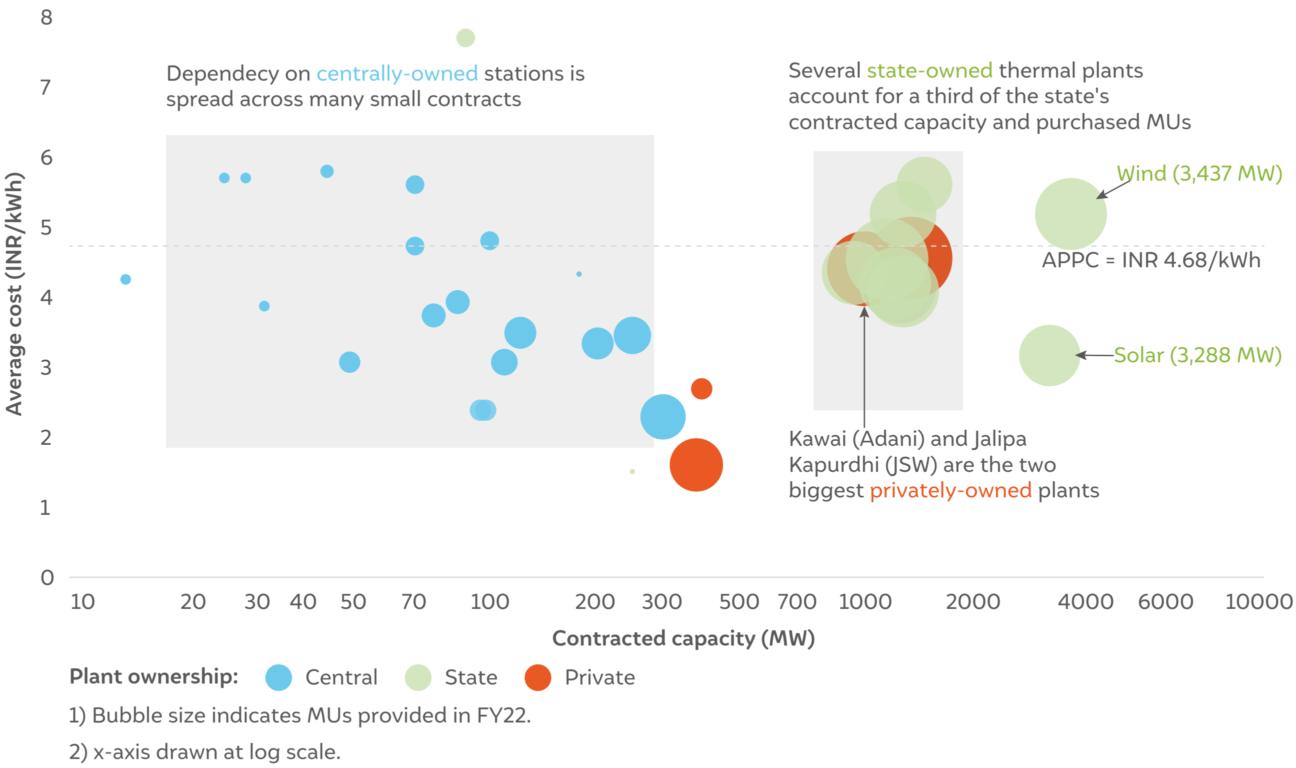
Note: Representing sample days selected from the annual despatch in 2030 (Case 2).

3. How can Rajasthan utilise its thermal fleet cost-effectively?

The Case 2 model presented in Chapter 2 shows that flexible TPPs will have an important role to play if Rajasthan's discoms are to meet their RPOs while serving the growing demand. The least-cost despatch model assumes that all resources, including TPPs, will be utilised cost-efficiently. However, the state currently faces challenges in maximising the TPP fleet's cost efficiency. In 2022, ~70 per cent of all power purchased by the discoms came from TPPs (RERC 2023a) At the same time, power purchase costs comprised 70 per cent of the costs built into the retail electricity tariff and 60 per cent of the discoms' disallowed costs (RERC 2023a). This indicates the need for the state to optimise the cost of power supplied by TPPs, which is predominantly higher for state-owned and private plants (Figure 6).

This chapter uses the example of eight large TPPs to analyse how addressing some key barriers can help improve the state TPP fleet's operational efficiency (see Box 2 for methodology). The eight TPPs together comprised over 40 per cent of the state's total contracted capacity of 23,482 MW and about half of the energy purchased in FY22. The three operational aspects of TPP utilisation were analysed: (1) improving plant availability, (2) economically efficient scheduling, and (3) accurate demand forecasting.

Figure 6 A few large state-owned and private TPPs drive the power purchase cost in Rajasthan



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: The six state-owned TPPs in the figure are Suratgarh, Suratgarh Super Critical, Chhabra, Chhabra Super Critical, Kalisindh, and Kota.

Box 2 Methodology and data sources

To analyse the thermal plants' operational patterns, the time block–level data (15 minutes) on plant-level despatch schedules obtained from the Rajasthan State Load Despatch Centre (RJSLDC) for FY22 was used. The plant availability factor was computed using the on-bar declared capacity (DC).[15] The variable cost (VC) for each plant was considered as notified in the fortnightly merit order despatch (MOD) by the RERC over the same period. To understand the operational challenges observed in the data, the detailed discussion and commentary provided in RERC's distribution tariff orders were referred to and supplemented with interactions with the Rajasthan Rajya Vidyut Utpadan Nigam (RRVUN), RJSLDC, and discom staff.

Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

3.1 State-owned thermal plants must enhance their operation and maintenance (O&M) activities to improve plant availability

In FY22, the on-bar DC of six state-owned plants ranged from 31.7 per cent to 68.3 per cent, which is below the normative target availability of 83 per cent (RERC 2019). This indicates that there is significant room for improvement.[16] The newer TPPs, such as Chhabra (2009–14) and Chhabra Super Critical (2018–19), had 59 per cent and 56 per cent as their actual maximum DC, respectively.

In FY22, about 900 MW of additional peak capacity would have been available if the DC of the six plants was equivalent to their maximum possible DC.[17] Furthermore, up to 17,000 million units (MUs) of additional energy would have been available if the plants with availabilities lower than the target availability of 83 per cent had met their targets, equivalent to about 15 per cent of the state's total energy procurement in the year. Higher availability of the existing fleet could have helped avoid capacity investments and reduced dependence on short-term or other costlier sources to meet the energy requirements.

Technical issues, statutory outages, and coal unavailability were the primary reasons for the outages in the six state-owned plants (Figure 7). In the first half of the financial year, statutory outages or planned/annual maintenance constituted a major share of the outages because maintenance activities were being carried out for some units ahead of the state's peak demand season. However, in October–March, nearly half the capacity was in outage for technical reasons,[18] equivalent to an average daily outage of 1,020 MW.

At the same time, RRVUN reported underutilisation of the O&M expenses allowed under RERC regulations for some plants, with spending varying from 50 per cent to 93 per cent of the allowed expenses for Kalisindh, Chhabra Super Critical, and Suratgarh (RERC 2023b). O&M expenses are underutilised even though the normative costs allowed to RRVUN under state regulations are lower than those allowed to central plants by the Central Electricity Regulatory Commission (CERC) (Table 1). One possible reason for such underutilisation could be long periods of standby operation, implying that the plants may have had a limited window or no window to conduct annual maintenance, potentially leading to underutilisation of the O&M budget and technical issues when it did get despatched later.

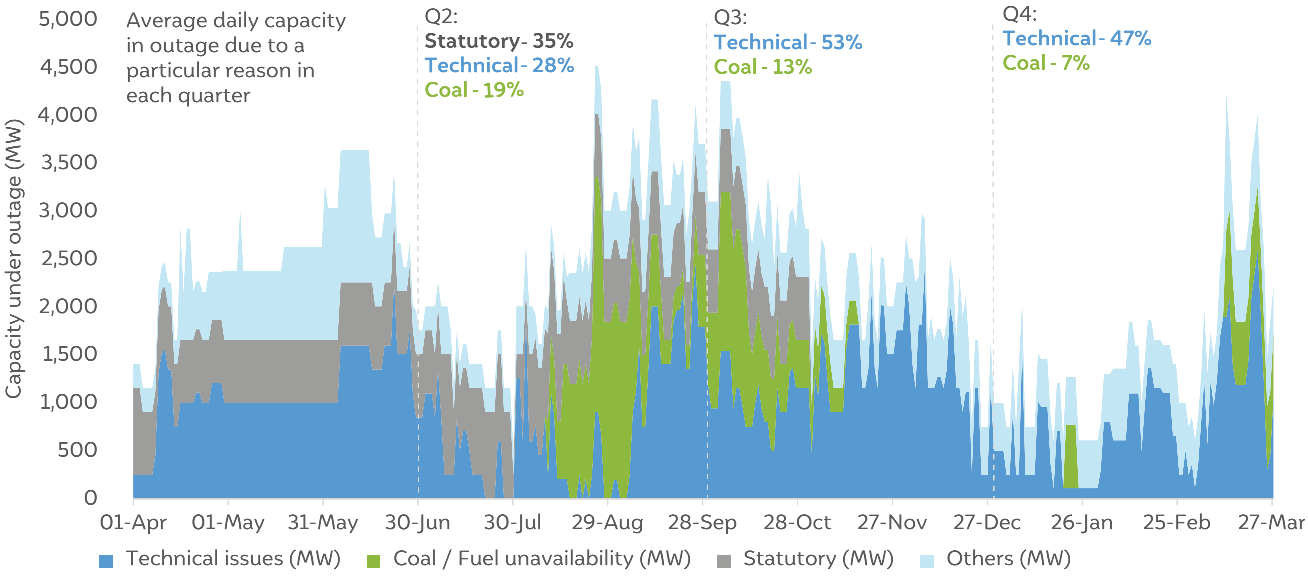
15 The plant availability factor was computed using only the on-bar capacity, whereas, the other approach could be to include hot, warm and cold stage operations to the on-bar capacity for each plant.

16 The private TPPs Kawai (supercritical unit) and Jalipa Kapurdi (Rajwest Power Ltd) had comparatively better availability at more than 75 per cent.

17 The maximum possible availability is estimated as the installed capacity less 10 per cent auxiliary consumption.

18 Technical issues include issues in the boiler (water tube leakages, drum-level issues, furnace-related issues, etc.), boiler auxiliary (electrostatic precipitator–related issues, fan problems, etc.), and turbine (governing system failure, bearing misalignment, vibration, etc.) and generator-related (transformer and cooling system –related issues, earthing, supply, and relay problems, etc.), and other issues.

Figure 7 Technical issues and statutory outages were the most common reasons for outages in FY22



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: The figure shows RRVUN-owned (six) thermal capacity in outage for each day in FY22

Table 1 O&M expenses allowed under RERC regulations are lower than those under CERC regulations

O&M expenses allowed to generating companies for different unit sizes (INR lakh/MW)						
	CERC regulations			RERC regulations		
Control Period	200/210/250 MW series	600 MW series	Annual escalation	110–250 MW	>250 MW	Annual escalation
FY15–FY19	23.90–30.51	14.40–18.38	~6.3%	16.09–20.20	14.48–18.18	5.85%
FY20–FY24	32.96–37.84	20.26–23.26	~3.5%	20.20–23.19	18.18–20.87	3.51%

Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Therefore, the following steps must be taken to ensure the cost-effective utilisation of state TPPs:

- RJSLDC and RRVUN must improve planning and enforcement of O&M schedules such that all plants can conduct annual maintenance;
- RRVUN must improve the utilisation of O&M expenses to reduce the incidence of technical outages; and
- RERC must update the O&M expenditure norms to align with the norms for central plants and to enable state TPPs to operate more flexibly.

3.2 Need for regulatory reforms to ensure scheduling and despatch of least-cost plants

The analysis shows that the state largely follows the merit order dispatch (MOD) principle, but there is room for improvement. As per the MOD principle, the cheapest plant should be utilised fully before utilising the next cheapest plant, and so on, until the last unit is supplied by the marginal plant. It was observed that during the peak demand months of November–March in FY22, scheduled generation from some lower-cost plants, such as the Kalisindh TPP (VC INR 3/kWh), deviated by more than 100 MW from its DC. Smaller deviations (~50 MW) occurred for other plants as well, including Kota TPP (VC INR 3.4/kWh) and Suratgarh TPP (VC INR 4/kWh).

Improved availability and utilisation of low-cost plants could yield significant cost savings for power utilities. Deviations of scheduled energy relative to DC could be due to high RE availability, lower-than-expected demand, grid congestion, or contractual obligations to provide minimum schedules to certain plants. However, to the extent that the deviations are observed during the peak demand and lean RE seasons, they represent opportunities for fuller utilisation of cheaper plants in the TPP fleet. For example, among the selected state-owned plants, replacing the ~3,400 MUs of energy procured from Suratgarh TPP (weighted average VC of INR 4.02/kWh) in FY22 with the energy obtained from lower-cost plants, such as Chhabra Super Critical TPP (VC INR 3.26/kWh) and the privately owned Kawai (VC INR 2.59/kWh) and Jalipa Kapurdi Rajwest TPPs (VC INR 2.6/kWh each), would have saved nearly INR 500 crore.

Addressing existing gaps in the method for calculating plant VC can help streamline the process of economically efficient scheduling. The method used by RUVITL – the state-owned energy trader – to build the weekly MOD stack for procuring energy on discoms' behalf should address the following gaps:

- **Non-inclusion of interstate transmission charges:** The VC of state-owned plants is calculated as the sum of the ex-bus cost of energy generation (the energy charge rate (ECR)) and the intrastate transmission charges. However, the VC for central plants excludes interstate transmission charges, possibly leading to their higher priority in the MOD stack relative to state-owned plants. This may have contributed to the lower utilisation of state-owned plants.
- **Delays in reporting ECR:** ECR can vary due to coal availability and quality, plant load factor, etc. (Table 2). Current practices require RRVUN to report the ECR of state-owned plants to discoms 45–55 days after the month of actual generation (RERC 2022).[19] However, there are often slippages in the timeline. As per the analysis, discoms had to shell out nearly INR 370 crore in additional costs in FY22 due to the usage of outdated ECRs in the scheduling of some plants.[20]

Table 2 VC variations led to additional power purchase costs for discoms in FY22

S. No.	Name of TPP	Approved generation (MUs)	Approved VC (INR/kWh)	Total actual generation (MUs)	Total cost at approved VC (INR crore) (A)	Total cost at actual VC (INR crore) (B)	Weighted average VC for all quarters (INR/kWh)	Variation in total VC (INR crore) (A – B)
1	Kota	4,852	3.39	6,277	2,128	2,116	3.38	12
2	Suratgarh Super Critical	2,958	2.74	2,015	552	658	3.27	–106
3	Chhabra	7,736	2.18	5,539	1,207	1,461	2.63	–253
4	Coastal Gujarat Power Ltd	2,140	1.89	413	78	82	2	–4
5	Farakka	49	2.81	46	13	14	3.07	–1
6	Kahalgaon 1	129	2.25	147	33	37	2.53	–4
7	Kahalgaon 2	497	2.12	651	138	155	2.39	–17
	Total				**4,149**	**4,524**		**–374**

Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: Considering quarterly FSA calculations provided by discoms.

19 In contrast, central and private plants provide bills after 10–15 days.

20 The analysis is based on the weekly MOD stack issued by RUVITL, the quarterly VCs, and the net generation used to calculate the quarterly fuel surcharge adjustment (FSA). The impact of interstate transmission losses and charges could not be included due to the unavailability of data.

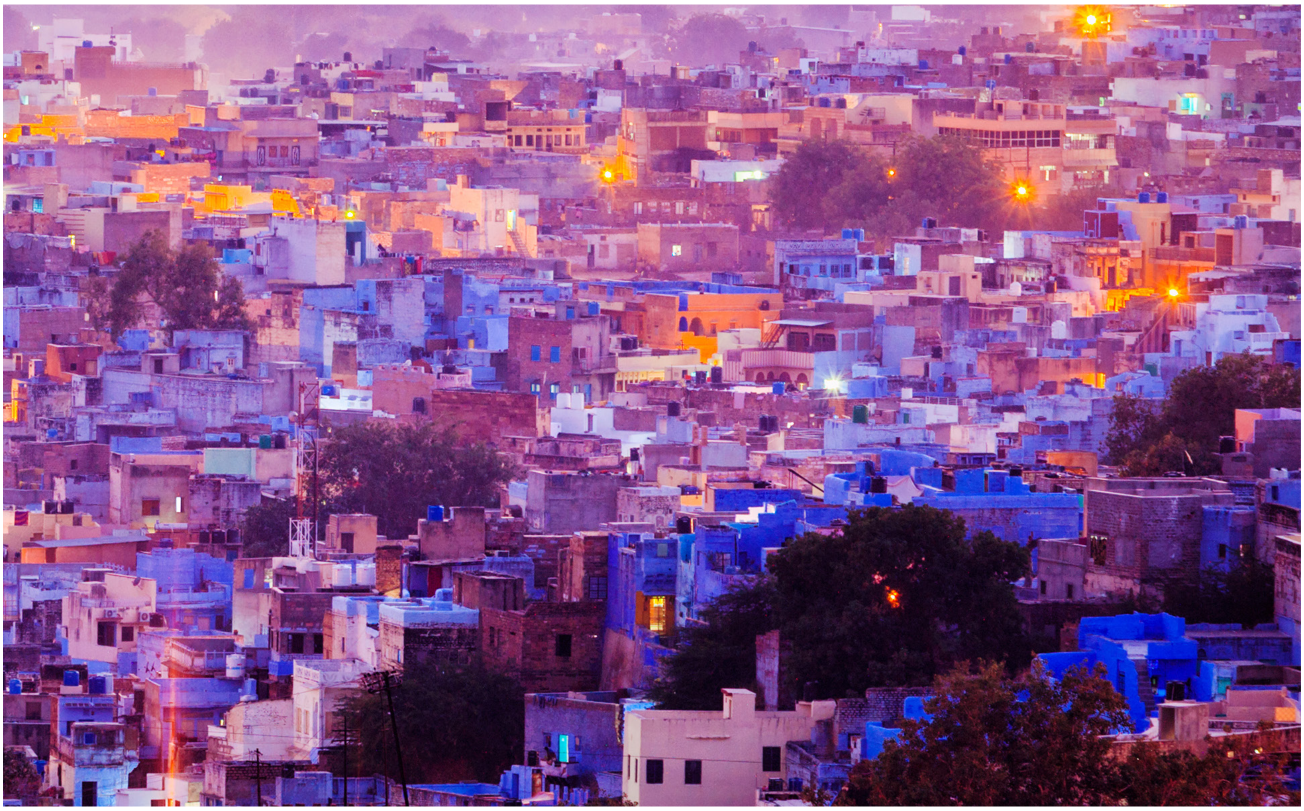


Image: iStock

- **Absence of plant operating guidelines:** The 2018 committee constituted by RUVITL to frame the methodology for preparing the MOD stack did not cover some crucial aspects, such as the plants' technical minimum, reserve margins of TPPs connected to the state transmission network, and the conditions for reserve shut down. Clarifying these operational metrics and their impact on plant ECR is important for streamlining VC computation.

In order to enhance despatch efficiency, the RERC must notify MOD regulations to clarify plant operational guidelines and VC computation, enabling adherence to least-cost despatch. Operating TPPs at lower plant load factors (PLFs) and frequent ramping to provide flexibility could cause higher VC variations. As TPPs ramp more frequently, such VC variations should be considered during scheduling. The methodology for computing VC may be notified through fresh regulations or by amending the state's grid code or the Multi-Year Tariff Regulations and must incorporate CERC's usage-based interstate transmission charges regulations and FSA treatment guidelines (CERC 2020).

Furthermore, enabling state resources to participate in national wholesale markets will ensure the efficient use of resources, thereby aiding the cost-effective integration of RE. The Ministry of Power's recent report on power market design proposes a nationwide economic despatch (starting with the security-constrained economic despatch (SCED) and eventually transitioning to MBED (MoP 2023a)). For Rajasthan to leverage wholesale markets for procurement cost optimisation, the RERC must commission studies to assess the costs and benefits of SCED and national MBED mechanisms.

3.3 Need for advanced demand forecasting methods and tools for higher accuracy and efficient resource scheduling

Errors in net load forecasts can lead to deviations from MOD-based scheduling and forgone opportunities to sell surplus energy. Rajasthan's actual consumer segment–wise energy demand has deviated from the CEA's and the Energy Assessment Committee's (EAC) forecasts since at least FY18 (Figure 8). Consultations with key stakeholders suggest that current day-ahead forecast accuracy is 80 per cent to 90 per cent, indicating scope for improvement. Demand uncertainty is driven by weather patterns and behavioural changes such as the adoption of cooling appliances, electric cooking, and electric vehicles (Harish, Singh, and Tongia 2020; IMD and POSOCO 2022) as well as distributed generation sources (Energy Department, Government of Rajasthan

2019).[21] Compounded annual growth rate (CAGR)–based projections and traditional statistical models suffer from the unavailability of reliable input data, dependence on assumed parameters such as network losses, lack of integration with diverse data sets such as socio-economic trends, and non-assessment of latent demand (World Energy Council India 2019).

Discoms, RUVITL, and the SLDC must adopt updated demand forecasting guidelines (CEA 2023b) **and utilise smart meter data to improve forecasting accuracy.** New statistical tools that combine 15-minute load data with weather events, maintenance schedules, consumer profiles, holidays, and so on, can achieve more accurate day- and week-ahead forecasts (SINE, MoP, and REC 2022). Socio-economic and demographic data collected through periodic surveys to understand technology adoption trends must also be used. The SLDC must leverage weather data and advanced techniques to improve the forecasting accuracy for RE generation as well as assist the EAC in incorporating weather data from the India Meteorological Department's Weather Power Portal in the demand forecasts. With improved demand and RE generation forecasting accuracy, RUVITL must leverage national markets to monetise surplus power in coordination with RRVUN-owned stations.

4. How Rajasthan's discoms can become enablers of its energy transition?

Discoms' financial health is a critical factor in a state's clean energy transition, as it determines discoms' ability to procure RE at competitive rates and invest in infrastructure upgrades and technologies essential for a successful energy transition. Discoms are the largest off-takers of RE. However, high off-taker risk is the most important barrier to clean energy investments in the states, which is linked to discoms' poor credit rating and delays in payments to generating companies (Gandhi, Hoex, and Hallam 2022).

Rajasthan's discoms are progressively reducing their losses, but their rising debt is unsustainable. Between FY20 and FY22, Rajasthan's discoms reduced their aggregate technical and commercial (AT&C) losses from 29.9 per cent to 17.5 per cent (PFC 2023a). However, they remain heavily indebted – their total debt is 111 per cent of annual revenue – and continue to incur revenue losses, adding to the already high accumulated losses (second highest in the country). As illustrated in Figure 9, discoms are caught in a vicious cycle of disallowed costs,[22] recurring losses, and rising debt as well as accumulated losses, poor credit ratings, and a high-interest burden.

In this chapter, interventions on three fronts that could help Rajasthan's discoms break out of the vicious cycle of losses and rising debt are discussed: (i) improving credit ratings, (ii) lowering accumulated losses by dissipating the unfunded revenue gap (URG), and (iii) mitigating concerns about disallowed costs by improving billing efficiency. Action on these fronts could be instrumental in re-pivoting the state discoms to become enablers of the energy transition.

4.1 Improving discoms' credit ratings to reduce the interest cost burden

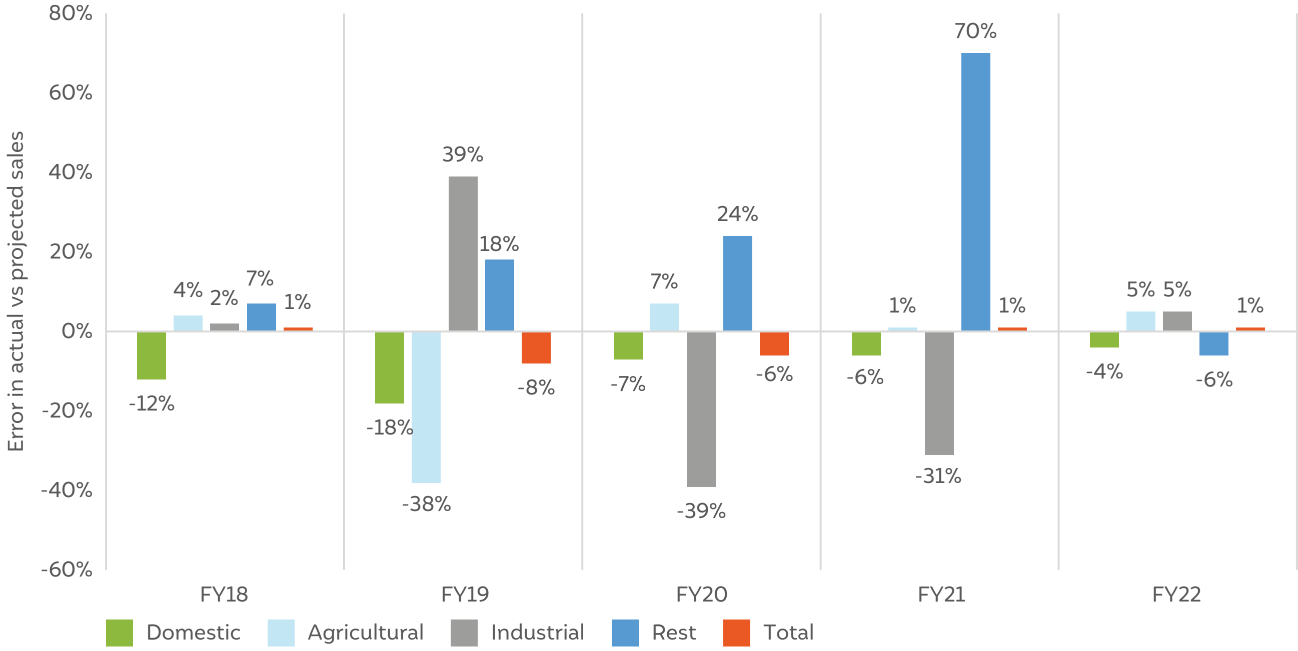
Improved ratings can help Rajasthan's discoms access low-cost loans and reduce the interest cost burden. The annual integrated ratings of the Power Finance Corporation (PFC) have a bearing on the terms on which discoms can mobilise finance for their capital and operational needs. In FY22, Rajasthan's discoms met 53 per cent of their total loan requirements from the REC and the PFC. Between FY20 and FY22, the Ajmer and Jaipur discoms (AVVNL and JVVNL, respectively) improved their credit ratings to B and B–, respectively, while the Jodhpur discom (JdVVNL) remained at C (PFC 2023b).

State discoms' shift to the A+ category would help reduce the interest burden for loans secured from the REC and the PFC by 0.75 per cent to 1.00 per cent. This means that the interest costs of ~INR 320 crore per annum, or ~INR 2,380 crore over five years (when compounded quarterly), could be avoided. An assessment of PFC's 11th rating and scores of Rajasthan's discoms indicates a need for action across 14 parameters (Table 3).

21 Based on the Saur Krishi Ajivika Yojana (SKAY) portal, almost 3 GW of demand may be served by decentralised RE installed under the KUSUM scheme by 2030 (JVVNL, AVVNL, and JdVVNL. 2023).

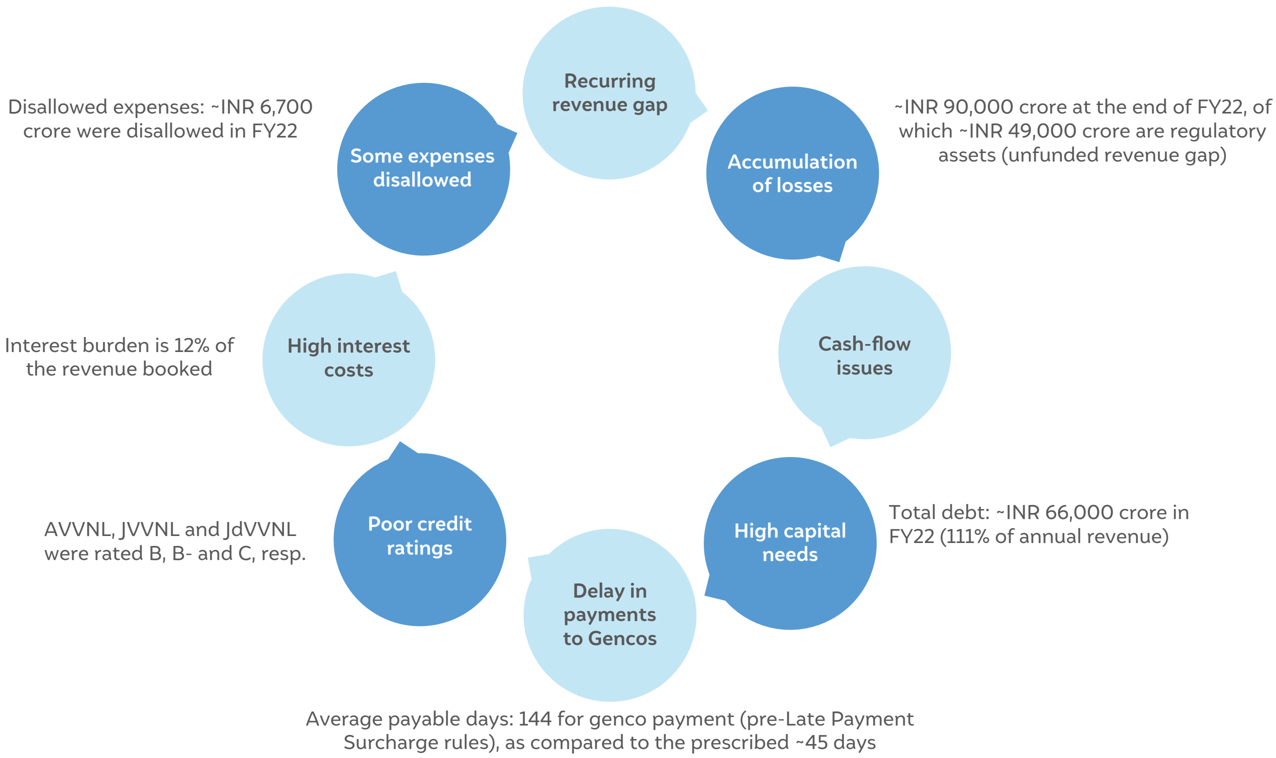
22 Discom expenses/costs disallowed by the state regulator during the true-up process are the key contributors to the discoms' accumulated losses in Rajasthan. In FY22, the RERC disallowed over INR 6,000 crore of the discoms' claimed expense, 59 per cent of which pertained to power purchases owing to gaps in forecasting and discoms' operational inefficiencies. Disallowed costs reflect as losses in the discoms' balance sheets, affect cash flows, and add debt and interest costs.

Figure 8 Consumer segment–wise energy demand has historically shown inaccuracy



Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Figure 9 Rajasthan's discoms need to break out of the vicious cycle of losses and debt to mitigate off-taker risks



Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Table 3 Scores for Rajasthan's discoms against different parameters determine their rating

Themes	Parameters		AVVNL	JVVNL	JdVVNL
		Max. score	B	B–	C
Financial sustainability (75 marks)	ACS–ARR gap (cash adjusted)	35	35	28.8	10.5
	Days receivable	3	3	3	3
	Days payable to gencos and transcos	10	0	0	0
	Adjusted quick ratio	10	2.8	0.9	1.6
	Debt service coverage ratio (cash adjusted)	10	4.4	3.4	0
	Leverage (debt/EBITDA[23]) (cash adjusted)	7	6.2	0	4.7
Performance excellence (13 marks)	Distribution loss (SERC approved)	2	2	0.8	0
	Billing efficiency (%)	5	1.8	0.2	0
	Collection efficiency (%)	5	3.7	3.5	2.3
	Corporate governance	1	0	0	0
External environment (12 marks)	Subsidy realised (last three FYs)	4	1.6	1.9	0.6
	Loss takeover by state government	3	3	3	2.8
	Government dues (last three FYs)	3	2.9	2.6	2.7
	Tariff cycle timelines	1	0	0	0
	Auto pass-through of fuel costs	1	1	1	1
	Gross score	**100**	67.4	49.1	29.1
Special disincentives (–66.5 marks)	Auditor's adverse opinion	–15	0	0	0
	Availability of audited accounts	–15	0	0	0
	Default to banks/Financial institutions	–15	0	0	0
	Audit qualifications	–4	–1	–1	–2
	Governance (audit committee)	–3	0	–1	0
	Tariff cycle delays	–4.5	–1.3	–1.3	–1.3
	Tariffs independent of subsidy	–1	0	0	0
	URG (current year)	–4	0	0	0
	Regulatory assets	–5	–3.1	–3	–5
	Total disincentives	**–66.5**	–5.3	–6.3	–8.3
	Net score		**62.1**	**42.8**	**20.9**

Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Note: Rows in grey and blue indicate parameters where short-term and medium-term actions, respectively, can help two or more discoms improve their score.

23 EBITDA stands for Earnings before interest, taxes, depreciation, and amortization

Discoms, with support from the state government and the RERC, can improve their grade through several short- and medium-term interventions:

- **In the short term:** Discoms must pursue the timely realisation of revenue, file their tariff petitions on time, meet audit qualifications, and adopt corporate governance. The state government must clear the pending subsidy receivables of ~INR 15,500 crore (MoP 2023b), and the RERC must release tariff orders on time. These initiatives could help discoms improve their scores by 8–11 points.
- **In the medium term:** Discoms must ensure timely payments to the generating companies (gencos) and systematically work towards reducing the average cost of supply–average revenue realised (ACS–ARR) gap[24] by optimising power procurement projections, improving billing efficiency, and dissipating built-up regulatory assets. These interventions would help improve the discoms' credit score by 16–46 marks.

4.2 Implementing a dissipation schedule for the URG to reduce accumulated losses

After Tamil Nadu, Rajasthan's discoms have the second-highest build-up of regulatory assets in the country (termed URG in Rajasthan), amounting to ~INR 49,250 crore (trued-up for FY22). These comprise more than half of the discoms' accumulated losses and have been growing at a CAGR of 11 per cent since FY11.[25]

Accumulation of a huge URG adversely impacts discoms and consumers by way of rising interest cost burden and, thereby, an increase in electricity tariffs. The URG forces discoms to raise additional working capital, which results in additional interest (carrying) cost expenses. Nearly three-fourths of discoms' interest and finance charges go towards servicing the URG, as per the latest tariff order for FY24.

- Between FY11 and FY23, discoms incurred a cumulative carrying cost of ~INR 49,300 crore on the accumulated URG, which was allowed to be passed on to the consumers. This, in turn, resulted in an interest cost burden on consumers equivalent to 8 per cent to 10 per cent (INR 0.58/kWh) of the average electricity tariff.
- If Rajasthan's discoms continue to be saddled with the existing URG, the consumers in the state would pay a carrying cost of ~INR 52,000 crore over the next decade.

A time-bound dissipation of the URG is critical to break the vicious cycle. It will significantly help improve discoms' financial performance by mitigating cash flow issues, reducing the interest cost burden, and improving their PFC credit ratings. Towards this end, discoms and the RERC must consider the following proposal:

- **Discoms must explore low-cost debt options to swap the expensive loans taken to service the URG and reduce associated carrying costs.** These may include transitional finance or government-guaranteed bonds, which could help reduce discoms' carrying costs by INR 960 crore annually (assuming a reduction of 200 basis points).[26]
- **The RERC must consider imposing a regulatory surcharge on electricity tariffs to help discoms generate additional revenue and liquidate the accumulated URG in a time-bound manner.** For instance, a surcharge of 4.69 per cent, in addition to loan swapping, would help dissipate the URG within the next 5–8 years (Figure 10 and Table 4).

24 ACS–ARR, or the per unit revenue gap, is a major parameter in grade determination. During FY20–FY22, Rajasthan discoms significantly reduced their revenue gap. While the ACS–ARR (cost-adjusted) difference was INR 13,652 crore in FY20, the discoms reported a surplus (barring JdVVNL) of INR 2,198 crore in FY22, mainly due to high subsidy disbursal by the state government. Sustaining a negative or zero revenue gap going forward will require concerted efforts.

25 Analysis based on data from RERC's true-up orders of FY09–FY22 and tariff orders for FY23 and FY24. The state government took over the entire revenue gap until 2009, so the current revenue gap has accumulated since FY10.

26 Rajasthan discoms are allowed an average carrying cost of 10.87 per cent on the URG. However, the coupon rates on the recently issued state government–guaranteed bonds have been 100 to 200 basis points lower on average (8.95 per cent to 9.95 per cent) (The Fixed Income 2023).

Table 4 Swapping of discoms' expensive loans against the URG with cheaper debt, together with a surcharge of ~4.69 per cent on electricity tariffs, can help dissipate the accumulated URG within 5–8 years and yield savings of INR ~17,300 crore to consumers

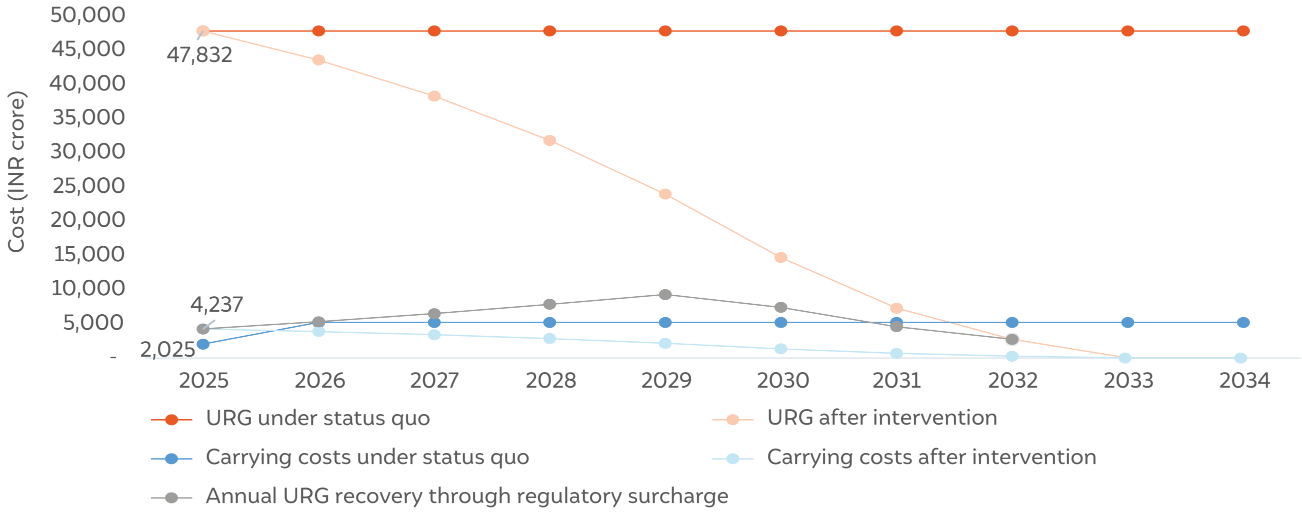
Particulars	Unit	Formula	Aggregate values
Projected energy sales for FY25	MUs	A	93,989
Opening URG for FY25	INR crore	B	47,832
Current carrying cost of URG (at average long-term interest rate)	Percentage	C	10.87
Projected revenue for FY25 (excluding carrying cost)	INR crore	D	66,254
Projected revenue for FY25 (including carrying cost)	INR crore	E = D + B × C	71,453
New carrying cost of URG upon loan swapping	Percentage	F =C – 2%	8.87
Gross regulatory surcharge on projected revenue (inclusive of new carrying cost after loan swapping)	Percentage	G	12.80
New projected revenue for FY25 (as per gross regulatory surcharge)	INR crore	H = D × (1 + G)	74,735
Number of years until full URG is dissipated	5–8 years (varying with discoms' URG)		
Net regulatory surcharge or effective increase in consumer bills during the dissipation period	Percentage	I = (H/E) – 1	**4.69**
Increase in average billing rate after loan swapping and surcharge	INR/unit	J = (H – E) × (10/A)	**0.35**

Source: Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Notes:

1. In FY24, the carrying costs of the URG for Rajasthan's discoms were 11.10 per cent, 10.75 per cent, and 10.69 per cent for JdVVNL, JVVNL, and AVVNL, respectively. At the aggregate level, the carrying costs of URG are estimated as a weighted average for all three discoms – that is, 10.87 per cent.
2. The gross regulatory surcharge is computed as 12.80 per cent. However, the current tariffs include the carrying costs of the URG; therefore, the net regulatory surcharge on consumer bills – inclusive of loan-swapping benefits – will be 4.69 per cent.
3. At an aggregate level, the net regulatory surcharge is computed as 4.69 per cent. However, it would vary from 2.90 per cent to 6.25 per cent for Rajasthan's discoms due to the accumulated URG and variations in carrying costs.
4. Annual revenue and sales growth rates of 8 per cent and 3 per cent are being assumed, respectively, as per past trends from the RERC tariff and true-up orders.
5. The revenue gap/surplus from FY25 onwards has been assumed to be zero.
6. The number of years for dissipation might increase with an increasing share of commercial and industrial consumers migrating towards other modes of power procurement under the Green Energy Open Access Rules and captive transactions.

Figure 10 The two interventions will help dissipate the accumulated URG and associated carrying cost within 5–8 years



Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

- **The proposed solutions will help consumers avoid paying a carrying cost of ~INR 33,000 crore over 10 years** due to the dissipation of the accumulated URG and reduced carrying costs. However, consumer tariffs will increase by ~4.6 per cent to recover the pending dues (i.e., the URG).
- **RERC must revisit the accounting mechanism for recovery of the revenue gap and carrying costs.** An effective dissipation strategy requires that the surcharge is levied separately on consumers' electricity bills and recorded separately in the discoms' billing database. A clear and separate accounting of the revenue gap and associated carrying costs will improve transparency and allow their time-bound recovery.

4.3 Leveraging the smart metering infrastructure to improve billing efficiency

Low billing efficiency is a key contributor to the recurring AT&C losses of Rajasthan's discoms. The notable decline in the AT&C losses of Rajasthan's discoms from FY20 to FY22 was mainly driven by an increase in collection efficiency, which rose to 100 per cent due to the subsidies booked and received. In contrast, their billing efficiency improved only marginally to 82.51 per cent. Moreover, JVVNL and JdVVNL, who have lower credit ratings, have multiple circles with high AT&C losses (>20 per cent) and require technology-enabled targeted efforts to improve billing efficiency.

Image: Milan Jacob/CEEW

The government of India's Revamped Distribution Sector Scheme (RDSS) presents a key opportunity for state discoms to improve their billing efficiency through smart meters. Poor billing efficiency is a result of factors such as electricity theft, provisional billing and under-billing of consumers, poor distribution infrastructure, and unmetered agriculture sales. Smart metering of user connections, feeders, and transformers can enable proper energy accounting and auditing as well as accurate billing. Rajasthan's discoms plan to install ~1.4 crore smart meters in the coming years, which will require an investment of ~INR 8,500 crore.[27]

So far, six lakh smart meters have been installed. **To ensure smooth smart meter deployment and capture returns on investment, the state energy department and discoms must focus on three key aspects:** [28]

- **Designing and conducting consumer engagement and awareness campaigns.** Independent surveys with smart meter users in Rajasthan indicate that past deployments have only partly influenced consumer satisfaction, with very few users experiencing the benefits of the technology (Agrawal et al. 2023). User experience in other states indicates that discoms need to play a greater role in supporting the uptake of smart

27 As per state discoms' RDSS action plan.

28 These themes have been developed based on learnings gathered through the survey of smart meter consumers and engagements with officials from discoms in MP, Assam, and Bihar on their experiences and best practices.

meter mobile apps, providing access to and ensuring awareness of bill composition, and enabling a smooth recharge/reconnection experience, which will be critical for consumer acceptance and use of smart meters.

- **Developing system architecture for secure and integrated data storage, sharing, and management systems.** Consultations with discom officials in other Indian states suggest that discoms must include suitable provisions in their contracts with metering service providers to (i) ensure interoperability between the meter data management system and discoms' billing platform and (ii) secure the system and smart meter data from unauthorised access and cyber threats.
- **Strengthening institutional capacity to leverage smart meter data for diverse use cases.** Many Indian discoms are enhancing internal capacity to develop context-specific use cases of smart meter data, such as profiling consumers' load and consumption, using pattern analysis, identifying locations with high energy losses and so on. The Rajasthan's discoms currently rely on metering service providers to gain limited insight into smart meter data. In order to realise the full potential of the smart metering infrastructure, state discoms must enhance institutional capacity through measures like creating well-staffed smart meter units, conducting periodic training for existing staff, and building a new cadre of discom staff trained in IT systems and advanced data analytics.

In parallel, it would be crucial for the state regulator to issue dedicated guidelines concerning the rights of smart meter users to ensure that discoms and associated entities deploy smart metering infrastructure in a consumer-centric manner.

5. State action plan for power sector transformation

Cost-effective integration of renewables in the grid and financially healthy discoms are two key outcomes that Rajasthan must pursue to realise its RE potential and achieve its ambitious target of 90 GW of RE capacity by 2030. Achieving these outcomes requires all key state actors to work in unison and ensure coordinated implementation of priority interventions, as summarised in Tables 5 and 6.

Different state-level institutions and actors must play their part by taking the lead on certain initiatives while supporting other institutions in fulfilling their evolving roles and responsibilities to facilitate the transition. For instance, a mandate from the RERC is vital to initiate a robust IRP exercise, which will require the state energy department to allocate adequate funds and supervise such an exercise, led by RUVITL, with necessary inputs and data support from discoms, RRVUN, RRECL, and the SLDC.

At the same time, in an interconnected system such as India's, one state's road to the energy transition is paved with support from other states and affects the whole system's ability to integrate clean energy reliably and cost-effectively. Identifying and resolving challenges – such as mobilising the capital to flexibilise TPPs, sourcing high-quality coal, etc. – would require the government of India to engage with state governments, coordinate with them, and provide necessary financial and technical assistance to them on a regular basis. All institutions must come together to create a power system that provides clean, reliable, and affordable energy to all.

Table 5 Action plan to transform Rajasthan's power sector for a clean energy future

Objective (why)	Priority intervention (what)	Stakeholder actions (who and how)					
		RERC	State energy department (including RRECL)	Discoms	RUVITL	RRVUN	SLDC + RVPN
Enabling cost-effective grid integration of RE	IRP	Mandate IRP submission as part of the ARR process Establish an IRP evaluation desk at RERC	Institutionalise a coordination mechanism and provide the requisite funds for conducting an IRP exercise every three years	Support IRP development with requisite data and inputs	Develop a detailed IRP for the state in coordination with discoms	Support IRP development with requisite data and inputs	
	Scaling up grid flexibility solutions (BESS, PSP, hydro, transmission)	Engage with the CEA for co-developing technical and connectivity standards for energy storage at various levels	Develop a roadmap to achieve the state's ESO targets for 2030 Incentivise energy storage demonstration projects for various use cases	Set up demonstration projects for distribution-level use cases	Procure storage services using suitable procurement models		Assess grid balancing needs to be met through storage Set up demonstration projects for transmission-level use cases Assess scheduling approaches for using hydroelectric projects for flexibility services
	Enhancing the state's coal fleet's flexibility	Enforce the CEA's flexibility norms via the State Grid Code	Allocate funds to undertake retrofitting measures in select units as pilots Co-develop a cost–benefit sharing framework to enable retrofitting and part load operations		Create a contingency power procurement plan aligned with the flexibilisation plan	Conduct feasibility and cost–benefit analysis for retrofitting coal plants Develop and implement a flexibilisation plan	Assist RRVUN in developing and implementing the coal plant flexibilisation plan
	Cost-effective operation of the state-owned coal fleet	Notify MOD regulations and plant operational guidelines Align normative O&M expenses with actuals or CERC norms Commission studies to assess the costs and benefits of SCED and national MBED mechanisms	Resolve coal-grade slippage issues in consultation with the government of India and its relevant agencies	Support robust demand forecasting for efficient resource scheduling through requisite data and inputs	Prepare MOD in line with notified principles/regulations Leverage national markets to monetise surplus power in coordination with RRVUN	Share plant VC with RUVNL within 10–15 days (or as defined in the MOD principles/regulations) Enhance O&M practices to improve plant availability Leverage national markets to monetise surplus power	Optimise annual O&M schedule to improve plant availability and supply reliability Conduct robust demand and RE generation forecasting using weather data and new statistical tools
	Expanding and modernising the transmission network	Update the state grid code to introduce provisions for reactive power support and management of inverter-based resources		Enhance the interface between distribution and the intrastate transmission grid for real-time demand management			Contribute to national evacuation infrastructure and investment planning to enable RE exports Implement advanced asset monitoring systems for improved visibility of grid conditions

Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Table 6 Action plan for improving discoms' financial health

Objective	Priority	Stakeholder actions		
		RERC	State energy department	Discoms
Improving discoms' financial health such that they can be enablers of energy transition	Improving credit ratings	Ensure timely release of tariff orders and timely dissipation of discoms' unfunded revenue gap	Ensure clearance of pending tariff subsidy dues to the discoms and upfront payment of subsidies in the future	Ensure timely filing of tariff petitions Adopt corporate governance norms
	Dissipating the unfunded revenue gap	Levy suitable regulatory surcharge on retail tariffs Revisit the accounting mechanism for the revenue gap and carrying cost recovery in the tariff order	Develop a dissipation plan with the discoms Explore transitional finance or private placement options for refinancing the unfunded revenue gap with cheaper loans	Co-develop a dissipation plan with the energy department
	Improving operational efficiency by leveraging smart meters	Issue guidelines on consumer rights (smart meter users) or incorporate suitable provisions in the state's standards of performance regulations to ensure a uniform consumer experience	Monitor progress on smart meter deployment and facilitate capacity building	Design and conduct consumer engagement and awareness campaigns Develop system architecture for secure and integrated data storage, sharing, and management systems Strengthen institutional capacity to leverage smart meter data for diverse use cases

Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

Annexure I: Modelling inputs, assumptions, and data sources

Table A1 **Modelling inputs and assumptions considered for case 1 and case 2 simulations**

Case 1: National-level model	Case 2: State-level model
• Each state acts as a node with interstate and inter-regional transfer capabilities • Base year: CY 2022; projection year: CY 2030 • INR 40/kWh was considered as a penalty for unserved energy • In 2030, 90 GW of RE capacity installed in Rajasthan • Conventional capacity additions and retirement were considered as per CEA's draft National Electricity Plan (NEP) 2022 (CEA 2023d) • 11 per cent unavailability (planned maintenance as well as forced outages) • Only cold starts were considered • 40% MTL for selected units, and rest at 55% • 1 per cent fuel cost escalation assumed for domestic as well as imported coal • Capacity utilisation factors (CUFs) for new solar and wind capacity in Rajasthan were considered to be 23 per cent and 30 per cent, respectively • 5 per cent of the load was considered as operating reserve for each region	• Copper-plate model, that is, no intrastate transmission constraints were considered • Base year: July 2021 to June 2022; projection year: July 2029 to June 2030 • INR 20/kWh was considered as a penalty for unserved energy • Along with the existing 8.4 GW of RE, an additional capacity of 21 GW capacity added to meet the RPO • Contracted capacity additions and retirement were considered as per the RUVITL plan,[29] CEA NEP 2023, and stakeholder inputs (MoP and CEA 2023) • 8 per cent planned maintenance and 7 per cent unplanned outages • Only warm start operating characteristics were considered • All coal-based units operate at 55% MTL • 2 per cent fixed and variable cost escalations were assumed for all fuels • 25 per cent and 28 per cent CUFs were considered for new solar and wind projects, respectively

Note: Demand projections are based on the CEA 20th Electric Power Survey, without any change in profile (CEA 2022). Other thermal operations characteristics such as start time, start-up cost, minimum downtime, and auxiliary and ramping rates were considered as per standard CEA norms

Source: Compilation based on Agrawal et al. 2023. Policy Study on Energy Transition Roadmap 2030. Jaipur: CMRETAC, Government of Rajasthan.

29 As per inputs received from RUVITL

Acronyms

ACS	average cost of supply
ARR	annual revenue requirement
AT&C	aggregate technical and commercial losses
AVVNL	Ajmer Vidhyut Vitran Nigam Limited
BESS	battery energy storage system
BU	billion unit
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commis sion
CMRETAC	Chief Minister's Rajasthan Economic Transformation Advisory Council
CUF	capacity utilisation factor
CY	calendar year
CAGR	compounded annual growth rate
DC	declared capacity
EAC	Energy Assessment Committee
ECR	energy charge rate
ESO	energy storage obligation
FDRE	firm and despatchable renewable energy
FSA	fuel surcharge adjustment
GoR	Government of Rajasthan
IMD	India Meteorological Department
IRP	integrated resource planning
JVVNL	Jaipur Vidhyut Vitran Nigam Limited
JdVVNL	Jodhpur Vidhyut Vitran Nigam Limited
KUSUM	*Kisan Urja Suraksha Evam Utthaan Mahabhiyan*
LDC	load despatch centre
MAPS	multi-area production simulation
MBED	market-based economic despatch
MOD	merit order despatch
MoP	Ministry of Power
MTL	minimum technical load
MU	million unit
NRLDC	Northern Regional Load Despatch Centre
O&M	operation and maintenance
PFC	Power Finance Corporation
PSH	pumped storage hydropower
PLF	plant load factor
RDSS	*Revamped Distribution Sector Scheme*
RE	renewable energy
RERC	Rajasthan Electricity Regulatory Commission
RJSLDC	Rajasthan State Load Despatch Centre
RPO	renewable purchase obligation
RRVUN	Rajasthan Rajya Vidyut Utpadan Nigam
RUVITL	Rajasthan Urja Vikas and IT Services Limited
SERC	State Electricity Regulatory Commission
SCED	security-constrained economic despatch
SHP	small hydro project
SKAY	*Saur Krishi Ajivika Yojana*
SLDC	State Load Despatch Centre
TPP	thermal power plant
URG	unfunded revenue gap
VC	variable cost

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COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW)

ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi - 110070, India
T: +91 (0) 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia

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