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Strengthening Adoption of Electricity Markets to Enable the Clean Energy Transition in Indian States

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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EXECUTIVE SUMMARY

Highlights

- This working paper helps understand how electricity market mechanisms have the potential to integrate renewable energy (RE) into the grid at the state level.
- Market participation in Indian power exchanges is currently thin. This paper offers state-level stakeholder views on the barriers that deter greater participation in real-time and day-ahead markets, such as the long duration of power purchase agreements (PPAs) that locks in older and less efficient resources, the perception of seller bias, and inaccurate forecasts of short-term RE demand and market prices.
- Market reforms such as re-evaluating existing PPA structures, exploring new PPA designs, adding more generation and demand-side resources to the competitive pool for accurate market price signals, and encouraging coordinated resource adequacy (RA) planning at the national and state levels can help reduce costs in the longer term and complement short-term markets.
- This paper recommends establishing robust frameworks at the state level that will encourage greater collaboration between state utilities to foster the regional resource sharing, effective resource utilization, and efficient power procurement that are needed to ensure a clean energy future.

Context

At the 26th Conference of Parties (COP26) in Glasgow, India committed to building 500 GW of installed capacity from non-fossil fuel (including RE and nuclear) by 2030 (MNRE 2023). India has taken noteworthy steps to transition to cleaner energy and as of March 2023 had more than 172 GW of RE installed capacity, which accounted for 41.3 percent of the total installed capacity (CEA 2023a). There are several ways in which markets can facilitate and accelerate the growth of RE in India's electricity supply. These include balancing supply-and-demand mismatches, managing RE variability, reducing potential RE curtailment scenarios and increasing power system flexibility (IEA 2021), increasing transparency in price discovery, enabling real-time adjustments to increase forecasting accuracy, promoting resource sharing, and integrating new technologies such as energy storage.

Electricity markets in India are still in the nascent stage. Whereas conventional day-ahead markets (DAMs)[1] have existed from 2008 onward, alternative market segments, such as term-ahead markets (TAMs),[2] real-time markets (RTMs),[3] green day-ahead markets (G-DAMs),[4] and ancillary services (ASs),[5] are recent additions. At the subnational level, many factors make it challenging for states to participate in electricity markets, such as complex regulatory frameworks, long-term PPAs, lack of technical capacity for resource planning, and the self-scheduling practices that state utilities use to optimize power procurement. Further, there is an increasing need for transparency in prices and tighter measures to mitigate potential misuse of markets, and innovative products to enhance market utilization in the future. Hence, overcoming these challenges will be vital to increase the adoption of electricity markets in India. This paper details the challenges stakeholders face in adopting these market mechanisms at the state level, and identifies options based on international lessons, stakeholder consultations, and our own analysis to improve the uptake of market mechanisms and thus enable the clean energy transition at the state level.

About this paper

This paper addresses the following questions:

- What is the status of electricity markets in India?
- What barriers do stakeholders face in adopting markets at the state level?
- What lessons can we learn from key international practices to tailor market options for India to overcome these barriers?
- What do stakeholder consultations and analysis of current market penetration trends reveal about how markets can enable the clean energy transition at the state level?

Our research is intended to guide distribution companies (DISCOMs), energy and planning departments, state electricity regulatory commissions (SERCs), the Central Electricity Regulatory Commission (CERC) and the Central Electricity Authority (CEA), power plant developers, independent RE developers, think tanks, and academia.

Key findings

Markets have the potential to help the states in their clean energy transition efforts, by allowing them to transition to RE resources, which typically have lower marginal costs than older, inefficient power plants. Markets can also enhance flexibility by dispatching resources from a larger pool, from a broader footprint, and at a more granular level, which can reduce renewable curtailment and ramp up the resources needed to balance variable renewables for DISCOMs.

The specific findings of our paper include the following:

- Existing power exchange[6] (PX) instruments account for only 7 percent of India's electricity demand. The Indian Energy Exchange (IEX) dominates the market and is responsible for 90–94 percent of PX transactions.
- RTMs have experienced the highest increase since its introduction in June 2020. RTMs are now responsible for 25 percent of the transactions in the PX space. However, the PX share of DAMs, which remain the major source of short-term transactions in India, dropped from 75 percent to 50 percent during the same period.
- States with a high share of coal, such as Chhattisgarh, Jharkhand, and West Bengal, are selling power in the short-term market, primarily DAMs and RTMs. In financial year (FY) 2023,[7] these regions sold power worth 11–26 percent of the demand through DAMs. This can help increase the utilization and plant load factor of thermal power plants in these states.
- States such as Maharashtra, Gujarat, and Tamil Nadu, which have wind power capacity, leverage RTMs to sell power during peak wind generation periods. This participation in RTMs can help address the intermittency challenges of RE and thereby integrate more RE sources into the grid.
- Major barriers that prevent stakeholders from adopting more market-based transactions include fluctuating market clearing prices[8] (MCPs), lack of accurate supply–demand forecasts and monitoring mechanisms, perception of seller bias, and the fact that most generating capacity is locked in long-term PPAs. Fuel price volatility (especially when fuel prices are high) pertaining to thermal plants may translate to market price changes; however, it can also encourage buyers to purchase cheaper power. Integrating more RE generators could potentially mitigate fuel price volatility.

- Despite fluctuations in MCPs, DAMs still offer savings potential compared to the long-term PPA-dominated[9] power procurement mix in different states. States such as Gujarat and Tamil Nadu show significant savings potential, with potential savings of INR 0.27 and 0.17 per kilowatt-hour if they choose to fulfill their demand needs through DAMs. Price fluctuations need to be carefully monitored when evaluating the savings potential.

Recommendations

- The existing PPA structures should be re-evaluated, and generation contracts could be renegotiated (wherever applicable). These adjustments would encourage greater market participation by both buyers and sellers and enable utilities to purchase low-cost energy from markets (IEA 2021).
- States need to plan for the adoption of demand-side bidding,[10] ASs, and aggregated demand response[11] for increased penetration of clean energy resources and integration of energy storage. Learnings from markets in the United States, Europe, and Australia could help establish a more robust market mechanism that encompasses all these proposed services.
- It is essential to maintain a balance between pooling capacity resources regionally and allowing states to contract resources that meet their individual needs and priorities. Coordination is needed between state and central planning agencies to optimize the power procurement mix in order to reduce system-level costs and avoid stranded capacities.
- Although the idea and benefits of having independent market monitoring mechanisms are well established, these mechanisms must be implemented to prevent manipulation and ensure transparency.
- Transparent wholesale markets are characterized by accurate price formation; they can thus share resources more efficiently and optimize the available grid capacity. There is a need to continuously improve market designs by learning from international experiences, especially those of the United States, Europe, and Australia.
- States must prioritize building technical capacity within utilities to help them recognize the benefits of these market mechanisms and understand how they can help promote RE integration. Joint efforts to create a knowledge-sharing platform at the state level would enable such sharing.

1. MOTIVATION FOR THE STUDY

India's electricity market has undergone several transformations in recent years, and studies have examined various aspects of this evolution. Short-term markets were introduced in 2008 with the aim of optimizing power procurement costs. These markets include bilateral transactions and power exchanges (PXs) whose transaction period does not exceed a year. The Central Electricity Regulatory Commission (CERC) provides an overview of the power sector in India, specifically focusing on short-term power transactions conducted using different mechanisms involving various market participants (CERC 2021). However, the lower market penetration rate of short-term markets still poses a challenge. In financial year (FY) 2022, the gross electricity generation in India reached 1,491.85 billion units (BU), with short-term electricity procurement accounting for approximately 12.5 percent of the total electricity purchased.

Several reasons explain the low market liquidity of PXs (i.e., limited trading activity with few buyers and sellers participating in PXs), such as the self-scheduling dispatch practices of distribution companies (DISCOMs), the dominance of legacy power purchase agreements (PPAs) with thermal power plants, and the lack of new and updated electricity regulatory reforms and alternative market structure (Poudineh et al. 2021). A study by Aggarwal (2022) observes that self-scheduling by DISCOMs in isolation leads to suboptimal utilization of low-cost generation capacities. This is because DISCOMs continue to purchase power using long-term PPAs instead of exploring cheaper power that may be available in the electricity market.

Some state-owned DISCOMs in India are burdened with substantial debt and have experienced year-on-year revenue deficits. Although there are several reasons for the poor financial health of DISCOMs, such as poor revenue collection, political priorities to subsidize certain category of consumers, operational inefficiencies, and lack of integrated resource planning, one of the primary reasons is the signing of long-term PPAs with high-cost generators. For example, if Indian DISCOMs had chosen to exit long-term PPAs with power plants older than 25 years,[12] they could have potentially saved a substantial sum of US$7 billion (INR 522 billion) annually by avoiding a minimum capacity charge of INR ~2/kWh (Srivastava and Shah 2021). Notably, the appetite of DISCOMs to sign new PPAs has been decreasing due to falling renewable energy (RE) prices. Lately, RE generators have also been hesitating to enter into PPAs with financially distressed DISCOMs (RMI 2023). This market shift opens opportunities for increased PX utilization, offering a reliable alternative for both DISCOMs and RE generators by ensuring assured and timely payments, in contrast to the uncertainties associated with PPAs. Another paper, by Chattopadhyay et al. (2023), evaluates the performance of India's wholesale spot markets, identifying historical oversights and constraints. Their paper suggests enhancing the market's efficacy by addressing liquidity, market design, and PPAs while emphasizing the importance of simplicity and evidence-based approaches to achieve economic efficiency.

Options for market reforms aimed at increasing RE integration and enhancing the electricity market structure have been highlighted in various studies (Udetanshu and Baghel 2020; CERC 2021). Reports suggest that the current RE capacity can be increased by adopting short-term power transactions (RMI 2023). Udetanshu and Baghel (2020) emphasize the importance of market mechanisms and measures to increase flexibility in both the supply-and-demand of electricity, enabling adaptation to changing demand patterns and the variability of RE supply. The ancillary market can incorporate distributed renewable systems to provide short-term flexibility (Poudineh et al. 2021). Garg (2021) noted that instead of investing in excess baseload thermal capacity (which is tied up in long-term PPAs), DISCOMs can meet the peak demand by using RE and flexible generation sources, such as aggregated demand response, battery, and pumped hydro storage, which can smooth price fluctuations.

The Indian government recognizes the need for market reforms to achieve cost-optimal procurement and improve the penetration of short-term electricity markets. The Ministry of Power (MoP) launched an electricity market roadmap in May 2023 that aims to overcome major barriers such as reliance on local self-scheduling by DISCOMs. Going beyond day-ahead markets, the authors, while emphasizing that the introduction of real-time markets in 2020 was an important step, also acknowledge the need for enhanced participation in RTMs in the coming years, given that the current penetration of RTMs was only about 2 percent as of FY2023 (Agrawal 2022).

To enable resource sharing and utilization of low-cost generators, market mechanisms focused on inter-regional supply–demand coordination, such as Market Based Economic Dispatch (MBED), have been introduced, which can play a crucial role. The MoP also explored alternative market designs, such as an integrated market (e.g., a single platform to enable all DAM mechanisms) and an exchange-based capacity market,[13] to complement the growth of RE generation. The MoP also outlined the need to increase RE penetration in the grid and provide firm ancillary reserves in a phased manner to help maintain grid stability by providing additional power quickly when needed and thus ensuring reliable supply (PIB 2023b).

Shah and Chatterjee (2020) note that market practices need to continuously evolve, given the expected increase in the share of renewables. They present a comprehensive review of day-ahead electricity markets worldwide, along with the key features of major electric PXs across the globe. Varhade et al. (2018) and Shah and Chatterjee (2020) highlight the significance of enhancing competition in both wholesale and retail electricity markets by advocating implementation of best practices and international learnings to improve the Indian market. Specifically, Varhade et al. (2018) propose a framework for India based on an analysis of the experience of the United Kingdom, Australia, Philippines, New Zealand, and California.

The studies also suggest that the introduction of models designed to give price signals at a granular level (e.g., at 5-minute intervals) can enhance grid reliability and promote higher penetration of RE, which aligns with India's ambitious RE commitments. Overall, these studies emphasize the need for policies to regulate seller or buyer dominance, as either scenario can lead to unfair pricing, limited choice, and potential market manipulation, ultimately harming consumers and market integrity. Although studies have been conducted on the benefits of different types of market mechanisms in both Indian and international contexts, to ensure optimum procurement of power, it is imperative to understand how the existing market mechanisms are utilized by different states and regions in India.

Our paper analyzes how Indian states are currently utilizing these market mechanisms in their power procurement portfolio and the barriers that hinder the adoption of markets by key stakeholders. Using a review of the secondary literature and market trends, focus group discussions (FGDs) with stakeholders, and learnings from international best practices, we explore options to help address these gaps so that increased adoption of markets can enable better power procurement practices and the clean energy transition at the state level.

We expect that the learnings from our paper will offer valuable insights to state-level policymakers and regulators in designing effective strategies and regulatory guidelines to implement and improve market mechanisms for more efficient power procurement. Policymakers, regulators, and market participants can utilize this research to inform the role of markets in enabling the clean energy transition in states.

2. METHODS

The research design uses the following approach to understand the current market regulations, the existing market procurement landscape across different regions in India, and the challenges faced by stakeholders in conducting power transactions through market mechanisms.

To understand the current trends shaping market adoption at the state level, we conducted a detailed secondary analysis that included a review of the existing regulations and policies governing electricity markets in India (see the following section). Next, we analyzed secondary data to understand the preferred market procurement mechanisms across India and how they have been evolving in recent years (CERC 2023a). To investigate state-level and regional market dependencies, we studied power transactions across different bid areas for FY2023, including an analysis of transaction volume patterns, pricing dynamics, and participant behaviors, to evaluate the extent of participation in market mechanisms, with a strong focus on DAMs and RTMs (IEX n.d.-a; PXIL n.d.). We also calculated the potential cost savings of state utilities by comparing the average market clearing prices from PXs with the variable costs of existing thermal plants (MoP n.d.). In this paper, the secondary-data-based analysis is primarily based on India's PX transactions because the majority of short-term transactions currently occur through PXs. However, because India is an evolving market, these analyses can be used as a template to update the data and findings in the future.

To understand the challenges encountered by states in moving toward short-term markets, we held FGDs with select officials from DISCOMs, state electricity regulators, and PXs. This was done to understand their perceptions of, willingness to participate in, and expectations of market mechanisms. For instance, we engaged in discussions with stakeholders to gauge how well they understood the benefits of the market mechanisms operating in India, such as DAMs, green day-ahead markets, and RTMs, and international mechanisms such as capacity markets. We also tried to understand the underlying factors that motivated their choice of a particular market mechanism in their power procurement strategy and their expectations regarding the support they needed from state and central governments. See Appendix D for the detailed questionnaire used for the FGDs, which were conducted with specific utilities and stakeholders. More discussions at the state level would help remove biases and can provide opportunities for further research.

Finally, we reviewed key international markets that were well-regulated and highly liquid (i.e., markets characterized by greater participation of sellers and buyers) and studied the challenges identified through the literature survey, secondary data analysis, and FGDs to understand the measures needed to strengthen market adoption in Indian states and thus enable the clean energy transition.

3. STATUS OF ELECTRICITY MARKETS IN INDIA

Background of Indian electricity markets

The Electricity Act (EA) of 2003 introduced trading in electricity as a licensed activity. Delicensing of generation; multi-buyer/seller market models; open access in interstate transmission; and unbundling of generation, transmission, and distribution activities were legalized to promote competition, optimize investments, and protect consumer interests (MoP 2003).

State utilities signed long-term PPAs to mitigate energy and peak deficits in India. Long-term PPAs were typically signed for 25 years or for the useful life of generating stations. The buyers were mostly DISCOMs, and the sellers were large power generating companies. Long-term PPAs provided certainty to private developers and investors who were interested in setting up power plant projects, because these contractual agreements ensured that DISCOMs would pay for the power they generated. Long-term PPAs became the dominant form of contracts in India but were considered inflexible due to various PPA provisions that limited the ability of DISCOMs to adapt to changing market conditions. In 2005, the National Electricity Policy (NEP) envisioned that 85 percent of power from new generating plants would be contracted through long-term PPAs to take care of the debt coverage and financing obligations of DISCOMs, the remaining power capacity being obtained through market mechanisms (CERC 2010c).

The EA of 2003 also contained provisions to promote cogeneration and generation of electricity from RE in the country. These were reiterated by the NEP notified in 2023 (PIB 2023a). The EA also required SERCs to specify a Renewable Purchase Obligation (RPO),[14] which is a regulatory mandate that requires procurement of a minimum percentage of electricity consumption through RE (CERC 2010a). Accountability and penalty enforcement have been common challenges in meeting RPO targets.

Regulatory frameworks to create an enabling environment for Indian electricity markets were introduced to cater to the changing needs of India's power system, which includes an increasing share of RE. However, despite regulatory changes aimed at increasing the share of RE and the groundwork laid out for energy markets, the contribution of RE sources to the overall electricity capacity and gross generation remained low. In July 2009, RE accounted for only about 8.5 percent of the total installed capacity in the country, and its actual generation was estimated to be about 3.5 percent of the total generation (CERC 2010a). To help meet the RPO requirements, the CERC established the Renewable Energy Certificate (REC) mechanism in November 2010. This mechanism enabled obligated entities (such as DISCOMs, Open Access consumers, and captive power producers) to meet their RPOs by purchasing certificates representing one megawatt-hour (MWh) of electricity generated from renewable sources. Thus, RECs facilitated the purchase, sale, and trade of RE (CERC 2010b). However, the lack of stringent RPO enforcement and transparency, coupled with the accumulation of unsold RECs due to declining REC prices[15] and the financial challenges facing DISCOMs, hindered the REC mechanism's ability to drive substantial RE capacity growth in India (Sawhney 2022).

The CERC started developing regulatory frameworks and operating guidelines for electricity markets in accordance with the mandate in Section 66 of the EA of 2003 to promote development of electricity markets. This was followed by the emphasis on electricity markets in the National Electricity Policy issued by the MoP in February 2005. An order passed in January 2007 for the "development of a common platform for electricity trading" was intended to establish and manage PXs. The purpose of developing an electricity market was to provide a platform where power sector participants could efficiently buy and sell power that was not tied up in long-term PPAs. In 2009, the first PX went into operation to help in price discovery[16] of electricity in DAMs. The first electricity market regulations were put in place in 2010. Now the country has three electricity exchanges—the Indian Energy Exchange, Power Exchange India Limited (PXIL), and Hindustan Power Exchange (HPX)—which provide a platform for trading electricity. The CERC (Power Market) Regulations were introduced in 2010 and amended in 2019, and new regulations were promulgated in 2021.

Types of market mechanisms in India

Electricity trading in India primarily consists of physical bilateral contracting, with around 90 percent of electricity being met through long-term and medium-term PPAs (Tata Power 2023). Short-term bilateral contracts [17] and day-ahead and week-ahead exchanges make up the remaining market (Poudineh et al. 2021).

Short-term power requirements can also be met through various market mechanisms such as DAMs, RTMs, TAMs, and green term-ahead markets (G-TAMs), which include intraday, contingency, and weekly markets, and their term typically does not exceed a year. In particular, DAMs and TAMs provide a platform for accurate planning and optimization well ahead of time. RTMs can help balance the variability in RE supply and serve as a cushion for last-minute demand supply variations. Markets can also contribute to grid stability by offering financial incentives to grid participants for maintaining their supply-and-demand balance.

Emerging trends in India's electricity market

Market offerings such as G-DAMs, DAMs, and RTMs provide flexibility, unlike long-duration PPAs, and can potentially help states integrate more variable RE sources. Further, where constraints such as land, for example, limit integration of renewables at a large scale, low-RE-capacity states can access power through markets. Additionally, green markets such as G-TAMs and G-DAMs were brought into PXs in FY2022 to provide additional sales avenues for existing and new renewable power projects with surplus energy. G-TAMs and G-DAMs, along with waiver of Inter-State Transmission System (ISTS) charges for trading electricity through the green markets, are expected to provide additional sales avenues for existing RE projects and bolster confidence in revenue streams for new RE project developers. A new DAM market segment, known as high-price DAM (HP-DAM), was created to provide avenues for generators with high variable cost (e.g., to help coal and gas plants avoid stranded capacities) that may not be able to participate in DAMs due to the existing price ceiling of INR 12/kWh. This HP-DAM market segment is also open to storage projects.

Additionally, new market options, such as *ancillary service (AS)* markets, *Security Constrained Economic Dispatch (SCED)*, *MBED*, *over-the-counter (OTC)* platforms, *market coupling*, and *tariff pooling*, to make electricity markets more efficient have been discussed recently.

AS markets can offer services to keep the grid balanced on various time scales (including seconds, minutes, and hours) and thus help maintain grid reliability. Power generators, including conventional and RE generators, demand response programs, energy storage, and distributed energy resources can provide ASs such as frequency regulation and reactive power support by adjusting their power output or by using specialized control equipment. AS markets are prevalent where wholesale markets are organized and exist in, for example, the United States, Australia, Canada, Europe, and China. These reserves can be used for both frequency and non-frequency purposes, with typical response times varying from sub-seconds to over 15 minutes. In India, ASs have been introduced across all PXs. These services were made available in DAMs and RTMs as of June 1, 2023 (CERC 2023c).

In April 2019, a pilot program for *SCED* was introduced to address the challenge of optimizing power generation to minimize costs while simultaneously maintaining the security and reliability of the power system. SCED is an algorithm, developed by the National Load Dispatch Center (NLDC), that is aimed at helping regulators make informed scheduling decisions (CERC 2019). SCED, an advance on the existing silo-based Merit Order Dispatch (MOD) model, aims to optimize the nation's overall power procurement cost by considering unutilized capacity from ISGS to meet DISCOMs' power requirements without hampering the technical constraints of power plants and the grid system. The outcome of this pilot demonstrated that SCED enabled substantial fuel cost savings, which are accumulated in the National SCED Pool Account and shared among generating stations. The pilot was successful and resulted in savings of INR 845 crores (cr.) [18] in fuel cost (a reduction of INR 0.03 per unit for the participating generators) (POSOCO 2020).

In February 2021, the *market coupling* model was introduced in the Indian power market regulations (CERC 2021). Market coupling is a process in which bids collected from all PXs are matched, after considering all bid types, to discover the uniform market clearing price (MCP) for DAMs, RTMs, or any other market notified by the CERC. Although the coupling mechanism can improve the liquidity of short-term market transactions and the usage of the available transmission infrastructure, some stakeholders opine that it may diminish the role of PXs and dampen innovation of new mechanisms, because coupling of PXs would centralize the bid matching platform. Currently, the CERC is holding discussions with stakeholders to understand the context of market coupling in the Indian electricity space (CERC 2023b).

Following this, in June 2021, the MoP released a discussion paper introducing the *MBED* model (MoP 2021), which proposes a centralized scheduling of power dispatch—both interstate and intrastate. This mechanism enables the entire country's generation and power demand to be scheduled through PXs. MBED aims to help states manage their power procurement decisions, including their own generating stations. Discussions are underway regarding how to implement the model or transition from SCED to benefit all the concerned stakeholders (MoP 2021).

Further, the Government of India issued guidelines and orders to enhance RE accommodation and short-term markets in India. In May 2022, the CERC issued guidelines for establishing and operating electronic *OTC platforms* to enable exchange of information among buyers and sellers of electricity (CERC 2022). In January 2023, the Central Electricity Authority (CEA) notified regulations that require coal-based thermal power generating units to have a flexible operation capability with a minimum power level of 40 percent (CEA 2023a). It also specifies differential ramping requirements at various stages of plant operation, which would ensure that adequate flexible capacity is available in the system to manage increased RE integration.

The inability to exit PPAs has been a key barrier to effective power procurement by DISCOMs. In April 2023, the MoP launched a *tariff pooling* scheme for thermal power plants whose PPAs with DISCOMs have expired (MoP 2023). Although DISCOMs were allowed to exit their PPAs after the PPA duration expired (from 2021 onward), they started exiting the PPAs of costlier plants (non-pithead coal stations and gas-based thermal generating stations) and chose to retain the PPAs of cheaper plants. To implement a uniform approach to PPA exits, the MoP notified that power from all central generating stations (CGSs) whose PPAs have expired shall be pooled and that the pooled power will be made available to willing beneficiaries if they enter into a PPA with a minimum duration of five years.

The above measures taken by the government to enhance market participation are expected to increase resource availability in the grid for multiple uses such as peaking, balancing, and flexing. Suitable policy, regulatory, and guiding frameworks for markets can further strengthen these new capabilities and help states to better forecast, plan, and optimize their power portfolios. This ability can potentially enable greater integration of RE into their supply. Table 1 summarizes the purpose, market structure, duration, and price discovery mechanism of different market mechanisms that are currently operational in India.

Table 1 | **Electricity market mechanisms in India**

TYPE OF MARKET	PURPOSE	MARKET STRUCTURE	TRADING DURATION	PRICE DISCOVERY MECHANISM
Bilateral[a]	Establishing power purchase agreements (PPAs) for power supply	Direct agreements between buyers and sellers or through traders Both long-term and short-term PPAs could be bilateral	Short term: Less than a year Medium term: Between 1 and 7 years Long term: Typically over 25 years Can be scheduled on a round-the-clock or slot-wise basis	Prices are negotiated at the time of contracting
Day-ahead markets (DAMs)/ green day-ahead markets (G-DAMs)[b]	To offer flexibility in power procurement cost optimization and demand management	Collective buy/sell transactions would be executed a day before (T – 1) the day on which power is physically delivered (i.e., T) G-DAMs offer bid categories to consumers for three different green products: solar, non-solar, and hydro, with separate quantity limits	For deliveries of any, some, or all 15-minute time blocks in 24 hours of the next day starting from midnight	Double-sided closed auction[c]
Real-time markets (RTMs)[d]	Balancing supply-and-demand variations in real time	Collective transactions occur on day T or day T – 1 and electricity is delivered on day T	Half-hourly market, comprising 48 auction sessions of 15-minute duration each	Double-sided open auction process
Weekly term-ahead markets (TAMs)[e]		For delivery of power on a term basis up to 11 days ahead	Duration varies with different delivery blocks such as round-the-clock (RTC) (all 24 hours), day (7–18 hours), night (0–7, 23–24 hours), and peak hours (18–23 hours)	Double-sided open auction process
Intraday, daily, and day-ahead contingency (DAC) markets[f]	Offering flexibility in power procurement cost optimization and demand management	Intraday: For delivery of power within the same day (T) DAC: Similar delivery mechanism as DAM, but transactions are processed through a separate window	Intraday and DAC: Electricity can be traded for any 15-minute time blocks for the same day Daily: Similar to weekly TAMs	Based on the spot trading value
Green TAMs[g]		Consists of intraday, daily, DAC, and weekly segments Bid categories offered for solar, non-solar, and hydro power	Intraday and DAC: Electricity can be traded for any 15-minute time blocks for the same day Daily: Similar to weekly TAMs	Intraday, DAC, and daily markets: Spot trading Weekly market: Double-sided open auction

Sources:

a. POSOCO 2022.

b. IEX n.d.-d.

c. A "double-sided closed auction" within an Indian power exchange refers to a trading mechanism in which electricity buyers and sellers confidentially submit their offers at the same time. The details, such as prices and quantities, remain undisclosed until the auction concludes, enabling efficient and discreet electricity trading.

d. CERC 2020.

e. IEX n.d.-b.

f. CERC 2021.

g. IEX n.d.-c.

4. ANALYSIS AND FINDINGS

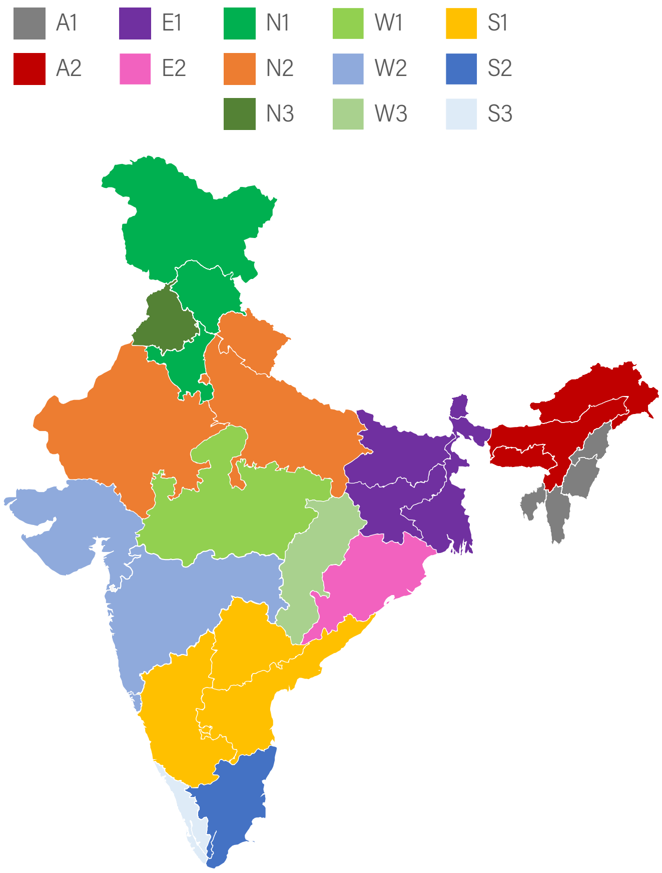
This section explores how major PX mechanisms are being utilized by Indian states to identify where and how energy markets could be expanded or strengthened. The PX has evolved as a key player in the short-term power market transactions space. Since its inception, the PX grew from a short-term transaction share of 8 percent in FY2009 to 53 percent in FY2023 (CERC 2023a). This section analyzes consumers' current use of PX instruments and assesses trends in electricity market prices and variations in power procurement patterns related to annual regional loads and RE trends across India. The regions considered in this study align with Indian PXs' bid areas,[19] as shown in Figure 1. Because more than 90 percent of PX transactions occur via IEX India, our analysis is based on data obtained from the IEX portal.

There are three PXs in India, with Hindustan Power Exchange being the latest PX; it was introduced in 2022 to the electricity market. IEX is responsible for 90–94 percent of the overall PX transactions, whereas PXIL's share is 6–7 percent. As far as PX market-mechanism-based transactions are concerned, DAMs have been the major contributor to date. TAMs, one of the oldest mechanisms available in the PX market, hold ~10–12 percent of the overall PX transaction volume. Based on the interval and duration of transactions, TAMs are further classified into intraday, DAC, daily, and weekly contracts. Currently, DACs are the preferred term-ahead instruments and are responsible for over 50 percent of TAM transactions.

Whereas TAMs hold a steady market share, newer green market-based products such as G-DAMs and G-TAMs have barely been noticed by consumers; they are only used by state DISCOMs to meet their RPO targets. Nevertheless, due to these newer mechanisms, such as RTMs, G-TAMs (launched in FY2021), and G-DAMs (launched in FY2022), the transaction share of DAMs fell from 87 percent in FY2020 to 50 percent in FY2023. The share of RTMs in PX transaction volume has been growing steadily and was 24 percent in FY2023 (see Figure 2).

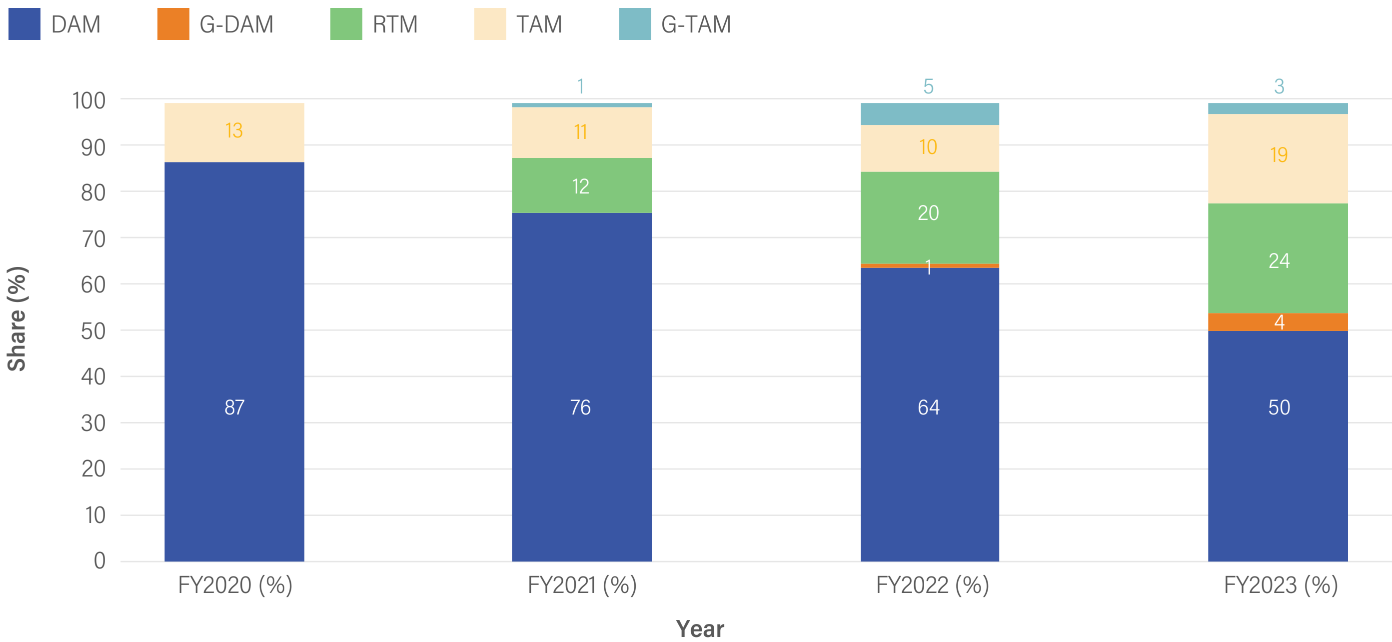
Figure 1 | **Indian power exchange areas**

BID AREA	STATES AND UNION TERRITORIES COVERED UNDER BID AREA
N1	Jammu and Kashmir, Himachal Pradesh, Chandigarh, and Haryana
N2	Uttar Pradesh, Uttaranchal, Rajasthan, and Delhi
N3	Punjab
E1	West Bengal, Sikkim, Bihar, and Jharkhand
E2	Orissa
W1	Madhya Pradesh
W2	Maharashtra, Gujarat, Daman and Diu, Dadar and Nagar Haveli, and North Goa
W3	Chhattisgarh
S1	Andhra Pradesh, Telangana, Karnataka, Pondicherry (Yanam), and South Goa
S2	Tamil Nadu, Pondicherry (Puducherry), Pondicherry (Karaikal), and Pondicherry (Mahe)
S3	Kerala
A1	Tripura, Manipur, Mizoram, and Nagaland
A2	Assam, Arunachal Pradesh, and Meghalaya



Source: IEX n.d.-e.

Figure 2 | **PX-based mechanisms in India and their market shares**



Note: DAM = day-ahead market; FY = financial year; G-DAM = green day-ahead market; G-TAM = green term-ahead market; PX = power exchange; RTM = real-time market; TAM = term-ahead market.

Source: WRI analysis based on CERC (2023a).

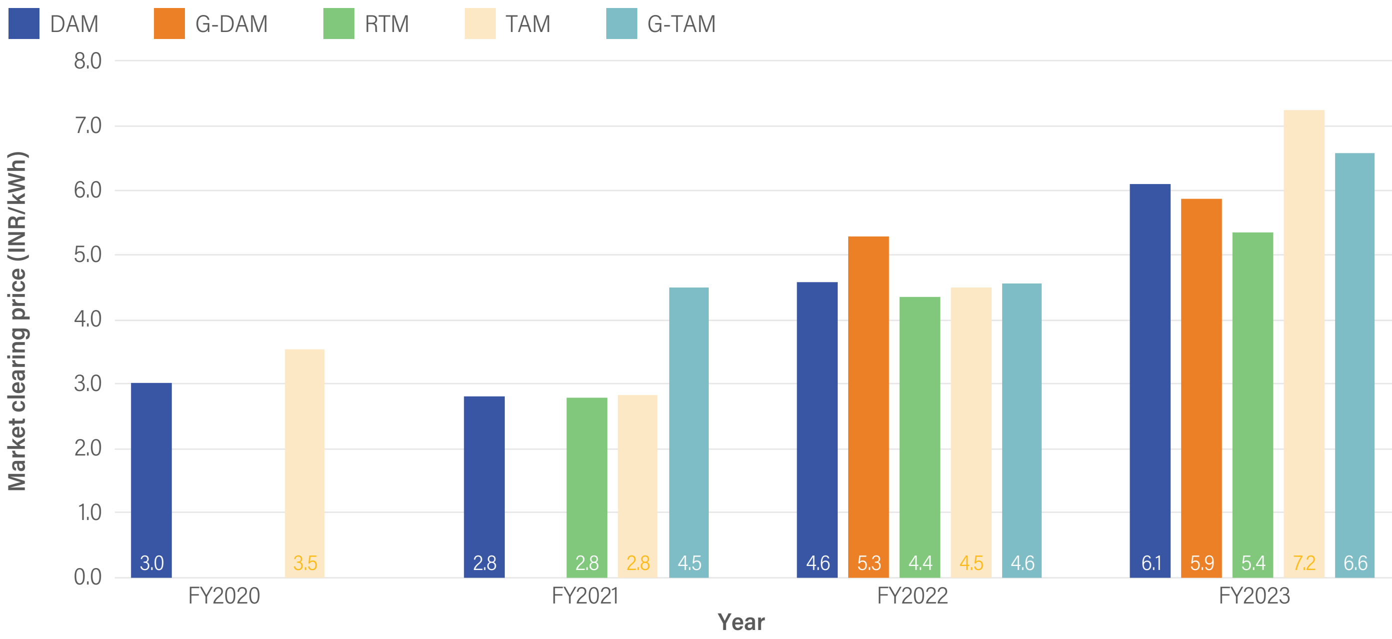
The average MCP of PXs increased from INR 3.1/kWh in FY2020 to INR 6.2/kWh in FY2023. We observe that the average clearing price of the PXs is closer to the DAM clearing price because the majority of transactions occur through the DAM mechanism. RTM transactions have the lowest MCP among the market mechanisms (see Figure 3), which can eventually promote RE. Thus, the MCP can enable DISCOMs to optimize the power procurement cost, which could enhance market participation and eventually help promote RE penetration.

Our research establishes that although the clearing price of the short-term market has been rising, this market still offers potential savings. To analyze this, we compared the existing variable prices of all the thermal plants that undergo merit order[20] scheduling (in a siloed manner) with the daily DAM MCP for FY2023. This analysis does not account for fixed costs. Figure 4 shows the accumulated savings potential across the months of FY2023 for the seven analyzed states. These states were selected based on their annual demand and data availability.[21] The figure shows that the savings potential was highest during the September to November period in FY2023 when there was surplus power availability and lower demand, and hence less dependence on the short-term market.

Generally, PPAs impose "take-or-pay" capacity charges, regardless of whether the fuel is used or not. PPA take-or-pay capacity charges are sunk costs, and it would be appropriate to compare the variable costs of generation under PPAs with those of market purchases, to determine which option is more cost-effective. The available data show that market purchases seem to benefit most states, although the potential savings vary (see Figure 4).

By purchasing power through PXs rather than through existing PPA agreements, Gujarat (GJ) and Tamil Nadu (TN) achieved the highest annual savings potential among the states (see Table 2). GJ's annual savings potential is INR 2,964 crores with an average savings potential of INR 0.28 for each scheduled unit, perhaps because it depends more on gas than other states and has faced high costs for gas and imported coal. For the past two years, GJ has relied on a few independent power producers, paying them an average of INR 8–10/unit. Similarly, TN can save up to INR 1,560 crores on variable/fuel cost with an average savings potential of INR 0.17 for each unit of scheduled power. The fuel costs of state-owned gas and relatively new coal power plants are major contributors to TN's high power procurement costs. Maharashtra's (MH's) savings potential was the lowest, and the other states could potentially save INR 0.02–0.04/scheduled unit with annual savings ranging from INR 100 to 340 crores. This analysis counts only possible savings from the seven states; thus, potential savings across the country could be much greater.

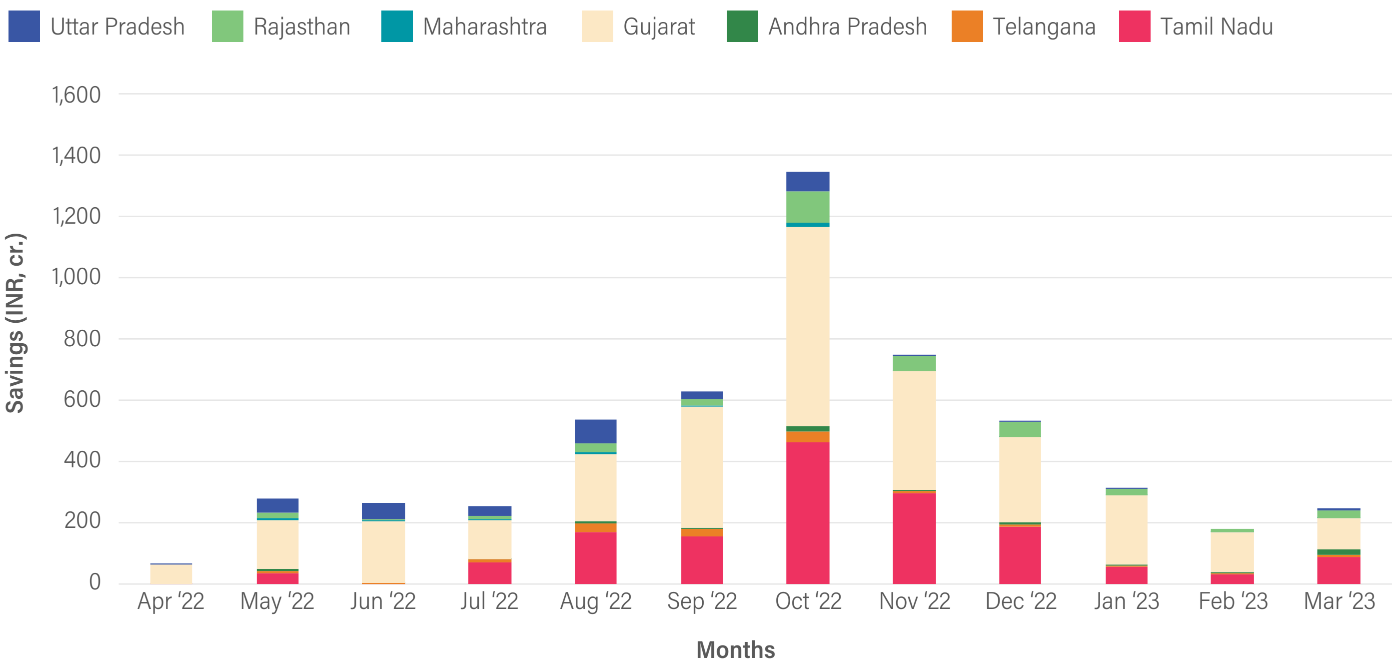
Figure 3 | **Average MCP of PX mechanisms in India**



Note: DAM = day-ahead market; FY = financial year; G-DAM = green day-ahead market; G-TAM = green term-ahead market; INR = Indian rupee; kWh = kilowatt-hour; MCP = market clearing price; PX = power exchange; RTM = real-time market; TAM = term-ahead market.

Source: WRI analysis based on CERC (2023a).

Figure 4 | **Monthly cumulative fuel cost saving potential of the considered states when purchasing power through PXs instead of using existing PPA agreements (FY2023)**



Note: cr. = crores; PPA = power purchase agreement; PX = power exchange.

Source: WRI analysis based on MoP (n.d.).

Table 2 | **State-level annual fuel cost savings potential and per-unit savings (FY2023)**

STATE	ANNUAL SAVINGS POTENTIAL (INR, cr.)	AVERAGE SAVINGS POTENTIAL (INR/ SCHEDULED kWh)
Tamil Nadu	1,559.35	0.168
Telangana	126.99	0.023
Andhra Pradesh	79.66	0.015
Gujarat	2,964.93	0.277
Maharashtra	40.90	0.003
Rajasthan	338.78	0.038
Uttar Pradesh	309.45	0.022

Note: cr. = crores; FY = financial year; INR = Indian rupee; kWh = kilowatt-hour.
Source: WRI analysis based on MoP (n.d.).

Our intention in this analysis is to provide an indicative comparison between procurement through existing PPAs and through PXs. This analysis does not incorporate the savings from a more robust market that dispatches the most efficient resources from a pool or the long-run savings from avoided investments. It also does not quantify the savings from avoided RE curtailments from a more flexible market (IEA 2021). A comprehensive analysis would require modeling short-term markets to account for the shifts in prices and quantities traded.

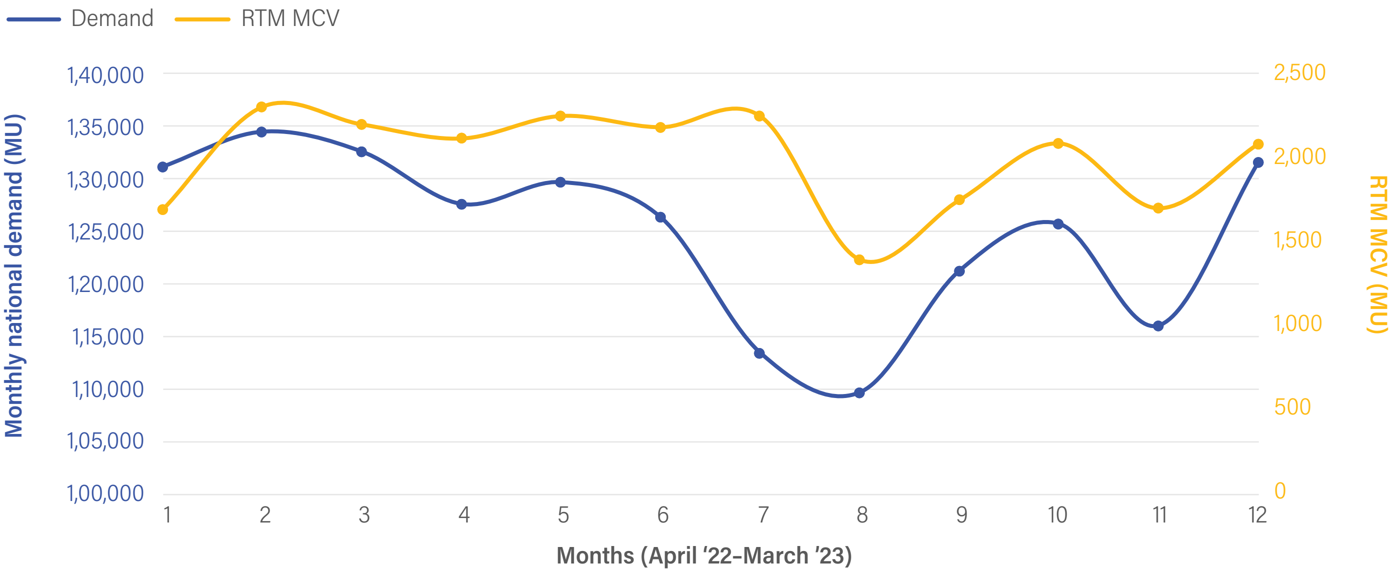
Understanding power procurement trends through PXs

To understand how states are utilizing market mechanisms and moving away from long-term PPA agreements, we examined purchases and sales of power in short-term power markets in India across all the regions, the reasons for these differences, and how and why usage of PX transactions fluctuates.

In general, DAM and RTM mechanisms account for 75 percent of PX transactions in India. The PX transaction volume generally follows the pattern of the national demand, especially the RTM market (see Figure 5). An RTM block is a half-hour period, and the auction gates[22] close an hour before the actual dispatch of power from the generators. This provides more visibility for market participants than other market mechanisms with respect to the quantity of power needed to meet the demand. Although DAM markets also follow the national demand trend, they are more susceptible to supply–demand mismatches, as explained below.

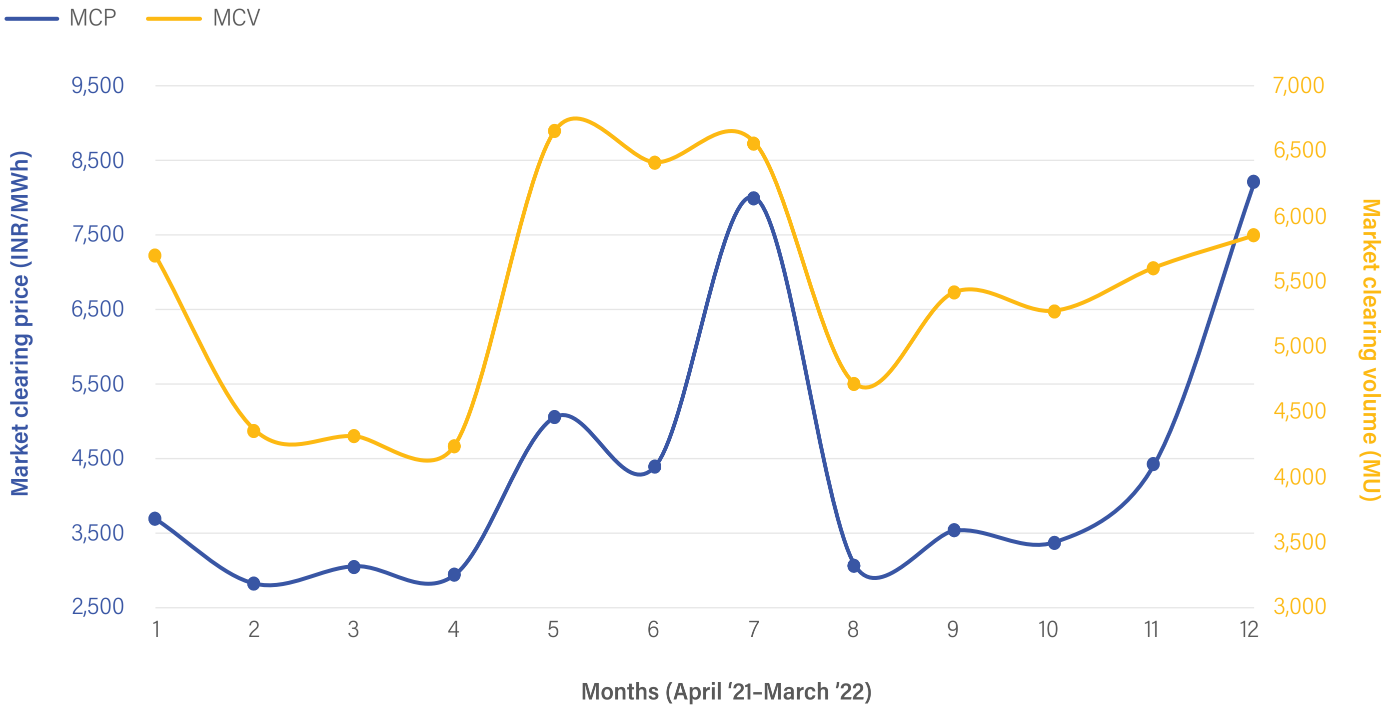
Figures 6 and 7 show that the MCP and MCV exhibited a similar pattern for both DAMs and RTMs except during the January to March period (depicted as months 10–12), when the MCP rise trend differed from the MCV rise trend. During this period, the generation from renewables was lower than that from coal in India. In FY2023, the expected generation from RE sources, particularly from hydro, was less than expected, which further increased the dependence on coal power (CRISIL 2023). Because DAMs cater to more demand than RTMs do, this supply constraint boosted the clearing price more than expected.

Figure 5 | **RTM clearing volume versus India's electricity demand (FY2023)**



Note: FY = financial year; MCV = market clearing volume; MU = million units; RTM = real-time market.
Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a)

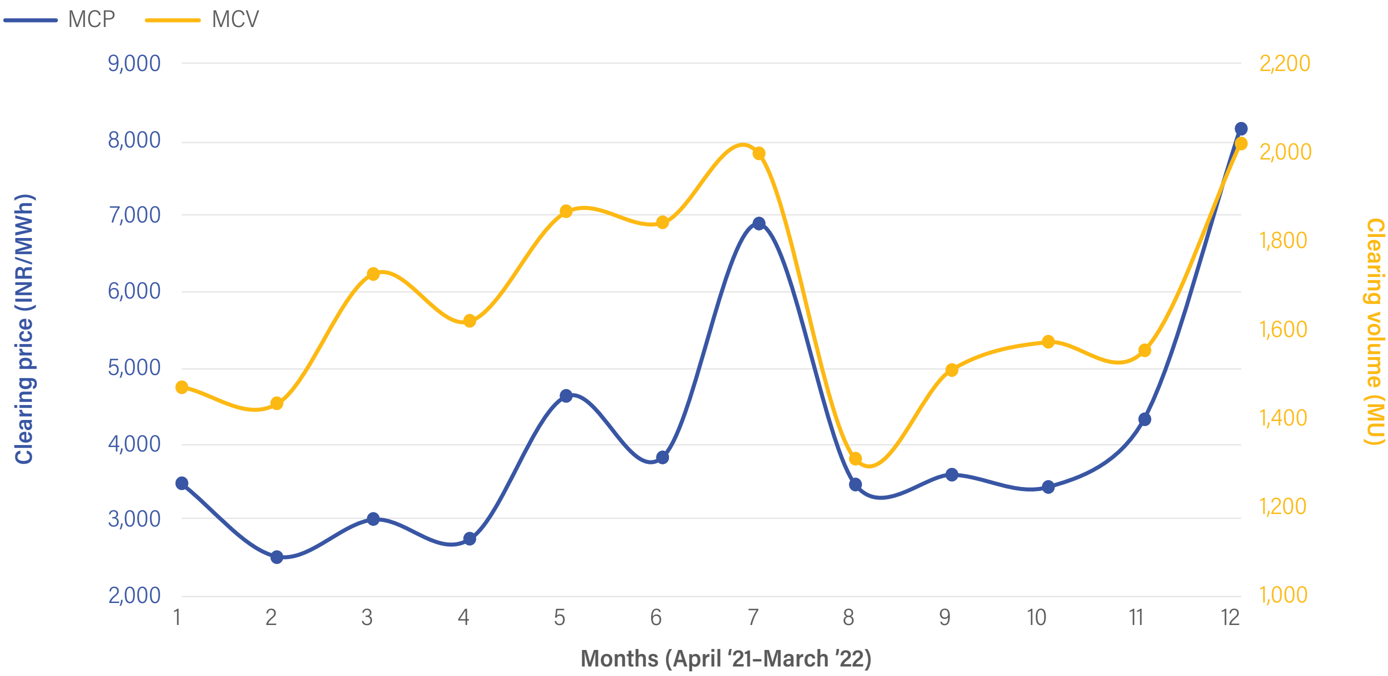
Figure 6 | **Market clearing price versus market clearing volume for DAMs (FY2022)**



Note: DAMs = day-ahead markets; FY = financial year; INR = Indian rupee; MCP = market clearing price; MCV = market clearing volume; MU = million units; MWh = megawatt-hour.

Source: WRI analysis based on IEX (n.d.-a).

Figure 7 | **Market clearing price versus market clearing volume for RTMs (FY2022)**



Note: RTMs = real-time markets; FY = financial year; INR = Indian rupee; MCP = market clearing price; MCV = market clearing volume; MU = million units; MWh = megawatt-hour.

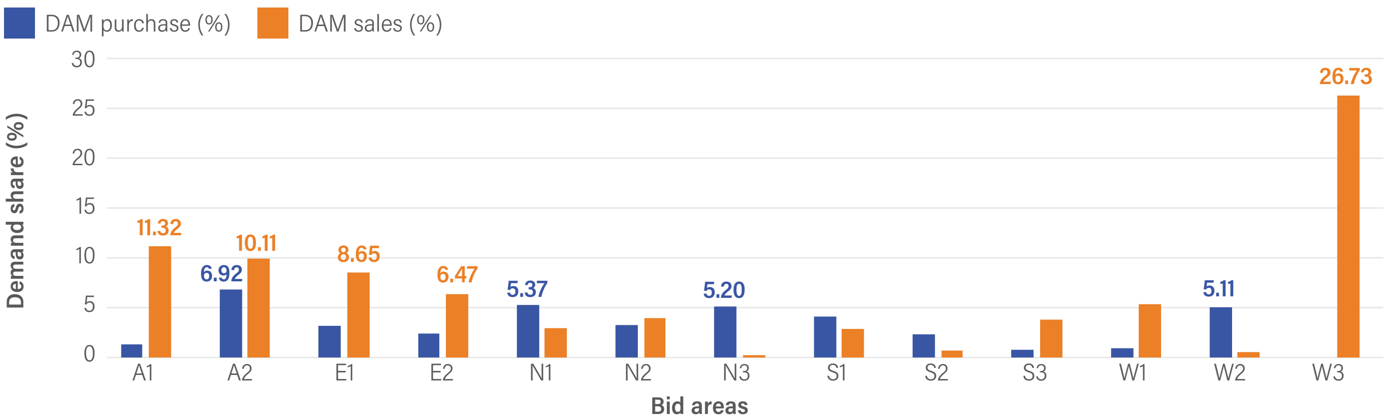
Source: WRI analysis based on IEX (n.d.-a).

Evaluating regional-level market participation for DAMs

An examination of the current trends in prices and which states are currently buying and selling power on DAMs can reveal where DAMs have the most room to expand. In this subsection, we compare buying trends across different regions (also termed *bid areas* in this paper) in DAMs. Figure 9 shows that the bid area W2 (consisting of Maharashtra, Gujarat, etc.) was a major buyer in the DAM segment in FY2023, followed by the areas S1 and N2. However, in these bid areas, the quantity of DAM transactions met less than 5.4 percent of their demand, as shown in Figure 8. On the other hand, bid area A2 (consisting of Assam and Arunachal Pradesh) was not among the top five buyers but used DAMs to meet about 7 percent of its demand. Bid areas S1, S2, and W2 had a greater RE share than the other bid areas and purchased power from DAMs and RTMs to manage their load imbalances.

To understand how DAMs can help states that have higher thermal capacities, we compare the trend of selling power across different bid areas in DAMs. Area W3 (Chhattisgarh) used DAMs to sell power that accounted for 26 percent of the state's demand, followed by A1, A2, and E1 (see Figure 8). These regions have high thermal power capacity. DAMs can help these states export unutilized surplus power, which may in turn help increase the plant load factors of thermal power plants. Based on transaction quantum data, E1 and N2 were the major sellers in the DAM market for FY2023 (see Figure 9).

Figure 8 | **Bid-area-wise participation in DAMs (FY2023)**

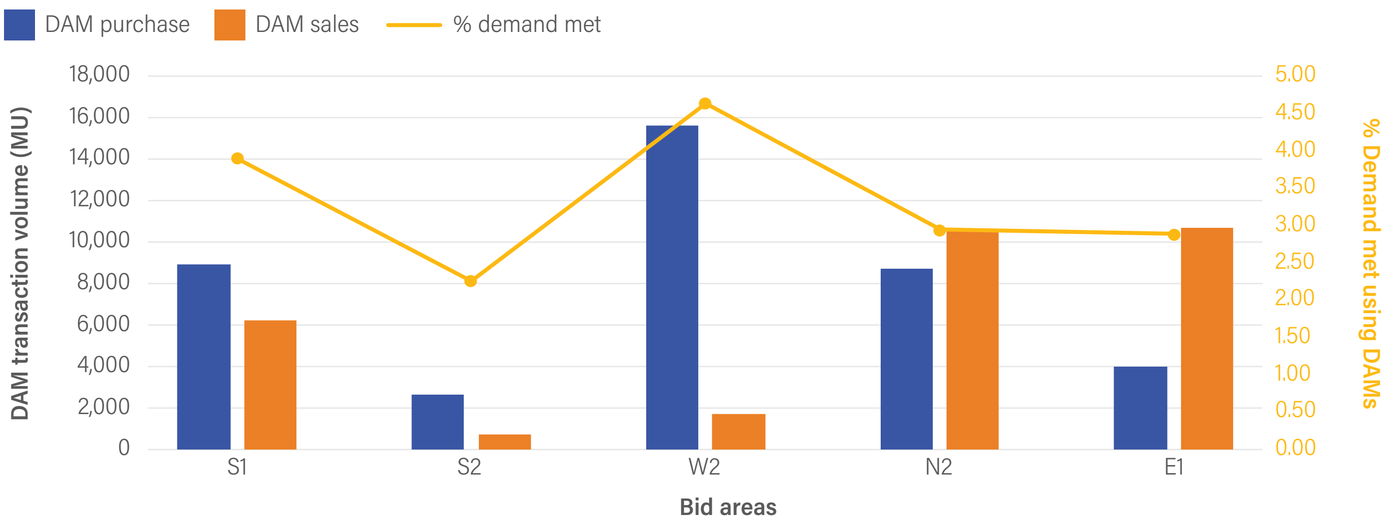


Note: DAM = day-ahead market; FY = financial year.

See Figure 1 for an explanation of the letter codes (A1, A2, etc.) in the figure.

Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a).

Figure 9 | **Major buying and selling bid areas in DAMs (FY2023)**



Notes: DAM = day-ahead market; MU = million units.

See Figure 1 for an explanation of the letter codes (S1, S2, etc.) in the figure.

Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a)

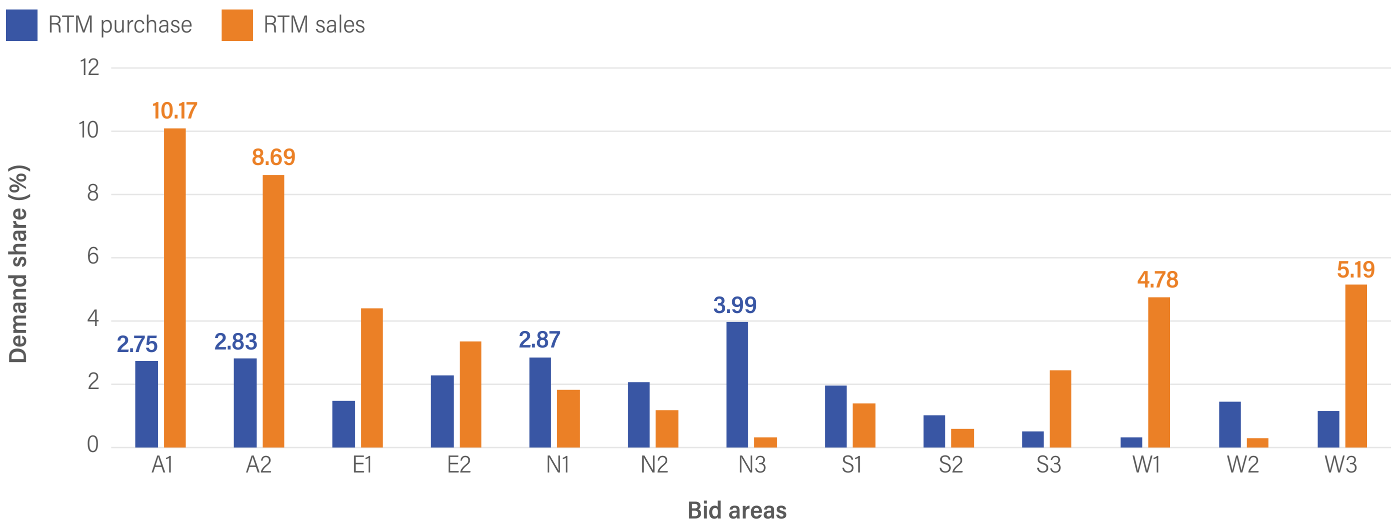
Evaluating regional-level market participation for RTMs

In this subsection, we compare the trend of buying and selling of power across different bid areas (as specified in Figure 1) in RTMs to understand which regions utilize RTMs for what purpose.

Regional participation in power purchases through RTMs was in the range of 1–4 percent (see Figure 10); for DAMs, it was in the range of 2–7 percent (see Figure 8). Bid areas with a huge annual demand such as N2, W2, and S1 were the major buyers in RTMs, and their power transaction volumes ranged from 4,154 to 5,494 MU (see Figure 11).

The northeastern areas, A1 and A2, with higher shares of generation coming from thermal plants, sold more power through RTMs, similar to their corresponding values for DAMs (see Figure 10). Their sales quantity ranged from 8.6 to 10.2 percent of their area's demand. The bid areas E1, N2, and S1 were major sellers in RTMs, with the quantities ranging between 3,000 and 5,496 MUs (see Figure 11). However, their sales share was less than 4 percent of their demand.

Figure 10 | **Bid-area-wise participation in RTMs (FY2023)**

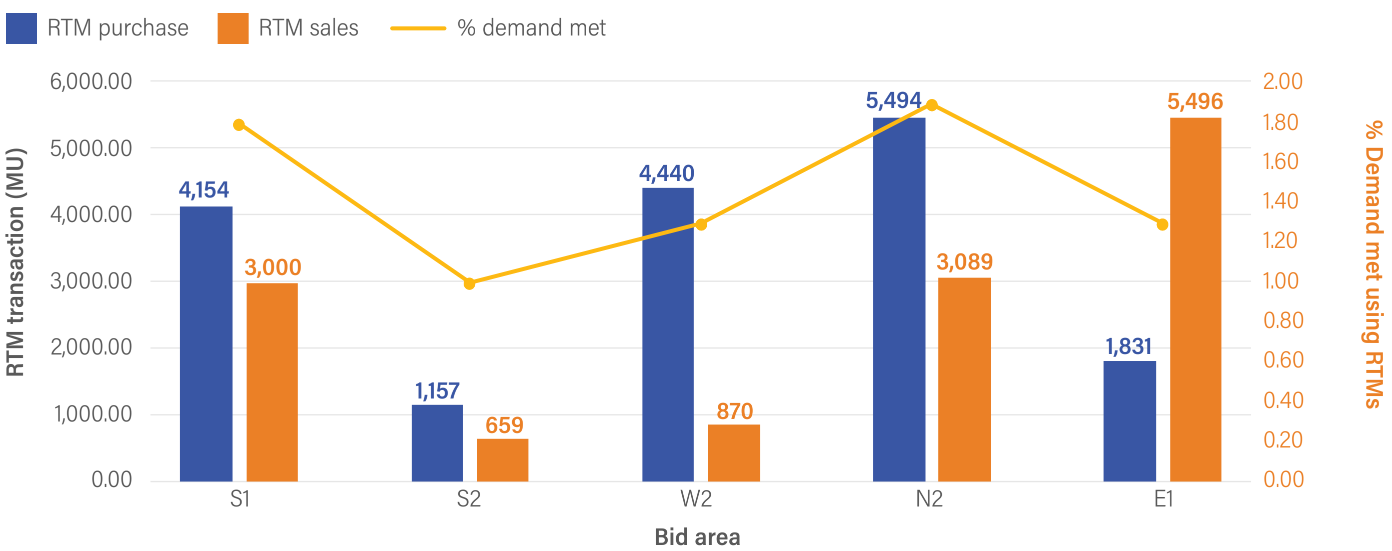


Note: FY = financial year; RTM = real-time markets.

See Figure 1 for an explanation of the letter codes (A1, A2, etc.) in the figure.

Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a).

Figure 11 | **Major buying and selling bid areas in RTMs (FY2023)**



Note: MU = million units; RTM = real-time market.

See Figure 1 for an explanation of the letter codes (S1, S2, etc.) in the figure.

Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a).

Understanding seasonal power transactions through PXs

To understand how power transactions vary across seasons—because renewable generation varies across seasons—in this subsection we first analyze the selling trend in RTMs and compare it with the RE generation pattern; next, we analyze the purchase trend in DAMs and compare it with the demand pattern in RE-rich areas.

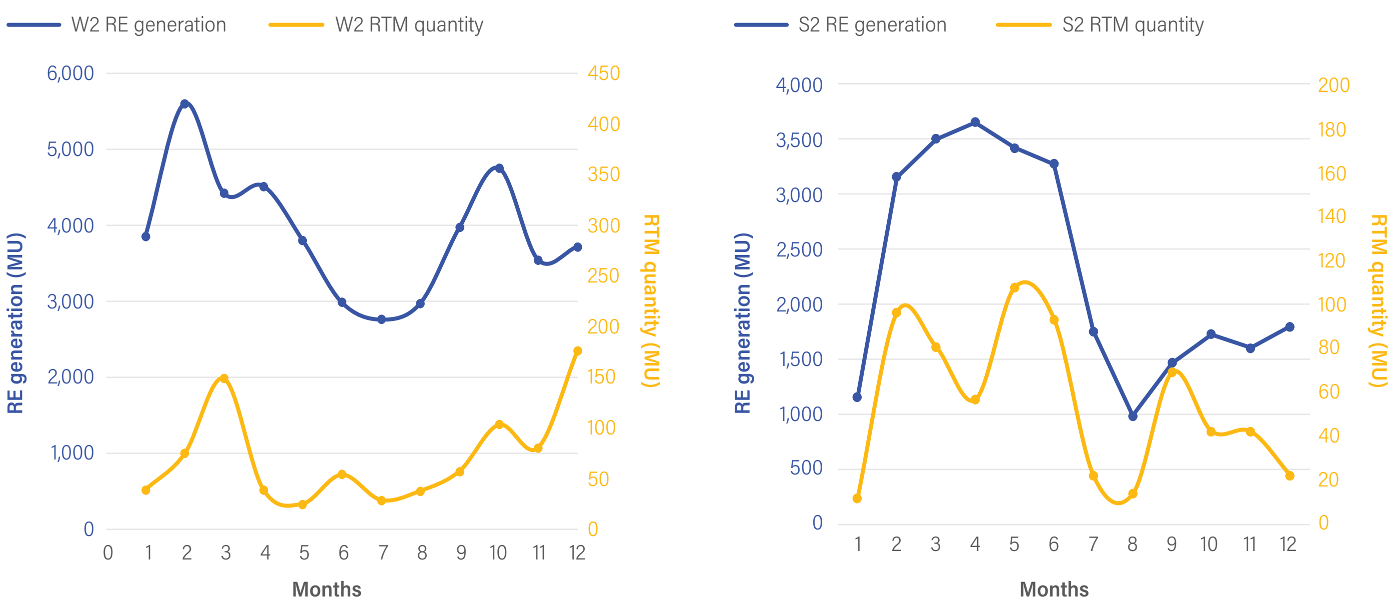
We observe that RTMs offer a way to accommodate the must-run and surplus RE generation during the peak renewable season. This trend is clearly observed in some of the RE-rich regions such as GJ, TN, and MH (which have a high share of wind power). For instance, GJ and MH in W2 have over 15 GW of wind capacity and TN in S2 has over 10 GW of wind capacity, which is reflected in high RE generation during the peak wind period in the respective regions.

Figure 12 depicts the sales trend in RTMs for FY2023 against the monthly RE generation quantity (MU) for the regions S2 and W2. The figure shows that RTM transactions follow the trend of the RE generation curve very closely, which explains why RTMs are likely to expand with increasing renewable penetration in the country. Figure 13 shows the southern region's power procurement trend in DAMs against the region's electricity net load (total demand less the available must-run RE). The figure shows that DAM procurement is proportional to the area's demand after accommodation of RE power.

To summarize, whereas RTMs help mitigate the intermittency issues due to RE by easing scheduling problems for DISCOMs, DAMs are used to manage the supply-and-demand gap based on the availability of generators (central, state, and IPPs), which are tied up in long-term PPAs. Even though the overall demand for RTMs varies from about 1 to 4 percent, the share of transactions through PXs has increased for RTMs. For example, the share of RTMs in PX transactions increased from 10 to 25 percent over the past three years (FY2021–2023). Since the introduction of RTMs, the share of DAMs dropped from 87 percent to 50 percent. Although the liquidity of short-term markets remains low, the preferred mechanism has been evolving.

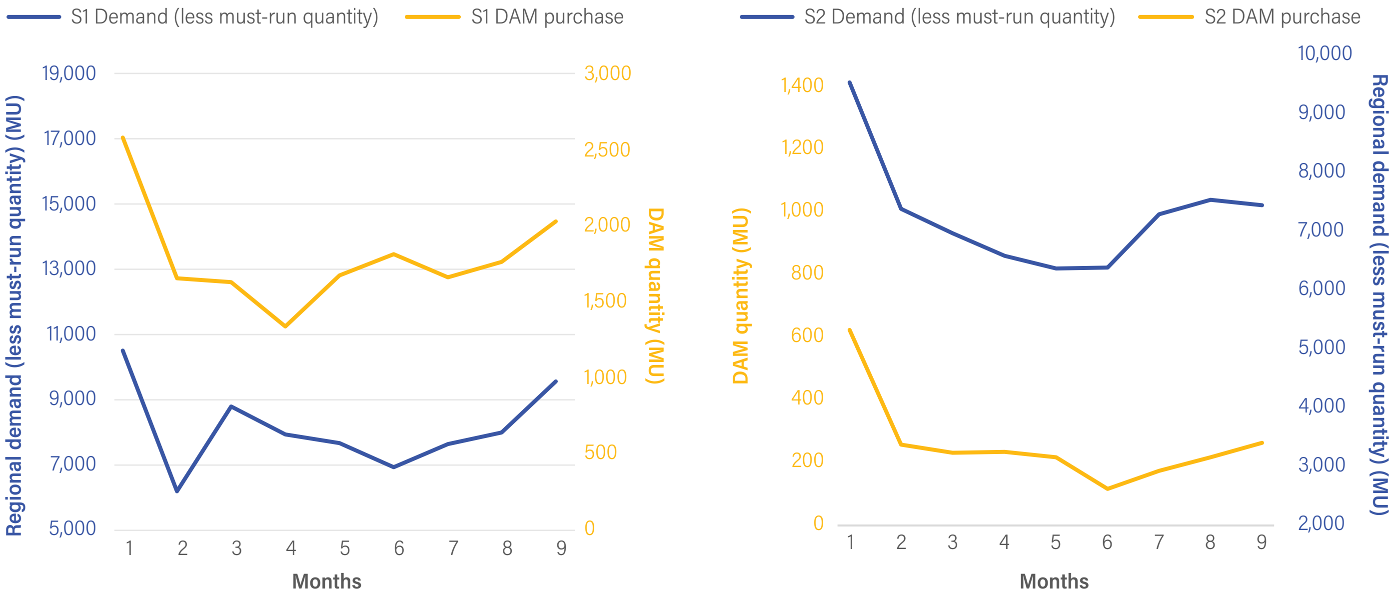
Except for the peak demand (which usually occurs from January to April in the southern region) when short-term to medium-term contracts are signed by state DISCOMs to manage scheduling gaps, DAMs are used to mitigate supply–demand imbalances and forecasting errors. Currently, the forecasting error limits should lie within ±15 percent for RE generators, with the available capacity of the generator being the reference point for calculating the error in the forecast; thus, the generators should not be penalized. However, wind generators, in particular, still face challenges in keeping their forecasts within this limit during the peak RE season (CERC 2015).

Figure 12 | **RE-rich areas: RTM selling trend versus RE generation pattern in bid areas S2 and W2 (FY2023)**



Note: MU = million units; RE = renewable energy; RTM = real-time market.
See Figure 1 for an explanation of the bid area letter codes S2 and W2.
Source: WRI analysis based on CEA (n.d.-b) and IEX (n.d.-a).

Figure 13 | **DAM purchasing trend versus demand pattern in bid areas S1 and S2 (FY2023)**



Note: DAM = day-ahead market; FY = financial year; MU = million units.
See Figure 1 for an explanation of the bid area letter codes S1 and S2.
Source: WRI analysis based on IEX (n.d.-a) and CEA (n.d.-a, n.d.-b).

Green market platforms introduced after the launch of RTMs (G-DAMs and ASs) are still in the nascent stage. In FY2023, G-DAMs had a transaction volume of 3,800 MU, which is much less than that for RTMs (24,175 MU) according to IEX. ASs are yet to be operationalized. Area S1 (especially Karnataka) seems to be the largest seller in G-DAMs, whereas W2 and E2 are the major purchasers. The current usage of G-DAMs seems to indicate that state entities are utilizing this market to meet only their RPO commitments, provided the G-DAM's MCP is below the average cost of power with the REC premium. Appendices A–C give the data used for this analysis.

Our analysis in this section indicates that short-term markets are still used mainly by DISCOMs in an ad hoc manner to manage supply-demand imbalances; however, they are not integrated during the power procurement planning exercise in order to optimize the overall power procurement cost. If states were to purchase power through markets instead of using the silo-based MOD mechanism, substantial savings would accrue to state DISCOMs (as shown in our analyses; see Table 2). However, we need to understand the challenges state-level stakeholders face in adopting market mechanisms that can enable the clean energy transition; this is covered in the next section.

Barriers to market participation and expansion in Indian states

Power procurement in India still relies on PPAs: 86 percent of thermal capacity and 95 percent of RE capacity are tied up in long-term PPAs (Kumar et al. 2022). Compared to the global level of electricity volume traded through electricity market platforms (40 percent), the corresponding figure for India's electricity market is only about 12 percent of the total electricity consumption, as mentioned earlier. In FY2023, the total volume traded through short-term markets in India was 194,300 MU, which is 12 percent of India's total transacted volume. Out of this volume, 102,950 MU (53 percent) was traded through PXs alone.

To understand the reasons for this low market liquidity, we conducted FGDs (see the earlier section titled "Methods") to understand institutional, regulatory, technical, and financial barriers to market participation. This exercise showed that some of the reasons for the lower uptake of markets were unpredictability in the MCP, inaccurate demand and RE supply forecasting, inflexible long-term PPAs, and technology and infrastructure constraints, which are explained in the following subsections.

Unpredictability in the MCP

The inability to predict market price trends has discouraged market participation at the state level. Prices have sometimes shot up as high as INR 20 for a unit of electricity through the markets. As a measure to prevent similar price escalations in the future, the CERC, with effect from April 1, 2022, imposed a cap of INR 12 per unit in DAMs and RTMs. On May 6, 2022, the CERC introduced capping in all segments. Further, high-price DAMs were recently introduced to accommodate the high prices of imported coal- and gas-based plants, which are reliant on international energy market trends. As of now, battery energy storage systems can also participate in this market. However, in the future, once AS markets become operational, such systems are expected to participate in them.

From our discussions with stakeholders, we learned that they were less motivated to purchase power from markets. Their preference for using the existing contracted power through PPAs is due to the following reasons. First, DISCOMs did not find markets attractive currently because of the lack of predictability of MCPs. Second, in our FGDs, stakeholders felt that markets were biased toward the seller; that is, prices may be inflated to favor sellers in the market. Third, the stakeholders were concerned that Indian markets were mainly dominated by one PX that facilitated 95 percent of market transactions. Stakeholders recommended introducing multiple platforms to promote competition. Finally, stakeholders opined that there was no institutional mechanism or agency that monitored the market dynamically. To ensure a level playing field and avoid market manipulation or misuse, transparency in reporting data is important. Presently, there is no market monitoring cell[23] at the state and regional levels to monitor market prices, trading activity, and the conduct of market participants, similar to the independent system operators in the United States. Surveillance mechanisms are needed that use a variety of analytical tools to detect unusual trading patterns and pricing anomalies that may indicate market manipulation or anticompetitive behavior.

Inaccurate supply-and-demand forecasting

Accurate short-term RE forecasts are critical for market participants to make informed price and quantity bids. The variable nature of solar and wind and unexpected surges or drops in RE generation can cause frequency and voltage fluctuations. The stakeholders cited inaccurate short-term forecasting of RE and net load[24] that inhibited states from participating in RTMs and G-DAMs, forcing them to resort to expensive long-term PPAs with generation from fossil fuel even when this could lead to stranded thermal capacities.

Inaccurate forecasting (supply and/or demand) will lead to suboptimal investment decisions and reduce both buyer and investor confidence in procurement from RE sources. There is a need for both customized decision support tools that can predict wind generation within a 10 percent margin and tools that can analyze cloud cover that impacts solar generation. There is also a growing need to maintain and analyze granular solar and wind generation data on a regular basis for accurate forecasting.

Whereas inaccuracy in short-term forecasting affects reliability, inaccuracy in long-term forecasting impacts resource adequacy.[25] This makes it necessary to maintain sufficient reserve margins within the system to withstand the variability of demand and supply. RA frameworks at the state level would help DISCOMs avoid contracting excess capacity via PPAs; such contracts may adversely impact power procurement costs.

Inflexible long-term PPAs

For decades, long-term PPAs, often spanning 25 years or more, were the primary choice for meeting the electricity needs of consumers. Long-term contracts facilitated investments in the power generation sector because developers and investors were assured of a stable revenue stream over an extended period. Further, by locking in prices for a significant duration, these contracts protected consumers from fluctuations in energy prices due to market volatility.

However, long-term PPAs have their own limitations. Long-term contracts often include inflexible provisions that can prevent power generators from participating optimally in the markets. Such provisions include the following:

- Take or pay: This clause mandates that buyers must pay the fixed cost for the agreed capacity per the contract, even if it is not utilized for electricity generation. Physical delivery PPAs can lock DISCOMs into specific generation assets despite the availability of lower-cost procurement opportunities in the markets.
- Right to revise schedules: Although DISCOMs schedule generators on a day-ahead basis, they have the right to revise the schedules up to a little over an hour before delivery. This restricts generators with surplus capacity from actively participating in day-ahead exchanges.
- Absence of market-linked pricing and settlement: The current long-term and medium-term contracts do not allow for market-based scheduling and pricing.

The inflexible provisions in long-term contracts should be amended. The Surplus Power Portal (PUShP) launched by the Government of India is an attempt to facilitate flexible operation of long-term PPAs. DISCOMs are supposed to indicate their surplus power in block times, days, or months on this portal (PIB 2023c), and those who need power will be able to requisition the surplus power. The new buyer will pay both the variable cost and the fixed cost. Once power is reassigned, the original beneficiary will have no right to recall, because the entire fixed cost liability is also shifted to the new beneficiary. The financial liability of the new buyer will be limited to the quantity of temporarily allocated or transferred power. This will reduce the fixed cost burden on DISCOMs and will potentially enable all the available generation capacity to be utilized.

Technology and infrastructure constraints

As India's RE capacity grows, the energy storage infrastructure becomes vital for tackling the intermittency challenges of renewable sources such as solar and wind. With ambitious RE targets, an enhanced transmission infrastructure to efficiently evacuate renewable power to other regions is also crucial. Although network congestion has in the main been avoided thus far, a coordinated effort between state and central transmission and load dispatch centers is necessary to optimize the usage of the evacuation infrastructure and avoid any stranded capacities. Table 3 summarizes the identified challenges and barriers to market adoption.

5. THE WAY FORWARD

Redesigning PPA structures

From our discussions with state stakeholders, it emerged that a key barrier preventing DISCOMs from purchasing low-cost energy from markets is PPAs that lock utilities into physical delivery of energy from specific generation assets.

To prevent utilities from getting locked into inefficient long-term PPAs, there should be provisions in the contracts that enable utilities to negotiate prices and revisit contract terms at regular intervals, such as every five years, and allow adjustments that reflect market dynamics. For example, future contracts can be designed to maximize benefits by bundling various services that allow power plants to offer not only energy but also commitments regarding future capacity, reactive power, inertia to maintain frequency stability, and other ancillary services. Further, DISCOMs could investigate options to stockpile fuel from take-or-pay contracts for emergencies or high-price periods instead of burning it for generation during normal operations.

The concept of *contract for differences* (CFDs) will play a pivotal role, especially for new RE projects in the future that can

Table 3 | **Categorization of barriers to electricity market adoption in India**

BARRIERS TO ADOPTION OF MARKETS	INSTITUTIONAL	REGULATORY	FINANCIAL	TECHNICAL
Unpredictability in the market clearing price (MCP)	Market monopoly in the power exchange (PX) space	Need for institutional mechanisms to regulate PX transactions	Seller-biased markets influencing prices	
Inaccurate demand and RE forecasting	Limited technical capacity to use tools for forecasting		Difficulty in predicting the revenue	Lack of tools for accurate forecasting
Inflexible long-term power purchase agreements (PPAs)		Right to revise schedules	Burden of paying fixed cost for underutilized capacity	Running thermal plants at suboptimal plant load factors (PLFs)
Technology and infrastructure constraints	Coordination among state and central agencies		Who will pay for the new technologies and infrastructure?	Network congestion

Note: A darker shade indicates high-priority problems that hinder liquidity in short-term markets.

Source: WRI analysis.

be contracted between aggregators or traders and RE project developers. CFDs would enable purchasers (DISCOMs) and sellers (RE generators) to enter into a contract in which the RE generator would be able to sell power on PXs and the purchaser is not obligated by the take-or-pay terms. Given that PX transactions have evolved to dominate the short-term market space (see the earlier section titled "Analysis and findings"), CFDs could also help enable increase the liquidity of the short-term market space in India. The contract is only for paying the difference between the agreed tariff and the market price, which will be settled between the involved parties. For example, if the RE generator makes a gain in the market over and above the agreed price, it shares the difference with the DISCOM, whereas the purchaser pays the difference if the RE generator gets a market price that is lower than the agreed price. The MoP is actively working to introduce CFDs in the Indian market soon (Srivastava 2023).

Alternatively, two separate contracts could be drawn up: a financial contract that ensures budget stability and a physical contract that ensures the sale of physical power in short-term markets such as the European market (IEA 2021). However, the detailed feasibility of this system of financial contracts coupled with PPAs for selling physical power in short-term markets needs to be assessed for the Indian context. Renegotiating an existing PPA contract could also finance RE assets. One way to accomplish this refinancing is through securitization, which involves raising low-interest bonds to buy off the remainder of an older PPA on an accelerated basis. Net benefits could result by retiring the PPA-supported resource early on when the avoided interest payments and avoided fuel expenses exceed the cost of the bond. If multiple PPAs support the same power plant, all the contracting parties may need to agree and coordinate on a plan. Sharing the savings with the asset owners and displaced workers can help incentivize them to accept a buy-out offer. However, securitization requires a guaranteed repayment of the bond to obtain low-interest financing. In the United States, there is a legislatively mandated fee, but other means of ensuring repayment could be explored.

Increasing resource sharing

States typically like to retain control over resources for local development, self-reliance, and independence or because of a preference for a certain generation mix. Improving and expanding regional power sharing through electricity markets can help reduce power procurement costs, boost reliability, and cost-effectively integrate RE. However, it is important to reserve for state DISCOMs the right to contract resource types based on availability, geographical constraints, and state-specific policies or targets. They also have their own preferred mechanisms for trading power. For example, we saw how the coal-power-rich regions opted for DAM mechanisms and RE-rich states sold more power through RTMs during peak RE seasons (see the earlier section titled "Analysis and findings"). Trading energy in RTMs and DAMs optimizes the use of existing resources but does not focus on long-term resource investments, especially in transmission infrastructure. It is important to evaluate how benefits and costs are shared across regions.

Transmission infrastructure is needed to trade and share resources regionally. Nodal markets optimize the available transmission capacity and signal where transmission upgrades and expansions are required. Financial transmission rights (FTR) markets allow customers to hedge against transmission constraints. These are financial contracts that allow market participants to hedge against transmission congestion charges in nodal markets (i.e., from insufficient transmission). This helps market participants gain more price certainty in markets with locational marginal pricing. The FTR holder can obtain revenues or be charged based on the congestion price difference across an energy path. These FTR markets exist in wholesale markets organized by regional transmission organizations and independent system operators in the United States, and may be traded in a monthly, annual, or long-term auction. Power pools[26] are a broader category of cooperative agreements between utilities that can enable resource sharing. Our review of international markets shows that power pools in some form exist in most continents. The efficiency benefits are not as robust as those from a more centralized automated exchange, and there is no market price formation, but this type of energy market preserves control for utilities.

There is a need to carefully evaluate (and perhaps conduct pilot studies) whether FTR and power pools are needed in India, and to increase resource sharing across states and help reduce overall costs. As a first step, it will be important to draft robust guidelines that would give clarity to DISCOMs regarding payment for usage of the national ISTS infrastructure pool, which would eliminate underutilization/stranded capacities (Vijayakumar 2023).

Improving forecasting and flexibility in the grid

Improved forecasting makes it easier to optimally share renewables across broader regions and will even out variability in generation as well as in the load. Flexible resources can quickly respond to variable RE generation and any unexpected mismatch between load and generation. RTMs enable participants to adjust bids and offer close-to-real-time delivery. They also support the AS market, which can enable integration of more flexible resources, such as storage in the grid. From our FGDs, we learned that accurate demand forecasting is important for effective power procurement planning at the state level.

PXs could potentially enable the demand flexibility needed to participate in markets through demand bidding, aggregated demand response, and distributed energy resources. Demand flexibility uses communication and control technology to shift electricity use across hours of the day. This flexibility will become increasingly important as more distributed RE is integrated in the grid. Demand response is still nascent in India, but it provides the ability to aggregate consumers who are capable of shifting or reducing their demand to participate in DAMs, RTMs, and the AS market (FERC 2023). Although there are mechanisms and targets to promote rooftop solar in Indian states, the share of rooftop PV remains low in the overall capacity mix. Such markets can increase the share of distributed rooftop solar in the coming years by enabling distributed energy resources to earn multiple revenue streams.

Recent extreme weather events have highlighted the importance of market efficiency, resource sharing with neighbors, and demand response to help stave off outages during extreme events. In 2020 and 2022, California and the western United States experienced extreme heat (Balaram 2022). Imports from neighbors and demand response helped California mitigate further outages. In the wake of these events, the California Independent System Operator (CAISO) suggested market reform to send better price signals to encourage demand response and imports from neighbors to serve the California load (California ISO 2021). In India, better forecasting techniques and demand flexibility could be explored to help make power systems more resilient.

Strengthening institutional mechanisms

Markets ought to be designed to select the most efficient resources capable of providing grid management services from a broad pool of sellers. Bringing more generation as well as demand-side resources into the markets to compete can help lower market prices. Multiple services can complement each other. However, multiple trading platforms may spread participants thinly.

Hence, we recommend having a range of well-defined services (instead of a proliferation of market platforms) where resources of all types can participate and provide services that are not mutually exclusive. Power traders (including sellers and buyers) should be allowed to compete based on their needs. This is an important market feature for multitasking resources, such as energy storage resources, which can combine revenues from different services. For services that a given resource cannot provide simultaneously, energy and AS market algorithms should be designed to co-optimize resource bids in order to determine whether it is more efficient to dispatch the resource as energy or hold it in reserve. Market clearing algorithms produce a transparent price for every time interval and locational node. Nodal markets operating on granular time intervals can help provide the locational and temporal flexibility needed to produce higher shares of variable renewables (Glachant and Rossetto 2022). For example, energy markets in Europe and Australia operate decentralized markets where transmission owners retain control over their systems but work with market platforms and dispatch as necessary to overcome transmission constraints (Shah and Chatterjee 2020; Glachant and Rossetto 2022; RMI 2023).

As seen in the section titled "Analysis and findings," RTM's transaction share increased to 25 percent in PXs within three years of its inception in India. Also, RE-rich states are inclined to sell more RE power in the peak RE seasons through RTMs (see the section titled "Analysis and findings"). With the share of RE increasing in the mix, India could benefit from having markets that consider supply-and-demand offers, along with transmission and system constraints on a granular time scale to enhance system efficiency and flexibility, and provide pricing signals indicating where infrastructure upgrades can help reduce congestion.

Second, regional and state load dispatch centers, which are primarily responsible for real-time monitoring, control, and grid balancing at the state and regional levels, need to be strengthened to leverage new market mechanisms for optimal scheduling and dispatch of electricity. For example, U.S. RTOs and ISOs have independent market monitors that not only ensure that market power is not abused and market rules are followed, but that also critique existing and proposed market rules from a customer and a reliability perspective (Buechler 2009). In addition, the U.S. Federal Energy Regulatory Commission (FERC) has investigation and enforcement authority (Murphy et al. 2014) over the transmission and sale of electricity and natural gas in interstate commerce. The FERC's Office of Enforcement focuses on fraud and market manipulation, anticompetitive conduct, serious violations of the electric reliability standards, threats to the nation's energy infrastructure and associated impacts on the environment and surrounding communities, and conduct that threatens the transparency of regulated markets (FERC 2023). Similarly, the European Union formed the Agency for the Cooperation of Energy Regulators (ACER), which was established as an independent body to monitor and ensure a transparent energy market, guaranteeing consumers fair prices and limiting market abusive behaviors (ACER n.d.).

In India, although market trading platforms serve as creditworthy counterparties by transparently providing data and prices, investments are needed to build institutions that can serve as independent market monitors, which would ensure that markets are competitive, transparent, well designed, and are not being abused.

Designing RA frameworks at the state level

Coordinated RA planning at both the national and DISCOM levels could lead to an optimal capacity blend over 5–10 years, reducing system costs. RA enables sufficient capacity to be tied up so that the expected demand of consumers in the DISCOM's license area can be reliably served in a cost-effective manner. The recent draft guidelines from the CEA are encouraging states to prepare an RA framework, which includes integrated resource planning, optimal reserve margin planning, and an institutional mechanism for compliance monitoring (CEA 2022).

Our analysis (see the section titled "Analysis and findings") and government data show that the demand pattern varies across different states across a year. For example, RE-rich states such as Gujarat, Tamil Nadu, and Karnataka have high demand for electricity during the period December–April, whereas states such as Assam, Uttar Pradesh, and Bihar have a high-demand period during May to September (PIB 2023b). In the section titled "Analysis and findings," we also indicated that the RE-rich states of India could benefit more by purchasing power through markets than through the PPA route (see Table 2) during peak RE season. This seasonal demand variation in India provides scope for RA planning, where the capacity commitment period can be much shorter than the lifespan of a typical generation asset to enable more granular capacity procurement. Participating in capacity markets could be made voluntary to begin with, as it is in the U.S. Midcontinent Independent System Operator (MISO), where utilities can meet RA needs through market and traditional planning mechanisms such as utility integrated resource plans[27] (MISO n.d.).

RA planning could enable the emergence of capacity markets for optimal contracting. Internationally, capacity markets in wholesale electricity markets are used to pay resources for making themselves available to meet peak electricity demand for both long and short durations. However, capacity markets may not provide certainty for some types of resources and may not reflect policy preferences for renewables. For instance, this approach may not always be the most efficient or cost-effective solution, and can potentially lead to the construction of fossil-fuel-based power plants that could turn into stranded investments over time (Pechman 2021). For example, capacity markets in the United States tend to purchase from gas plants, but seasonally variable renewable generation may be more compatible with a seasonal capacity market (Newell et al. 2018). While reviewing international capacity markets, we learned that these markets are more controversial where they are either mandatory or impose a procurement target for each utility, or where they are the only means of meeting the RA target.

Markets can indirectly facilitate public policy goals by promoting power system efficiency, flexibility, and access, and by providing pricing and emissions data transparently. In India, explicitly defining electricity market services with target resource attributes will be necessary. Otherwise, markets that purchase the lowest-cost basic megawatts without distinguishing between clean and fuel-based capacity resources can end up with fossil fuel resources and not necessarily the levels of renewable generation needed to meet policy goals. A well-designed market can enable customers to rely on a broader pool of resources for improved reliability at a lower cost while relying less on long-term contracts. To more directly serve clean energy goals, markets would need to be explicitly designed to target specific resources or attributes. Hence, market design would need to consider the clean energy transition goals of the state.

APPENDIX A
Monthly renewable energy generation of bid areas in MU (FY2023)

AREAS	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
N1	393	366	389	553	567	604	479	441	261	198	214	271
N2	3,964	4,671	4,409	3,453	3,596	4,010	3,917	3,809	4,147	4,523	4,339	4,833
N3	307	281	314	257	299	308	371	371	389	377	430	466
E1	182	185	176	183	188	182	202	196	211	189	185	202
E2	85	90	64	105	117	128	135	101	89	92	98	89
W1	937	1,167	942	727	711	686	596	488	597	726	614	682
W2	3,868	5,607	4,427	4,524	3,815	2,995	2,769	2,983	3,982	4,759	3,555	3,727
W3	174	170	164	113	134	139	148	124	208	216	199	215
S1	3,888	5,003	4,903	5,311	5,123	4,326	3,637	3,653	4,027	4,678	4,198	4,680
S2	1,157	3,175	3,521	3,673	3,441	3,292	1,762	988	1,475	1,737	1,608	1,808
S3	125	122	137	199	196	213	165	181	152	193	119	145
A1	5	9	11	11	18	25	25	25	25	13	12	13
A2	21	31	37	31	45	36	30	29	31	30	25	31

Note: MU = million units.

Source: CEA n.d.-b.

APPENDIX B
Monthly electricity demand of bid areas in MU (FY2023)

AREAS	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
N1	7,131	8,415	9,213	9,362	9,660	8,940	7,123	6,644	7,295	7,498	6,567	7,091
N2	25,011	28,317	29,395	27,516	27,188	26,567	21,480	21,053	22,742	23,618	20,369	23,713
N3	4,838	6,292	7,478	8,131	8,906	7,617	4,952	3,732	4,273	4,595	4,181	4,366
E1	12,630	12,133	12,405	13,499	13,034	12,495	11,588	9,409	9,662	10,576	8,997	11,913
E2	3,495	3,862	3,885	4,012	4,056	4,030	3,771	3,077	2,972	2,998	2,871	3,400
W1	8,026	8,119	7,107	6,533	6,508	6,786	6,735	6,411	9,790	9,694	8,398	7,893
W2	31,316	32,246	28,571.5	24,957	25,654	25,317.5	25,087	27,061	30,096.5	29,265.5	27,761	29,393
W3	3,467	3,125	2,926	2,980	3,027	3,243	3,426	3,346	3,348	3,347	3,147	3,184
S1	20,967	17,771	17,560.5	16,604	17,977	17,825.5	16,415	16,909	18,541.5	21,084.5	21,389	25,273
S2	10,702	10,566	10,495	10,260	9,820	9,694	9,063	8,545	8,933	9,462	8,981	11,433
S3	2,468	2,361	2,259	2,119	2,199	2,206	2,322	2,233	2,305	2,308	2,228	2,691
A1	336	340	327	356	340	369	346	323	356	353	299	317
A2	1,009	1,194	1,219	1,494	1,542	1,471	1,268	1,036	1,114	1,123	996	1,119
Total (MU)	**131,396**	**134,741**	**132,841**	**127,823**	**129,911**	**126,561**	**113,576**	**109,779**	**121,428**	**125,922**	**116,184**	**131,786**

Note: MU = million units.

Source: CEA n.d.-a.

APPENDIX C
Monthly power exchange transactions of bid areas in MU (FY2023)

Day-ahead market: Monthly transactions of different bid areas in MU

	A1		A2		E1		E2		N1		N2		N3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	8	33	34	88	685	211	21	343	382	274	331	1,078	160	0
May	10	23	86	167	339	297	37	229	425	305	633	278	450	0
Jun	8	22	83	240	404	641	138	131	455	126	857	439	207	1
Jul	13	44	154	180	454	543	120	44	90	271	460	669	38	72
Aug	5	43	178	172	331	558	189	129	216	345	481	485	65	80
Sep	6	56	106	73	318	866	120	189	325	340	1,086	523	360	2
Oct	0	54	88	125	114	1,137	124	149	110	311	746	825	374	6
Nov	0	24	49	45	80	1,724	45	188	519	177	1,301	1,169	114	3
Dec	0	33	46	95	125	1,514	47	282	537	87	913	1,054	301	1
Jan	0	52	30	87	369	1,287	41	313	691	59	792	1,116	376	0
Feb	1	44	30	67	356	1,125	26	241	479	113	598	1,293	447	1
Mar	4	30	70	55	423	807	33	216	414	189	550	1,621	336	6

	S1		S2		S3		W1		W2		W3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	1,190	539	626	73	9	55	27	391	542	123	101	906
May	260	697	257	64	25	67	83	380	542	138	26	528
Jun	819	576	231	94	24	33	76	643	760	249	22	890
Jul	634	380	235	59	13	172	111	462	1,192	81	3	538
Aug	575	717	217	66	9	272	113	339	1,092	60	57	263
Sep	421	926	117	87	8	228	66	219	1,077	129	38	412
Oct	574	826	175	13	15	36	89	351	1,910	61	5	433
Nov	649	482	219	14	19	7	55	181	2,031	96	1	973
Dec	984	307	264	42	34	18	17	438	1,690	161	19	944
Jan	897	328	231	77	45	31	35	431	1,428	270	12	898
Feb	1,008	230	52	83	13	47	80	421	1,524	162	43	832
Mar	914	226	47	96	3	63	78	355	1,842	217	5	838

Real-time market: Monthly transactions of different bid areas in MU

	A1		A2		E1		E2		N1		N2		N3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	5	37	22	128	167	501	32	45	240	81	176	315	112	3
May	4	61	43	146	304	487	101	54	222	188	457	324	345	7
Jun	15	27	30	191	190	493	99	62	236	145	547	193	170	35
Jul	15	26	35	133	223	226	117	94	134	156	374	358	96	51
Aug	9	33	56	152	272	245	132	80	151	179	451	285	181	40
Sep	8	19	36	74	237	287	120	150	125	246	635	180	188	55
Oct	8	41	27	99	115	349	100	110	260	154	682	215	341	3
Nov	4	48	40	95	36	476	14	102	267	71	351	180	42	4
Dec	8	34	36	46	60	593	12	95	244	96	506	250	87	1
Jan	11	29	24	50	84	705	59	149	225	100	533	293	369	0
Feb	4	29	9	43	60	606	44	187	145	92	413	229	328	1
Mar	22	29	32	42	81	529	41	154	228	68	367	267	220	5

	S1		S2		S3		W1		W2		W3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	372	242	198	12	7	85	28	76	299	39	45	138
May	327	425	101	97	11	64	56	226	313	75	35	166
Jun	425	320	108	81	23	40	16	331	317	149	37	147
Jul	462	331	145	57	7	53	23	460	469	40	30	147
Aug	332	355	94	108	5	156	17	515	493	25	73	90
Sep	368	280	82	93	7	128	35	553	319	54	30	72
Oct	176	377	77	22	7	19	14	774	445	29	12	71
Nov	202	151	84	14	13	3	10	108	340	38	3	118
Dec	341	115	82	69	24	24	12	231	338	58	13	151
Jan	323	141	108	42	19	30	14	294	302	104	29	166
Feb	276	116	42	42	5	31	22	74	331	81	33	184
Mar	550	147	36	22	5	20	21	445	473	177	23	193

Green day-ahead market: Monthly transactions of different bid areas in MU

	A1		A2		E1		E2		N1		N2		N3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	0	0	5	0	39	0	3	0	2	13	30	81	62	0
May	0	0	9	0	56	0	14	0	9	2	70	96	176	0
Jun	0	0	21	0	64	0	2	0	2	15	51	150	71	0
Jul	0	0	26	0	58	0	24	0	11	16	66	108	31	0
Aug	0	0	40	0	44	0	7	0	15	33	41	66	4	0
Sep	0	0	26	0	61	1	18	0	4	19	44	54	40	0
Oct	0	0	27	0	35	3	6	0	38	5	50	14	2	0
Nov	0	0	2	0	27	1	2	0	1	14	77	46	1	0
Dec	0	0	2	0	23	0	5	0	7	13	26	5	6	0
Jan	0	0	0	0	41	0	12	0	0	16	28	7	34	0
Feb	0	0	0	0	28	1	10	0	1	11	11	6	20	0
Mar	0	0	0	0	25	5	16	0	2	9	21	8	14	0

	S1		S2		S3		W1		W2		W3	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Apr	13	107	0	0	1	0	0	8	59	6	1	0
May	24	363	3	0	6	2	0	12	127	19	1	0
Jun	22	120	1	0	8	0	0	49	119	28	2	0
Jul	21	248	5	0	5	7	5	36	186	31	9	0
Aug	11	147	3	0	2	9	13	23	138	43	4	0
Sep	13	207	1	0	1	5	15	1	98	38	1	0
Oct	20	248	12	0	10	0	19	1	73	23	0	0
Nov	18	210	14	0	23	0	35	4	86	13	2	0
Dec	20	189	15	0	8	0	13	5	100	19	7	0
Jan	27	219	19	0	3	0	1	6	110	37	7	0
Feb	15	201	7	0	1	0	6	10	148	24	6	0
Mar	31	262	6	0	0	0	13	12	159	1	9	0

Note: MU = million units.

Source: IEX n.d.-a.

APPENDIX D
Focus group discussion survey topic: Assessing stakeholder interests to understand market options and participation

1. What is your interest in the market?

Roles: Utility, state load dispatch center, exchange, regulator, seller, buyer

2. How important do you believe these markets are
   - To optimize power procurement?
   - To increase renewable energy deployment?
   - To manage supply–demand and imbalances?
   - For reliability?
   - For flexibility?
3. What are your goals in learning more about them?
4. How familiar are you with the concept of markets (India/Internationally)?
5. Do you or your team have the technical capacity? What support are you looking for?
   - Bilateral markets
   - Day-ahead markets (DAMs)
   - Real-time markets (RTMs)
   - Market Based Economic Dispatch (MBED)
   - Security Constrained Economic Dispatch (SCED)
   - Capacity markets (especially for storage, demand flexibility)
   - Ancillary services markets (especially for storage, demand flexibility)
   - Green term-ahead markets (G-TAMs) for renewables
   - Financial transmission rights (FTRs)
6. What challenges do you foresee in adopting these mechanisms or participating in them?
7. How often are you willing to utilize these market mechanisms?
8. What opportunities do you see for implementation of markets at the central or state level?
9. How familiar are you with training and support provided by the Center?
   - Does it serve your needs?
   - What is missing that could be useful to you?
   - Are these resources good, high level, insufficiently detailed, long, not customized?
   - How could they be better tailored or targeted to your needs?
10. What would you like to see in a new set of resources and what would be your preferred format?
    - State- or India-specific information (regional disparities, geographical constraints, design options to cater to regional stakeholder concerns)
    - Information regarding how to participate in existing markets (such as a handbook or manual covering rules, regulations, protocols, institutional structure)
    - Information about new market options (such as peer-to-peer trading, distribution system operator [DSO] framework)

ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
AS	ancillary services
BESS	battery energy storage systems
BU	billion units
CAISO	California Independent System Operator
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CGS	central generating stations
CO_2	carbon dioxide
DAC	day-ahead contingency
DAM	day-ahead market
DISCOM	distribution company
EA	Electricity Act
ERCOT	Electric Reliability Council of Texas
ESC	Energy Savings Certificate
FERC	Federal Energy Regulatory Commission, United States
FGD	focused group discussion
FTR	Financial Transmission Right
FY	financial year
G-DAM	green day-ahead market
GJ	Gujarat
GOI	Government of India
G-TAM	green term-ahead market
GW	gigawatt
HPDAM	high price day-ahead market
HPX	Hindustan Power Exchange Ltd
IEX	Indian Electricity Exchange Ltd
INR	Indian rupee
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISGS	inter-state generating station
ISO	independent system operator
ISTS	Inter-State Transmission System
LT	low tension
MBED	Merit Based Economic Dispatch
MCP	market clearing price
MH	Maharashtra
MISO	U.S. Midcontinent Independent System Operator
MOD	Merit Order Dispatch
MW	megawatt
NEP	National Electricity Policy
NLDC	National Load Dispatch Centre
OTC	over the counter
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PLF	plant load factor
POSOCO	Power System Operation Corporation
PPA	power purchase agreement
PUShP	High Price Day Ahead Market and Surplus Power Portal
PV	photovoltaic
PX	power exchange
PXIL	Power Exchange India Ltd
RA	Resource Adequacy
RE	renewable energy
REC	Renewable Energy Certificates
RMI,	Rocky Mountain Institute
RPO	Renewable Purchase Obligation
RTC	round the clock
RTM	real-time market
RTO	Regional Transmission Organizations
SCED	Security Constrained Economic Dispatch
SEEM	Southeast Energy Exchange Market
SERC	State Electricity Regulatory Commission
SPP	Southwest Power Pool
SPP	Solar Power Plant
TAM	term-ahead market
TN	Tamil Nadu
TSO	transmission system operator
VOLL	value of lost load

GLOSSARY

Ancillary services	Ancillary services encompass supplementary functions in the electricity sector, such as frequency regulation and voltage control, which ensure grid stability.
Battery energy storage systems	Battery energy storage systems (BESS) are installations designed to store electrical energy for grid support and increased reliability.
Capacity market	A capacity market compensates power generators for committing to provide a predetermined amount of electricity capacity in the future, assuring grid reliability.
Central generating stations	Central generating stations are large-scale power plants, typically government-owned, responsible for substantial electricity generation.
Day-ahead market	The day-ahead market is where electricity is traded for delivery the following day, allowing for advanced planning of electricity needs.
Demand-side biding	Demand-side bidding refers to the practice where electricity consumers can submit bids indicating how much electricity they are willing to buy and at what price, thus influencing market dynamics and pricing.
Double-sided closed auction	A double-sided closed auction is an auction format where both buyers and sellers submit confidential bids, with results revealed after the auction concludes.
Electricity contract	An electricity contract is an agreement for the sale and purchase of electricity or Renewable Energy Certificates or Energy Saving Certificates.
Energy Savings Certificate	Energy Savings Certificates are awarded for achieving energy conservation through efficient measures and can be traded or used for compliance.
Focus group discussions	Focus group discussions involve structured, small-group discussions led by a moderator to explore specific topics, gather opinions, and gain insights.
Financial Transmission Right	A Financial Transmission Right (FTR) is a financial instrument that entitles the holder to receive compensation for congestion costs that arise when the transmission grid becomes congested.
Gate closure	Gate closure refers to the time at which the bidding for a specific delivery period closes and no further bidding or modification of already placed bids can take place for the said delivery period.
Green day-ahead market	The green day-ahead market specializes in trading electricity generated from renewable energy sources for delivery the following day.
Green term-ahead market	The green term-ahead market focuses on trading longer-term contracts for electricity generated from renewable sources.
High price day-ahead market	The high price day-ahead market sees electricity traded at elevated prices due to increased demand or supply limitations.
Hindustan Power Exchange Ltd.	Hindustan Power Exchange Ltd. is a power exchange in India that provides a platform for trading different electricity products. It is a significant player in the Indian power exchange sector, facilitating electricity trading.
Indian Electricity Exchange Ltd.	The Indian Electricity Exchange Ltd. is India's first power trading exchange regulated by the CERC, offering a platform for transactions.
Inter-State Generating Station	Power generation facilities located in one Indian state that primarily supply electricity to other states. These generating stations play a crucial role in addressing electricity demand in multiple regions and facilitate power exchange among different states.
Market clearing price	The market clearing price is the settlement price for electricity transactions, determined by the intersection of supply-and-demand curves in a power exchange.
Merit Order Dispatch	A system for scheduling electricity generation sources based on their operational costs, prioritizing lower-cost generators.
Monitoring cell	A regulatory body responsible for overseeing and ensuring the fairness, transparency, and integrity of operations within a power exchange. It is often involved in market surveillance and monitoring for any irregularities or market manipulation.
Network congestion	Network congestion occurs when the power grid lacks the capacity to transport electricity due to infrastructure limitations.

Net load	The net load is the difference between the forecasted demand by the utility or scheduler and the forecasted RE generation in the control area.
Over the counter	Over the counter (OTC) refers to the direct trading of financial instruments between parties, bypassing centralized exchanges.
Plant load factor	The plant load factor measures the operational efficiency of a power plant, indicating how close it operates to maximum capacity.
Power purchase agreement	A power purchase agreement (PPA) is a contractual agreement specifying the terms and conditions for electricity supply.
Power exchange	A power exchange is a centralized platform for electricity trading among market participants.
Power pool	A power pool is an entity that handles scheduling and dispatch functions for a group of power plants owned by multiple entities. Power pools are typically created by groups of utilities that desire the higher reliability and lower costs available from optimizing generation across a region.
Resource adequacy	Resource adequacy is understood as a system's capacity to provide sufficient electricity and energy to meet consumer needs reliably, accounting for both expected and unexpected system component outages now and in the future.
Renewable Energy Certificates	A tradable instrument representing the environmental attributes of one megawatt-hour of electricity generated from renewable energy sources. These certificates allow entities to meet renewable energy goals and environmental regulations.
Renewable Purchase Obligation	A Renewable Purchase Obligation mandates that electricity consumers purchase a percentage of their electricity from renewable sources.
Real-time market	A real-time market refers to a market mechanism that enables the trading of electricity in real time, typically on a 15-minute scheduling interval, to respond promptly to changes in supply-and-demand, enhance grid stability, and optimize the use of available electricity resources.
Security constrained economic dispatch	Security constrained economic dispatch is an area-wide optimization process designed to meet the electricity demand at the lowest cost, given the operational and reliability limitations of the area's generation fleet and transmission system.
State Electricity Regulatory Commission	An independent regulatory body responsible for regulating and overseeing the electricity sector within a specific state in India.
Term-ahead market	The term-ahead market is a specialized marketplace for trading electricity contracts with extended durations, enabling market participants to plan for electricity supply-and-demand over longer time frames.
Wholesale electricity market	The wholesale electricity market is where bulk quantities of electricity are traded among generators, suppliers, and large consumers, serving as the primary marketplace. This is crucial for the stability of the power system because it allows for balancing of demand and supply.

ENDNOTES

1. A day-ahead market refers to a market mechanism where electricity is traded a day in advance. Power producers and consumers submit their bids and offer to buy or sell electricity for the next day. This market helps plan and secure electricity supply to meet the expected demand, ensuring a smooth and reliable power supply for everyone.

2. A term-ahead market is a specialized marketplace for trading electricity contracts with extended durations, enabling market participants to plan for electricity supply-and-demand over longer time frames.

3. A real-time market refers to a market mechanism that enables the trading of electricity in real time, typically at 15-minute scheduling intervals, to respond promptly to changes in supply-and-demand, enhance grid stability, and optimize the use of available electricity resources.

4. A green day-ahead market is a market segment dedicated to the trading of electricity generated exclusively from RE sources, promoting sustainable energy practices.

5. Ancillary services in the electricity market refer to specialized support functions, such as grid stability, voltage regulation, and backup power, that ensure the reliability and security of the electric grid.

6. A power exchange is a virtual trading platform where electricity producers and electricity consumers meet. It is one of the short-term power market options.

7. FY2023 refers to the period 2022–23; i.e., the year after "FY" denotes the ending year of the period.

8. The market clearing price is the price at which electricity is traded and cleared in electricity markets, reflecting the equilibrium point where electricity supply matches demand. It helps determine the price at which power is bought and sold in electricity markets.

9. A PPA is a legal contract between a power producer and a purchaser, outlining the terms of the electricity quantity, price, and duration of the electricity supply.

10. Demand-side bidding refers to the practice where electricity consumers, rather than just suppliers, can submit bids indicating how much electricity they are willing to buy and at what price, thus influencing market dynamics and pricing.

11. Aggregated demand response in the electricity market refers to the collective ability of multiple consumers or devices to adjust their electricity usage in response to market signals or grid conditions, helping balance supply-and-demand and enhance grid stability.

12. DISCOMs such as BSES are locked into paying ~INR 6/kWh for power from the NTPC Dadri-I plant, and Rajasthan faces a similar commitment with a rate of ~INR 15/kWh from the NTPC Anta Gas plant. This is in contrast to the discovery of RE tariffs as low as INR 1.99/kWh in the country.

13. Capacity markets provide a mechanism for maximum development of the power system by allowing markets to choose the least cost mix of generation, transmission, and energy efficiency resources.

14. RPO is a regulatory mandate that requires certain electricity consumers and utilities to buy a set percentage of their power from renewable sources, thus promoting renewable energy adoption and sustainability.

15. Despite the initial success with a sharp rise in the renewable certification rate from 2 percent in FY2011 to 15 percent in FY2014, the REC mechanism's effectiveness declined due to plunging REC prices and an accumulation of unsold RECs. This led to a decline in the renewable certification rate to ~6 percent in FY2019.

16. Price discovery refers to the process of determining the market price of electricity in DAMs. The PX that began operations in 2009 played a crucial role in this process by facilitating the determination of market prices through competitive bidding and trading.

17. A bilateral electricity contract is an agreement for the sale and purchase of electricity, RE certificates, or energy saving certificates.

18. 1 Crore = 100 lakh = 10 million. The terms *crore* and *lakh* will be used throughout the manuscript to better suit the Indian context of this working paper.

19. Each electrical region of the country has been further divided into two or more bid areas to accommodate any exigencies due to congestion in intra-regional transmission systems.

20. Merit order is a method of ranking energy sources in ascending order of price, with the result that the cheapest sources get selected first.

21. Data were collected from the MERIT data portal, Government of India. Data on the majority of eastern and northeastern states were either only partially available or unavailable.

22. *Gate closure* refers to the time at which the bidding for a specific delivery period closes and no further bidding or modification of already placed bids can take place for the specified delivery period.

23. "A monitoring cell is an independent or federally regulated body constituted by the state or central government to monitor the power market compliance with rules, screening for and investigation of anti-competitive behaviour, evaluation of market performance, and compilation of information and preparation of reports" (Lesieutre et al. 2004).
24. The net load is the difference between the demand forecasted by the utility or scheduler and the forecasted RE generation in the control area. This net load will be subject to power procurement through PPAs and short-term markets.
25. RA is understood as a system's capacity to provide sufficient electricity and energy to meet consumer needs reliably, accounting for both expected and unexpected system component outages now and in the future.
26. A power pool is an entity that handles scheduling and dispatch functions for a group of power plants owned by multiple entities. Power pools are typically created by groups of utilities that require the higher reliability and lower costs that optimizing generation across a region enables.
27. Retailer reliability obligation is designed to support resource adequacy by incentivizing retailers and some large energy users to contract for or invest in resources to cover their share of the expected peak demand in regions and for times when there is a forecasted gap.

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