Global Energy Alliance for People and Planet
GEAPP

Powering Progress: Batteries for Discoms

A Market Action Report on Accelerating Battery Energy Storage in India

Report / November 2023

About RMI

RMI is an independent nonprofit founded as **Rocky Mountain Institute** in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions by at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. RMI has been supporting India's mobility and energy transformation since 2016.

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About GEAPP

The **Global Energy Alliance for People and Planet** (GEAPP) brings together philanthropy including the IKEA Foundation, the Rockefeller Foundation and the Bezos Earth Fund, governments, technology, policy and development partners and the private sector to tackle the twin challenges of energy access and transition in emerging and developing countries. By 2030, we aim to expand clean energy access to one billion people, enable 150 million new jobs and reduce 4 gigatons of future carbon emissions. We believe clean energy is development: without it, every other form of progress is undermined so we're building a movement to unlock a new era of inclusive green economic growth that accelerates universal energy access while enabling the global community to meet critical climate goals during the next decade.

For more information, please visit **www.energyalliance.org** and follow us on Twitter at @EnergyAlliance.

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Table of Contents

Abbreviations

ASC-ARR GAP	Average cost of supply and average realisable realisable revenue gap
AT&C LOSSES	Aggregate technical and commercial losses
BESS	Battery energy storage system
BMS	Battery management system
BTM	Behind-the-meter
CAGR	Compounded annual growth rate
CAISO	California Independent System Operator
CAPEX	Capital expense
CEA	Central Electricity Authority
CEM	Capacity expansion modelling
CERC	Central Electricity Regulatory Commission
DAM	Day-ahead market
DISCOM	Distribution company
DLS	Distribution-located storage
DNO	Distribution network operator
DNSP	Distribution network service providers
DSM	Deviation settlement mechanism
EMS	Energy management system
EPC	Engineering, procurement, and construction
ERPC	Eastern Regional Power Committee
ESCO	Energy service company
ESO	Energy storage obligation
ESS	Energy storage system
FY	Fiscal year

GDP	Gross domestic product
GoI	Government of India
GW	Gigawatt
GWh	Gigawatt-hour
HP-DAM	High-price day-ahead market
IEX	Indian Energy Exchange
kW	Kilowatt
kWH	Kilowatt-hour
LCOS	Levelised cost of storage
MoP	Ministry of Power
MU	Million units
NBI	Neighbourhood Battery Initiative
NDC	Nationally determined contribution
NREL	National Renewable Energy Laboratory
NRPC	Northern Regional Power Committee
NGR	Non-generator resource
NYISO	New York Independent System Operator
PCS	Power conversion system
PFC	Power Finance Corporation Limited
PLI	Production-linked incentive
PPA	Power purchase agreement
PRAS	Primary reserve ancillary service
PSP	Pumped hydro storage project
RA	Resource adequacy
RaaS	Resilience-as-a-service
RE	Renewable energy

RFP	Request for proposal
RIIO	Revenue = incentives + innovation + outputs
RPO	Renewable purchase obligation
RTM	Real-time market
SCADA System	Supervisory control and data acquisition system
SERC	State Electricity Regulatory Commission
SLDC	State Load Despatch Centre
SMUD	Sacramento Municipal Utility District
SOC	State of charge
SRAS	Secondary reserve ancillary service
TOU	Time-of-use
TRAS	Tertiary reserve ancillary service
TWH	Terawatt-hour
UK	United Kingdom
US	United States of America
VGF	Viability gap funding
VGF Scheme	Viability Gap Funding for Development of Battery Energy Storage Systems Scheme
VRE	Variable renewable energy
WACC	Weighted average cost of capital

Foreword

On behalf of GEAPP and RMI, we are delighted to present this comprehensive report, **'Powering Progress: Batteries for Discoms'**, which elaborates on a very important subject of energy storage in the Indian energy sector. We have had the privilege of witnessing the transformative energy landscape of India over the past 3 decades. With the achievement of universal electricity access and the remarkable growth in demand propelled by the nation's economic expansion, the integration of renewable resources has become a cornerstone of our sustainable energy future. Given India is enroute to achieve its target of 500 GW renewables by 2030, this report comes out at a pivotal time as the energy sector and particularly Discoms prepare to absorb high levels of variable renewables in their total energy mix.

In line with the Union Budget for Fiscal Year (FY) 2023–24, which recognised the imperative need for substantial investments to foster a resilient and flexible grid, the focus on energy storage, particularly battery energy storage systems (BESS), has garnered significant attention.

This report addresses the pivotal role of energy storage, emphasising the critical importance of effectively integrating BESS assets at the distribution level to meet the evolving demands of power system flexibility, meet challenges of burgeoning peak demand and provide Indian population with clean and reliable electricity.

With a profound understanding of the unique challenges faced by distribution companies (Discoms) and the broader energy landscape, this report underscores the significance of distribution-located storage (DLS) in India's grid. By elucidating the diverse benefits of DLS, ranging from grid balancing and power cost optimisation to ensuring system reliability and effective peak load management, this report provides a comprehensive framework for Discoms to navigate the evolving energy paradigm in India.

Moreover, by highlighting the techno-economic aspects of a 10 MW/20 MWh BESS project and outlining the multiple value streams BESS can provide, this report serves as a guiding light, facilitating informed decision-making and fostering a conducive environment for the seamless integration of BESS assets into our country's electricity network. It is our firm belief that this report will not only provide valuable insights but also inspire a collective commitment to embrace innovative energy storage solutions, thereby steering India toward a sustainable and resilient energy future.

We extend our heartfelt appreciation to RMI and GEAPP teams for their incredible efforts in bringing out this report as a knowledge resource for all the power sector stakeholders not only in India, but the global south. BESS is a global priority for GEAPP and RMI as part of the Global Utility Innovation Coalition. We are working closely with Discoms, state regulators and the project developers to enable first wave of grid-connected BESS projects in India. We are optimistic that our concerted efforts will pave the way for Indian to meet its energy transition targets, enable a sustainable and prosperous energy landscape for India and create a roadmap for energy transitions globally.

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Executive Summary

India's power system is shifting to a new phase as universal electricity access is achieved, economic growth continues to drive electricity demand, and over 125 gigawatts (GW) of renewable energy resources have been deployed.[1] The Union Budget for fiscal year 2023–24 recognised the need for major investments in the power system to achieve a reliable, resilient and flexible grid.

The budget highlighted energy storage as a critical piece, with the Government of India announcing the intent to provide viability gap funding for 4 gigawatt-hours (GWh) of battery energy storage systems (BESS).

Building out sufficient energy storage will be essential for India's grid to successfully integrate increasing generation from renewable resources and to meet future load demands. To maintain a reliable and economic power grid, the Central Electricity Authority projects that India will require over 60 GW of energy storage by 2030, with 42 GW (208 GWh) of BESS capacity to meet grid needs for integrating 392 GW of variable renewable energy. The ability to site and size BESS assets according to grid needs allows these resources a high degree of flexibility, providing services across multiple points of the grid. BESS can be coupled at each stage of the electricity system, including with generators, in transmission and distribution networks, and behind the meter for consumers.

This report explores the market opportunity for front-of-meter BESS within India, with an emphasis on the power distribution sector and distribution companies (Discoms). Discoms are responsible for the procurement of conventional and renewable energy and for maintaining an efficient, economic and reliable distribution network. To ensure rapid deployment of battery storage to meet system needs as costs decline, it is essential that Discoms are informed of BESS value and have strategies to effectively procure and utilise storage technologies. Siting BESS assets at the distribution level allows for added system services that are not available when assets are sited further upstream at points of generation or transmission.

There is a unique place for distribution-located storage (DLS) to contribute to the duties of Discoms, such as maintaining a cost-effective distribution network and improving service to end users. DLS can provide benefits in terms of distribution system capacity deferral at the substation level, particularly in dense urban areas experiencing peak load increases where there is limited space to expand the physical footprint of the distribution system. DLS can also meet Discoms' portfolio needs by providing resource adequacy value and minimising Deviation Settlement Mechanism penalties and voltage support. BESS can meet grid balancing needs by participating in wholesale markets such as energy arbitrage and ancillary services.

At present, many of these value streams are not fully monetisable. While the long-term value propositions could be favourable to a Discom investing in DLS (as compared with other alternatives that may increase overall system costs), the inability to accurately assess future revenue streams is inhibiting project approval. Furthermore, insufficient institutional knowledge of how to assess BESS projects is slowing down state electricity regulatory commissions (SERCs) in approving DLS proposals.

There are several factors that could guide a state and its Discoms in early adoption of DLS assets, even though value streams for DLS have yet to become fully monetisable. These factors include increasing load peakiness, renewables balancing needs and local reliability challenges. States with increasing load peakiness are good candidates for DLS assets, as DLS can be leveraged through peak shaving for deferring distribution system capital expense (capex) investments and reducing costs of power purchases to meet peak demand. DLS assets increase overall utilisation of the distribution system by increasing the system load factor, reducing overall power delivery costs.

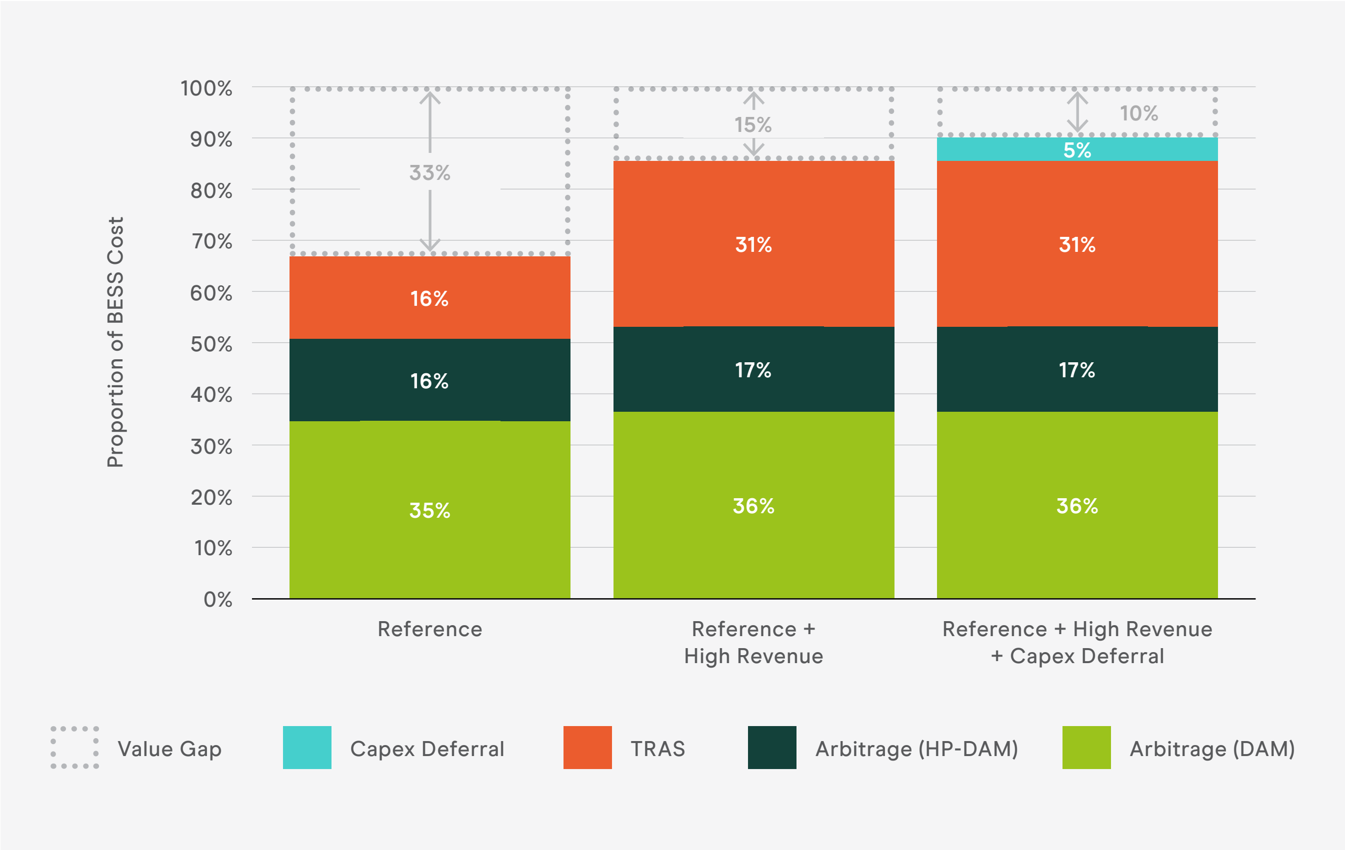
India's power system remains vulnerable to unplanned power outages and system reliability challenges. Within distribution networks, transformers and other pieces of electricity distribution equipment are failing closer to customer loads. DLS assets colocated at the distribution substation or other location closer to the customer distribution network (e.g., pole-top DLS) can promote overall reliability.

Though BESS can provide a range of beneficial services for Discoms, uncertainty around quantifying value streams has hindered project planning and deployment. This report explores the economics of an illustrative 10 MW (20 MWh) BESS project to evaluate the economic sensitivity to changes of different key value streams.

Distribution network benefits enabled by a BESS asset will need to be stacked with monetisable opportunities in wholesale markets to improve a project's economic viability. Wholesale markets currently accessible to BESS in India include the tertiary reserve ancillary service (TRAS), and arbitrage in both the day-ahead market (DAM) and the high-price day-ahead market (HP-DAM). In the reference case, an economic value gap of over 30% of project cost persists, but project economic viability improves as additional values are stacked, as shown in Exhibit 1 (see next page).

Even though energy market participation and ancillary services value streams are not the highest priorities for a Discom considering investment in a BESS asset, these currently available value streams are critical to making a project economically viable, enabling early pilots and providing a conducive environment for Discoms learning to incorporate BESS assets into their portfolios. Improvements to distribution network performance, such as avoided Deviation Settlement Mechanism penalties, are the primary benefit for Discoms, but process uncertainties and lack of price data create challenges for quantifying benefits. Capacity payments from resource adequacy are also anticipated, but implementation of the resource adequacy framework is still in the early stages. As these value streams are established in the medium term, they will bridge the project economic viability gap and make BESS assets more suitable for Discoms' portfolios.

Exhibit 1 Current Economic Value Gap and Levers to Reduce It for Illustrative 10 MW (20 MWh) BESS



BESS capital costs remain comparatively high in India, with additional costs associated with import duties. Over time, BESS capex costs are expected to decrease globally as battery and inverter prices decline, and the establishment of domestic manufacturing capacity as promoted by the production-linked incentive scheme will further reduce costs in India. However, in the short term, policy interventions like viability gap funding (VGF) are required to lower capex costs and close the economic viability gap.

Both primary and supplementary value streams for Discom BESS projects face large process uncertainties and lack of price data. These value streams include distribution network benefits like capex deferral, voltage support, deviation mechanism settlement penalty avoidance as well as secondary reserve ancillary services (SRAS) participation and possible capacity payments through implementation of the resource adequacy framework. As these value streams are established in the medium and long term, our analysis indicates they will bridge the project economic viability gap.

The Government of India has taken several policy steps laying the groundwork for an enabling environment for energy storage. These policies have included defining energy storage systems, extending key renewable energy generator benefits to energy storage assets, subsidies, market development and procurement targets. The National Framework for Promoting Energy Storage Systems released by the Ministry of Power (MoP) in August 2023 details these policies and is a step towards creating a comprehensive national roadmap for accelerating storage development in the coming years.

Establishing the full value streams for BESS will require India's power system stakeholders to operationalise the national framework — shifting from national guidelines to accelerated adoption, planning and integration of BESS projects across the power system. This report outlines a series of recommended actions to be taken in both the near term (next one to two years) and medium term (next two to five years) to improve the BESS ecosystem in India through national policy, state-level readiness and further development of markets. These recommended actions include:

National-Level Activities

Near-Term Recommended Actions

- **Clarifying VGF off-taker eligibility:** The VGF scheme, providing up to 40% capital cost subsidies for 4 GWh of BESS, will be critical for early offtake of BESS projects. However, it is currently unclear whether the targeted VGF subsidy of BESS projects will be accessible to all Discoms, or if privately held Discoms will be ineligible.

- **Temporarily reducing import duties on BESS hardware:** High upfront costs limit the economic competitiveness of BESS. While India's domestic battery manufacturing capacity grows to meet local demand, import duties imposed on hardware for BESS projects (including battery packs and inverters) should be temporarily reduced.

- **Undertaking gap analysis to evaluate the need for and impact of BESS pilots:** The value of a BESS asset will vary based on geography, point of connection and the portfolio mix and load profile of the Discom or other off-taker. Ministry of Power should work with local entities such as Discoms and State Load Dispatch Centres (SLDCs) to perform a gap analysis to identify and prioritise which projects can provide the highest-value learnings to further understanding of how BESS can maximise system performance and capacity utilisation.

- **Providing additional resource adequacy (RA) framework implementation clarity:** This includes insight for Discoms on RA implementation and enforcement, as well as strategies for least-cost RA planning. Institutional knowledge-building for Discom and SERC staff should be initiated to create internal capabilities to plan, evaluate and execute RA assessments. BESS assets should also be explicitly recognised as being able to serve as a capacity resource under the RA framework. The RA value could be a key enabler for closing the BESS project viability gap. The guidelines on the RA framework released by MoP in June 2023 are a starting point.

- **Cataloguing distributed BESS projects:** An initiative should be undertaken by CEA to identify and understand the volume, applications and dispatch profiles of existing and planned distributed BESS resources.

Medium-Term Recommended Actions

- **Creating competitive bidding guidelines (CBG) for Discom procurement of BESS:** Development of CBG for BESS can provide standardisation and uniformity in the processes and a risk-sharing framework between stakeholders. This CBG for Discom procurement of BESS should be distinct from guidelines for procurement of pumped hydro storage or other energy storage systems, and the CBG should inform the creation of a standard bidding document.

- **Aligning capacity and network planning:** As the RA framework is implemented, a process should be developed to align local capacity and national and regional grid network planning. Concurrently, a transparent tariff and its implications on system planning should be considered.

- **Establishing a centralised BESS knowledge hub:** A publicly accessible means to compile findings from BESS pilots across the power system should be created to allow for learnings and best practices to be shared with all stakeholders.

- **Creating national safety guidance for BESS:** Safety requirements and risk identification should be undertaken for transportation, installation, operation and decommissioning of BESS assets, with applicable international standards adopted and applied.

- **Developing a framework to enable distributed BESS to aggregate:** Distributed BESS resources can provide additional system flexibility when proper parameters are established. A framework can outline how distributed assets can aggregate, and it can establish minimum standards for participation to meet grid and distribution needs. Grid and distribution services could include providing ancillary services through the power exchanges or contracting with Discoms to improve demand response programmes.

State-Level Readiness

Near-Term Recommended Actions

- **Developing institutional knowledge- and capability-building programmes for state-level entities:** State Energy Regulatory Commissions (SERCs), State Load Dispatch Centres (SLDCs) and Discoms will require additional training and support to close knowledge gaps around BESS project planning, grid services, operation and contributions to resource adequacy. Resource adequacy planning and the role BESS plays should be aligned with SERCs' regulatory evaluation process. State-level entities should be aware of the capability of BESS to provide not just energy, but capacity and non-wire alternative services.

- **Achieving uniform technological readiness across all state-level entities:** Governance mechanisms should be adopted by Discoms and other stakeholders to provide the accurate status of current communications systems, and a scheme should be developed to modernise all communications systems.

- **Developing standardised data disclosure forms and mandating data reporting in regulations:** State-level data on load profiles, generation, deployment and substation and feeder performance will be critical for project planning and finding critical metrics such as value of lost load and curtailment frequency.

Medium-Term Recommended Actions

- **Deploying software interventions enabling optimal operation of BESS:** Once legacy communications systems are identified, upgraded and automated, a roadmap should be created to prepare for the integration of software to improve system intelligence. This will require revised grid modernisation programmes and studies of area control errors and frequency deviations.

- **Creating a publicly accessible data repository to collect and archive state-level data:** Once standardised reporting forms are developed and reporting is mandated, a central repository should be created where data reported by state-level entities will be readily accessible.

Market Development

Near-Term Recommended Actions

- **Shifting ancillary services procurement to market mechanisms:** Of the three ancillary services products procured, only TRAS is met through a market mechanism. Both secondary reserve ancillary services (SRAS) and primary reserve ancillary services (PRAS) should be exchanged on the market, and BESS should be enabled to compete for all categories.

- **Publicly reporting clearing prices for all market products and other ancillary services:** Publicly available data on clearing prices will provide market signals to project planners and developers on an asset's economic viability and will enable discovery of the marginal cost for meeting peak power and ancillary services.

- **Revisiting commitment charges:** Resources participating in ancillary services markets receive a commitment charge for the hours that they are cleared to supply/withdraw energy, regardless of whether energy is dispatched. Raising the cap on commitment charges will incentivise participation in ancillary markets, as BESS can get more value from being available to provide ancillary services for many hours of the day.

Medium-Term Recommended Actions

- **Introducing additional market products:** Services such as fast frequency response, voltage support, black start, long-duration arbitrage and capacity can be economically provided through market products and can aid in both immediate and longer-term project planning.

- **Assessing penalties for load shedding:** Some buyers are reluctant to participate in the power exchanges, especially during periods of higher prices, preferring to shed load instead. Penalties should be imposed to disincentivise behaviour that harms power reliability.

Through implementation of these recommendations, BESS assets in India will have greater access to markets that enable them to provide full value to the power system while being part of a holistic and economic planning process for the power sector and Discoms. As India shifts from improving electricity access to improving quality of electricity service and reliability, new regulatory frameworks and business models need to be developed and implemented to support these needs. Discoms have a unique opportunity to play a role in integrating BESS into their portfolios. These actions are the next steps in improving the conditions for deploying innovative technology solutions that will help India become a global leader, successfully integrate renewables with growing demand and provide a model of energy transition to the world.

1.0 **Introduction**

Energy storage was a critical piece of the Union Budget for fiscal year (FY) 2023–24, announced in February 2023. The budget provided ₹35,000 crore (approximately US$4.2 billion) of capital investment towards the energy transition, including the intent for viability gap funding (VGF) for battery energy storage systems (BESS).[2]

The Union Cabinet announcement in September 2023 approved ₹3,760 crore (approximately US$460 million) in VGF for BESS, supporting the development of 4 GWh of BESS projects with financial support of up to 40% of the capital cost.[3] The announcement of VGF for battery storage is a critical policy piece that recognises the significant role BESS will play for India, and it signals the intent to engage with stakeholders across the power system to both achieve India's ambitious national targets and maintain a rapidly evolving electricity system that underpins economic growth.

India has made commitments through its nationally determined contribution (NDC) that include achieving 50% of cumulative electric power installed capacity from nonfossil resources and reducing the emissions intensity of the gross domestic product (GDP) 45% by 2030.[4] The past decade has seen impressive growth within India's power sector, including reaching universal electricity access.[5] The national commitments will continue this growth and provide critical milestones on the path to the declared goal of net zero by 2070.

Universal electricity access and economic growth, among other factors, continue to drive electricity demand in India. Energy needs are projected to reach nearly 2,474 terawatt-hours (TWh) by FY 2031–32, an increase of more than 79% in 10 years. Peak demand is anticipated to grow at a similar pace, exceeding 366 GW in FY 2031–32.[6] Meeting projected demand growth while also achieving the NDCs will require a reliable, stable and flexible power system. Integrating the necessary volumes of variable wind and solar generation will require the ability to ensure resource adequacy, network adequacy, frequency stability and voltage stability across the system.[7]

Energy storage will be critical to supporting the transition, as recognised in the Union Budget. India has already taken steps to establish itself as a global leader in an innovative technology, such as jump-starting a domestic battery manufacturing sector through the production-linked incentive (PLI) for advanced chemistry cell batteries announced in March 2022.[8] Approximately 2 GW of grid storage tenders were announced between 2020 and 2022, with bids requested for both stand-alone storage and colocated storage and renewable resources.[9] These tenders show an early interest in a growing energy storage market. However, storage deployment must significantly accelerate to meet grid needs and help integrate renewables into the electricity system.

This report explores the market opportunity for front-of-meter BESS within India, with an emphasis on the power distribution sector and equipping Discoms with applicable information on BESS value streams and procurement best practices. The report also shares broader policies and recommendations shaping BESS deployment, as they influence adoption of BESS at all levels of interconnection (generation, transmission and distribution). To ensure rapid deployment of battery storage to meet system needs as costs decline, it is essential that Discoms have strategies to effectively procure and utilise storage technologies. The report is organised as follows:

- **Section 2** provides a pan-India and state-level assessment of BESS needs and highlights the national framework of energy storage policies established to accelerate BESS. These policies include efforts to define energy storage, provide subsidies, develop markets and drive procurement.

- **Section 3** discusses the persistent challenges facing India's power distribution sector and identifies the range of services BESS can provide to improve quality of distribution. BESS services for distribution include addressing growing demand peakiness,[i] providing balancing services for portfolios with high variable generation, improving system reliability and deferring capital expenses.

- **Section 4** quantifies key value streams for an example distribution-located BESS asset, calculates the existing economic viability gap and discusses levers to close the project economic viability gap over time.

- **Section 5** addresses the preparatory steps Discoms can take to plan a BESS project within the distribution network.

- **Section 6** outlines the pathway forward for BESS in India. The next steps require operationalising the National Storage Policy Framework — shifting from national guidelines to accelerated adoption, planning and integration of BESS projects across the power system.

i. In this report, peakiness is defined as the ratio of annual peak demand to annual generation at the state level.

2.0 Assessing Battery Energy Storage to Meet Grid Needs Across India

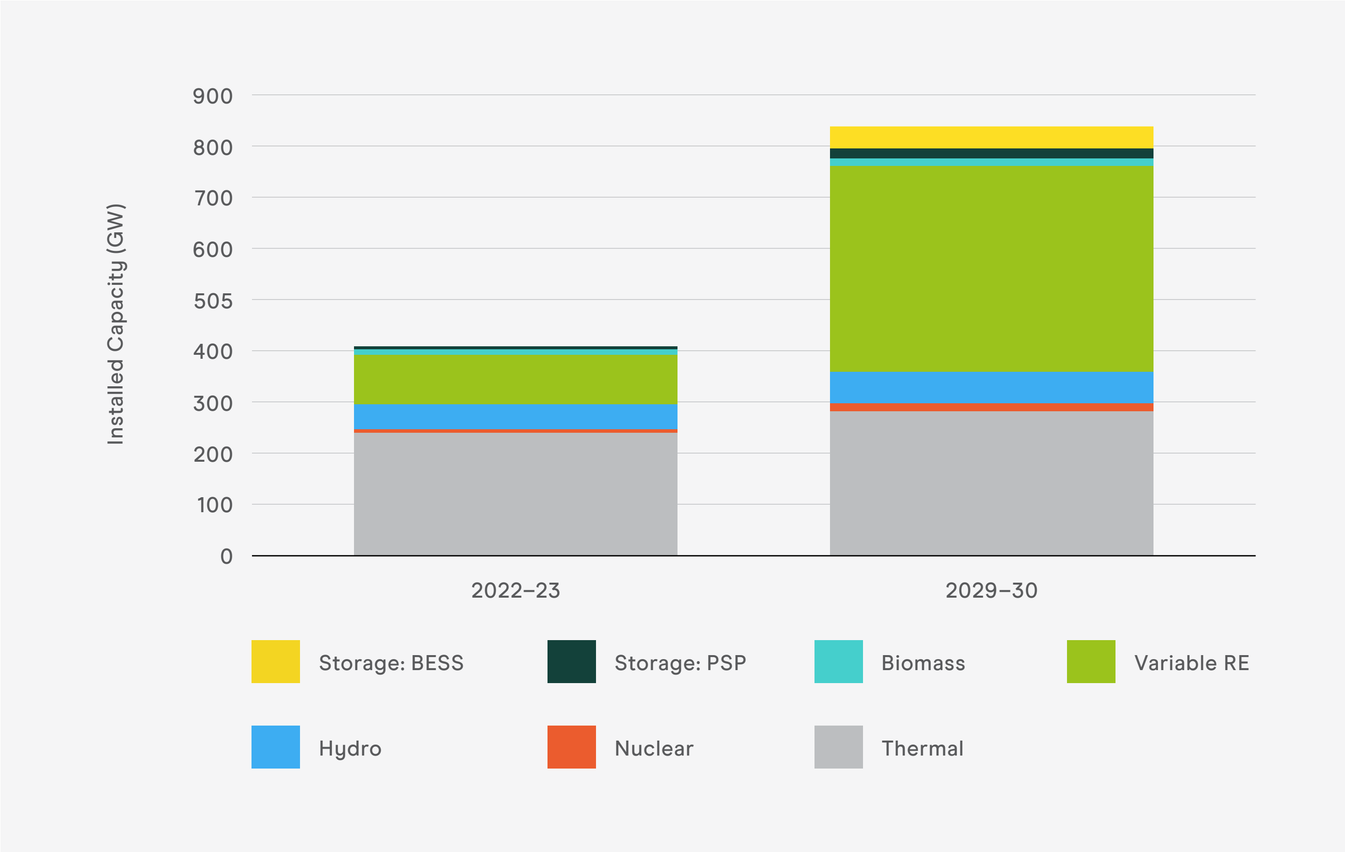
Building out sufficient energy storage will be essential for India's grid to successfully integrate increasing generation from renewable resources and to meet future load demands. To maintain a reliable and economic power grid, the Central Electricity Authority (CEA) projects that India's optimal mix will require over 60 GW of grid energy storage capacity by 2030.

CEA's optimal mix projection encompasses multiple technologies, including pumped hydro storage projects (PSP) and BESS as two leading storage technologies for the Indian grid by 2030 (see Exhibit 2 on the following page).[10]

PSP and BESS technologies complement each other in enhancing grid reliability and performance. The selection of the appropriate energy storage technology depends on factors such as the use case, required discharge duration, physical site and size constraints, risk associated with extreme weather events, deployment time frame and the competitiveness of both power and energy capacity costs.[11,ii] Declining costs globally and flexible project planning, sizing and application have made BESS technologies an increasingly significant contributor to power systems seeking to integrate high volumes of variable renewable energy (VRE) generation, as well as other distributed energy resources. Projections within India estimate that installed capacities of 19 GW (128 GWh) of PSP and approximately 42 GW (208 GWh) of BESS will be required to integrate 392 GW of VRE (100 GW of wind and 292 GW of solar) by 2030.

ii. Power capacity cost is defined as rupee per installed megawatt (₹/MW); energy capacity cost is defined as rupee per megawatt-hour generated (₹/MWh).

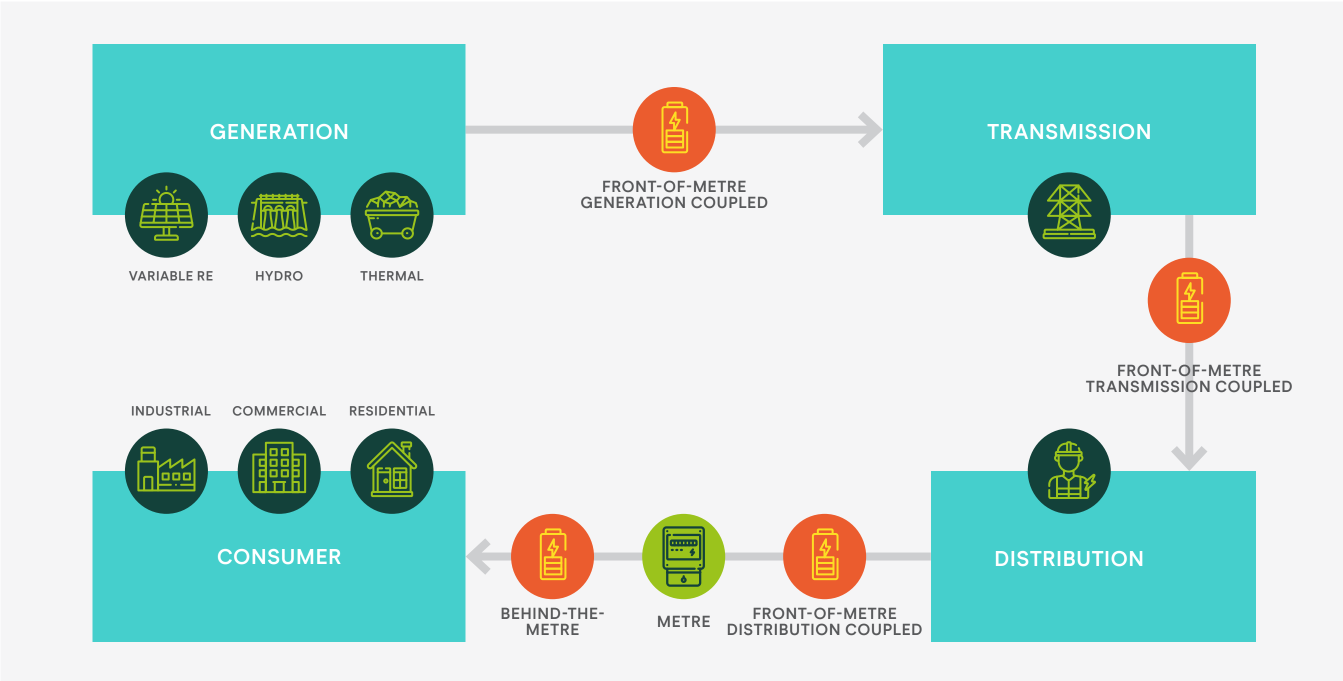
Exhibit 2 Installed Capacity Projected by FY 2029–30



Note: Projections based on CEA's Base Scenario from the Report on Optimal Generation Mix 2030. It finds the optimal generation capacity mix to meet the projected regional peak electricity demand and electrical energy requirements, considering possible technology options, intermittency associated with VRE sources and constraints (fuel availability, technical operational constraints, financial considerations, etc.). For additional detailed system capacity projections across 2030 studies, see Appendix I. | **Source:** CEA

The ability to site and size BESS assets according to need allows these resources a high degree of flexibility, providing services across multiple points of the grid. BESS can be coupled at each stage of the electricity system, including with generators, with transmission and distribution networks and behind the meter for consumers (see Exhibit 3).[12] Each of these applications can provide unique value to the coupled entity, while also providing benefits to the entire system and transmission and distribution utilities. The value of these applications will vary depending on the nature of local generation mix, load, infrastructure and load profile, among other factors. For example, distribution system upgrade needs are driven by peak demand events that occur during a few predictable events each year. Distribution deferral will be greater in areas with anticipated rapid growth of peak demand and an older distribution network. Combined, these applications demonstrate how BESS will be an important component of improving India's grid security, reliability and cost-efficacy.

Exhibit 3 BESS Applications and Services across the Electricity System



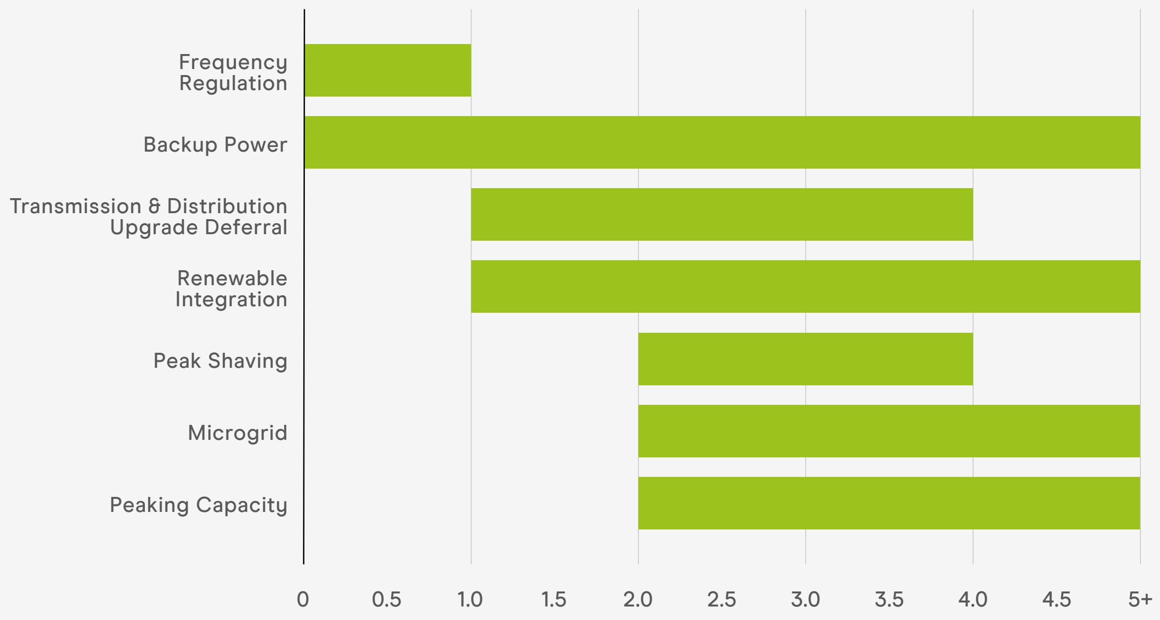
	TRANSMISSION	DISTRIBUTION	BEHIND-THE-METER
System Services	**Energy Arbitrage:** Purchase of wholesale electricity while price is low and sale when price is highest. India has power exchange markets, clearing energy purchases under the day-ahead market (DAM), high-price day-ahead market (HP-DAM) and real-time markets (RTM).		
	Ancillary Service — Spin/Non-Spin Reserve: Generation available to serve load in response to contingency events. This is similar to the Tertiary Reserve Ancillary Service (TRAS) introduced by the Central Electricity Regulatory Commission (CERC) 2022 Ancillary Services regulation.		
	Ancillary Service — Frequency Regulation: Immediate and automatic response to a change in locally sensed system frequency, required to ensure that system-wide generation is perfectly matched with system-level load on a moment-by-moment basis to avoid grid instability. This is similar to the Secondary Reserve Ancillary Service (SRAS) introduced by the CERC 2022 Ancillary Services regulation.		
	Ancillary Service — Voltage Support: Ensures reliable and continuous electricity flow across the power grid to keep transmission and distribution system voltage within acceptable range and match both real and reactive power production with demand.		
	Ancillary Service — Black Start: Required in the event of a grid outage to restore operation to larger power stations and bring the regional grid back on line.		

	TRANSMISSION	DISTRIBUTION	BEHIND-THE-METER
Utility Services	**Resource Adequacy (RA):** A planning exercise to ensure adequate investments in generation and storage to reliably meet 24/7 demand. The RA framework in India is still in early stages of development. Many international markets provide capacity payments ($/kilowatt (kW)-month or $/kW-year) to meet RA compliance.		
	Schedule Compliance: Minimising the risk of deviation from a submitted schedule and associated penalties from the Deviation Settlement Mechanism (DSM).		
	Transmission Congestion Relief: Assets used to avoid utilising congested transmission corridors, such as a battery asset downstream that is discharged during high-congestion periods.		
	Transmission Deferral: Delaying, reducing the size of or avoiding investments in transmission system upgrades.		
		Distribution Deferral: Delaying, reducing the size of or avoiding distribution network upgrades to meet projected load growth in a specific area.	
Consumer Services			**Backup Power:** In the event of grid failure, backup power ranges from second-to-second power quality maintenance for industrial operations or daily backup for residential consumers.
			Bill Management: Reducing fixed demand or capacity charges. Minimising purchases during periods with high electricity rates and shifting purchases to periods with lower rates (time-of-use rates).
			Increased Captive VRE Consumption: Minimising export of electricity generated by captive systems to maximise financial benefit of variable local systems.

Note: This report focuses on downstream applications of BESS, emphasising system and utility benefits of distribution-located battery storage. Applications and benefits of generator-sited BESS have not been included. "Utility Services" in this report refers to services provided to both Discoms and Transmission Companies (Transcos). | **Source:** Adapted from Garrett Fitzgerald et al., The Economics of Battery Energy Storage, RMI, 2015, **https://rmi.org/insight/economics-battery-energy-storage/**

As the energy storage market within India matures, the storage discharge duration needed will begin to shift. Discharge duration is the ratio of energy discharge to power capacity. Shorter-duration BESS is well suited to providing grid services such as reserves, frequency regulation and voltage support. Many international markets allow battery projects to provide primary reserves or other fast-responding ancillary services products due to near-instantaneous response times. These initial high-value products are generally met through shorter-duration battery assets, sometimes discharging for only seconds or minutes. As the initial ancillary services markets become saturated through battery responses, longer-duration assets will be required to economically provide other services, such as energy arbitrage (see Exhibit 4).[13]

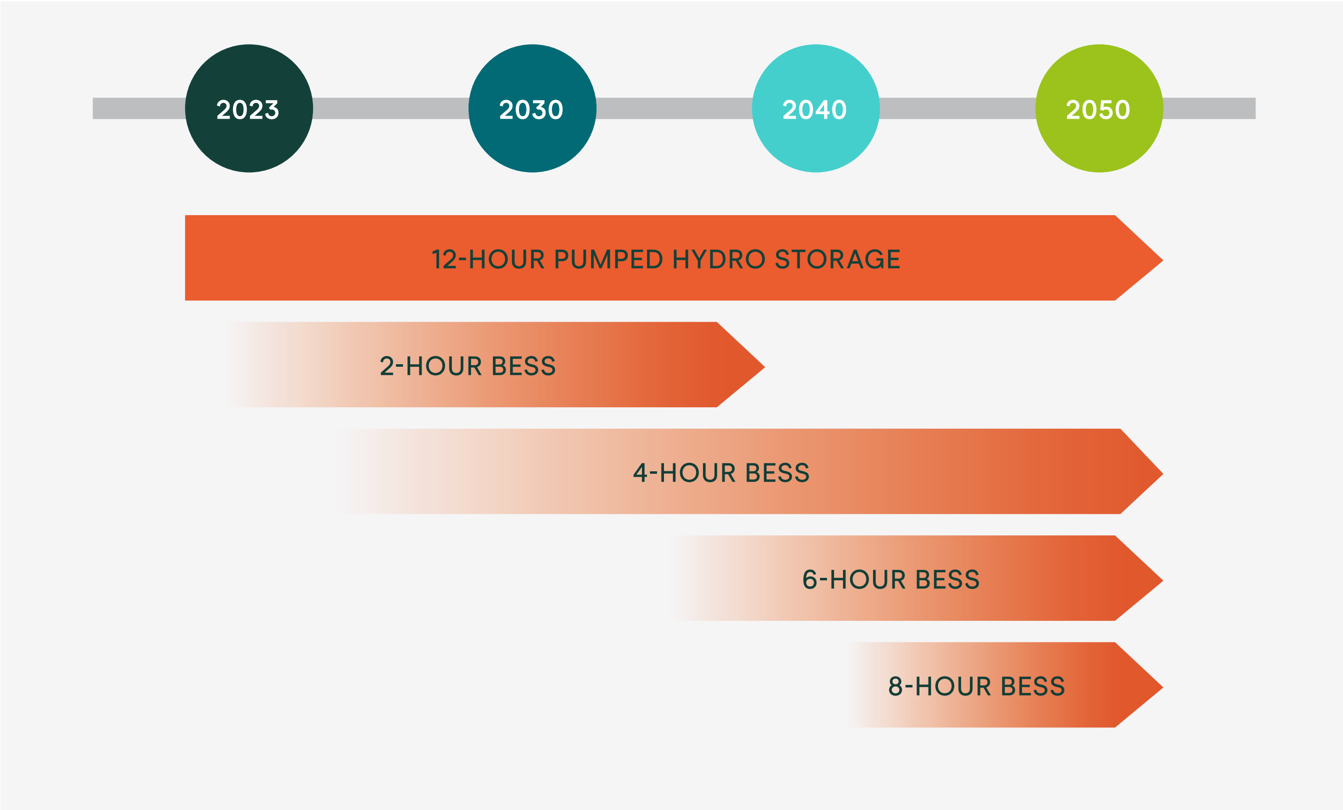
Exhibit 4 Stackable Value Streams for BESS Projects



Source: Asia Development Bank

BESS duration needs in India are projected to follow similar trends as seen in international markets (see Exhibit 5). Ensuring an enabling environment that rewards the deployment of longer-duration BESS will be critical for creating an economically efficient power system, especially as markets for short-duration assets reach saturation.

Exhibit 5 Timeline of Projected Storage Duration Needs in India



Source: Ilya Chernyakhovskiy et al., Energy Storage in South Asia: Understanding the Role of Grid-Connected Energy Storage in South Asia's Power Sector Transformation, National Renewable Energy Laboratory, July 2021, **https://www.nrel.gov/docs/fy21osti/79915.pdf**

2.1 Status of Existing Policies and Incentives for Battery Storage

The Government of India (GoI) has taken several impactful policy steps laying the groundwork for an enabling environment for energy storage. These policies have included defining energy storage systems (ESS), extending key renewable energy generator benefits to ESS assets, subsidies, market development and procurement targets (Exhibit 6 on the next page). The National Framework for Promoting Energy Storage Systems, released by the MoP in August 2023, details these policies and represents a step towards creating a comprehensive national roadmap for accelerating storage development in the coming years.[14] The high-level policy framework is important for signalling sector readiness for storage, but further actions will be necessary to operationalise and accelerate deployment.

Exhibit 6 Timeline of BESS Policies

2019

FEB 2019
Inclusion of ESS in Technical Standards for Connectivity to the Grid

2021

JUN 2021
Secondary Reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS) products notified

NOV 2021
Waiver of Inter State Transmission Charges on ESS commissioned through June 2025

2022

MAR 2022
Production Linked Incentive Scheme Awardees announced

MAR 2022
Guidelines for BESS procurement announced

JUN 2022
Energy Storage Obligations notified

AUG 2022
SECI 500 MW stand-alone BESS tender awarded

SEP 2022
Resource Adequacy Framework announced

OCT 2022
Storage Systems recognised as essential hardware

DEC 2022
Energy Storage Systems defined in Electricity (Amendment), 2022

2023

MAR 2023
High Price Day Ahead Market (HP-DAM) launched

JUN 2023
TRAS launched

AUG 2023
National Framework Promoting ESS released

SEP 2023
Viability Gap Funding for 4 GWh BESS announced

Source: MoP

Defining Energy Storage

Some important policy steps have defined the role of energy storage. The Electricity (Amendment) Rules of 2022 granted legal status to ESS, making storage a delicensed activity similar to generators, but requiring independent ESS owners to register with CEA.[15] The Department of Economic Affairs included ESS in the Harmonised Master List of Infrastructure Subsectors, which guides agencies responsible for supporting infrastructure.[16]

The GoI has implemented policy concessions for energy storage similar to those that successfully initiated deployment of innovative renewable generation technology. These policies include waiving of interstate transmission system charges for battery systems commissioned through June 2025 (under stated conditions). Transmission charges for the interstate transmission network will then gradually increase for ESS projects commissioned through June 2028. GoI has also provided critical guidelines for procurement of ESS, which seek to ensure transparency and fairness in the procurement process to promote competition and improve project bankability.[17]

Subsidies

Battery production subsidies: Though BESS costs have seen rapid declines globally over the past decade, current materials costs and reliance on imports result in persistently high capital costs for BESS projects and high import duties. To date, the GoI has undertaken two critical schemes to address BESS costs: the production-linked incentive (PLI) scheme and viability gap funding (VGF). The PLI scheme for advanced chemistry cell batteries provided ₹18,100 crore (approximately US$2.5 billion) to establish a domestic battery manufacturing sector. The scheme, launched in 2021, secured bids from 10 companies totalling 128 GWh of capacity, which was 2.6 times the targeted tender. Winning bids were announced in March 2022.[18]

Capital subsidies in the form of VGF: Details of the Viability Gap Funding for Development of Battery Energy Storage Systems Scheme (VGF Scheme), announced in the Union Budget for FY 2023–24, were provided in September 2023. The VGF Scheme will provide funding for 4 GWh of BESS projects to be developed by FY 2030–32, with an initial outlay of ₹9,400 crore (approximately US$1.13 billion). The VGF Scheme targets achieving a levelised cost of storage (LCOS) of ₹5.50–6.60 per kilowatt hour (kWh) and requires that a minimum of 85% of the project capacity be made available to Discoms. Awardees will be chosen through a competitive bidding mechanism, and funding will be disbursed in five tranches.[19,iii]

iii. LCOS refers to the total lifetime cost of the storage investment divided by its cumulative delivered electricity. It is used to compare the cost-effectiveness and commercial potential of storage technologies.

Market Development

While BESS assets can provide a wide range of services and value to the system, maximising the potential of a BESS asset requires markets to enable monetisation of these services. Mature markets with a range of products to meet system needs, both short- and long-term, can create valuable avenues for BESS participation. Indian markets are evolving fast, with the recent implementation of market-based ancillary services to create a short-term market for BESS and progress on the RA framework guidelines to provide long-term signals. However, these short-term and long-term market initiatives are yet to reach their full maturity and achieve a streamlined implementation.

Ancillary services: The Central Electricity Regulatory Commission announced the creation of three ancillary services products in January 2022: primary reserve ancillary services (PRAS), secondary reserve ancillary services (SRAS) and tertiary reserve ancillary services (TRAS).[20] These products are intended to replace the singular reserve product previously procured. Ancillary services provide the grid with stability, such as addressing deviations from frequency or contingency events that misalign demand and supply. The three ancillary services products vary in response time, required duration and minimum capacity.

- PRAS is the ancillary service that immediately comes into service in the event of a sudden change in frequency. It is procured through governor action of the generator or other system stakeholder (similar to fast frequency response in other international markets). BESS are well suited to provide PRAS given their instantaneous response. However, batteries cannot currently participate in this service.

- SRAS, which includes both SRAS-Up and SRAS-Down, is an injection or decrease of drawal or consumption that responds within 30 seconds to a control signal from the Nodal Agency, can meet the obligation for at least 30 minutes, and has a minimum response of 1 MW (similar to 'frequency up' and 'frequency down' ancillary services in other international markets). SRAS regulation currently allows administered procurement, but there is no price transparency, and SRAS market participation rules are currently unclear for BESS. The MoP plans to implement market-based procurement for SRAS within the next year according to the roadmap in the Report of the Group on Development of Electricity Market in India,[21] which should ease BESS asset participation in SRAS. SRAS has been a key contributor to early market development for BESS in many countries in Asia and globally.

- TRAS is procured through a market mechanism and must respond within 15 minutes when activated and sustain service for 60 minutes (similar to spin/non-spin ancillary services in other international markets). TRAS recently started trading on power exchange platforms in India, and BESS can currently participate in this market. However, additional data on clearing price and frequency of dispatched resources will be needed to further strengthen regulators' confidence in this revenue stream.

BESS assets are currently regulatorily permitted to provide SRAS and TRAS, enabling some monetisation of battery storage's capabilities to provide short-term system support. However, there is still no market price clarity for SRAS and TRAS, which impacts BESS revenues (further discussed in Section 4). Stakeholders anticipate that demand for these services will be high due to projected electricity demand growth rates, but there may be some seasonal variation.[22] The announcement of these products is an important step for maturing and deepening India's electricity markets. Ancillary services have been critical initial monetised services for BESS resources in international markets, even within less mature electricity markets in Asia (see Box 1).

Box 1 BESS Ancillary Services Market Participation in Asia

Taiwan's Energy Trading Platform Allows BESS to Provide Ancillary Services

The state-owned Taiwan utility Taipower established an Energy Trading Platform in July 2021 to attract private-sector participation in BESS, which features a day-ahead ancillary services market and a capacity reserve market. The primary driver for early BESS projects (public and private) was the initial Dynamic Regulation Reserve (dReg) product. BESS services are now procured through the day-ahead Automatic Frequency Control Ancillary Service and Reserve Capacity markets auctions, and Taipower settles payments on a monthly basis.

As of May 2023, 50 qualified private developers with a total participating capacity of 441.3 MW had been registered to provide frequency regulation. This market is evolving to serve longer-duration services (Enhanced Dynamic Regulation), helping to incrementally transition towards a fully functioning trading platform operated by the utility.

BESS Procurement through Energy PPAs and Ancillary Service Agreements in the Philippines

The increasing intermittency from solar and wind on the Philippines' lengthy transmission lines necessitates the use of battery storage to act as a frequency regulator. Procurement schemes for BESS include PPAs for firm energy and capacity, as well as ancillary service agreements.

The 20 MW (20 MWh) Kabankalan BESS is 100% utility-owned and provides frequency and voltage support to stabilise the grid through a bilateral ancillary service contract. It was tactically deployed on the Visayas grid, which features the largest volume of solar generation in the Philippines. The grid operator will use the BESS in automatic generation control to provide frequency regulation, voltage control and reactive power management. Through an ancillary service purchase agreement with the grid operator, the project is paid ~$46/MW per hour for reserve capacity not discharged.

Initial Use Case of Largest BESS Project in Singapore Is Only Ancillary Services

The 200 MW (285 MWh) project commissioned in December 2022 by Sembcorp Industries provides frequency response and reserve services. The BESS is registered as a market participant with a generation license. It is compensated through market payments for spinning reserve for the first two years, and primarily for frequency regulation for the remaining lifetime. There is potential for value stacking from year three onwards, and its planning considered utilisation of different value streams throughout the asset's lifetime.

Energy arbitrage: The GoI announced a high-price day-ahead market (HP-DAM) in March 2023. The current day-ahead market (DAM) and real-time market (RTM) are capped at ₹10 per kWh, which may limit the ability of high marginal cost units (such as natural gas plants) to economically participate on the exchanges. The HP-DAM is a separate market with a higher capped price of ₹20 per kWh.[23] By enabling trading above the typical price cap, the HP-DAM improves the economic opportunity of energy arbitrage for BESS assets. HP-DAM is still relatively new, and it is yet to be seen how much electricity demand clears through this market over time. Within international markets, energy arbitrage becomes increasingly valuable for BESS as ancillary services markets saturate (Box 2).

Resource adequacy (capacity value): The MoP announced the guidelines for the Resource Adequacy Planning Framework for India (RA framework) in June 2023.[24] The objective of the RA framework is to ensure Discoms tie up sufficient capacity to reliably serve expected demand in a cost-effective manner. BESS assets can play an important role in providing flexible capacity to meet the Discom and state-level RA requirements. However, the details of the RA framework's implementation are yet to be finalised, including the national and state-level planning reserve margin (a certain percentage of peak load) and capacity credits that battery resources could provide.[iv]

RA planning, and its close relationship with the capacity market, has been an essential tool for US and EU grid operators in electricity market operations. For instance, capacity payments through an RA compliance programme in California have been critical to bringing over 5 GW of BESS capacity on line in two years.[25]

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iv. Capacity credits reflect the percentage of a resource's installed capacity that can be depended on during periods of high outage risk.

Box 2 Market Enablers for Battery Assets in California

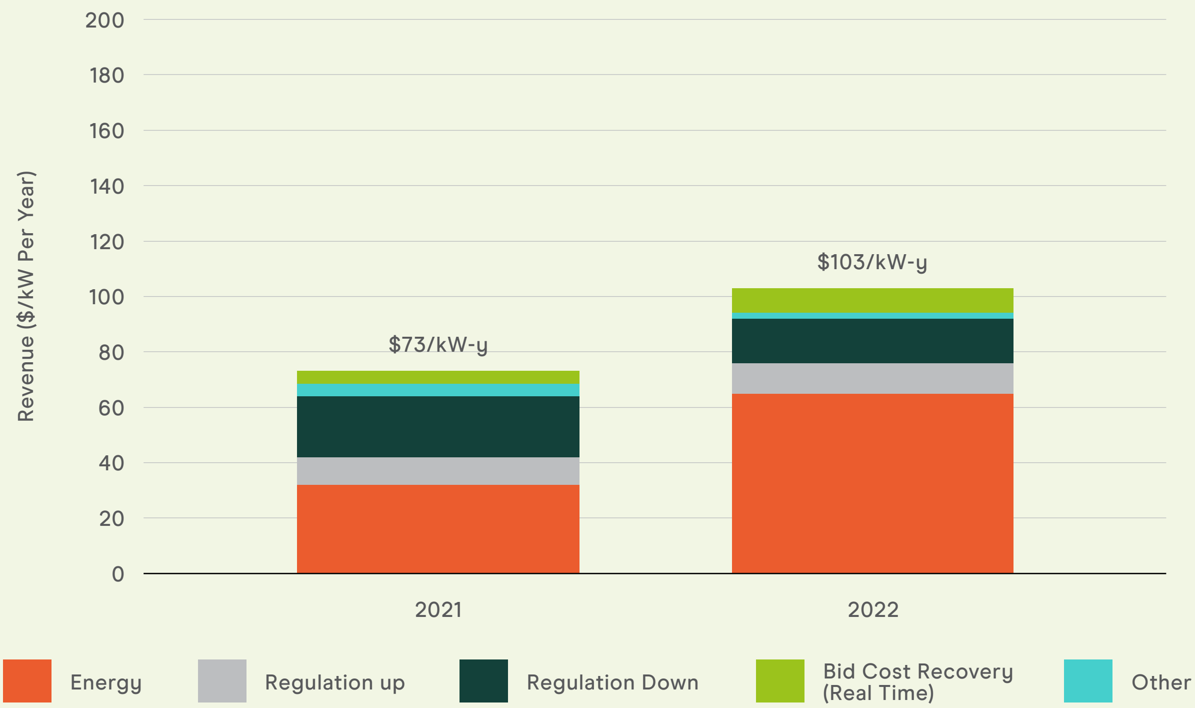
Battery Market and Resource Adequacy Participation in California

BESS is playing an increasingly important role in California's electricity markets. Battery storage capacity has grown from 500 MW in 2020 to over 5,000 MW in May 2023, equal to approximately 6% of the state's total installed capacity.[26] The California Independent System Operator (CAISO) runs day-ahead and real-time markets for energy and ancillary services markets. BESS resources are dispatched based on multi-interval optimisation by CAISO. In addition to the market participation, BESS assets are also eligible to receive capacity payments when they contract with load-serving entities (LSEs) to meet their system, local and flexibility RA requirements.

The early adoption of battery resources was initiated with maximum participation and revenue collection from ancillary services markets, principally 'frequency up' and 'frequency down' services. As BESS installed capacity increases and ancillary services markets are saturated, energy arbitrage is becoming the predominant market revenue source for batteries (Exhibit 7). Moreover, most BESS assets are simultaneously supported by RA programme capacity payments. In 2022, BESS projects participating in CAISO markets contributed 69%–95% of their available capacity towards RA depending on the month, with higher percentages in the summer months of June through August (Exhibit 8).

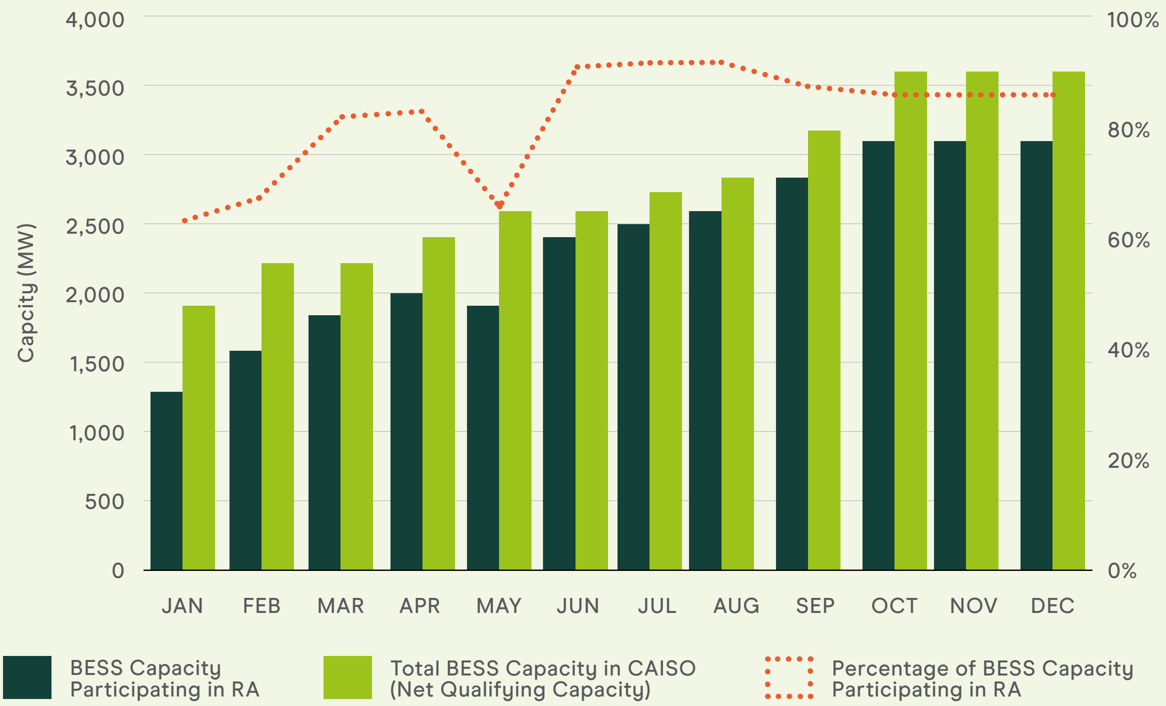
The BESS capacity in California is expected to grow to 50–80 GW by 2045, driven by the state's 100% clean energy goals, deployment mandates and improved affordability of BESS technologies.

Exhibit 7 Average Revenues for Batteries with Full Year of Operation in CAISO Market



Box 2 Market Enablers for Battery Assets in California (continued)

Exhibit 8 CAISO BESS Capacity Participating in RA Programme in 2022



Details of the currently available market value streams applicable for distribution-located BESS assets in India are discussed in Section 3.2, and market value estimates are shared in Section 4.

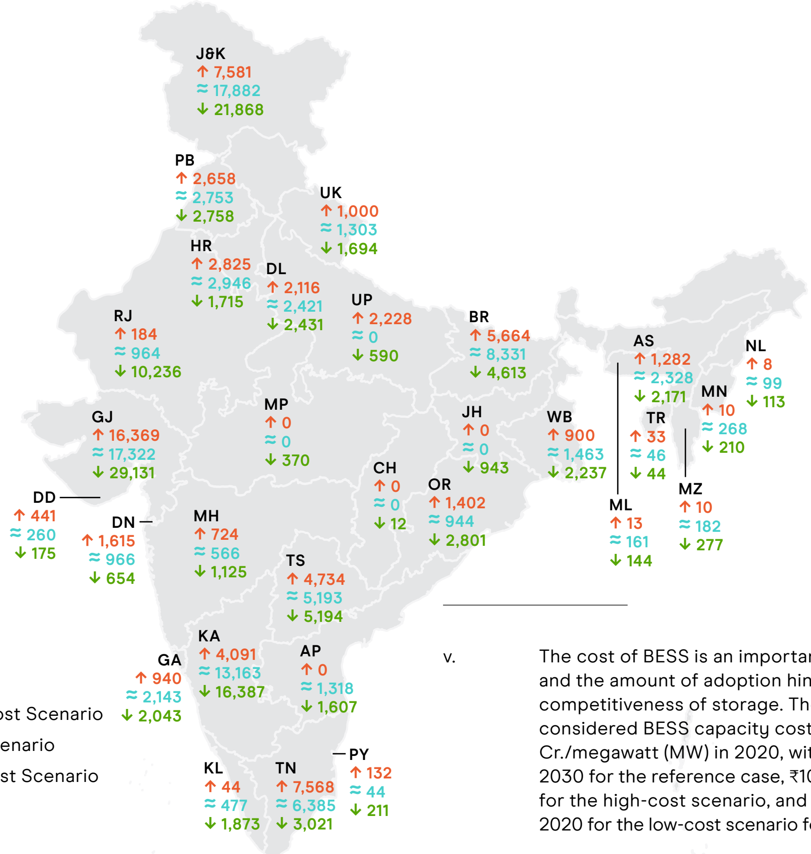
2.2 State-Level Grid Needs for Energy Storage

While the picture for pan-India storage needs is well understood, demand for storage will vary greatly across states and union territories. Generation mix, infrastructure quality, demand and peakiness growth, and geography may all impact state-level storage demands. Understanding state-level storage needs is vital for Discom resource planning. For example, Discoms contracting high levels of variable renewable generation will face high balancing needs for their resource portfolios. This section discusses projected 2030 grid storage needs at the state level.

The CEA Report on Optimal Generation Mix 2030 aggregated the assessment of new resources needed for the five regional zones and estimated 30.5 GW (152.5 GWh) of BESS needed for the northern regional grid and 11.1 GW (55.5 GWh) for the southern regional grid. However, the study stops short of providing any further breakouts at the state level. The NREL 2021 study is the only published study to date that attempts to assess state-level grid storage needs.[27] The study quantified new storage demand by 2030 for all states in India in three scenarios: reference, low BESS costs and high BESS costs (see Exhibit 9 below).[v] The top few states for grid storage deployment include Gujarat, Jammu and Kashmir, Karnataka, Bihar, Tamil Nadu and Telangana.

Overall, there is significant demand for grid storage across the country (50–80 GW), but there are only limited insights to date into how that might be translated to state-level grid storage needs. The interstate transmission build-out over time is a major factor influencing state-level grid storage development. The annual and 10-year-ahead national and Discom-level integrated resource planning (IRP) and RA analysis, to be initiated under the RA framework proposed by the MoP, could bridge this knowledge gap and provide timely investment signals for the development of state-level storage assets.

Exhibit 9 **Estimate of New Grid Storage Capacity Needed by 2030, per State and Union Territory (in MW)**



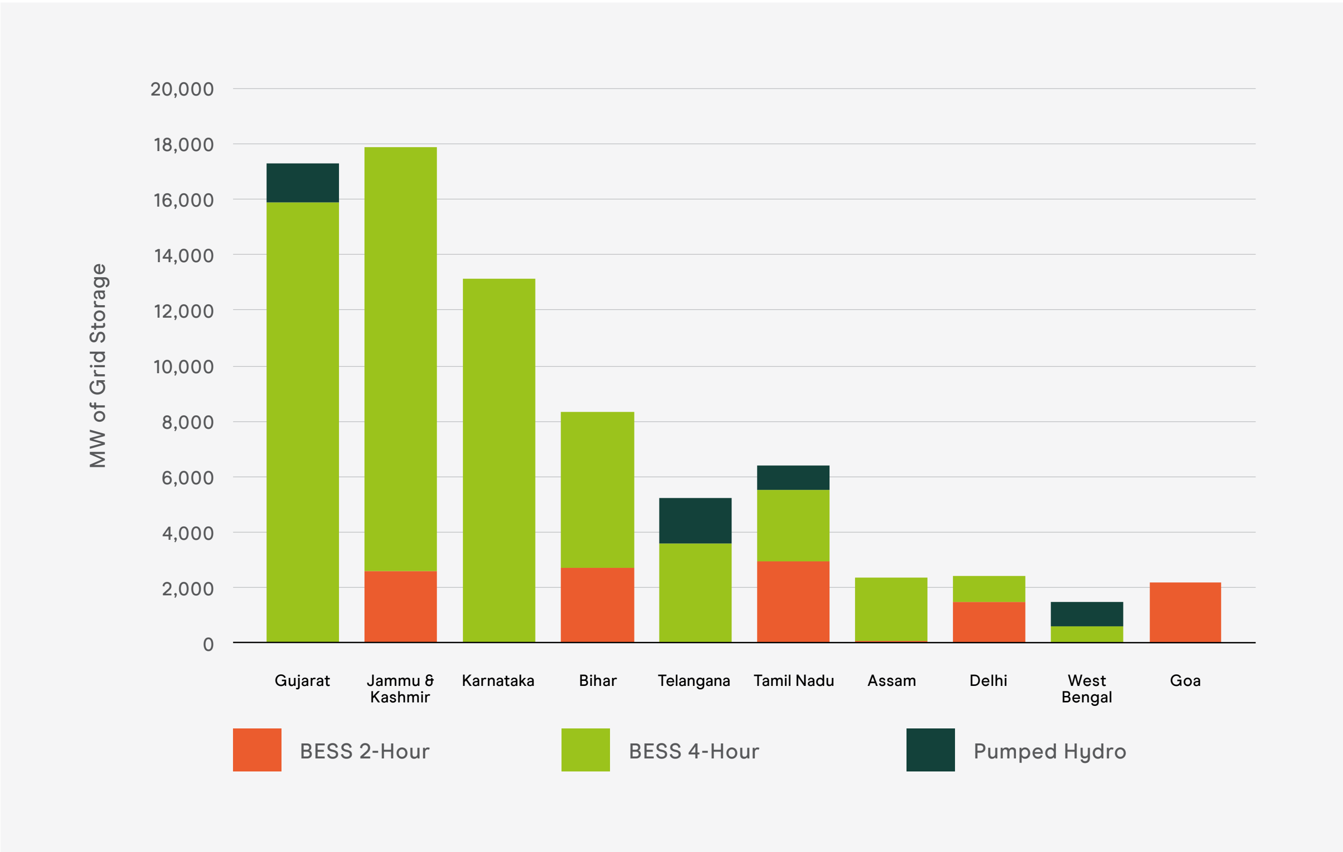
↑ High BESS Cost Scenario
≈ Reference Scenario
↓ Low BESS Cost Scenario

Source: NREL

v. The cost of BESS is an important consideration, and the amount of adoption hinges on the cost-competitiveness of storage. The study considered BESS capacity costs of about ₹8.5 Cr./megawatt (MW) in 2020, with ₹5 Cr./MW in 2030 for the reference case, ₹10 Cr./MW in 2020 for the high-cost scenario, and ₹6 Cr./MW in 2020 for the low-cost scenario for a 4-hour BESS.

NREL's 2021 study also shows the grid storage breakdown by technology type for the top 10 states. The new storage technologies assessed by the NREL study include two-hour BESS, four-hour BESS and new PSP (see Exhibit 10 below). By 2030, the majority of the installed BESS capacity is expected to be four-hour batteries, with two-hour batteries making up the remaining capacity.

Exhibit 10 New Storage Needs by 2030 by Storage Technology Type, Top 10 States



Source: NREL

3.0 Battery Storage for Distribution

Battery storage is a highly flexible resource, with a wide variety of applications across the electricity supply chain. Though there is a strong use case for applying battery storage assets at the generation and transmission levels to improve system performance and reliability, the distribution sector will be an especially critical point of application for leveraging the full value of BESS. Siting BESS assets at the distribution level also allows for added system services that are not available when assets are sited further upstream at generation or transmission points.[28]

Understanding how BESS assets can benefit the distribution network, how their performance can be optimised, the conditions that make an asset economically viable and how the existing regulatory and market frameworks can evolve to best ensure an efficient and effective electricity system will be essential to deploying and integrating the projected volumes of battery storage required to meet national goals.

While a large portion of the 42 GW (208 GWh) of pan-India BESS assets that are needed to integrate renewables by FY 2029–30 are expected to be hybrid storage colocated with renewables or stand-alone transmission-connected storage, there is a unique place for distribution-located storage (DLS). DLS assets can provide benefits of distribution system capacity deferral at the substation level, particularly in dense urban areas experiencing peak load increase where there is limited space to expand the physical footprint of the distribution system. Other distribution network benefits may include voltage support and avoiding frequency deviations. DLS assets could contribute to grid balancing needs by participating in wholesale power exchange markets such as energy arbitrage and ancillary services. Providing grid services through the wholesale markets is currently critical for making a BESS project economic, though there could be technical and regulatory considerations to fully capturing these value streams at the distribution level.

The MIT Future of Energy Storage study estimated 29 GWh of DLS potential by 2030 for distribution system capacity deferral for four megacities in India: Bengaluru, Delhi, Kolkata and Mumbai (see details in Appendix I).[29] While this study focused on megacities, many other dense cities in India with rising peak demand could be candidates for DLS, and 29 GWh is likely at the lower end of DLS needs by 2030. A growing number of system and state-level drivers are supporting investments in DLS assets, even when long-standing financial and operational performance challenges exist for many Discoms. In this section, we provide an overview of the persistent distribution sector challenges, the value streams available for DLS and the major state-level drivers favouring Discom investments in DLS. In section 4, we share illustrative results for DLS value stack, the current viability gap and the pathway forward to close the viability gap.

3.1 Challenges in the Distribution Sector

The distribution sector in India faces many challenges. Financial shortfalls resulting from systemic issues in metering, billing, collection, losses and regulatory challenges have hindered the ability of Discoms to operate effectively, including limiting their ability to make necessary investments to maintain the distribution network. Reforms passed in recent years, such as the Revamped Distribution Sector Scheme and the Late Payment Surcharge Rules 2022, have sought to address systemic challenges in the distribution sector. These policy interventions have resulted in marked improvements: aggregate technical and commercial (AT&C) losses declined to 16.5% in FY 22, a nearly 5% improvement over the preceding fiscal year. Further, the gap between average cost of supply and average realisable revenue (ACS-ARR gap) declined to 40% per unit in FY 22 from 79% per unit in FY 20, and Discoms have generally seen their integrated ratings improve.[vi,30]

vi. The integrated rating evaluates the financial status of state and private Discoms on 15 basic metrics categorised by financial stability, performance excellence, external environment as well as nine specific disincentives. The full methodology can be found in the 11th Annual Integrated Rating & Ranking: Power Distribution Utilities.

Despite general positive trends, challenges persist. In July 2023, Discoms' cumulative liabilities rose to ₹596 billion (~$7.2 billion), with late payment surcharges potentially posing additional financial risks.[31] Of the 57 Discoms evaluated by Power Finance Corporation Limited (PFC), over half demonstrated moderate financial and operational performance or worse.[32]

Chronic operational losses have forced Discoms to manage cash flow by delaying payments to suppliers and taking on additional debt for working capital loans that don't contribute to asset creation.[33] Such loans contribute to booked return on equity provided by states falling below the 10% specified by the Ministry of Finance for calculating the internal rate of return for projects with identifiable streams of financial returns.[34] Limited cash flows have impacted performance. Lengthy payment delays to generators have created stressed assets, with high risks to project development and counterparties. The result is increased sector risk premiums that have reduced investment.

The Indian power sector has already overcome many of these challenges to set up a successful ecosystem for investment in new renewable resources. A similar approach could be taken for the development of the energy storage ecosystem, along with paving the way for enabling policies, regulations and market value creation to unlock BESS and DLS value for Discoms.

3.2 Battery Storage Market and Value Streams for Distribution Companies

A DLS asset can monetise and stack different value streams, as enabled by existing policies and regulations (discussed in section 2.1). However, at present, many of these value streams are not fully monetisable. Exhibit 11 summarises these value streams, the ease with which a Discom can monetise them, and considerations for co-optimisation and revenue stacking. The long-term value propositions could be favourable to Discom investments in DLS (as compared with other alternatives that may increase overall system costs), but the inability to accurately assess the future revenue streams is slowing down state regulators in approving Discom investments in DLS assets. Section 6 discusses the path forward to unlock the full value stack created by existing policies and regulations.

Exhibit 11 DLS Value Streams and Ease of Current and Future Market Monetisation for Discoms

DLS Value Streams	Current Ease of Market Monetisation (2023–24)	Expected Future Ease of Market Monetisation (by 2025–26)	Considerations for Co-Optimisation/Revenue Stacking
Energy arbitrage	Relatively easy to monetise	Will further streamline with increase of price caps/more clearance through markets	DLS asset operator to optimise and schedule between RTM, DAM and HP-DAM
Ancillary services: PRAS	Not allowed by the CERC 2022 AS regulation	Likely to remain difficult to shift to market-based procurement	
Ancillary services: SRAS	Allowed by CERC AS regulation, but no clarity yet on prices and DLS participation process	Expected to move to market-based procurement in a year; clarity expected on DLS participation process	Not easily stackable with energy revenues (as SRAS Up may be needed at same time as high energy prices, and conversely for SRAS Down)
Ancillary services: TRAS	Allowed by CERC AS regulation, some clarity on prices and DLS participation process	Further clarity is expected on prices and DLS participation process	DLS asset operator can optimise between energy and TRAS markets
Distribution capex deferral	Discoms and state regulators need to identify and implement deferrals proactively	Needs detailed local network analysis for proactive planning	Operating DLS asset to provide local peak reduction, while balancing market participation
Reducing DSM penalties	Value of DSM penalty reduction via DLS is unclear to external stakeholders	Early pilots to establish DLS value for reducing DSM; VRE-rich states going first	No clarity yet whether it could be co-optimised/stacked with other value streams
Resource adequacy (RA)	RA regulation still in early stages of formulation; no clarity yet on Discom RA obligations and value of capacity credits DLS can provide	Successful implementation of RA framework expected with participation from CEA, Grid-India and state Discoms	Easily stackable value stream with energy and AS participation opportunities

Easy to Monetise	Partially Monetisable Need further clarity in participation process	Non-Monetisable Regulation exists, but no clear price signals

- **Energy arbitrage:** This value stream is readily comprehensible, with clear mechanisms to monetise. Batteries can participate in energy arbitrage on the power exchanges in India, such as the Indian Energy Exchange (IEX), which trades electricity on the real-time market (RTM), day-ahead market (DAM) and high-price day-ahead market (HP-DAM).[35] The IEX platform accounts for the majority of the energy trading amongst the three power exchanges currently operating in India. At present, less than 10% of the total annual electricity need is procured though the power exchanges, while most of the power is procured through long-term power purchase agreements (PPAs) by Discoms.[36] However, an ongoing shift has led to increased power sales though market mechanisms and less reliance on long-term PPAs.[37] A DLS participating in power exchange energy markets may require some additional technical and market participation considerations, such as identifying a delivery point to the periphery of the regional transmission system.[38] Thus, higher-voltage distribution substations that are closer to the regional transmission network are ideal for early DLS pilots.

- **Ancillary services (AS):** As discussed in section 2.1, the CERC 2022 ancillary services regulations introduced three types of AS products: PRAS, SRAS and TRAS. The regulations also provided a mechanism for procurement through administered as well as market-based mechanisms. BESS are currently eligible to provide SRAS and TRAS. However, state-level rules and processes for a DLS to participate in AS are yet to be fully established. Early DLS pilots can create clarity on the AS participation process.

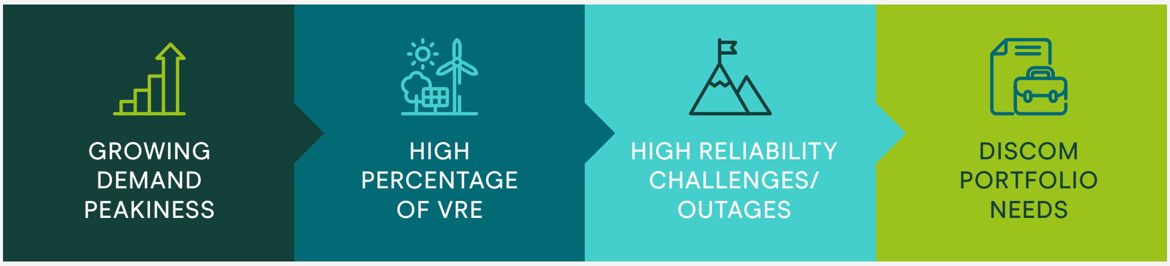
- **Distribution upgrade capex deferral:** Batteries can be used to shift peak load for feeders and distribution substation infrastructure that are currently overloaded or projected to be overloaded in the near term. The distribution transformer and wire upgrades needed to support higher loads on the feeder may be deferred if the peak load can be shaved by batteries. This is especially valuable in dense urban areas where there are space limitations to expanding substation and distribution infrastructure. Discoms and state regulators need to work closely for timely identification and deployment of the battery project to capture the distribution capex deferral value.

- **Other value streams:** Batteries can also provide value by helping Discoms avoid Deviation Settlement Mechanism (DSM) penalties and by providing resource adequacy, black start and voltage support capabilities. However, these value streams are either not readily available for participation by BESS, or they lack data that would be necessary to quantify their value and impact on a battery asset's value stack.

3.3 Emerging Forces Encouraging States and Discoms to Consider Investing in DLS

There are several factors supporting a state and its Discoms in early adoption of DLS assets, even though value streams for DLS have yet to become fully monetisable. In this section, we discuss a set of conditions for states and Discoms to evaluate their readiness for DLS adoption. A combination of these conditions — or a strong presence of one of them — that significantly increase power procurement, peak power or system operations costs and reliability challenges can guide state regulators and Discoms in the near-term opportunities to consider investing in DLS assets. However, further due diligence would be needed by the Discoms to identify on-the-ground DLS project location, size, financing and economic viability.

Exhibit 12 Supportive Conditions for States/Discoms to Consider Investing in DLS Assets

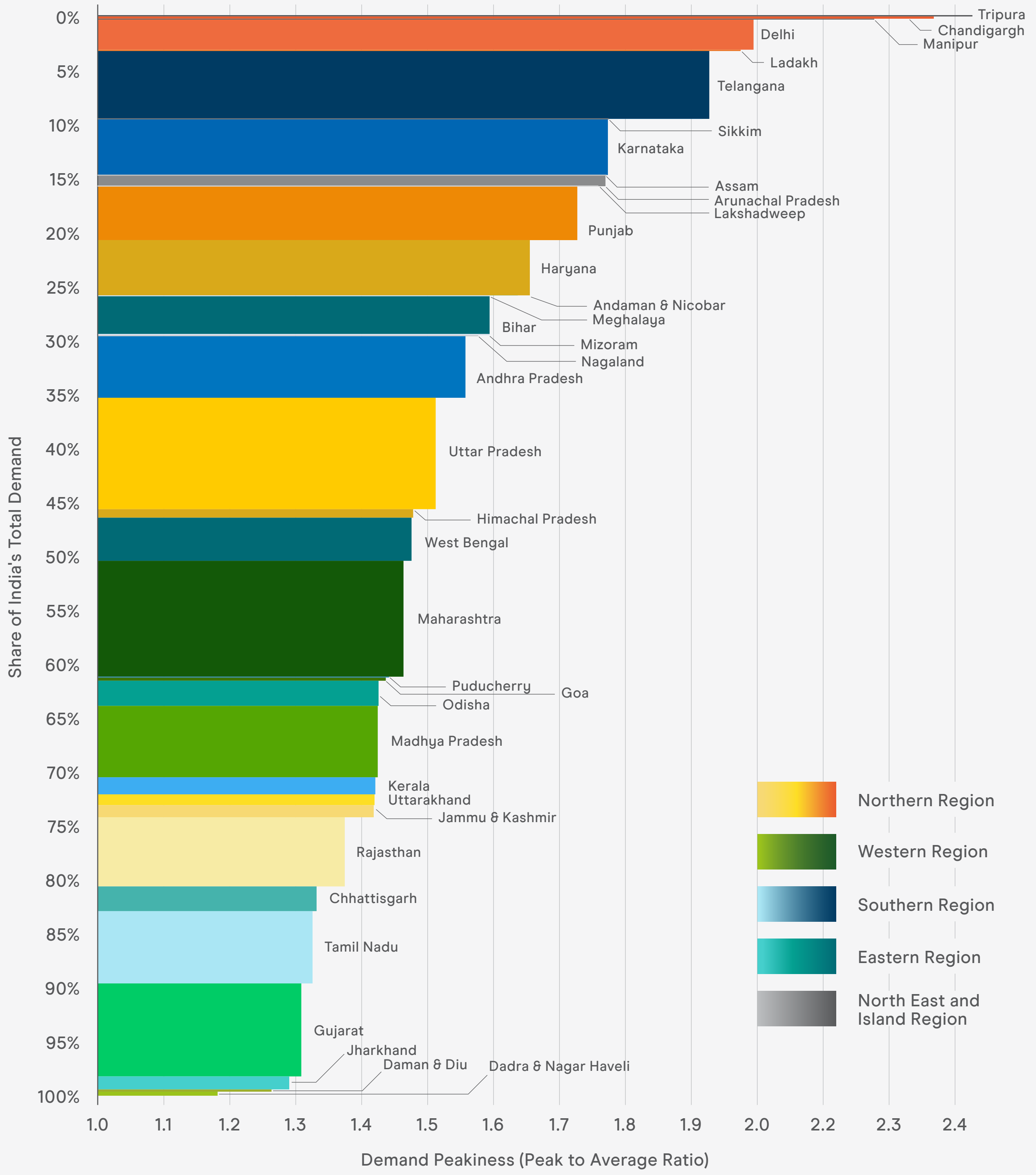


Growing System Demand Peakiness

India's power system demand is growing fast, with economic growth, increasing industrialisation and a significant rise in cooling demands. The all-India system peak reached a record 240 GW in September 2023 and is projected to reach 366 GW by 2031–32. Peak loads at the state level are also increasing, and some states are experiencing a sharper increase in load peakiness. Exhibit 13 on the next page shows the states with increasing load peakiness over time.

These states are good candidates for DLS assets, as DLS can be leveraged for deferring distribution system capex investments and reducing costs of power purchases to meet peak demand. DLS assets could also increase overall utilisation of the distribution system by increasing the system load factor, thus bringing overall power delivery costs down. The states of Telangana, Tripura and Odisha and the national union territories of Delhi and Chandigarh are projected to have the largest increase in load peakiness.

Exhibit 13 Expected System Load Peakiness and Demand Share by State in 2030–31



Note: The width of the bar represents the state's peak demand in 2031–32. Most states have an average demand peakiness index of 1.5 (equivalent to a load factor of 65%). The states reaching a peakiness index of 2 and above have less than 50% load factor. Load factor is a standard measure to determine the electrical energy usage utilisation rate. It is the ratio of the average load over a given period of demand to the peak demand. The 20th EPS report by CEA includes projections for the load factor at the national and state level. | **Source:** CEA 20th Electric Power Survey (EPS)

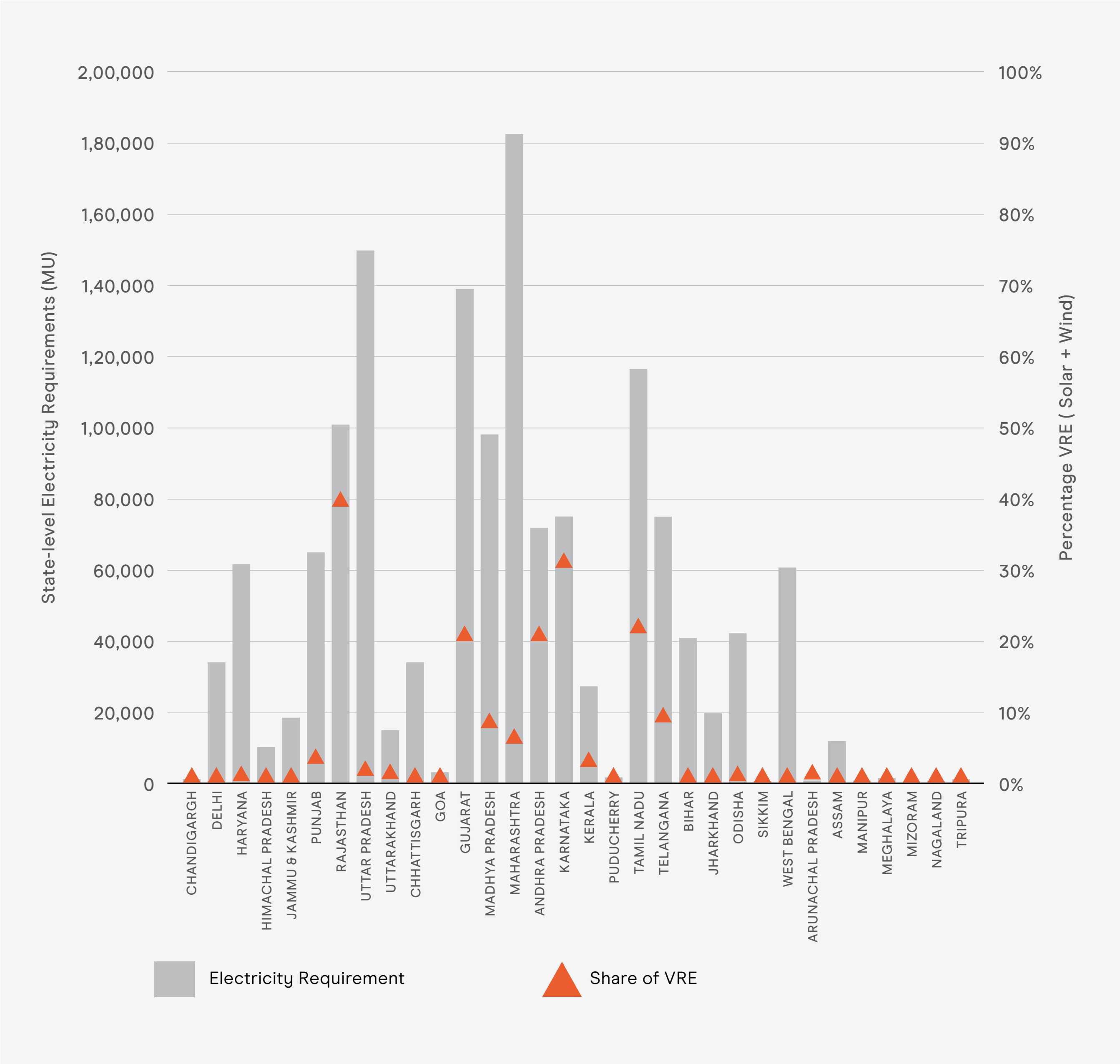
High Percentage of VRE Generation

Integrating increasing amounts of VRE resources (solar and wind) is a major factor that drives grid storage adoption. Exhibit 14 shows the annual electricity demand in million units (MU or GWh) and the percentage of that energy demand met by VRE generating resources in 2022–23 (on an annual electricity generation basis).[39] The leading renewables states of Rajasthan, Gujarat, Andhra Pradesh, Karnataka and Tamil Nadu are already experiencing 20% or more of annual VRE generation in their portfolios. By 2030, many more states are expected to have increasing shares of VRE in their portfolios. For example, the state of Uttar Pradesh has set a clean energy goal of 22 GW of solar by 2026–27, and Delhi has a draft solar policy considering a mandate of 6 GW of solar resources by 2025.[40]

All Discoms are subjected to penalties under the DSM. Imbalances between demand and supply of electricity result in fluctuation of the grid frequency, with significant drops resulting in blackouts. New DSM regulations introduced in 2022 tie penalties to market rates — the highest of the weighted average clearing price in the day-ahead market or real-time market charge across all regions. This reform has led to increased penalties, especially for some states with large amounts of renewable resources.[41] DLS in these states can help Discoms effectively balance their portfolios in day-ahead and real-time market operations and reduce potential DSM penalties. The states experiencing high VRE growth can consider DLS assets as an option to effectively schedule and operate their energy portfolios and minimise DSM penalties.

Moreover, increasing VRE over time can create significant energy arbitrage opportunities at the regional level, with lower prices when renewables are generating electricity and much higher prices during the other hours.

Exhibit 14 State-Level Electricity Requirements and Percentage VRE in FY 2022–23



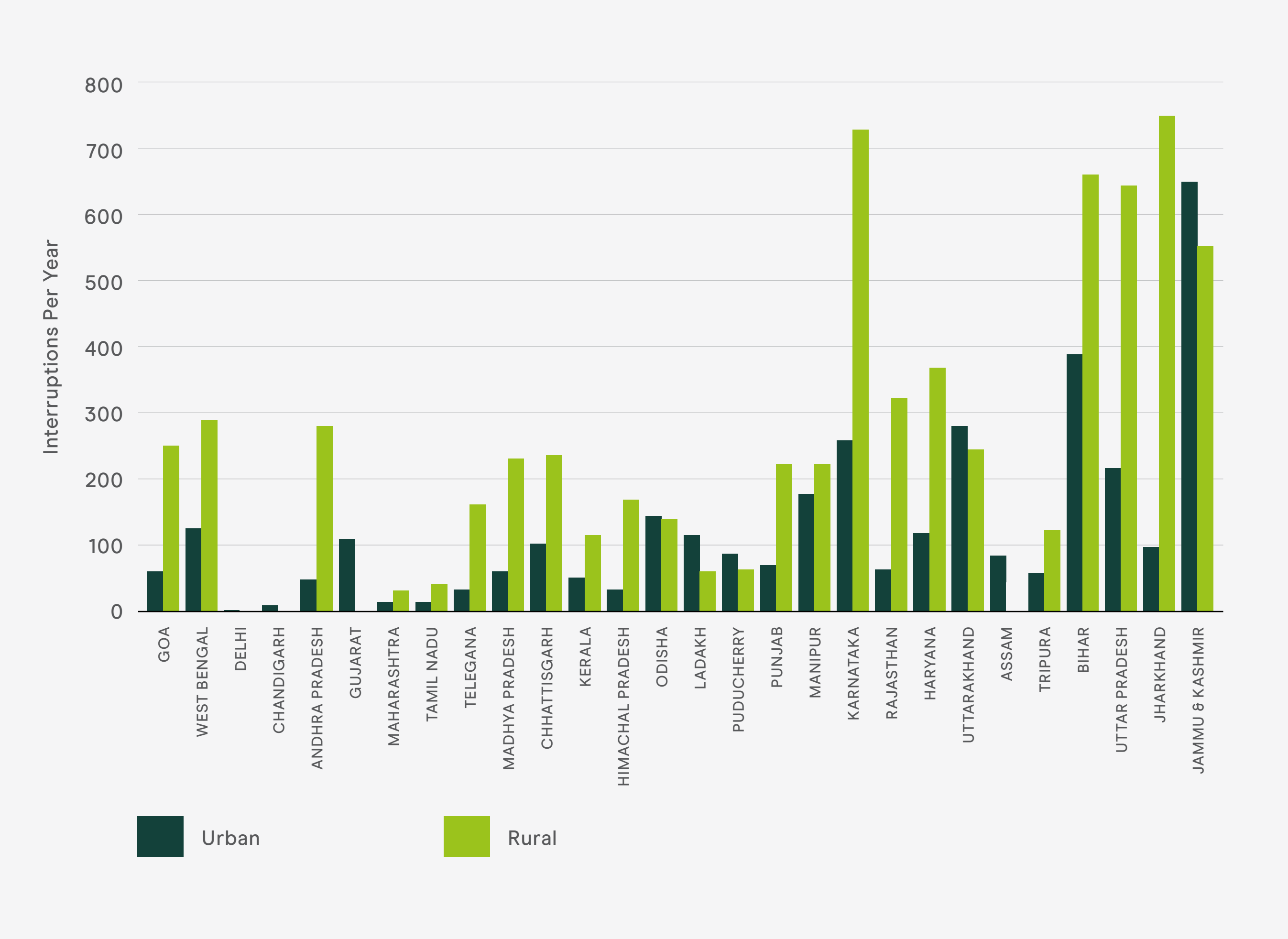
Source: CEA

System Reliability Challenges

India's power system remains vulnerable to unplanned power outages and system reliability challenges. The Indian power system often faces distribution reliability challenges, with transformers or other electricity distribution equipment failing closer to the customer load. Seasonal power supply shortages or inadequate resources also lead to power cuts. The reliability in remote and rural areas is often poorer than in dense urban areas. Exhibit 15 below shows the FY 2021–22 interruptions per feeder over a year for urban and rural feeders.[42] The rural feeders in the states of Karnataka, Bihar, Uttar Pradesh and Jharkhand observed the highest frequency of interruptions per year. The latest amendments to the Electricity (Rights of Consumer) Rules have introduced different metrics for Discoms to track system and customer reliability, but these metrics are not yet publicly reported.[viii]

DLS assets colocated at the distribution substation or other location closer to the customer distribution network (e.g., pole-top DLS) can promote overall reliability. Behind-the-meter (BTM) or customer-sited storage in areas experiencing frequent and long-lasting outages could also improve reliability at the customer premises.

Exhibit 15 Interruptions Per Year in Urban vs. Rural Feeders by State for FY 2021–22



Source: Customer Service Rating of Discoms FY 2021–22

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vii. These reliability metrics include System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI) and Momentary Average Interruption Frequency Index (MAIFI), included in amendments to Electricity (Rights of Consumer) Rules 2020 **https://pib.gov.in/PressReleasePage.aspx?PRID=1886876**.

Discom Portfolio Needs

Indian states and Discoms are experiencing changing energy supply portfolio needs with rising demand, increasing additions of renewable energy and reductions in the annual capacity factor and utilisation of the thermal fleet. To maintain 24/7 reliable power and ensure timely investments in new generation and storage capacities, the MoP introduced the Guidelines for Resource Adequacy Planning Framework in June 2023 (as discussed in section 2.1).[43] Resource adequacy is a power system planning concept that minimises the risk of blackouts or brownouts while balancing the costs of maintaining a reliable power system. Resource adequacy is just one pillar of power sector reliability, which also includes transmission stability, distribution reliability, operational reliability and resilience.[44]

Resource adequacy planning is a long-standing practice for many United States (US) electricity markets, and the resulting capacity prices provide a strong investment signal. For example, the resource adequacy capacity payments in the California Independent System Operator (CAISO) market have been instrumental in bringing 5 GW of storage capacity on line over the past two years.[45] The Discom-level resource adequacy assessment is in the early stages of implementation for the Indian states. As this process matures over the coming years, DLS, along with grid storage, could play a crucial role in meeting Discoms' future portfolio capacity needs.

4.0 Valuing Battery Storage Applications in India

Determining the economic viability of a BESS project requires a thorough techno-economic analysis. In this section, we quantify the value streams available for an example DLS asset and how they stack against the cost of the asset. We quantify the currently monetisable value streams of energy arbitrage, TRAS and distribution capex deferral.

The mature market streams that are available at present are necessary to establish the economic viability of BESS assets and support early DLS pilot projects. Avoiding DSM penalties and providing resource adequacy value could represent more lucrative value streams to incentivise Discoms to invest in DLS, but data is lacking and there are significant uncertainties in the participation process. Nevertheless, initial Discom pilot projects with support from the VGF subsidy and existing monetisable value streams can demonstrate the value of DLS to jump-start more investment and clarity in participation for future use cases.

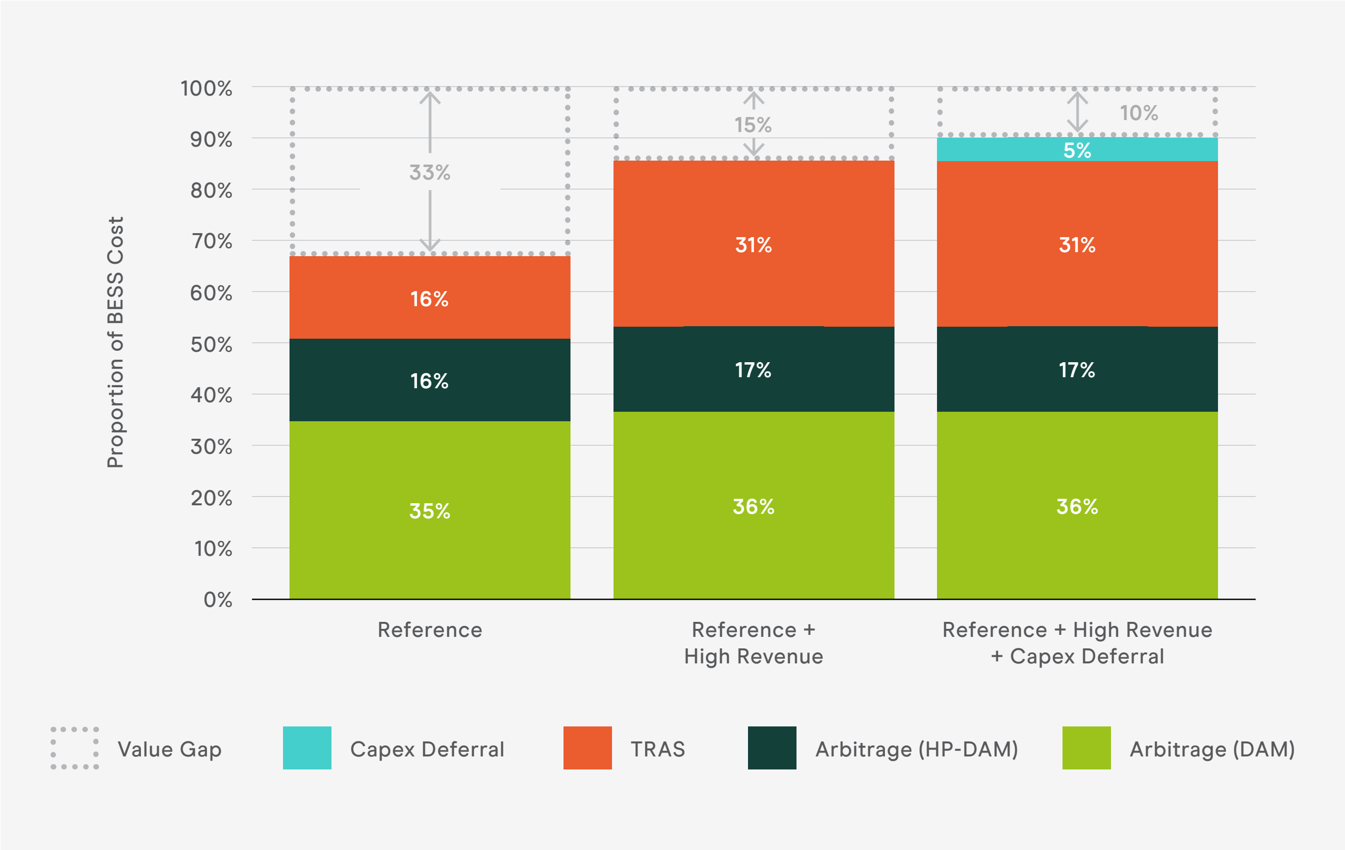
This analysis considers an illustrative 10 MW (20 MWh) distribution-sited BESS system. Since the power exchange markets have observed similar hourly prices across different zones over the past year due to minimal transmission congestion, location is not a key consideration at this stage. However, this may change as renewable penetration increases in certain regions, especially if transmission capacity does not expand at the same rate. The main goal of this analysis is to show the potential to stack values from various value streams, where gaps exist in existing regulations to provide investment signals for a new storage asset, the viability gap to commercialise these projects and the potential financing and policy options to bridge the project viability gap.

4.1 Analysis Results

Overview of Value Gap

For our illustrative example, a value gap of over 30% is expected today between BESS revenues for existing value streams and BESS costs, as shown in the Reference scenario in Exhibit 16 (see next page). Several value streams provide critical levers to collectively reduce the value gap in the near term, given that they are monetisable in today's market. Arbitrage and ancillary service revenues are expected to rise due to increased renewable penetration and more extreme temperatures, which will require more ramping and grid flexibility. Both DAM and HP-DAM markets have administrative caps on prices, and arbitrage revenue could grow significantly if these caps are revised upwards. The Reference case uses conservative TRAS revenue assumptions due to a lack of public ancillary service dispatch data, but the value from TRAS is likely higher due to increased grid flexibility needs in peak seasons (reflected in the High Revenue bar). Moreover, distribution capex deferral could be leveraged by colocating BESS in parts of the distribution system with increasing peak load that require infrastructure upgrades.

Exhibit 16 Current Economic Value Gap and Levers to Reduce It for an Example 10 MW (20 MWh) BESS



Source: RMI Analysis

Energy arbitrage (with participation in DAM and HP-DAM) provides around 50% of revenues, followed by TRAS participation, and then some revenues from distribution capex deferral. The details of the assumptions and methodology of the value stream analysis are shared in Appendix II. The High Revenue scenario assumes a 5% increase in arbitrage revenues, which is likely with increased renewable penetration and more extreme temperatures, and a 90% increase in revenues for TRAS participation, based on higher day-ahead TRAS margin estimates for peak seasons instead of emergency TRAS margin values only.

BESS capex costs are expected to decrease in general globally as battery prices continue to decline, and this cost reduction is expected to accelerate in India as the PLI scheme rolls out and domestic battery manufacturing capacity increases. Lower capex costs will further reduce the economic value gap. Both primary and supplementary value streams such as PRAS and SRAS participation, avoiding DSM penalties, voltage support and possible capacity payments through implementation of the resource adequacy framework are not included in this analysis. These value streams face either large process uncertainties or a lack of price data. We expect these value streams to be further established in the coming years (as discussed in section 6.2) and to further bridge the project economic viability gap.

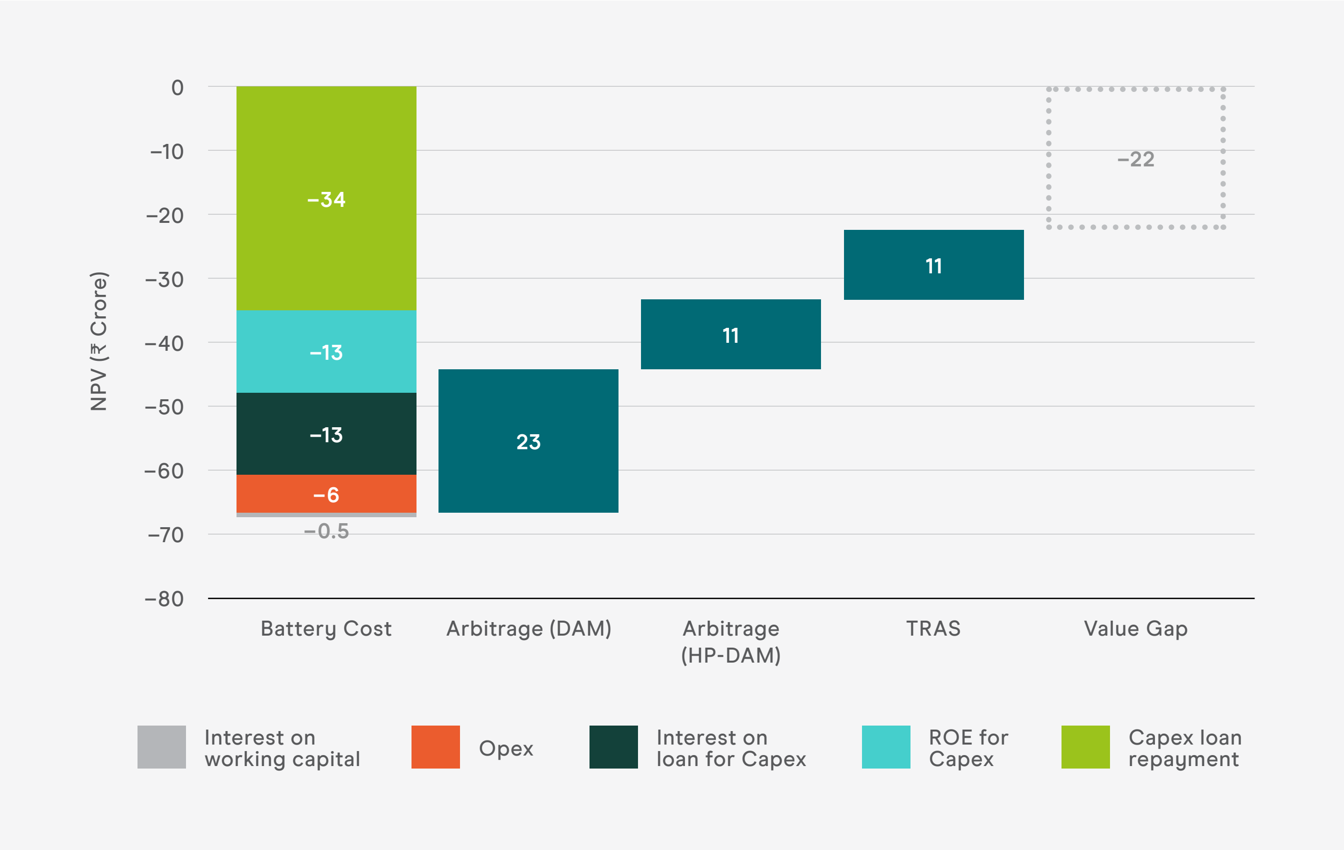
PRAS and SRAS could take over as primary economic value sources for BESS once there is more clarity on the process for market-based procurement. BESS has more value in these markets due to a shorter required response time, which batteries are well suited to provide. However, ancillary services are still in the early stages of development for the Indian grid, and the process for DLS to participate in these markets is not yet fully established. If the ancillary services markets become saturated, energy arbitrage would remain the main economic value stream available to BESS in the long term. Arbitrage revenues will likely continue to be available for BESS, since more energy is expected to be available for trading on energy exchanges due to a gradual shift away from long-term PPAs.[46]

Battery Cost Breakdown

From our analysis, BESS costs are driven by battery capex, broken down by capex loan repayment and related financing costs, including return on equity (ROE) and interest on debt. The waterfall chart in Exhibit 17 shows the net present value (NPV) breakdown of costs for our illustrative case, as well as how the different revenue streams in the Reference case can offset them. The ₹22 crore NPV value gap corresponds to the Reference case's 33% gap in Exhibit 16. Each battery system's project finance will have a unique combination of debt and equity financing, setting up the annual cash flow and NPV of the project.

In the near term, the VGF scheme announced by the Union Budget of FY 2023–24 will help make more BESS projects financially viable.[47] Discoms can tap into the proposed VGF programme to cover up to 40% of battery capex costs, as the details of the VGF programme's implementation are further established. The current analysis assumes no VGF programme support, and the financing assumptions for this example project are discussed in Appendix II.

Exhibit 17 Waterfall Chart for 10 MW (20 MWh) BESS Reference Case



Source: RMI Analysis

Value Stream Analysis Details

BESS is expected to get most value from energy arbitrage on the DAM and HP-DAM markets. If HP-DAM is not present, DAM alone could provide about 90% of combined DAM and HP-DAM revenues (further discussed in section 4.3). Since its implementation in April 2023, HP-DAM has observed higher prices during peak months but has no prices in some months. The demand for HP-DAM is not yet strong, as it is expected that some Discoms may prefer shedding load over buying from HP-DAM. For the current analysis, a conservative estimate of six months per year for HP-DAM participation is assumed. When BESS is allowed to participate in both DAM and HP-DAM, it is optimal to maximise revenues across both markets.

BESS can also benefit from participation on the TRAS market. However, the lack of transparency in price data, the participation process and the frequency of expected dispatch leave a large variation in potential revenues. In addition, we estimate stand-alone SRAS revenue to be ~50% of the battery cost for the Reference scenario (using prices from regional power committees, detailed in Appendix II). It is likely that SRAS would require frequent battery dispatch, and so dispatch for arbitrage may be sacrificed. Given the lack of price and dispatch transparency and the process uncertainties around BESS participation, SRAS revenue is not accounted for in Exhibits 16 and 17.

Distribution capex deferral is a smaller value stream, and if local feeder peaks match the energy market used for arbitrage, this may not require customised dispatch. However, if local peaks frequently differ from DAM and HP-DAM, it would not be optimal to dispatch the battery specifically to reduce local peaks at the expense of arbitrage and ancillary service value streams. This trade-off is further explained in Appendix II with a chart illustrating feeder and hourly energy price peaks.

4.2 Key Uncertainties and Lack of Public Data to Quantify Existing Value Streams

Additional price transparency and participation process clarity are required to fully understand all existing value streams. More data on TRAS and SRAS prices and expected dispatch requirements in different seasons can improve estimates for anticipated revenues from these services, and likely for BESS commitment needs as well. At present, ancillary service price data on the regional power committee websites — such as the Northern Regional Power Committee (NRPC) and Eastern Regional Power Committee (ERPC) — is only available for a few recent weeks, and dispatch requirements are not publicly available.

The DSM penalties data, meanwhile, is not available at granularity beyond the state level. The weekly DSM reports are shared across regional power committee websites, but currently there is no standard reporting of monthly and annual DSM trends. Understanding how Discoms and generators are being penalised for deviations will help build estimates of how a battery sited at the Discom level could reduce penalties. More complex storage dispatch modelling would also be required to simulate how a battery would need to be charged and discharged to reduce penalties and how this would interact with dispatch for arbitrage and ancillary services to optimise total revenues.

The resource adequacy (RA) framework proposed by the MoP is in the very early stages of implementation, and we have assumed no revenues in the form of capacity payments in the value gap analysis. The RA programme could provide up to 20–25% of project revenues to BESS assets, as observed in jurisdictions where RA programmes are fully functional (for example, Germany and California).[48] This could significantly bridge the BESS economic viability gap, as this value stream is complementary and easily stackable with energy arbitrage and ancillary service market participation.

4.3 Arbitrage Results Details

A significant portion of the value stack for a Discom-sited BESS comes from energy arbitrage. The battery earns revenue by charging, or buying electricity from the grid, when the wholesale electricity price is low and then discharging, or selling electricity to the grid, when the price is high. ('Arbitrage' refers to capitalising on prices swings in general.) The fundamental reason for this price variation in India is the need for energy shifting due to load variation (e.g., air conditioning/cooling or heating demand) and supply variations (e.g., hydro availability and renewable variability, especially solar in the middle of the day). We built an arbitrage model to find optimised revenues from BESS participation, and the modelling logic can be found in Appendix II. Historical hourly DAM and HP-DAM prices from the IEX are considered for this analysis.

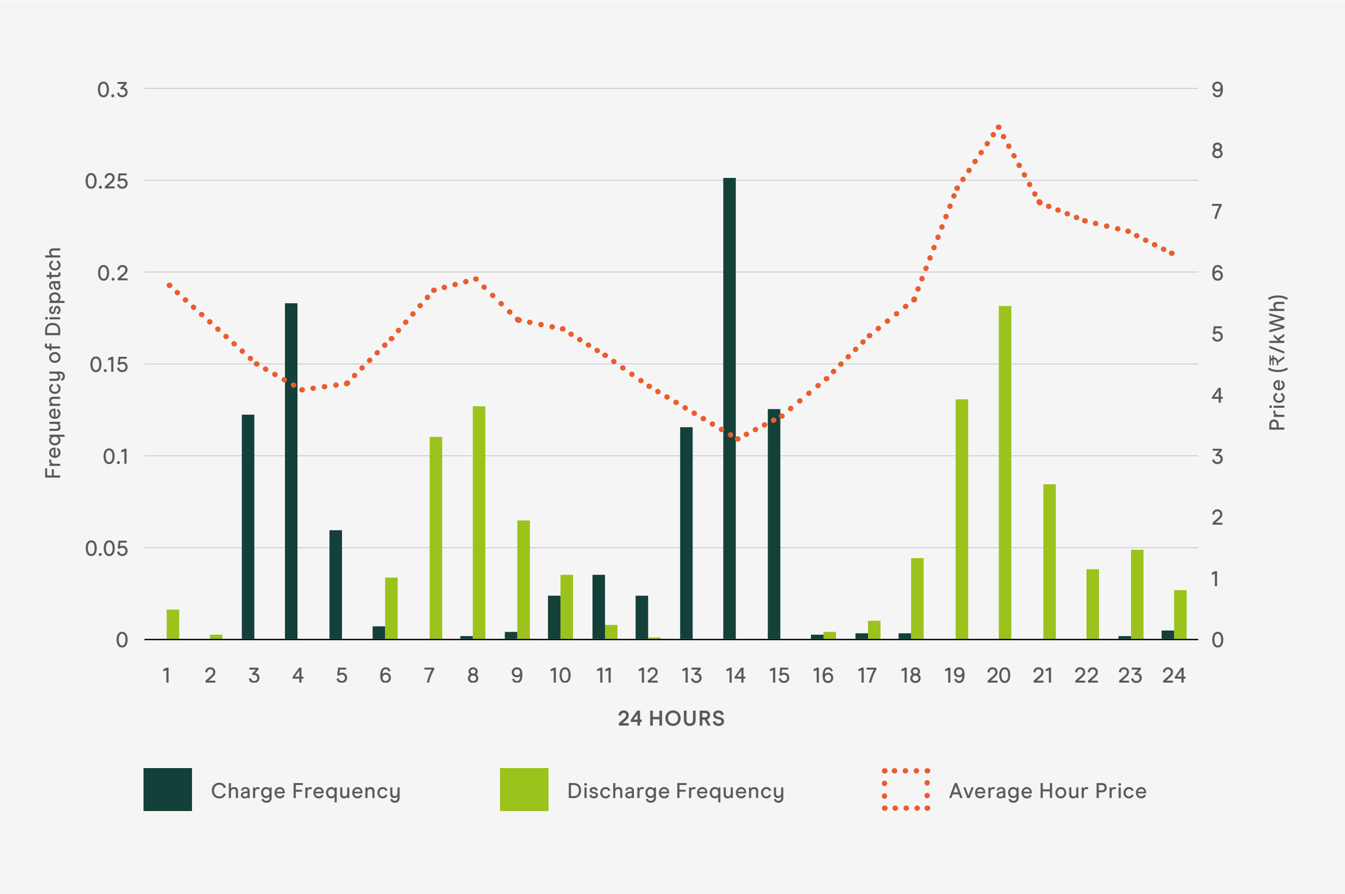
Dispatch Trends

Averaging the charge and discharge hours dispatched over the entire year (October 2022 to September 2023) for the DAM in the N2 region of IEX (which includes Uttar Pradesh, Uttaranchal, Rajasthan and Delhi) shows clear trends in the time of day that the battery should be dispatched to maximise revenue. The historical hourly price values in other zones of IEX are similar to those in N2, so although we show results only from this zone, they are applicable to projects located in other zones.

These trends are shown in Exhibit 18, where the bars show frequency of dispatch for each hour, or how often the battery charges or discharges in each hour over a year. Frequent charging hours include 12 p.m.–2 p.m. and 2 a.m.–4 a.m., with the bulk of charging occurring in midday hours where solar PV would be generating lower-cost electricity and in the middle of the night, when load is low. The battery will typically be discharged around 6 a.m.–8 a.m. and 6 p.m.–8 p.m., which generally correspond to peak load times.

The hourly dispatch frequency can be correlated to the average hourly price: a high charge frequency corresponds to a relative minimum in the average hourly price data, whereas a high discharge frequency corresponds to a relative maximum in the average hourly price data. From this, the average charge price (₹4.1/kWh), discharge price (₹6.7/kWh) and price delta (₹2.6/kWh) can be determined, offering key price benchmarks. These hourly trends can provide Discoms with some level of certainty when planning battery dispatch decisions.

Exhibit 18 Frequency of Dispatch and Average Price for Each Hour of the Day



Note: Values calculated from the DAM in IEX's N2 region for a 2-hour 10 MW (20 MWh) battery from October 2022 to September 2023. | **Source:** RMI Analysis, IEX

Participation in DAM and HP-DAM

Discoms in India will be able to stack multiple revenues from energy arbitrage by participating in multiple markets. The HP-DAM was introduced in March 2023, with a price ceiling of ₹20,000. We used the available HP-DAM data from April to September 2023 and extrapolated the trends to analyse a year's worth of data, taking into account that the HP-DAM will likely be zero in some months (see methodology in Appendix II). Allowing the battery to participate in HP-DAM in addition to DAM for the year of October 2022 to September 2023 increases the yearly revenue by 12%. When we model participation in both DAM and HP-DAM, only about 16% of battery cycles are dispatched in HP-DAM instead of DAM, but this accounts for about 30% of total revenue since HP-DAM has higher prices. The battery is only dispatched for one additional cycle when it participates in both DAM and HP-DAM, so participating in the HP-DAM would allow Discoms to generate more revenue without sacrificing battery lifetime. The battery is used for six hours a day, encompassing both charging and discharging, when dispatched for both DAM and HP-DAM. Optimised utilisation for arbitrage leaves 18 hours for co-participation in ancillary markets, and we conservatively assume the battery has enough charge to be dispatched in 60% of these remaining hours.

Exhibit 19 Total Annual Revenue Increases When BESS Participates in Both the DAM and the HP-DAM

OCTOBER 2022–SEPTEMBER 2023, N2	NUMBER OF CYCLES DISPATCHED TO DAM PER YEAR	NUMBER OF CYCLES DISPATCHED TO HP-DAM PER YEAR	DAM REVENUE (₹ LAKH)	HP-DAM REVENUE (₹ LAKH)	TOTAL REVENUE (₹ LAKH)
DAM only	566	–	417	–	417
HP-DAM + DAM	471.5	93.5	320	147	467

Note: Values calculated from the DAM in IEX's N2 region for a 10 MW (20 MWh) battery from October 2022 to September 2023.

Arbitrage Value Variation between States

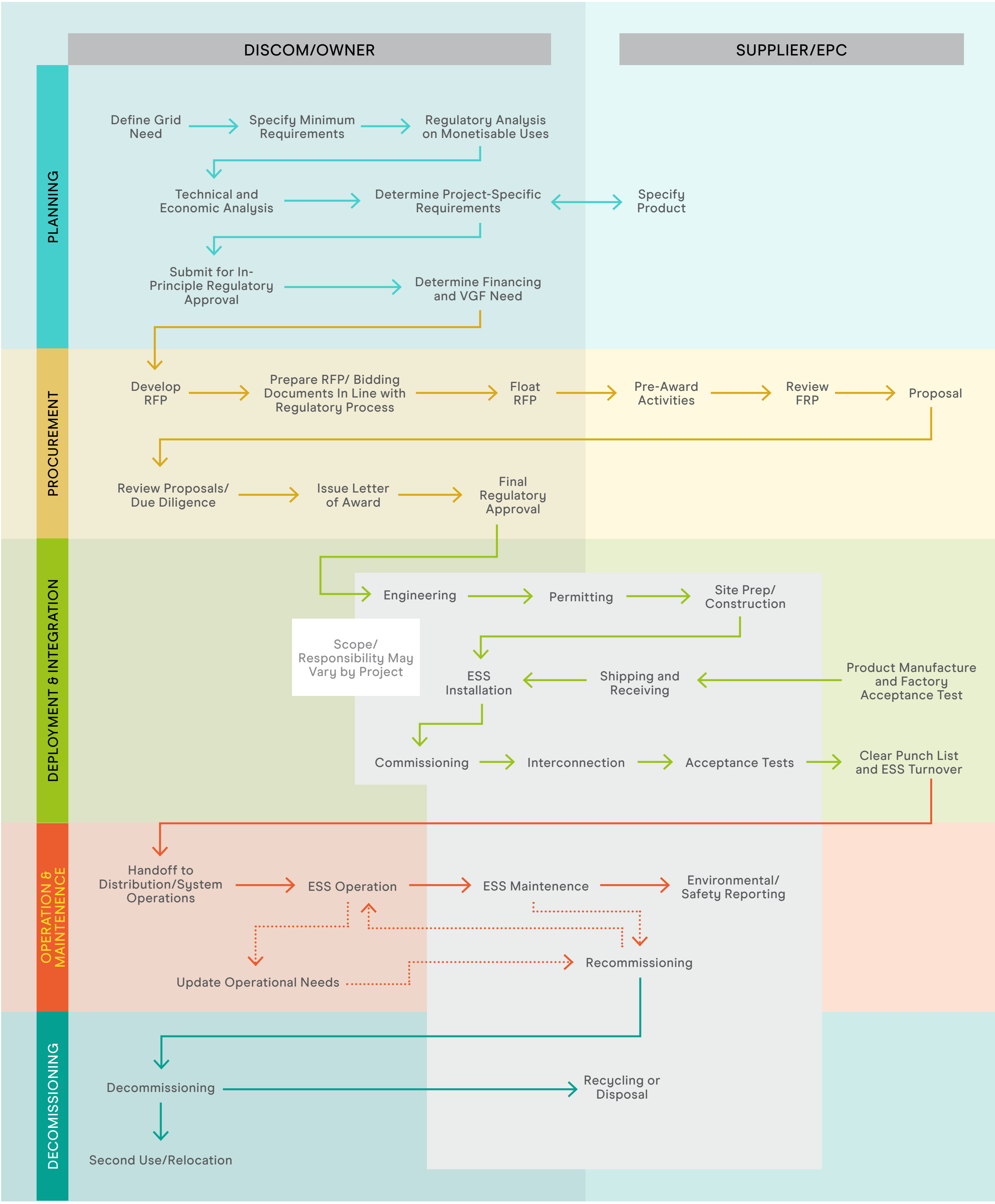
The value of batteries from arbitrage is consistent across states due to the consistency in hourly price data across the country (across trading zones in IEX). A single price is discovered across the power market because of low transmission congestion, due to wide-scale transmission growth in the past decade.[49] This may change as more renewables come on line, but the MoP plans to continue building more transmission infrastructure to keep up with planned renewable growth.[50]

5.0 Factors to Prepare for a Battery Project in India

When a Discom has made the determination to invest in a battery asset, and if project economic viability has become feasible with monetisable value streams and the VGF programme, multiple decisions need to be made to go from conceptualisation to contracting to connection and operation of the asset.

Key issues will include determining the appropriate ownership model: whether the Discom wishes to pursue a capex model (owning the asset) or contracting with a third-party for services. The Discom must also consider how to determine the appropriate location and size to optimise the value of the BESS for the priority use case. Prior to issuing a request for proposal (RFP) for the project, the Discom should determine target contracting terms and create a framework for evaluating RFPs. Discoms should also be familiar with IT and safety readiness considerations and should be prepared to navigate the life cycle of an energy storage project (see Exhibit 20 on the next page).[51]

Exhibit 20 **Five Phases of Energy Storage Project Life Cycle**



Note: hese steps are adapted from the Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide (**https://www.epri.com/research/products/000000003002013533**), which can serve as a practical reference guide for BESS planning. This is intended as a global resource, and Discoms may need to anticipate additional India-specific steps not covered. | **Source:** Adapted from EPRI

5.1 Ownership Models

Selecting a preferred ownership model will be an important initial decision in a BESS project. Generally, a utility (such as a Discom) either outright purchases the BESS or contracts with a third party, such as an energy service company (ESCO). Under the latter model, the BESS asset is owned and operated by a third party that provides specific storage services according to a contractual agreement, in an arrangement similar to a PPA.[52] The model selected should reflect the needs and preferences of the Discom; relevant factors are listed in Exhibit 21 (see below).[53]

Exhibit 21 Ownership Models

DISCOM-OWNED	THIRD-PARTY OWNERSHIP
Use case defines technical specifications	Use case defines desired results
Located within distribution network	Flexibility with location
Greater financing burden	Lower entry cost
Greater responsibility for EPC	Monitors development
Responsible for commissioning	Pay for performance agreement (₹/kWh)
Responsible for operations or contracting out operations	Responsibilities defined per agreement and warranties
Operational changes allowed within limits of warranties	Limited changes allowed, as defined or negotiated
Greater flexibility	**Lower risk**

Note: Third-party ownership may encompass contracting with BESS at the Inter-State Transmission System (ISTS), with other stand-alone front-of-meter projects, or with behind-the-meter distributed storage resources. | **Source:** Adapted from North Carolina State University

Utility ownership or contracting services from third parties represent the most common ownership models for BESS assets. The flexible nature of BESS has enabled distribution network operators (as well as other power system stakeholders) to explore innovative models of contracting services for specific uses (see Box 3).

Box 3 Innovative BESS Models in International Markets

Resilience-as-a-Service in the United Kingdom (UK)

In the UK, distribution network operators (DNOs) are incentivised to explore innovative approaches to improving service for end users. Scottish & Southern Electricity Networks, a DNO in rural Scotland, is piloting a resilience-as-a-service (RaaS) market solution to improve rural and remote area network resilience. The project aims to demonstrate how a RaaS provider can provide fast black start (response in less than 60 seconds) in the case of a fault, with support of a battery asset. Fast response from the battery allows RE generators to continue exporting. While the RaaS provider is contracted to provide fast black start services, it can continue to participate in the ancillary services and wholesale electricity markets.[54]

Exhibit 22 RaaS BESS Model

Challenges to solve to mitigate risk of RaaS provider:

- Standardisation of requirements
- Operational optimisation
- Inclusion of local renewables
- Equipment supply chain

RaaS supply chain:

- RaaS Provider as single contractor to DNO
- Technology agnostic and cost-optimised procurement structure

Source: SEEN Innovation

Box 3 Innovative BESS Models in International Markets (continued)

StorageShares Programme in Sacramento Municipal Utility District (SMUD)

Innovative ownership models can even be applied to distribution-located storage to reduce cost hurdles. SMUD, a municipally owned utility in California, launched its Energy StorageShares programme in January 2019. Under the programme, commercial customers can invest in an off-site battery storage system, located within the distribution network, and enjoy associated energy cost savings without siting batteries at their facilities. Commercial customers are encouraged to invest in the programme for storage shares, which are equivalent to 1 kW of demand charge reduction savings credited to the monthly customer bill over a 10-year term. SMUD bundled the investments to invest in a 4 MW (8 MWh) utility-scale battery interconnected at the distribution level.[58]

The programme provides guaranteed savings to the commercial customer without impacting business operations or imposing maintenance obligations, while enabling the utility to site a BESS asset to defer distribution capex costs. In this ownership framework, the utility can maximise distribution system benefits while minimising capital expenditure.

5.2 BESS Sizing and Location

The Discom will need to determine an approach for identifying the optimal BESS sizing and location to suit the use case. When planning for the use case and operational modes, Discoms should understand the site's electricity requirements. These include the typical load profile, including peak and average demand, the expected load for the BESS to carry, the minimum time frame that the BESS must carry the load, and the voltage and frequency of electricity supplied by the BESS. Higher-voltage assets sited closer to the regional transmission network will have improved technical access to wholesale market participation, which can impact the project's economic viability. These factors will guide a project development team in designing the system and determining the appropriate battery power, energy capacity and storage duration.[55]

BESS can be installed anywhere within a distribution system, but appropriate placement can facilitate optimal operation for power quality improvement, peak demand mitigation, overall network cost reduction and system effectiveness. A comprehensive survey of the distribution network including power-flow analysis, fault analysis and load profiling will be required to adequately determine how to approach optimising location and size within the distribution network.[56] Discoms should anticipate calculating optimal location and sizing, either through established software or with consultant services.

5.3 Contract Terms

Rapid evolution of the energy storage market requires that a request for proposal (RFP) is comprehensive and recognises the unique qualities of storage. For a complex project with potentially broad impacts to grid and distribution network operations, it is especially critical for clear recognition of the responsibilities of each party. Preparing a comprehensive RFP calls for articulating the particular characteristics of storage within a rapidly developing industry.[viii] The RFP should define all key terms, whether they apply to technical requirements or financial elements. Similar diligence must be undertaken in the proposal evaluation process to keep all stakeholders in sync when interpreting the RFP.[57] Some conditions for evaluating proposals are found in the exhibit below.

Exhibit 23 Considerations for Evaluating an RFP

	TECHNICAL	FINANCIAL/CONTRACTUAL	OPERATIONAL
1 Primary	Capacity (MWh for fixed duration)	PPA price	Permits and approvals
	Round trip efficiency (%)	Energy price	Maintenance requirements
	Maximum charging power (MW)	Performance guarantees	
	Technology type/class		
2 Secondary	Discharge ramp rate (MW/min)	Warranty	Time availability
	Charging ramp rate (MW/min)	Maintenance costs	Forced outage rate
		Contractor success record	Contractor's previous experience
3 Tertiary	System degradation (%/year)	Method of termination	Size profile
	Self-discharge rate	Invoicing and payment method	Actionability of response
		Right of first offer on defaulted debt	

Source: North Carolina State University

viii. ESIC has prepared an Energy Storage Request for Proposal Guide to outline RFP sections, examples and references that can support the procurement process **https://www.epri.com/research/products/000000003002017242**.

The Discom should also develop a plan to monitor and support the project throughout the construction process. Designated site personnel assigned to the project should have adequate time to oversee and inspect, with regular construction period updates and document reviews.

5.4 Monitoring and Control Infrastructure

An efficient control mechanism is necessary to ensure high reliability and safe operation of the BESS asset. Monitoring and controlling the battery will require sufficient IT infrastructure readiness to coordinate the physical and control strategy for the BESS. The BESS system is composed of physical assets: the battery modules and storage enclosures (with thermal management), the battery management system (BMS), the power conversion system (PCS), the energy management system (EMS) and the supervisory control and data acquisition (SCADA) system (see exhibit below).[59]

Exhibit 24 BESS Control and Management Systems

BMS	Controls the proper operation of the battery cells in order to maintain system voltage, current and temperature within specified limits. Calibrates and equalises the state of charge among cells.
PCS	Handles the AC to DC conversion or DC to AC conversion, which requires a bidirectional inverter. Usually grouped in a conversion unit, including all the auxiliary services needed for proper monitoring.
EMS	The link between the grid demand and the BMS. Continually monitors what the grid needs and how that energy can be transferred from the BESS via control logic. The EMS sends an input signal to either charge or discharge the battery depending on the control logic requirement and SOC of the battery system.
SCADA System	Communicates with the BMS for general monitoring and control, including alerting the operator when there are issues with battery health, temperature, fire warnings, output, voltage, or SOC.

For the highest-efficiency use of the BESS asset, the Discom should be technologically prepared to run these digital control and monitoring tools. Thermal management and operational strategies should be included within the RFP for the entire housing as well as the battery modules and rack. The RFP should also include requirements for regular firmware/software updates through the expected life of the equipment. This should cover security patches and updates to BMS antivirus software.[60]

6.0 The Pathway Forward

Meeting pan-India BESS deployment needs by 2030 will require interventions at multiple stages of the value chain. The existing national framework is an important step towards creating a robust ecosystem for BESS in India, but high BESS material costs and low bankability also hinder deployment.[61]

The resource adequacy framework will be critical to advancing holistic, long-term investments for local system needs, but existing regulatory frameworks are inadequate for evaluating the performance and capacity benefits enabled by BESS. Market access and products, and improved visibility into market values, can help project planners and system integrators better understand battery economics.

RMI and GEAPP introduced the Battery Energy Storage Accelerator in October 2023. This event convened stakeholders from across the power and energy storage system to assess the critical areas where additional intervention is required to operationalise the national framework and advance the adoption and deployment of BESS assets, especially at the distribution network. Participants included representatives and staff from Central Government entities, Discoms, power exchanges, system integrators, think tanks, multilateral organisations and financiers, and private organisations.

Three working sessions identified barriers and solutions for Discom readiness, regulatory and policy action and accessing finance. These sessions informed actions that central and state-level stakeholders can take to reduce barriers to BESS deployment. The actions proposed here are applicable across the BESS value chain, to projects colocated with renewable generation assets or to stand-alone transmission- or distribution-connected BESS. The proposed actions include addressing upfront costs, outlining procurement needs, and advancing market development, regulatory reforms and institutional knowledge-building. Finally, the national framework heavily focuses on centralised front-of-meter assets; additional recognition should be given to the critical role of DLS and behind-the-meter (BTM) BESS.

6.1 Reducing Upfront BESS Project Costs

Upfront capital costs are a major cause of the continuing economic viability gap for BESS projects in India. High material costs, especially for battery packs and inverters, make up the majority of capex costs. A lack of domestic manufacturing also requires project developers and system integrators to rely on imports that are liable to duties. In the long term, global battery material costs are anticipated to decline, and domestic manufacturing industries are expected to establish themselves and mature. In the short term, policy interventions are necessary to enable project development.

Targeting Incentives for Diverse Grid Storage Battery Applications

The economic viability gap creates a perception of high risk for BESS projects amongst Discoms and financiers in India, which is partly a consequence of high upfront capital costs. The economic viability gap also results from lack of clarity into monetisable uses and quantification of value streams, both under existing policy and application of anticipated frameworks. Addressing capital costs is a critical step for motivating initial BESS projects and resolving uncertainties through the sector that contribute to perceived risk, especially for providing solutions to Discoms. Having initial projects with a diverse set of business models that are sited across the electricity system, including transmission-sited, distribution-located and BTM storage, can inform best practices and guide the broad range of future deployment necessary to economically meet Discom needs. Incentive programme design should take these goals into consideration.

The VGF scheme approved by the cabinet in September 2023 is a valuable opportunity. The VGF scheme will support 4 GWh of BESS development by FY 2030–31, determined through a competitive bidding process. The VGF scheme intends to achieve an LCOS of ₹5.50–6.60 per kWh to make BESS viable for managing peak demand, and 85% of project capacity will be made available to Discoms, with the goal of passing savings on to ratepayers. A detailed framework for bidding has yet to be released and should provide a better understanding of who can participate and the criteria for determining recipients. The VGF scheme could enable industry stakeholders to explore the variety of use cases and business models that can contribute to improving system flexibility and reliability, and these factors should be criteria for evaluating submissions. Such subsidies have already been applied in international markets (see Box 4 on page 72).

Near-Term Recommended Actions

VGF off-taker eligibility should be clarified. The VGF, as announced, will require that 85% of subsidised project capacity be made available for Discoms. It is unclear whether the targeted rates enabled by the VGF will be accessible to all Discoms or limited to public entities. Clarity should be provided on whether private Discoms are also allowed to contract at the subsidised rates.

Gap analysis required to evaluate highest-impact BESS pilots. A BESS asset's value stack will vary depending on criteria such as geographic location, point of connection and the portfolio mix and load profile of the Discom or other off-taker. Round-the-clock renewable tenders are active, while VGF targets Inter-State Transmission System–located BESS. An additional need exists for understanding how BESS can provide beneficial services through connections at intra-state transmission, the distribution network and behind the meter. MoP should engage with system operators, Discoms, researchers and consultants to perform a gap analysis to identify which projects can provide the highest-value learnings that further understanding of how BESS can maximise system performance and capacity utilisation.

Medium-Term Recommended Actions

Competitive bidding guidelines (CBG) should be created for Discom procurement of BESS. Development of CBG can provide standardisation and uniformity in processes and a risk-sharing framework between stakeholders. CBG can help reduce off-taker risk, encourage investments and enhance bankability of projects, and improve profitability for investors. MoP should convene a committee with the Ministry of New and Renewable Energy (MNRE), Ministry of Finance (MoF), CEA, CERC, Grid-India and Discoms to draft and finalise the CBG. MNRE would develop tender forms informed by experience with solar and wind bids; MoF would provide expertise on taxation and duties; CEA would provide technical and connectivity guidelines; CERC would create regulations around tariff structure, markets and penalties; Grid-India would develop connectivity, metering and settlement mechanisms; and Discoms would provide expertise on needs and utilisation strategies. The CBG should then inform the creation of a standard bidding document (SBD). Competitive bidding guidelines for Discom procurement of BESS should be distinct from guidelines for PSP or other ESS procurement.

Box 4 BESS Incentives in the United States

US Incentives through the Inflation Reduction Act (IRA) and Bipartisan Infrastructure Law (BIL)

Investment Tax Credit for Energy Storage

- Stand-alone energy storage of at least 5 kWh is eligible
- Base tax credit of 6% of qualified investment, with increases possible depending on meeting domestic content requirements, prevailing wages and location within high-needs communities
- Base credit has a 5x multiplier if projects meet certain requirements, enabling a tax credit of up to 30% and up to 50% (with two 10% adders)
- Applicable for projects beginning construction before January 2025

Energy Storage Demonstration and Pilot Grant Programme

- $355 million available in grants for demonstration or pilot projects
- Uses include improving reliability of transmission and distribution systems for rural areas; optimising transmission or distribution system operation and capex deferral uses; providing peak supply; reducing peak loads for behind-the-meter applications; improving and advancing power conversion systems; providing ancillary services for grid stability

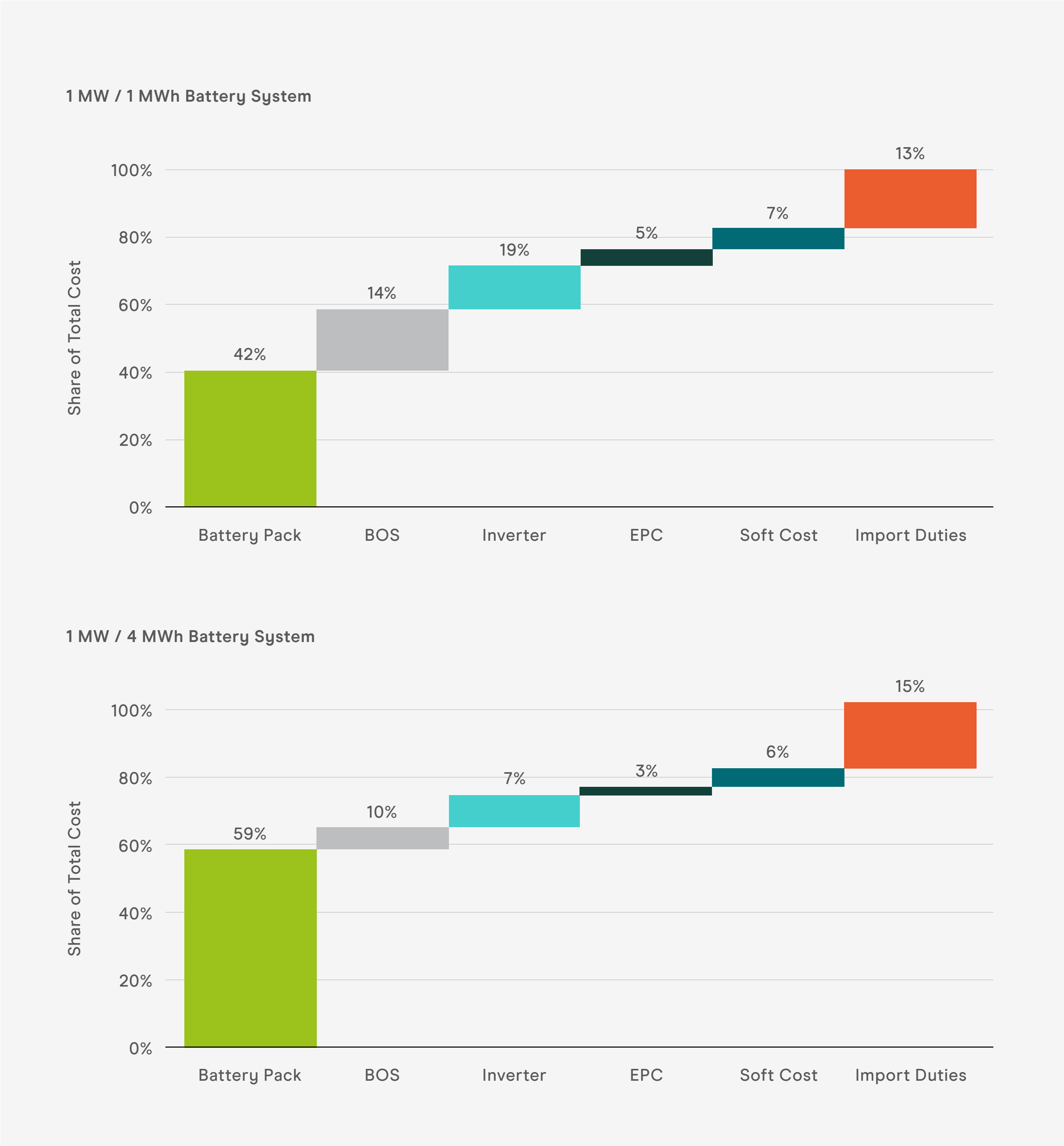
Long-Duration Energy Storage Demonstration Initiative and Joint Programme

- $150 million available as grant, cooperative agreement or other reward
- Funding targets projects that demonstrate promising long-duration energy storage technologies at different scales and that help innovative technologies reach commercial viability
- Eligible entities include technology developers; industry, state and local governments; tribal organisations; community-based organisations; national laboratories; universities; and utilities

Addressing Import Costs

The PLI scheme selected bids in March 2022, launching an effort to build out India's domestic battery manufacturing sector with the intent of achieving 50 GW of domestic manufacturing capacity by 2030. While establishing a domestic battery manufacturing sector will be critical to assuring energy security, reducing cost barriers to deployment should be prioritised in the short term. Industry stakeholders have expressed that high import duties create an additional hurdle to project economics, dissuading investments in battery assets.[62] Imported hardware, including battery packs and inverters, already represent the majority of BESS costs in India. Import duties of up to 22% are applied to imported hardware.[63] These import duties further drive up project costs, representing approximately 13–15% of capital investment in BESS (see Exhibit 25 below).[64]

Exhibit 25 Cost Breakdown of 1 MW (1 MWh) and 1 MW (4 MWh) Battery Systems



Source: RMI, adapted from LBNL and BNEF

Temporarily reduce import duties for BESS project hardware. Temporary reduction will accelerate necessary battery system deployments until sufficient domestic manufacturing capacity is on line to meet hardware needs. These temporary reductions should be applied to battery packs and inverters imported for BESS applications.

Near-Term Recommended Actions

6.2 Policy and Regulatory Interventions

As grid battery technologies mature and global and domestic costs decline, Indian power sector stakeholders must be prepared to rapidly deploy and integrate high volumes of BESS assets to meet system needs. Regulators and policymakers should establish a comprehensive battery storage framework to address stakeholder knowledge gaps around BESS asset ownership and operation in anticipation of BESS becoming cost-competitive in India's market. Critical areas where policy interventions may be considered are provided in Exhibit 26 on pages 75, 76 and 77.

Accelerating Procurement

Current Status

In October 2023, MoP announced a revision to the RPO, replacing the previously announced Energy Storage Obligation (ESO) with a distributed renewable energy (DRE) target.[65] The ESO was pan-India, not necessarily a reflection of regional or state needs. The ESO lacked clarity on volumes of storage to be met. Clear and binding obligation targets can be a major driver of battery storage deployment, and BESS should be considered a vital resource under the newly announced DRE targets. The RA framework could also be an effective driver for determining and signalling local long-term BESS needs.

Near-Term Recommended Actions

Additional resource adequacy (RA) implementation clarity should be provided. The resource adequacy framework is an important tool for holistic long-term system planning, and CEA is taking steps to guide some Discoms through the first steps of meeting RA requirements, including needs surveys and procurement. As these initial exercises are undertaken, additional guidance on the RA implementation and enforcement mechanisms should be provided. Guidance that includes least-cost resource adequacy planning strategies should be provided for all Discoms. Institutional knowledge-building for Discom and SERC staff should be initiated to create specific internal staff capability to plan, evaluate and execute RA assessments. BESS assets should also be explicitly recognised as a capacity resource under the RA framework.

Medium-Term Recommended Actions

Capacity and network planning should be aligned. As the RA framework is implemented by state-level entities, a process should be developed to align local capacity and national and regional grid network planning. Current system capacity utilisation should be assessed, and Discom-level guidelines should be developed to integrate these activities. Lighthouse projects should be undertaken with selected Discoms to better inform this process, and findings from the lighthouse projects can then be utilised to develop knowledge-sharing materials to better socialise the aligned planning process. Concurrently, the implication of cost-reflectiveness on system planning should also be studied by CERC and set by SERCs.

Market Development

Current Status

Ancillary Services

Historically, India has procured ancillary services through an administered mechanism but has recently introduced three ancillary services products: PRAS, SRAS and TRAS. Despite being well suited to providing PRAS, battery storage assets are not currently allowed to provide this high-value, fast-responding service.

Unlike PRAS and SRAS, TRAS is procured through auction-based mechanisms administered by the power exchanges. CEA and Grid-India should work to strengthen the movement towards a market mechanism for procuring PRAS and SRAS, with an emphasis on providing transparency into clearing prices for all ancillary services.

Resource Adequacy/Capacity Market

While RA guidelines are in place and may be an effective signal for determining local BESS needs, Discoms' propensity to adhere to these guidelines has yet to be established. Mechanisms to encourage compliance are needed. Further, many international power markets hold capacity auctions, which can economically meet system needs and maximise the value of a battery asset. The RA programme in California (valuing capacity) and two capacity market auctions in the UK have been critical to bringing 5 GW and 2.3 GW of storage on line, respectively. The Indian power market has yet to evolve to value capacity resources such as BESS.

Day-Ahead Market

Trading through the power exchanges for arbitrage enables BESS to help level loads while creating an additional opportunity for battery assets to realise value. The establishment of markets that more closely align with cost of production enables BESS to improve project economics. The recently introduced HP-DAM increases the price cap on the IEX. However, viable demand for electricity traded through HP-DAM is still to be established, and Discoms should be incentivised to preference procurement from the HP-DAM over load shedding. Further reforms that similarly capture the true cost of production may be critical for driving the value of BESS within India.

Other Services

An opportunity exists to develop procurement mechanisms for other products that will benefit system stability while capturing the value of BESS. In use cases like black start and voltage support, efforts are needed to clearly enable access for BESS to provide these critical services — either through development of a market or explicitly allowing BESS to contract for these services. No formal framework currently exists to allow for participation of BESS.

Continued »

Near-Term Recommended Actions

Ancillary services products should shift to procurement through market mechanisms. Of the three ancillary services products procured, only TRAS is met through a market mechanism. CERC and Grid-India should shift both SRAS and PRAS to market mechanisms and enable BESS to compete to provide all categories of currently recognised ancillary services.

Clearing prices for all market products should be publicly reported. Publicly available data on clearing prices will provide market signals to BESS project planners and developers, enabling improved forecasts of project values and optimal operation strategies. This data will enable the discovery of marginal cost for meeting peak power and ancillary services. Grid-India and the power exchanges should work to make clearing prices publicly reported in a standardised format.

Commitment charges should be revisited. Resources participating in ancillary services markets receive a commitment charge for the hours that they are cleared to supply/withdraw energy, regardless of whether energy is dispatched.[66] Raising the cap on commitment charges will incentivise participation in ancillary markets, because BESS can get more value from being available to provide ancillary services for many hours of the day, making it worthwhile to forgo arbitrage revenues during these hours, even when ancillary services are only required infrequently.

Medium-Term Recommended Actions

Additional market products should be developed. Services such as fast frequency response, voltage support and black start can be cost-effectively procured through market mechanisms. In addition, products for long-duration arbitrage and capacity can aid in meeting resource adequacy projections. Finally, market products can be developed that emphasise the services BESS can provide to the grid, such as fast and flexible ramping support. This is especially important in geographies with high levels of solar generation penetration. CERC, Grid-India and the power exchanges can collaborate to create and introduce these products.

Penalties should be assessed for load shedding. The HP-DAM is seeing low participation from buyers; many Discoms prefer to shed load than purchase at higher rates. CERC and the FOR should seek to develop a framework for determining and penalising load shedding that occurs in lieu of participation in the HP-DAM.

Regulatory Reform

Current Status

Guidance on Transmission and Distribution Deferral Services

Currently, there is no clear guidance and regulatory framework for using BESS as a distribution system capacity deferral asset. There is a need to streamline ways to establish value to the system as financial savings such that state regulators adequately allow for revenue realisation through the annual Aggregate Revenue Requirement (ARR) process. BESS can be utilised as a non-wire alternative for transmission and distribution network planning in place of traditional investment and can encourage loss reduction. This need for reforming how such services are accounted for especially applies in dense urban areas where there are space constraints for expansion of distribution system infrastructure.

Time-of-Use Tariffs

Even for established value streams like energy arbitrage and ramping support, enabling policies like time-of-use (TOU) tariffs can greatly strengthen the value of flexibility that BESS can provide to end-use customers. TOU tariffs are leading to increasing adoption of BTM BESS in international markets (e.g., California).

DSM Reform

DSM penalties may be a major incentive for Discoms to invest in BESS. Greater transparency and granularity of deviation data, coupled with tighter bands and tying penalties to greater deviations, could improve grid stability and reliability, while motivating investment in improved forecasting and DLS. The impact of increasing DSM penalties may be especially pronounced in states with higher regional levels of renewable resources.

Innovative Regulatory Frameworks

Innovative regulatory frameworks, such as allowing Discom–customer co-ownership of BESS assets or performance-based regulation that accounts for non-monetisable services beyond peak procurement, can help incentivise Discoms, where appropriate, to invest in innovative technologies. Regulators should develop a deeper understanding of system needs and services where BESS can be a solution. The RIIO (revenue = incentives + innovation + outputs) model explored under the UK system may be one potential model for encouraging Discoms to meet needs through cost-effective means.

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	Near-Term Recommended Actions	**Uniform technological readiness should be achieved across all state-level entities.** Governance mechanisms should be adopted by Discoms to provide an accurate status of current communications systems, such as SCADA systems. By establishing an accurate picture of the level of technological readiness across Discoms, a needs assessment can be undertaken and schemes created to ensure that all Discoms are capable of integrating software interventions and accurately and quickly reporting data from the distribution network. **Standardised data disclosure forms should be developed and data reporting mandated by regulations.** CEA should initiate a stakeholder engagement process to identify critical data, including load profiles, generation data, deployment data, and substation- and feeder-level data. The drive towards a more economic power system will be aided by quantifying the value of lost load and curtailments. The results can be communicated to SERCs through the Forum of Regulators.
	Medium-Term Recommended Actions	**Software interventions should be deployed enabling optimal operation of BESS.** As legacy SCADA systems are identified, upgraded and automated, a roadmap should be created to prepare for the integration of software to improve system intelligence. This will require system-level studies on area control errors and frequency deviation. Regulators should then devise and approve grid modernisation programmes, enabling the standardisation of communications across Discoms. **A publicly accessible central data repository should be created to collect and archive the reported state-level data.** Once standardised data-reporting forms are developed and reporting is mandated by regulation, state-level entities should regularly contribute data to a centralised repository. The repository can be maintained by a national entity, such as CEA or Grid-India.
Institutional Knowledge-Building	**Current Status**	Guidance for BESS Operators As India's power markets develop, battery assets will begin providing services for a range of applications. In the absence of a centralised market operator to set participation standards across uses, regulators should consider creating and providing guidance for battery operators to ensure obligations are met. Guidance should consider best practices for battery management across multiple markets, requiring minimum state of charge for participation across markets, or explore management of battery assets across multiple owners, such as Discoms and commercial and industrial end users.
		Long-Term Planning for Interconnection Multiple international electricity markets are experiencing lengthy delays with reviewing, approving and connecting battery assets to the grid due to the high volume of projects. Such connection delays will not be relevant within India until the volume of battery projects increases. However, system operators should consider connection frameworks to anticipate and avoid potential future delays.
	Near-Term Recommended Actions	**Institutional knowledge- and capability-building programmes should be developed for state-level entities.** State-level entities, including SERCs, SLDCs and Discoms, will require additional training and support to close knowledge gaps around BESS project planning, grid services, operation and contributions to resource adequacy. Resource adequacy planning and BESS's role in meeting resource adequacy needs should be aligned with SERC's regulatory evaluation processes. State-level entities should be informed on BESS's capability to provide not just energy, but capacity and non-wire alternative services. **National safety guidance for BESS should be solidified.** Existing safety guidance for grid-scale and BTM BESS is insufficient. For Discoms, developers and system integrators, a standard safety framework and permitting process will provide clarity during project planning, construction and operation. These can include outlining or adopting applicable standards developed internationally, such as IEC, NFPA or IEEE standards. Safety requirements and risk identification should be undertaken for transportation, installation, operation and decommissioning. A robust end-of-life management process should be established, with clear steps for handling waste.
	Medium-Term Recommended Actions	**A centralised BESS knowledge hub should be established.** Learnings from projects across the power system should be compiled into a centralised resource centre maintained by the MOP. This will enable the creation of benchmarks for project evaluation and provide access to all stakeholders for learning best practices in project planning, construction and operation.

6.3 Behind-the-Meter Storage

Behind-the-meter (BTM) batteries are battery storage assets that are connected through electricity meters to commercial, industrial and residential customers. BTM batteries are generally smaller than front-of-meter, grid-scale BESS assets, with a typical size of 3 kW to 5 MW; often BTM batteries are paired with rooftop solar or another captive variable generator. BTM batteries can provide a number of benefits for consumers, including reducing their bill through demand-side management, increasing demand flexibility and improving electricity reliability.[67] BTM batteries may be especially attractive investments for commercial or industrial consumers that experience a high frequency of outages that disrupt production.

Policy and market design interventions can have a significant impact on the adoption of BTM batteries, and multiple business and ownership models have been explored internationally (see Box 5). Given the wide range of economic and system benefits that BTM batteries can provide, power sector stakeholders, including policymakers, should undertake an in-depth analysis of the opportunities and pathways for BTM batteries for consumers in India.

Near-Term Recommended Actions

A catalogue of distributed projects should be developed. MoP should undertake an initiative to identify and compile the scale and scope of distributed BESS resources. This will provide insight into the ability of distributed BTM BESS to provide grid and utility services.

Medium-Term Recommended Actions

A framework should be developed to enable distributed BTM BESS to aggregate. Aggregation of distributed BESS resources can enable contributions to grid and utility services. These aggregated resources should be allowed to act as market participants to provide energy or ancillary services, under specified conditions. Aggregated BESS should also be enabled to contract with Discoms to improve flexibility and support demand response programmes.

Box 5 Behind-the-Meter BESS Pilot in Australia

The Neighbourhood Battery Initiative

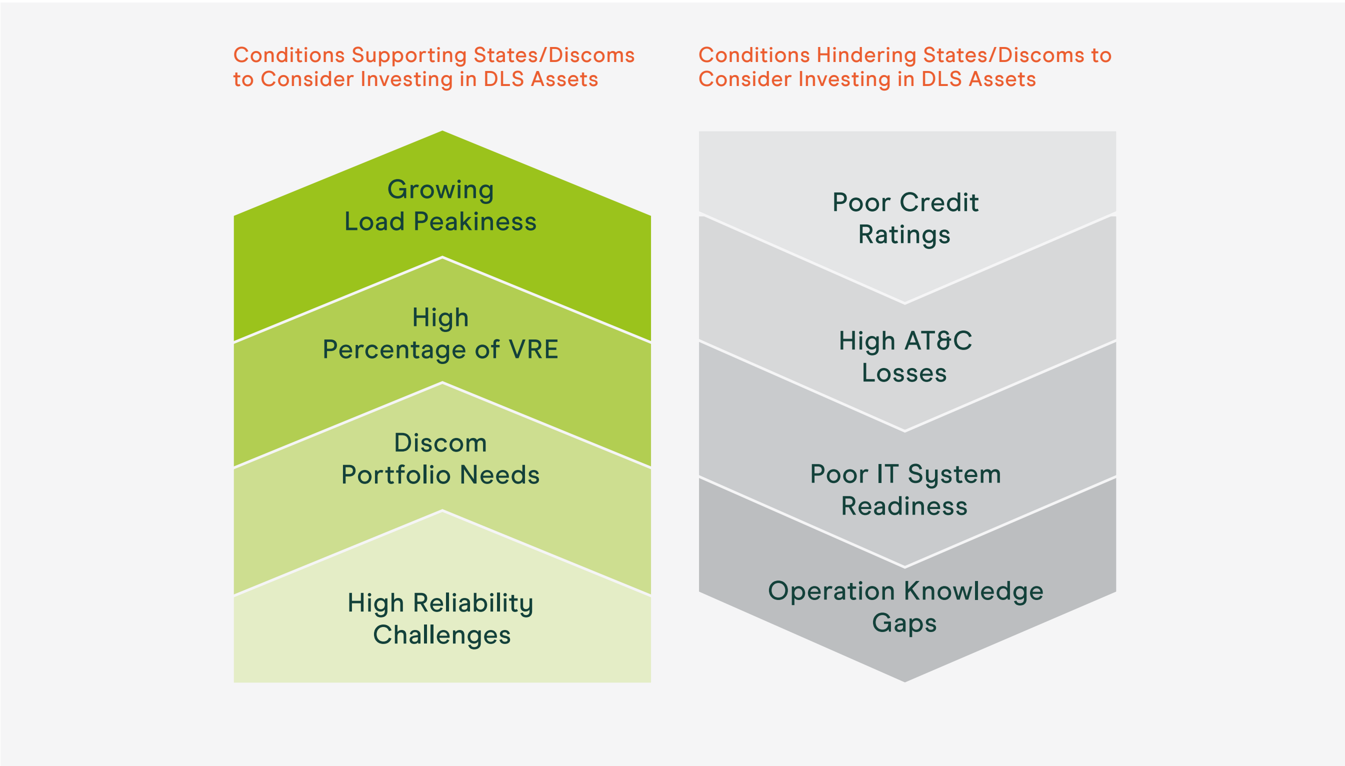
The state of Victoria in Australia launched the Neighbourhood Battery Initiative (NBI) in August 2021, with the intent of increasing distributed energy resources. The NBI aims to support understanding of the full range of benefits that neighbourhood-scale batteries can provide, as well as overcome barriers to deployment and inform regulatory reforms. The programme supports batteries between 100 kW and 5 MW and intends to enable further rooftop solar by deploying accompanying storage resources to shift load to higher demand periods. The NBI seeks to explore a range of ownership and operating models and is open to a variety of entities including distribution network service providers (DNSPs), third-party market participants, community organisations, or partnerships between such entities.[68] Findings from this initiative are released through a public knowledge hub.[69]

7.0 **Conclusion**

India has the opportunity and goal to ensure reliable electricity access and accelerate industrialisation. Growth in electricity generation is fundamental to maintaining robust economic development.

The country has set an ambitious target of meeting 50% of installed electricity generation capacity from nonfossil sources by 2030, underpinning the ambitious climate targets set by the government. As VRE capacity increases and represents a higher degree of the generation mix, a higher volume of energy storage will be required at all points across the electricity system to maintain a stable, resilient and cost-effective grid. Over 60 GW of storage will be required by 2030, and 42 GW will likely be met by battery storage. Innovations in BESS technology and declining global costs have made this technology an attractive solution, able to provide numerous values to system operators and transmission and distribution utilities. The GoI has taken important initial policy and regulatory steps, but rapid deployment will require further actions to improve stakeholder and Discom readiness. For example, BESS assets can be an important component within distribution networks, addressing major challenges Discoms anticipate. However, existing knowledge gaps around financing, integration and operation of this novel technology continue to be a barrier (see exhibit below).

Exhibit 27 Factors Influencing BESS Investment Decisions



BESS assets bring improved flexibility and reliability to distribution networks, but traditional regulatory frameworks for determining system investments are inadequate for evaluating these qualities. Greater access to markets and improved visibility into market values can help project planners and system integrators better understand battery economics. Growing electricity demand and increased VRE integration are driving needs for ancillary services, which fast-responding BESS assets are well suited to provide.

As India shifts from improving electricity access to improving the quality and reliability of electricity service, new regulatory frameworks and business models need to be developed and implemented to support these needs. Actions to improve the conditions for deploying innovative technology solutions will help India become a global leader and create lasting benefits for the country and the world.

8.0 Appendices

Appendix I: National Grid Storage Needs — Literature Review

As India aims to achieve 50% of nonfossil generation capacity installed by 2030, grid storage technologies are needed to integrate the country's emerging renewable-rich grid. The latest studies estimate a need of 60–90 GW (252–380 GWh) of grid storage by 2030 at the national level. Estimates of storage coming from PSP and BESS vary across studies. The Report on Optimal Generation Mix 2030, by the Central Electricity Authority (CEA 2023),[70] has highest estimate of PSP capacity, with 19 GW (128 GWh) projected to come on line by 2030. This is because of the recent focus by the MoP on supporting PSP deployment in India.[71] The CEA study estimates 42 GW (208 GWh) of BESS needs. The NREL 2021 study estimates the highest need for BESS technology at 84 GW (304 GWh) by 2030 and estimates 6 GW (76 GWh) of PSP needs by 2030.[72]

The primary driver for grid storage needs is integrating increasing amounts of variable renewable energy (VRE) resources, mainly solar and wind technologies, to meet increasing electricity demand. A combined VRE (solar and wind) capacity of 92–450 GW is expected to come on line by 2030. Exhibit 28 below summarises the grid storage needs and VRE projections by 2030 across these national studies.

Exhibit 28 National Grid Storage Needs and Likely VRE Capacity by 2030

STUDY NAME	2030 STORAGE NEEDS	PSP	BESS	VRE
CEA 2023	60 GW (336 GWh)	19 GW (128 GWh)	42 GW (208 GWh)	392 GW (292 GW solar + 100 GW wind)
LBNL 2021 — least-cost case	63 GW (252 GWh)	–	63 GW (252 GWh)	459 GW (307 GW solar + 152 GW wind)
NREL 2021 — reference case	90 GW (380 GWh)	6 GW (76 GWh)	84 GW (304 GWh)	450 GW (250 GW solar + 200 GW wind)

All of these studies use state-of-the-art grid modelling called capacity expansion modelling (CEM). Given future electricity demand and other system constraints, CEM predicts the optimal generation and storage resource mix. For example, CEM considers the cost of new generation technologies, storage technology prices, technical specifications, and current and future transmission network topology to develop an optimal amount of new generation and storage investments. Although the basic modelling construct is similar across these studies, the system topology, transmission network, technology costs and other input assumptions often vary, leading to varying results in new grid storage needs.

Distribution-Located Storage (DLS) Potential for Distribution Deferral in Cities

The MIT Future of Energy Storage study (MIT 2022) is the only study to date that has assessed the detailed local network topology to estimate the DLS potential for distribution capacity deferral.[73] However, the analysis is limited to a few urban areas in India. The authors estimate 29 GWh of DLS potential by 2030 for distribution system capacity deferral for four megacities in India: Bengaluru, Delhi, Kolkata and Mumbai (see exhibit below). While the MIT 2022 estimates focus on megacities, many other dense cities in India with rising peak demand could be candidates for DLS, and 29 GWh is likely at the lower end of DLS needs by 2030.

Exhibit 29 DLS Potential to Meet Distribution Capacity Deferral Needs for Megacities in India

	2019 DEMAND (TWH)	DLS POTENTIAL (GWH) BY 2030
Bengaluru	10	3
Delhi	23	14
Kolkata	4	1
Mumbai	15	11

Source: MIT

Appendix II: BESS Value Modelling Assumptions and Methodologies

Exhibit 30 BESS Cost, Financing and Technical Assumptions

ASSUMPTION	REFERENCE SCENARIO
BESS System Cost	• Capex: ₹6.5 Cr/MW • Opex: ₹150 lakh per year
Financing	• 70% debt, 30% equity with 16% return on equity and 25% tax for all scenarios • 10% WACC – 9.5% interest rate on debt; market-rate estimate according to Ujwal Discom Assurance Yojana (UDAY)
BESS Technical Assumptions	• Round-trip efficiency of 85% • 12-year lifetime • 20% degradation over life • Two cycles per day, equivalent to 40 MWh dispatchable storage capacity per day

Exhibit 31 Value Stack Assumptions

FRAMEWORK	VALUE STREAM	DETAILS	ASSUMPTIONS	
			REFERENCE SCENARIO	HIGH REVENUE SCENARIO
Value stack that is currently monetisable (included in analysis showing viability gap)	**Energy arbitrage on day-ahead market (DAM)**	Indian Energy Exchange (IEX) historical DAM hourly price data used for the analysis. Escalation rate of 3.5% assumed, equivalent to the increase in the compounded annual growth rate (CAGR) of the weighted average variable costs of CERC-regulated thermal stations. Historical data showed almost identical price data across states/zones due to minimal transmission congestion. Congestion may increase as more renewables come on line in different regions.	Hourly historical prices from the IEX for October 2022–September 2023.	5% higher revenue compared with reference assuming increased price variability due to more renewables causing more extreme peaks and some transmission congestion. Plexos fundamental price forecasting variance between states is 20% (average +/- 10%), but this underestimated prices and peaks compared to IEX.
	Energy arbitrage on high-price day-ahead market (HP-DAM)	This market is still in its early days. Historical price data used from April 2023 to June 2023 (since the launch of HP-DAM). 3.5% escalation rate assumed.	Historical prices from IEX for April–June 2023, extended for a year.	5% higher revenue compared with reference scenario; same reasoning as DAM.
	Tertiary Reserve Ancillary Service (TRAS)	We assumed the remaining battery capacity after daily arbitrage is available for TRAS. There is a lack of price transparency and data on frequency of TRAS deployment. NRPC has price data for day-ahead, real-time and emergency TRAS markets for three weeks in August–September 2023 (weeks 19, 20, 21). There was no public data on dispatch frequency, but we learned through discussions with stakeholders that TRAS is required daily in peak seasons. Battery conservatively assumed to have enough charge for dispatch in 60% of available hours each day. 3.5% escalation rate assumed.	For 67% of the year: average emergency compensation margin (TRAS-Up minus TRAS-Down): ₹3.2/kWh. Average day-ahead and real-time commitment charge: ₹0.2/kWh. Battery dispatched to TRAS every day since TRAS for emergencies at lower margins is seen in all weekly reports.	For 25% of the year: average day-ahead compensation margin (day-ahead TRAS-Up minus average energy DAM price): ₹11.7/kWh. Day-ahead TRAS at higher margins is needed during peak seasons. For 42% of the year: average emergency compensation margin from Reference scenario: ₹3.2/kWh. Average day-ahead and real-time commitment charge of ₹0.2/kWh.
	Distribution capex deferral	Our assessment of DAM and HP-DAM data compared to local load on a few feeders showed that peak hours matched up in the evening hours, so we can assume batteries can defer upgrades. Further capex deferral modelling details below.	Feeder is not overloaded and does not need upgrades.	**Capex Deferral Scenario:** Transformer and circuits are overloaded and need upgrades, battery shaves peak to avoid upgrades.

Continued »

FRAMEWORK	VALUE STREAM	DETAILS	ASSUMPTIONS	
			REFERENCE SCENARIO	HIGH REVENUE SCENARIO
Value stack that could be monetisable by 2025 with clarity on prices and rules (not included in viability gap analysis)	SRAS	Data is currently lacking in terms of price transparency and how a storage asset could get committed. Storage use for SRAS is supporting early adoption in other international markets (UK, California), where batteries used for SRAS do not also participate in arbitrage due to frequency of dispatch for SRAS. Price data averaged from NRPC and ERPC weekly reports.	Compensation charge of ₹3/kWh; performance incentive of ₹0.7/kWh. Assuming the battery is used entirely for SRAS as a stand-alone value stream, revenues make up 50% of battery cost.	
	DSM	There is data from NRPC and ERPC on historical statewide deviations and amounts payable and receivable, though modelling how a battery could reduce these deviation costs is out of this report's scope. BESS would need to be dispatched specifically for this purpose since deviations occur constantly, and so the battery would forgo arbitrage and ancillary service revenues.	–	–

Energy Arbitrage Modelling Methodology

The model works by finding the charge-discharge hour-pairs that will produce the highest revenue from the hourly price data inputs. The model structure resembles the battery model logic from the New York Independent System Operator (NYISO) demand curve parameters report.[74] Like the NYISO model, the arbitrage model uses charge-discharge hour-pairs to guarantee that energy from charging and discharging will be balanced. It also limits the battery's energy capacity so its state of charge (SOC) stays between 0% and 100%. The model assumes all efficiency penalties are applied during discharge; no self-discharge occurs; and that if a battery charges or discharges in an hour, it does so at its power rating. A round-trip efficiency of 85% is applied.

For every hour in the price data, the model calculates the potential revenue from charging in the current hour and discharging in the subsequent hours over a 12-hour loop. After calculating the revenue for each potential charge-discharge pair, it continually takes the maximum of all possible revenues, allowing only one discharge hour for a charge hour. For example, if the maximum revenue comes from charging at 12 a.m. and discharging at 6 a.m., the model will not consider any additional revenue from discharging at 7 a.m. for the same 12 a.m. charge. The model then checks to make sure no SOC violations occur. A two-hour battery is physically unable to charge for three hours in a row at its power rating, as an example, and so for any periods where the battery would overcharge, the model takes only the two hour-pairs of that section with the maximum revenue.

Optimisation of Looping Timescale for Arbitrage Model

To maximise potential revenue through arbitrage, the optimal number of hours to 'loop ahead' in the model was determined by evaluation. As can be seen in Exhibit 32, the looping interval does impact monthly revenue. For July, an 11-hour looping interval maximises revenue, while for December a 13-hour looping interval maximises revenue. Higher revenue correlates to a greater number of hours dispatched. A 12-hour looping interval was therefore chosen for all months of the year from July 2022 to June 2023.

Exhibit 32 Model Interval Analysis for July and December 2022 in IEX's N2 region and DAM

JULY 2022, N2 DAM REVENUE (₹ LAKH)	8-HOUR LOOP	11-HOUR LOOP	12-HOUR LOOP	13-HOUR LOOP	14-HOUR LOOP	24-HOUR LOOP	36-HOUR LOOP
20 MW (40 MWh)	81.0	84.0	84.2	84.3	82.9	60.9	39.2
20 MW (80 MWh)	139.3	148.5	149.8	150.56	149.3	114.4	72.3
20 MW (120 MWh)	171.8	189.7	192.0	193.8	193.6	154.7	97.2

DECEMBER 2022, N2 DAM REVENUE (₹ LAKH)	8-HOUR LOOP	10-HOUR LOOP	11-HOUR LOOP	12-HOUR LOOP	13-HOUR LOOP	24-HOUR LOOP	36-HOUR LOOP
20 MW (40 MWh)	98.6	98.8	98.8	84.3	65.0	54.8	33.7
20 MW (80 MWh)	152.7	156.0	156.4	137.5	113.7	99.0	57.7
20 MW (120 MWh)	165.6	174.0	174.7	163.4	148.2	134.5	74.9

HP-DAM Projection Summary

To allow comparison with the potential arbitrage revenue from participation in the DAM only versus participation in both the DAM and HP-DAM from October 2022 to September 2023, hourly prices for each market were needed. Due to the significant number of hours with a price of zero in the HP-DAM in recent months and the knowledge we gained from stakeholder engagement that some Discoms prefer shedding load over buying from the HP-DAM, we conservatively estimated the revenue potential of the HP-DAM by making it zero for six months (September to February).

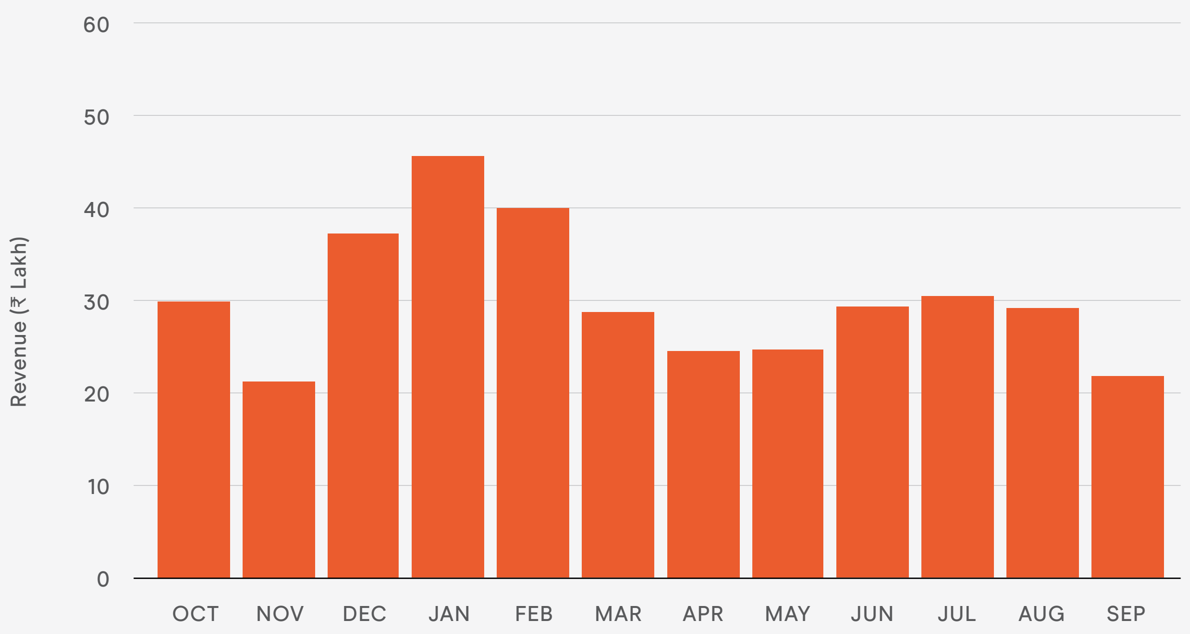
Historical HP-DAM price data was used for April to August 2023. HP-DAM price data was extrapolated for March 2023 using trends from the May 2023 HP-DAM price data. The HP-DAM data was projected by adding the 'average difference' to existing DAM prices, whenever the DAM prices reached the price ceiling. The average difference parameter is the mean of the DAM price subtracted from the HP-DAM price each hour, excluding when the HP-DAM is zero and when the HP-DAM peaks to its price ceiling. The average difference for the month of May was used for the HP-DAM projection, in accordance with the seasonal trends documented in a 2020 NREL report.[75]

The HP-DAM data for April 2023 varied significantly from May and June, likely due to it being the first full month of the HP-DAM, so it was not used in the HP-DAM projection. The average number of 'super peaks', or when the HP-DAM reaches its price ceiling, was also calculated, as was the average duration of the peak for the month of May. To mimic this peaking behaviour in the projected HP-DAM prices, randomly placed super peaks were added for the month of March using the average occurrence and duration from May.

Seasonal Variation in Arbitrage Revenue

There are clear monthly differences in revenue potential, which could impact how a battery is dispatched throughout the year and cause seasonal fluctuations in revenues. As more ancillary services and DSM penalty reductions become monetisable, dispatch decisions between these value streams may also vary by season. Comparing monthly revenues in Exhibit 19 to the average hourly price profiles for each month in Exhibit 33 illustrates that a higher revenue correlates to a greater monthly price fluctuation. An important factor to note is that until March 2023, the maximum price ceiling on the DAM was ₹12,000, but starting in April it dropped to ₹10,000. The October 2022 to March 2023 price data was scaled to a ⊙10,000 price ceiling to allow for consistent monthly comparisons for the year. The seasonal hourly price variation seen in the year of October 2022 to September 2023 is consistent with previous years; NREL reports that IEX prices from 2016 to 2019 demonstrate similar trends.[76] June through October correlate to both higher electricity demand and higher renewable generation, which helps explain the seasonal price profiles.

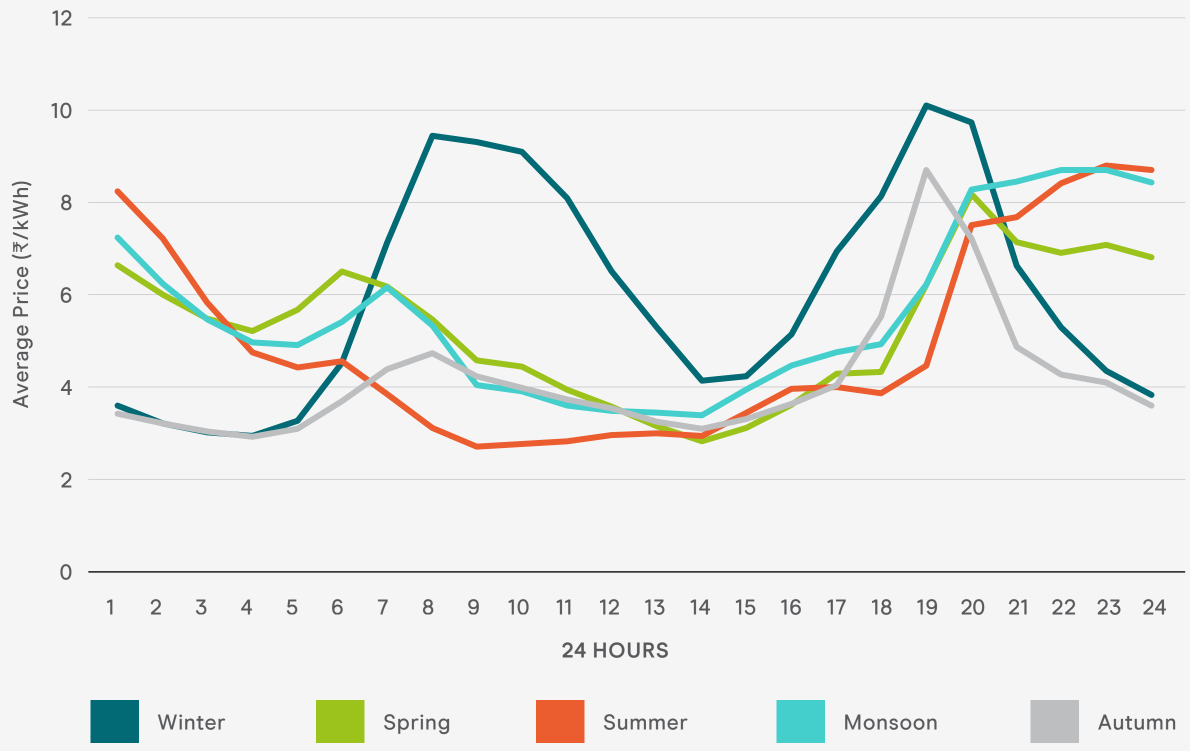
Exhibit 33 Monthly Arbitrage Revenue Potential



Note: Values calculated from the DAM in IEX's N2 region for a 10 MW (20 MWh) battery from October 2022 to September 2023, with October 2022 to March 2023 prices scaled to ₹10,000 price ceiling to maintain consistency across the full annual analysis period.

Exhibit 34 (see next page) shows daily price profile variation by season. Winter has two large price peaks during a day, due to water heating and space heating in the morning and evening. The higher prices at the beginning and end of the day in the summer months are consistent with the steep and costly ramp rates that a large penetration of solar creates for thermal generators, with air conditioning needs continuing through the night. Monsoon has similar temperatures to summer, so it has a high evening peak due to air conditioning. Spring and autumn have smaller morning peaks and larger evening peaks.

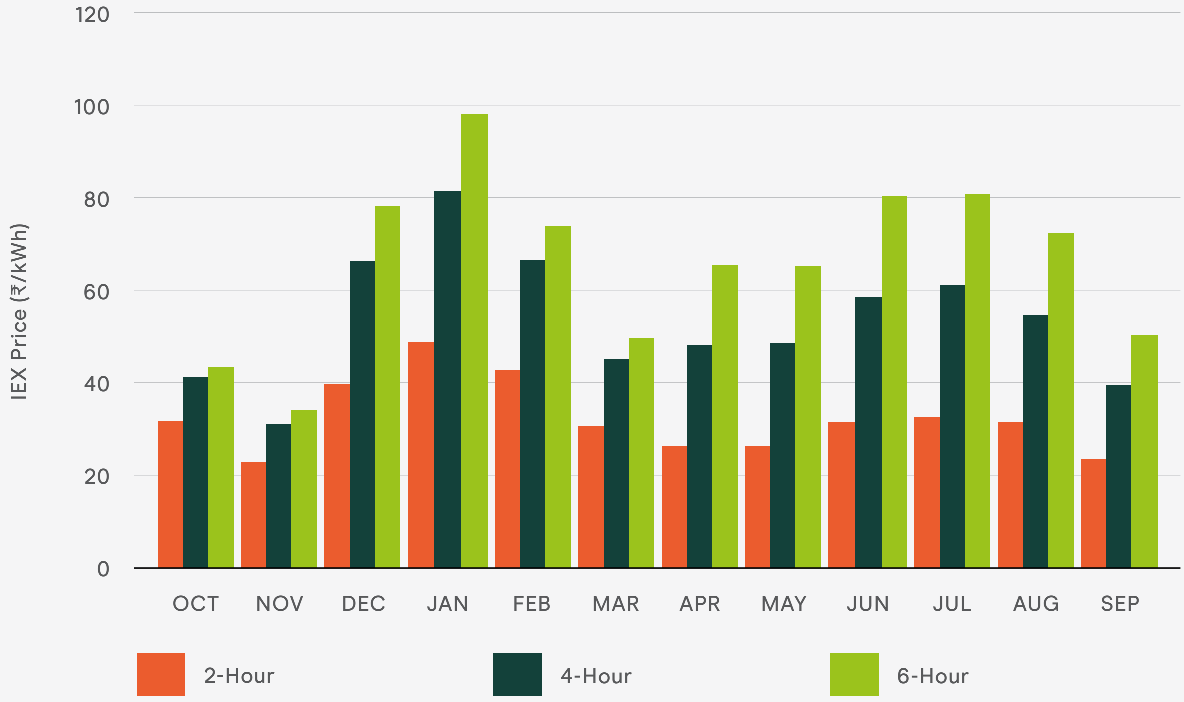
Exhibit 34 Average Hourly DAM Price for Each Season from October 2022 to September 2023 in IEX's N2 Region



Note: Values calculated for a 10 MW (20 MWh) battery from October 2022 to September 2023, with October 2022 to March 2023 prices scaled to ₹10,000 price ceiling. In this exhibit, seasons are calculated by averaging monthly prices: winter is December–February, spring is March–April, summer is May–June, monsoon is July–September and autumn is October–November.

The duration of the battery impacts the yearly revenue potential as well as the number of cycles the battery is dispatched. Our optimisation results in a battery cycling 1.55 times a day to maximise arbitrage revenues, with the rest of the capacity available for ancillary services. Because a higher-duration battery can charge for more hours when the price is low and then discharge for more hours at a high price in one cycle, a six-hour battery would make more yearly revenue with fewer dispatched cycles than a four-hour or a two-hour battery and have a longer life span. However, a longer-duration battery requires more upfront capital to install and is found to have a larger overall viability gap today. Exhibit 35 demonstrates the duration dependency of the seasonal revenue trends. A two-hour battery creates more revenue in winter with the two shorter peaks, and as the battery's duration increases it can capitalise on a greater share of the high prices in the evening peak. The July and June revenue potentials are the second largest after January for the six-hour battery.

Exhibit 35 Monthly Revenue Potential as a Function of Battery Duration



Note: Modelled for a 2-hr (10 MW, 20 MWh), 4-hr (10 MW, 40 MWh) and 6-hr (10 MW, 60 MWh) battery. Values calculated from the DAM in IEX's N2 region from October 2022 to September 2023, with October 2022 to March 2023 prices scaled to ₹10,000 price ceiling.

Ancillary Services Modelling Details

Stand-Alone SRAS

We assume batteries used for SRAS do not also participate in arbitrage due to frequency of dispatch for SRAS, which is consistent with other markets. SRAS providers receive a compensation charge for providing SRAS-Up regulation and pay a drawal or charging cost for providing SRAS-Down regulation. SRAS providers also receive a performance incentive for responding on time to the control signals for SRAS, with the incentive varying depending on how the provider performs.[77] Public data on system requirements (prices and times that the service is generally required) for SRAS-Up and SRAS-Down services was not available, so we conservatively estimated that the battery would have sufficient charge levels to provide SRAS-Up or SRAS-Down services in 60% of hours, and that it would provide an equal amount of both services.

Arbitrage and TRAS

Generally, only TRAS-Up (injecting supply) is seen in day-ahead and real-time markets, where the supplier is compensated for providing this service. However, there are emergencies where TRAS-Down (drawal) is needed, and the participant is charged for drawing energy. We assume remaining battery capacity after participation in arbitrage is available for TRAS. Providers receive a compensation charge for providing TRAS-Up reserves, and a commitment charge for being available to provide reserves.[78] Again, we conservatively assume that the battery would have sufficient charge levels to provide TRAS in 60% of available hours, due to a lack of data on times of day that the service would likely be needed.

Capex Deferral Modelling Details

The most common upgrades for overloaded substations are transformer upgrades and feeder line replacement or reconductoring. We obtained transformer cost data from public Discom compliance documents and used the MIT 2022 study to estimate the cost of circuit replacement and reconductoring. In areas with space constraints such as Delhi or Mumbai, reconductoring is a more suitable solution than building new wires for overloaded circuits, even though it is more expensive. We assumed an average of line replacement and reconductoring costs for our example.

For BESS to defer capex upgrades, the battery would need to reduce local peaks. This may happen through arbitrage dispatch if local peaks match peaks on the IEX market, or times when ancillary services are required. However, if the peaks do not match up, the battery would need to be dispatched to reduce local peaks to avoid capex upgrades and may need to forgo revenues from arbitrage and ancillary services. This forgone value would need to be compared with the cost of distribution upgrades to assess the optimum dispatch for the battery to maximise value. Exhibit 36 compares average daily load for a representative substation feeder with IEX prices. Since the distribution peak occurs in the same hours as the IEX price peak (8 p.m.–11 p.m.), arbitrage in this month would also shave the local system peak. Discoms will make more detailed projections on expected maximum peaks throughout the year to ensure the battery can support these use cases if deferring capex upgrades.

Exhibit 36 Illustrative Feeder Load Compared with IEX Price Data, July 2022

Note: Data points in graph reflect daily averages from July 2022. | **Source:** IEX, Stakeholder Engagement

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