# Policy and Regulatory Environment for Utility-Scale Energy Storage: India

Amy Rose, Claire Wayner, Sam Koebrich, David Palchak, and Mohit Joshi

*National Renewable Energy Laboratory*

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# Preface

This report—Policy and Regulatory Environment for Utility-Scale Energy Storage: India—is part of a series investigating the potential for utility-scale energy storage in South Asia. This report is the first in a series of country-specific evaluations of policy and regulatory environments for energy storage in the region. These evaluations apply the previously developed Energy Storage Readiness Assessment[1] to evaluate the policy and regulatory environment for energy storage in India. Forthcoming reports will expand this analysis to other countries in South Asia. These evaluations are designed to provide insights on the opportunities and barriers for energy storage growth and deployment in each country.

A complementary component of the policy and regulatory analysis for countries in South Asia consists of techno-economic analysis to understand the drivers of energy storage investments in the region. Using NREL's power system planning and operational models of South Asia, this analysis will identify potential storage applications and growth opportunities under various cost, policy, and demand growth scenarios. In addition, the regulatory and policy barriers and incentive mechanisms identified in the energy storage readiness assessments will be incorporated into the modeling to understand their impact on energy storage deployment and operation.

Together these studies will inform the applications and value of energy storage for power systems in South Asia, and policy and regulatory pathways to realize this value. The results of these collaborations are forthcoming and will soon be available online.

[1] For more information, see the forthcoming publication by Rose, A., S. Koebrich, D. Palchak, I. Chernyakhovskiy, and C. Wayner: R*eadiness Assessment Framework for Utility-Scale Energy Storage.*

# Acknowledgments

The authors are greatly indebted to several individuals for their thoughtful feedback and guidance, including Mark Pituch and Ruth Ku (U.S. Department of State). And thank you to Jeff Logan and Ilya Chernyakhovskiy (NREL) as well as Pankaj Batra (SARI/EI/IRADe) and Kadam Ravindra (Central Electricity Regulatory Commission) for their reviews. Liz Breazeale provided editorial assistance. Any errors and omissions are solely the responsibility of the authors. This work was funded by the U.S. Department of State, Bureau of Energy Resources.

## List of Acronyms

| | |
|---|---|
| AGC | automatic generation control |
| AREAS | Association of Renewable Energy Agencies of States |
| CEA | Central Electricity Authority |
| CERC | Central Electricity Regulatory Commission |
| BNEF | Bloomberg New Energy Finance |
| DPV | distributed photovoltaic |
| FERC | Federal Energy Regulatory Authority |
| FTM | front-of-the-meter |
| IEGC | Indian Electricity Grid Code |
| IESA | India Energy Storage Alliance |
| IEX | Indian Energy Exchange |
| ISTS | interstate transmission system |
| MNRE | Ministry of New and Renewable Energy |
| MoP | Ministry of Power |
| NLDC | National Load Dispatch Center |
| NREL | National Renewable Energy Laboratory |
| NYSERDA | New York State Energy Research and Development Authority |
| POSOCO | Power System Operation Corporation |
| PSH | pumped storage hydropower |
| RLDC | Regional Load Dispatch Center |
| Rs | Indian rupee |
| SECI | Solar Energy Corporation of India |
| TTC | total transfer capacity |

# Executive Summary

India's electric power system is in the midst of a dramatic shift. Government initiatives to provide round-the-clock power and increase the share of renewable energy in the electricity sector are transforming the country's electricity supply. On the demand side, government programs and economic growth are driving simultaneous growth in overall electricity demand and shifts in the daily patterns of demand. The combined changes in the mix of generation resources and patterns of electricity demand present new challenges and opportunities in operating and maintaining a reliable power system. Energy storage has the potential to help meet these challenges and accelerate India's energy transition. Declining costs for some energy storage technologies make them increasingly cost-effective solutions to provide a wide range of grid services. Previous analyses of energy storage in India have identified a number of potential applications for storage at the bulk system level, including energy arbitrage, ancillary services, and transmission network support.

The potential for storage to meet these needs depends on many factors, including physical characteristics of the power system and the policy and regulatory environments in which these investments would operate. This report applies an Energy Storage Readiness Assessment[2] developed by NREL for policymakers and regulators to identify priority areas of focus as they continue to develop the appropriate suite of policies, programs, and regulations to enable storage deployment. This assessment uses a simple evaluation scheme (Figure ES-1) to identify the barriers and opportunities for utility-scale energy storage within India's policy and regulatory environment.

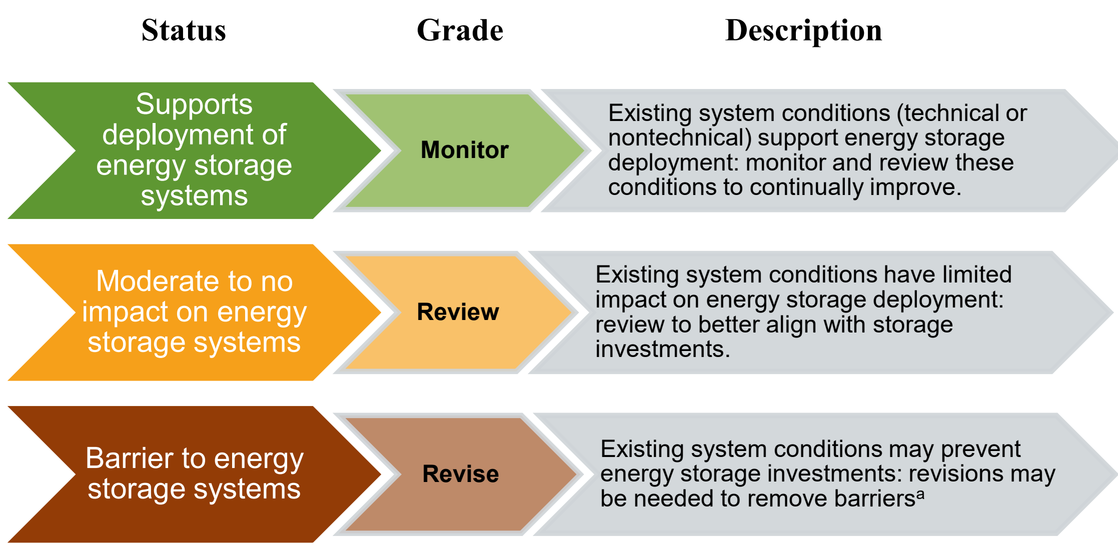


**Figure ES-1. Evaluation scheme for energy storage readiness assessment**

[a] Revisions may not be recommended for system characteristics where conditions that are good for the overall system (i.e., high levels of system flexibility and reliability) may not support energy storage investments.

[2] For more information on the Readiness Assessment itself, see Rose et. al. 2020a.

Table ES-1 summarizes the results of the energy storage readiness assessment for India. In general, the system characteristics of the Indian power system are favorable for energy storage (green), while the policy and regulatory frameworks are largely moderate (orange) or unsupportive (red); however, this is mostly due to an absence of storage considerations in current frameworks rather than poorly designed energy storage policies or rules.

**Table ES-1. Results of Readiness Assessment for India**

| Topic | No. | Criteria | Assessment | Notes |
|---|---|---|---|---|
| System Characteristics | 1 | Low or decreasing load factor in electricity demand | | Load factors are decreasing, as are daily and seasonal market price fluctuations |
| | 2 | Inadequate or costly provision of ancillary services | | System experiences shortages of fast-responding resources |
| | 3 | Inadequate or costly supply options during peak demand periods | | Storage is increasingly cost-competitive with gas and coal plants for peak demand management |
| | 4 | Increasing levels of transmission congestion | | Limited congestion overall but large RE parks cause localized congestion |
| | 5 | Proposed network upgrades with low anticipated utilization | | Changes in net load result in underutilized transmission capacity |
| | 6 | Low flexibility in the generation mix | | Increasing flexibility needs will exceed capabilities of existing thermal fleet |
| | 7 | Increasing curtailment of variable renewable energy | | Curtailment is limited, but storage could reduce strain on thermal fleet required to back down |
| Policy | 8 | Inclusion of storage in energy policy and master plan | | Storage included in national planning but absent from national energy policy |
| | 9 | Targets for storage deployment | | No specific targets or programs for utility-scale storage |
| | 10 | Energy strategy promotes operational flexibility | | Recent initiatives have added flexibility, but opportunities for storage to meet flexibility needs are limited |
| | 11 | Support organized knowledge sharing and delivery for scale up and replication | | Limited government facilitation while research and development funding is nascent but increasing |
| | 12 | Domestic industrial policy supports storage manufacturing | | Currently limited to electric vehicle applications |
| | 13 | Targeted support to early adopters | | Existing support limited to hydropower or hybrid projects |
| Regulation | 14 | Utilities and private developers allowed to make storage investments | | Ownership rules have been discussed but not formalized |
| | 15 | Interconnection processes give storage the right to interconnect and obtains transmission service | | Both stand-alone and hybrid storage projects allowed to interconnect |
| | 16 | Promotion of high quality standardized technologies through safety standards for storage technologies | | Work underway to establish safety standards and procedures for storage |
| | 17 | Operating requirements for fast-responding assets | | Energy storage not eligible to provide most services |
| | 18 | Electricity services charges reflect value of and increase price transparency for energy services | | Advanced pricing mechanisms for energy and other services are limited |
| | 19 | Storage able to compete with other grid assets to provide multiple services | | Some storage applications are limited through explicit restrictions or lack of compensation mechanisms |
| | 20 | Storage able to receive revenue for providing multiple services | | Compensation for services beyond power provision is not available or not well-defined |

Note: Green: supports storage deployment; Yellow: moderate to no impact on storage; Red: barrier to storage

The technical system characteristics of the Indian power system are favorable for energy storage to reduce operating costs and improve system reliability. There are opportunities for storage to provide energy arbitrage, ancillary services, and potentially defer transmission investments. India's energy policy framework largely excludes energy storage from key policy programs and initiatives. The current lack of policy guidelines and supporting programs to direct the scope and scale of energy storage deployment present a barrier for investments. Existing regulations present a useful framework for enabling energy storage deployment. However, current regulations that do not facilitate storage from providing services or earning revenue for those services present a barrier to maximizing the value of storage investments.

If Indian policymakers want to broaden the role of energy storage, an important first step is to include energy storage in national energy policies and programs. This can accelerate the identification and implementation of appropriate energy storage solutions and enable regulatory authorities to begin implementing necessary regulations to achieve these policy outcomes. Chief among these in India are regulations that enable energy storage to provide a wider range of grid services and accompanying compensation mechanisms—whether through regulated tariffs or markets—to earn revenue for those services.

As the Indian power system continues to transform, energy storage technologies can contribute to meeting evolving system needs for flexibility and reliability. Comprehensive policy and regulatory frameworks can enable economically viable storage technologies to meet these needs.

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# 1 Introduction and Background

## 1.1 Purpose of Report

The electric power sector in India is transforming from a system with large centralized thermal and hydro power plants to one with higher levels of variable renewable energy, higher amounts of distributed energy resources, and shifting demand patterns. This transformation presents new challenges in balancing supply and demand. Energy storage has the potential to help meet these challenges, and declining costs for some energy storage technologies make it an increasingly cost-effective option to do so (NREL 2020). However, the potential for energy storage deployment on the grid depends on many factors, including physical characteristics of the power system and the policy and regulatory environments in which these investments would operate.

This report has been prepared by the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of State to inform a broader dialogue around the future direction of India's approach to enabling energy storage investments. This report applies an Energy Storage Readiness Assessment[3] developed by NREL for policymakers and regulators to identify priority areas for focus as they continue to develop the appropriate suite of policies, programs, and regulations to enable energy storage deployment.

This assessment aims to identify the barriers and opportunities for utility-scale energy storage within India's policy and regulatory environment. As such, the report does not address applications for distributed energy storage[4] (i.e., connected to the low- and medium-voltage networks), rural grid or stand-alone systems, or electric mobility. Importantly, the report does not inform whether energy storage is the best solution, among a wide range of possible technical and nontechnical interventions, to meet system needs.

## 1.2 India's Changing Energy Landscape

India's electric power system is in the midst of a dramatic transformation. On the supply side, the Government of India has launched a number of initiatives to eliminate supply deficits across the country and increase the share of renewable energy in the electricity sector. Chief among these are the goals to achieve 175 GW of renewable energy by 2022 and 450 GW by 2030 (Press Trust of India 2020). As a result, India's installed capacity has more than doubled over the past decade, and the share of capacity from renewable energy has increased from 10% in 2010 to 23% in early 2020 (GOI 2012a; CEA 2020a). Nationally, renewable energy accounts for 10% of electricity generation (CEA 2020b; CEA 2020c), but individual states are already experiencing annual and instantaneous penetration levels as high as 23% and 90%, respectively (Narasimhan 2019).

On the demand side, government programs and economic growth are driving simultaneous growth in overall electricity demand and shifts in the daily patterns of demand. Over the past 5 years, the annual growth rate in electricity consumption has exceeded 6%, driven by the

[3] For more information on the Readiness Assessment itself, please see Rose et. al. 2020a.

[4] See Zinaman et. al. 2020 for a detailed discussion of policy and regulatory design of distributed energy plus storage systems.

commercial and industrial sectors and national programs to increase electricity access among households (CEA 2018; REC India 2020). This growth was interrupted in 2020 as the COVID-19 pandemic led to a significant drop in economic activity, and electricity demand fell by 30% in April 2020. Despite this drop, electricity demand is projected to return to previous levels by 2022 and more than double by 2050 (Bridge to India 2020).

At the same time that total demand is growing, the country is experiencing changes in the patterns of electricity demand. The government's Grid-Connected Rooftop and Small Solar Power Plants Programme catalyzed investments in distributed photovoltaic (DPV) systems. As of September 2019, cumulative DPV capacity in India was 5,252 MW, exceeding the program's 2019–2020 target of 4,200 MW. The government has since approved Phase II of the program to achieve 40,000 MW of DPV by 2022 (MNRE 2019). Notably, over 70% of DPV capacity to date is deployed in the commercial and industrial sectors, resulting in reduced electricity demand growth in these sectors relative to residential and agricultural sectors (BNEF 2017; GOI 2019a). Already the Central Electricity Authority (CEA) has noted a decrease in the country's annual load factor, indicating the shape of daily electricity demand is becoming more variable throughout the day, with higher peaks in evening demand and lower troughs mid-day (CEA 2018). Electrification of other sectors may further influence demand patterns. Under Phase II of the Faster Adoption and Manufacturing of Electric Vehicles in India Scheme, the government is supporting adoption of thousands of electric buses and passenger cars, as well as the creation of charging infrastructure (GOI 2019b).

The combined changes in the mix of generation resources and patterns of electricity demand are impacting the technical and economic conditions for India's electric power sector. As the resource mix shifts toward higher penetrations of renewable energy, increased system flexibility is required to maintain a constant balance of supply and demand while, at the same time, the share of dispatchable resources available to provide load-following services is decreasing. The International Energy Agency estimates India will be the country with the greatest need for additional flexibility in the coming decades (IEA 2020a). Increased generation from inverter-based resources also raises concerns about frequency control, as the magnitude and rate of change in frequency swings may increase (CERC Expert Group 2019). Programs to accelerate renewable energy deployment such as the Ultra Mega Solar Park scheme have led to issues with network stability and congestion, in some cases, as large volumes of renewable energy generation are injected into the network from a single location (POSOCO 2020a). Finally, increased penetrations of generation from zero-marginal cost resources with variable patterns of output may affect daily electricity price patterns, resulting in increased price volatility and frequency of very low-priced hours (LBNL 2018). These changes can meaningfully impact long-lasting investment and operational decisions for supply.

## 1.3 The Role of Energy Storage in India's Energy Transition

Energy storage has the potential to help meet these challenges and accelerate India's energy transition. Previous analyses of energy storage in India have identified a number of potential applications for storage at the bulk system level. Table 1 shows the range of services identified and the timescale at which these services would be provided.[5]

[5] For further discussion on the services energy storage can provide at the bulk system level, see Rose et al. 2020a.

**Table 1. Types of Services Energy Storage Can Provide at Bulk-System Level**

| Type of Service | Description | Timescales<br>Text block: response time<br>Shaded area: response duration<br>mSec / Sec / Min / Hr / Day | Previous Analysis |
|---|---|---|---|
| Energy and Capacity | Effectively increase available load during periods with excess generation for peak demand management and reducing renewable energy curtailment | Energy Arbitrage | IESA 2019; CEA 2020d; BNEF 2019; CERC 2017; Rose et al. 2020b |
| | Stabilize net electricity demand to minimize thermal unit ramping and cycling and minimize errors in renewable energy and demand forecasts | Load Following | BNEF 2019; CERC 2017 |
| | Provide capacity to meet generation requirements during peak loading periods and contingency events | Resource Adequacy | CERC 2017; Rose et al. 2020b |
| Ancillary Services | Provide power to maintain generation-load balance and prevent frequency fluctuations | Frequency Regulation | IESA 2019; IEA 2020b; CERC 2017 |
| | Inject or absorb incremental voltage to maintain voltage stability on the transmission system | Voltage Regulation | CERC 2017 |
| | Provide immediate response to maintain electricity output during contingency events | Spinning Reserve | CERC 2017; Rose et al. 2020b |
| | Maintain electricity output during contingency events within a short time period | Non-spinning Reserve | CERC 2017 |
| | Start main turbine of grid-connected generator or feed power into the grid so that other plants can start up and restore power | Black Start | CERC 2017 |
| Transmission | Provide extra capacity to meet anticipated load growth for the purpose of delaying, reducing, or avoiding transmission system investments | Upgrade Deferral | IESA 2019; IEA 2020b; CERC 2017; Rose et al. 2020b |
| | Absorb power to reduce network congestion | Congestion Management | IEA 2020b; CERC 2017 |

There are a number of different technologies under consideration to provide these services. **Pumped storage hydro** (PSH) is the primary form of energy storage in India. Of the nine existing PSH facilities, seven are operable with a total operable capacity of 3.3 GW, accounting for less than 1% of India's installed capacity (CEA 2019a; CEA 2020a). These plants are already providing load following and resource adequacy services. An additional 2.6 GW of PSH is under construction, and a further 3.8 GW is under survey for development (CEA 2019a); however, expansion of PSH may be limited by concerns around displacing agricultural lands, forests, and communities, in addition to interstate disputes over water rights.

More recently, battery technologies are being piloted in India to serve a wide range of grid applications. Batteries can respond to signals to charge or discharge in less than a second, making them suitable for fast-response grid stability services such as frequency regulation. They can also be scaled to meet large demand needs by configuring multiple batteries in parallel with a discharge duration of minutes to hours, enabling them to provide longer-duration services such as resource adequacy, energy arbitrage, and load following.

**Lithium-ion batteries** are the most widely used battery storage option today and control more than 90% of the global grid battery storage market (Mongird et al. 2019). Compared to other battery technologies, lithium-ion batteries have a high energy density, are lightweight, and cost less. These cost and performance advantages make lithium-ion the primary battery storage option being considered in India today. The Greening the Grid program is piloting lithium-ion—along with advanced lead acid and flow batteries—to provide grid support and reduce renewable curtailment (USAID 2020). Tata Power has deployed a 10-MW, 10-MWh battery storage system to provide grid stabilization, peak load management, and enhanced flexibility and reliability (AES 2019). Several studies find the potential market for grid-scale lithium-ion batteries could grow significantly. Bloomberg New Energy Finance (BNEF) estimates lithium-ion batteries will become cost-competitive with open-cycle gas turbine plants to meeting peak demand in India by 2025 (BNEF 2019). Lithium-ion batteries paired with wind or solar projects are expected to become economic even sooner. Estimates for deployment of 4-hour energy storage for load following and resource adequacy and energy arbitrage applications by 2030 range from 2 GW (Rose et al. 2020a) to 27 GW (CEA 2020d).

**Lead acid** batteries are among the first battery technologies used for energy storage; however, compared to lithium-ion batteries, they have a low energy density and shorter cycle and calendar life. As a result, lead acid batteries are increasingly limited to backup power or remote grid applications. Recent efforts on advanced lead acid batteries seek to overcome the issue of poor life cycle and slow charging rates. In India, POWERGRID is piloting a 500-kW, 250-kWh advanced lead acid battery for energy arbitrage and frequency regulation (USAID 2020).

**Flow** batteries present an emerging alternative to lithium-ion. This technology stores energy directly in the electrolyte solution for longer cycle life and quick response times. Flow batteries are in early stages of commercialization compared to other battery technologies; however, their long life cycles, higher depth of discharge, and easy scalability offer advantages over other systems (Mongird et al. 2019). Flow batteries are among the technologies being piloted in India. A 250-kW, 1,000-kWh flow battery system is currently under development for testing by POWERGRID (USAID 2020).

**Text Box 1. The Energy Storage Market in the United States**

Energy storage has been rapidly growing in the United States, driven by falling technology costs and public policies. While PSH still accounts for 95% of front-of-the-meter (FTM) energy storage capacity in the United States, over 1 GW of nonhydro battery capacity has been added to date. The share of nonhydro FTM energy storage investments is expected to increase further with an additional 81 GW projected to be added by 2025 (Wood Mackenzie 2019). Cost declines for FTM systems are expected to continue in the coming years. System prices for long- and medium-duration FTM systems are expected to decline by 15% from 2019 to 2021.

The growing penetration of renewables in states across the United States has been a key driver for the storage industry. Thirty-seven states have either legally binding renewable portfolio standards or voluntary renewables goals (NCSL 2020). Seven states have also set targets or mandates explicitly for storage (Burwen 2020). Many utilities are installing storage through requests for proposals for capacity fulfillment or as an add-on to solar and wind projects. Other states encourage storage through pilot installations. On the federal level, attempts to pass storage incentives have so far stalled, although storage projects charged by renewables for >75% of the time can take advantage of existing investment tax credits as well as a Modified Accelerated Cost Recovery System depreciation reduction (Elgqvist 2018).

As investments increase, regulators at the federal and state level are responding to remove barriers for energy storage and better capture the unique features of storage technologies. The Federal Energy Regulatory Commission's (FERC) Order 841 directs U.S. markets to create rules for energy storage to participate in wholesale, capacity, and ancillary service markets on a nondiscriminatory basis alongside other assets (FERC 2018). While FERC Order 841 seeks to remove barriers for energy storage, it gives each market discretion to design their own rules for compliance allowing for multiple solutions.

Other regulations seek to improve existing compensation mechanisms to better capture the value that energy storage and other technologies provide to the system. For instance, FERC Order 755 requires U.S. markets to adopt a two-part market-based compensation mechanism for frequency regulation services: a capacity payment that reflects the opportunity cost of not using the resource for some other service and a market-based performance payment that rewards faster-ramping resources (FERC 2011). In the PJM territory, this led to a tripling of fast-moving resources available for frequency regulation (Tweed 2013). Because these resources can respond to signals more quickly and accurately, PJM was able to lower its regulation requirements.

In Texas, the state legislature amended a rule to allow municipal utilities and electric cooperatives to own energy storage facilities without registering as a power generator. This change enables utilities to use storage facilities to defer or avoid the need for network investments (Mai 2019).

The United States is in a familiarization phase with energy storage. Policy programs have been instrumental in directing the scope and scale of storage deployment, while regulatory reforms have focused on establishing a level playing field for energy storage to provide grid services and be compensated for those services without being overly prescriptive.

# 2 Energy Storage Readiness Assessment

The Energy Storage Readiness Assessment developed by NREL identifies 20 technical and nontechnical factors that enable energy storage investments and operation (Rose et al. 2020a). These factors are grouped into three topics: System Characteristics, Policy, and Regulation (Table 2).

**Table 2. Components of the Energy Storage Readiness Assessment**

| Topic | No. | Criteria |
|---|---|---|
| System Characteristics | 1 | Low or decreasing load factor in electricity demand |
| | 2 | Inadequate or costly provision of ancillary services |
| | 3 | Inadequate or costly supply options during peak demand periods |
| | 4 | Increasing levels of transmission congestion |
| | 5 | Proposed network upgrades with low anticipated utilization |
| | 6 | Low flexibility in the generation mix |
| | 7 | Increasing VRE curtailment |
| Policy | 8 | Storage included in energy policy and master plan |
| | 9 | Targets for storage deployment |
| | 10 | Energy strategy promotes operational flexibility |
| | 11 | Support organized knowledge sharing and delivery for scale up and replication |
| | 12 | Domestic industrial policy supporting storage manufacturing |
| | 13 | Targeted support to early adopters |
| Regulation | 14 | Utilities and private developers allowed to make storage investments |
| | 15 | Interconnection processes give storage the right to interconnect and obtain transmission service |
| | 16 | Promotion of high quality standardized technologies through safety standards for storage technologies |
| | 17 | Operating requirements for fast-responding assets |
| | 18 | Electricity services charges reflect value of and increase price transparency for energy services |
| | 19 | Storage able to compete with other grid assets to provide multiple services |
| | 20 | Storage able to receive revenue for providing multiple services |

The system characteristics capture the technical aspects that qualitatively describe the power system, such as changes in load shape, adequacy in capacity and ancillary services, and utilization of the transmission network. This section identifies operational and planning challenges that commonly afflict rapidly changing grids where energy storage could contribute to the solution. These characteristics can help identify whether there is a technical or economic need for utility-scale energy storage.

The policy criteria cover the set of guidelines that direct the scope and scale of storage deployment. These topics span early-stage exploration into the feasibility of integrating energy storage through establishing deployment targets and support programs to grow the industry. The goal of these activities is to accelerate the identification and implementation of appropriate energy storage solutions should the Indian government decide to do so.

The regulatory topics capture the set of rules necessary to define how energy storage technologies should be treated. These include rules around ownership and planning, as well as operational practices, tariffs, and safety standards. The regulations could enable energy storage to compete on a nondiscriminatory basis with other grid assets to provide grid services and be compensated for those services.

To complete the Readiness Assessment, each criterion is assigned a color-based grade based on the evaluation scheme in Figure 1.

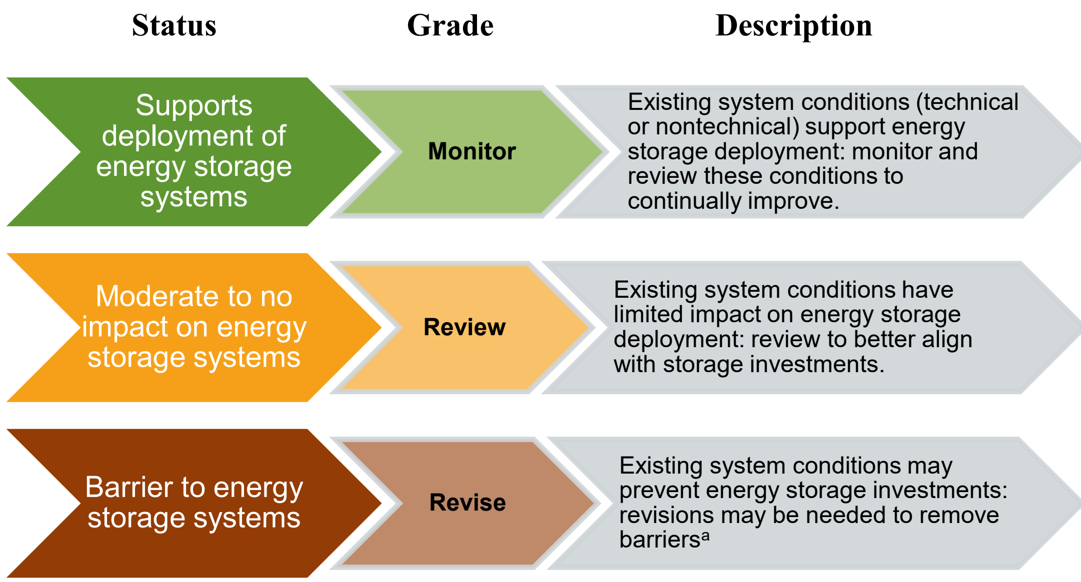


**Figure 1. Evaluation scheme for energy storage readiness assessments**

[a] Revisions may not be recommended for system characteristics where conditions that are good for the overall system (i.e., high levels of system flexibility and reliability) may not support energy storage investments.

The "Monitor" grade indicates existing system conditions support energy storage deployment. These conditions should be monitored to identify areas for continued improvement. In cases where system conditions have limited impact – positive or negative – on energy storage deployment, a grade of "Review" can be given. This indicates the need to review and, if desirable, update policy or regulatory frameworks to better align with energy storage deployment. Finally, criteria that present a barrier to energy storage are given a grade of "Revise" indicating action may be required to remove existing conditions that may be preventing investments in energy storage.

This assessment is designed to allow policymakers and regulators to quickly gauge how well existing policy and regulatory frameworks support energy storage. As such, it is not designed to recommend specific policy or regulatory solutions but rather to identify priority areas for focus. It is also not designed to inform whether energy storage is the best solution among other possible technical and nontechnical interventions to meet system needs. Furthermore, a given system may need to be reassessed periodically as system conditions change.

# 3 Application of the Readiness Assessment: India

As interest in energy storage grows, policymakers and regulators in India are evaluating the appropriate suites of policies, programs, and regulations to enable energy storage investments and maximize their value to the system. In this section, we apply the energy storage readiness assessment to the Indian power system to inform this dialogue and identify priority areas for focus moving forward.

## 3.1 Brief Overview of India's Power Sector Governance

India's electricity sector is governed on a national level by the Ministry of Power (MoP). The CEA is the main advisory body to the MoP, providing assistance with the technical coordination of the electric grid as well as collecting and disseminating data and implementing various national programs and goals. The Ministry of New and Renewable Energy (MNRE) is responsible for all matters related to renewable energy, and its public sector undertaking, the Solar Energy Corporation of India (SECI), facilitates the implementation of renewable energy policies and programs. Research and development of new energy technologies is coordinated by the government's national think tank, NITI Aayog.

Under the Electricity Act of 2003, the Central Electricity Regulatory Commission (CERC) is responsible for developing and monitoring the competitive electricity markets and tariff setting, licensing India's interstate transmission system (ISTS), and maintaining grid security. CERC's Forum of Regulators facilitates coordination and communication among India's State Electricity Regulatory Commissions.

The nationwide electricity grid is operated by the Power System Operation Corporation (POSOCO). Under POSOCO, the National Load Dispatch Center (NLDC) and five Regional Load Dispatch Centers (RLDCs) coordinate with the load dispatch centers of each state to monitor and control the network operations and dispatch of power.

Long-term contracts or power purchase agreements are the primary mechanism for energy sales. Market trading through India's two wholesale power exchanges is limited. The Indian Energy Exchange (IEX), India's largest exchange, made up 4% of market share in annual generation in the 2019–2020 operating year (IEX, MOP 2020).

## 3.2 Assessment Summary

Table 3 summarizes the results of the energy storage readiness assessment for India. Subsequent sections present detailed analysis of how the results are obtained for each criterion. In general, the current system characteristics of the Indian power system are favorable for energy storage, while the policy and regulatory frameworks are largely unsupportive; however, this is mostly due to an absence of storage considerations in current frameworks rather than poorly designed energy storage policies or rules.

**Table 3. Results of Readiness Assessment for India**

| Topic | No. | Criteria | Assessment | Notes |
|---|---|---|---|---|
| System Characteristics | 1 | Low or decreasing load factor in electricity demand | | Load factors are decreasing, as are daily and seasonal market price fluctuations |
| | 2 | Inadequate or costly provision of ancillary services | | System experiences shortages of fast-responding resources |
| | 3 | Inadequate or costly supply options during peak demand periods | | Storage is increasingly cost-competitive with gas and coal plants for peak demand management |
| | 4 | Increasing levels of transmission congestion | | Limited congestion overall but large RE parks cause localized congestion |
| | 5 | Proposed network upgrades with low anticipated utilization | | Changes in net load result in underutilized transmission capacity |
| | 6 | Low flexibility in the generation mix | | Increasing flexibility needs will exceed capabilities of existing thermal fleet |
| | 7 | Increasing curtailment of variable renewable energy | | Curtailment is limited, but storage could reduce strain on thermal fleet required to back down |
| Policy | 8 | Inclusion of storage in energy policy and master plan | | Storage included in national planning but absent from national energy policy |
| | 9 | Targets for storage deployment | | No specific targets or programs for utility-scale storage |
| | 10 | Energy strategy promotes operational flexibility | | Recent initiatives have added flexibility, but opportunities for storage to meet flexibility needs are limited |
| | 11 | Support organized knowledge sharing and delivery for scale up and replication | | Limited government facilitation while research and development funding is nascent but increasing |
| | 12 | Domestic industrial policy supports storage manufacturing | | Currently limited to electric vehicle applications |
| | 13 | Targeted support to early adopters | | Existing support limited to hydropower or hybrid projects |
| Regulation | 14 | Utilities and private developers allowed to make storage investments | | Ownership rules have been discussed but not formalized |
| | 15 | Interconnection processes give storage the right to interconnect and obtains transmission service | | Both stand-alone and hybrid storage projects allowed to interconnect |
| | 16 | Promotion of high quality standardized technologies through safety standards for storage technologies | | Work underway to establish safety standards and procedures for storage |
| | 17 | Operating requirements for fast-responding assets | | Energy storage not eligible to provide most services |
| | 18 | Electricity services charges reflect value of and increase price transparency for energy services | | Advanced pricing mechanisms for energy and other services are limited |
| | 19 | Storage able to compete with other grid assets to provide multiple services | | Some storage applications are limited through explicit restrictions or lack of compensation mechanisms |
| | 20 | Storage able to receive revenue for providing multiple services | | Compensation for services beyond power provision is not available or not well-defined |

## 3.3 System Characteristics

The technical characteristics of the Indian power system are favorable for energy storage investments and operation. There are opportunities for storage to provide energy arbitrage, ancillary services, and potentially defer transmission investments.

**1. Low or Decreasing Load Factor in Electricity Demand** Monitor

Load factor is an expression of the utilization of the system. Low load factors indicate volatility in demand and sometimes require that capital-intensive generation or transmission resources be built to serve load only for a short time. Load factors in India have been declining and are projected to continue to do so, indicating a growing opportunity for energy storage to provide energy arbitrage or resource adequacy services (CEA 2018, POSOCO 2016). Over the 2016 to 2020 period, India's load factor declined by 2%. CEA forecasts that the total load factor will decline by an additional 4% by 2037 before stabilizing. Regions predicted to see the steepest declines include the Western and Southern regions with declines of 7% and 6%, respectively, from 2020 to 2037 (Figure 2).

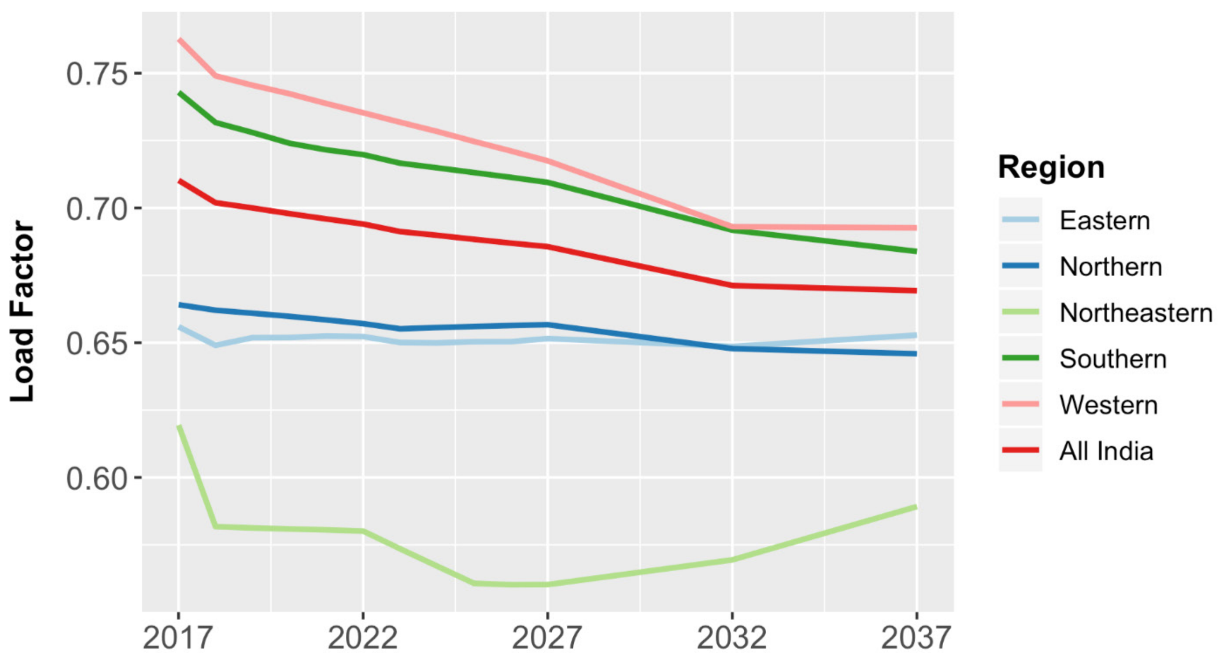


**Figure 2. Forecast changes in load factor 2017–2037 by region and for all of India**

Source: CEA 2018

As the daily load profile in these regions becomes more variable with larger swings between peak and off-peak electricity demand, energy storage technologies can help stabilize electricity demand by providing load following or peak demand management services. These opportunities already exist in some locations, such as Delhi and Kerala, that already experience large daily swings in electricity demand.

Another approach to understanding potential opportunities for energy arbitrage is by analyzing price fluctuations in the wholesale energy market. While 90% of demand in India is met through long-term contracts, wholesale market exchanges are growing, with the IEX being the predominant option (IEA 2020b). We analyzed IEX price data from 2016 to 2019 and found an increase in the size and frequency of daily price fluctuations with a pronounced seasonal pattern (Figure 3) (IEX n.d.). Higher fluctuations were observed from June to October, when both electricity demand and renewable generation is highest. The seasonal nature of price variations suggests that a modular and easily deployable energy storage technology may be preferable to investments in transmission or conventional generation because the energy arbitrage opportunity may only exist for a few months of the year.

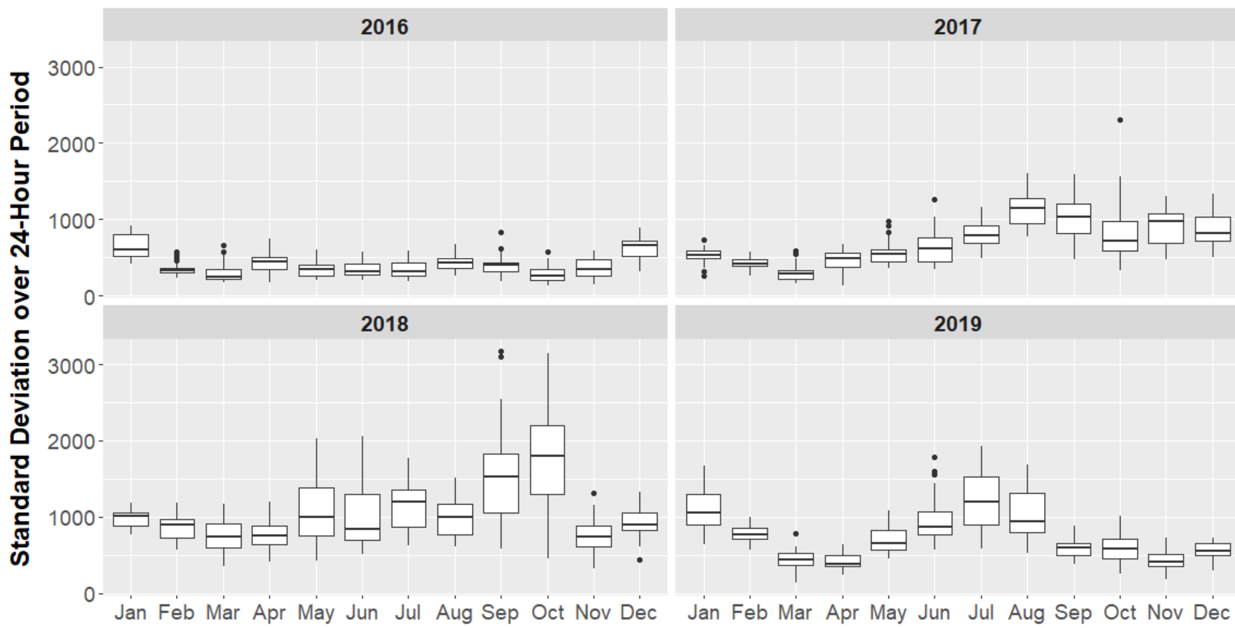


**Figure 3. Daily standard deviation of IEX prices (over 24-hour period) by month and year**

Source: IEX

Understanding the size, frequency, and duration of daily IEX price spikes can also inform which energy storage technologies may be best suited to provide peak load management or energy arbitrage services. We find the number and duration of daily price spikes vary during different times of year. Summer months tend to have flatter price curves with only one peak at the end of the day that lasts, on average, 4 hours. Winter months, by contrast, experience a morning and evening price spike lasting, on average, 6 hours.

Analysis of India's electricity demand forecast and market prices reveals a growing opportunity for energy storage to provide energy arbitrage and resource adequacy services. To maximize this opportunity, the appropriate storage technology would require daily or twice-daily cycling with up to 4 hours of discharge capability.

### 2. Inadequate or Costly Provision of Ancillary Services — Monitor

India is in the process of expanding its ancillary services sector, presenting a growing opportunity for energy storage. The current ancillary services include inertial, primary, and slow tertiary response. There is no ancillary services market in India; system needs are met through regulatory requirements in the grid code or through unscheduled surplus capacity.

Inertial and primary response services are automatic adjustments to maintain grid stability within seconds or minutes of a deviation. While generators are required to provide these services, actual primary response has been lower than desired at times due to technical difficulties for units to respond in time and some generators not retaining adequate capacity on reserve (Shrivastava 2017).

Slow tertiary response, also referred to as Reserves Regulation Ancillary Services (RRAS), is provided by unscheduled capacity from interstate generating stations. Because these services are only obtained through uncommitted surplus capacity, there is no guarantee the generation capacity will be available when needed. POSOCO reports inadequate surplus to meet requirements for RRAS during some peak demand hours (CERC 2018a). Over the 2018–2020 operating years, India's grid frequency fell below its lower limit of 49.9 Hz in 9% of operating periods (POSOCO 2019a, POSOCO 2020b). Further, the primary sources of ancillary support are thermal generators, which are limited in how quickly they can ramp their output levels up or down.

CERC has outlined the need to expand the range of ancillary services and types of technologies eligible to provide these services (CERC 2018a). For example, secondary reserves through automatic generation control (AGC) connected to generating units and controlled centrally are currently being piloted (CERC 2018b). And a separate pilot was initiated in 2018 to capitalize on the inherent flexibility of hydropower technologies.

Energy storage—including hydropower and non-hydropower technologies—could further expand the quantum of fast-response technologies available for ancillary services. Technologies such as flywheels and batteries can respond to control signals at subsecond time levels. Further, improving the accuracy and speed of response can reduce the amount of ancillary services that must be procured.

### 3. Inadequate or Costly Supply Options During Peak Demand Periods

Monitor

Investments in generation and transmission infrastructure have reduced India's supply deficit in recent years. Total and peak demand shortfalls have fallen to less than 0.5% nationally (Figure 4). At the regional levels, there are persistent differences in system reliability with the Northern region experiencing the highest levels of unmet demand; however, these deficits amounted to less than 2% of Northern region annual and peak demand not met in 2019 (CEA Monthly Reports Archive).

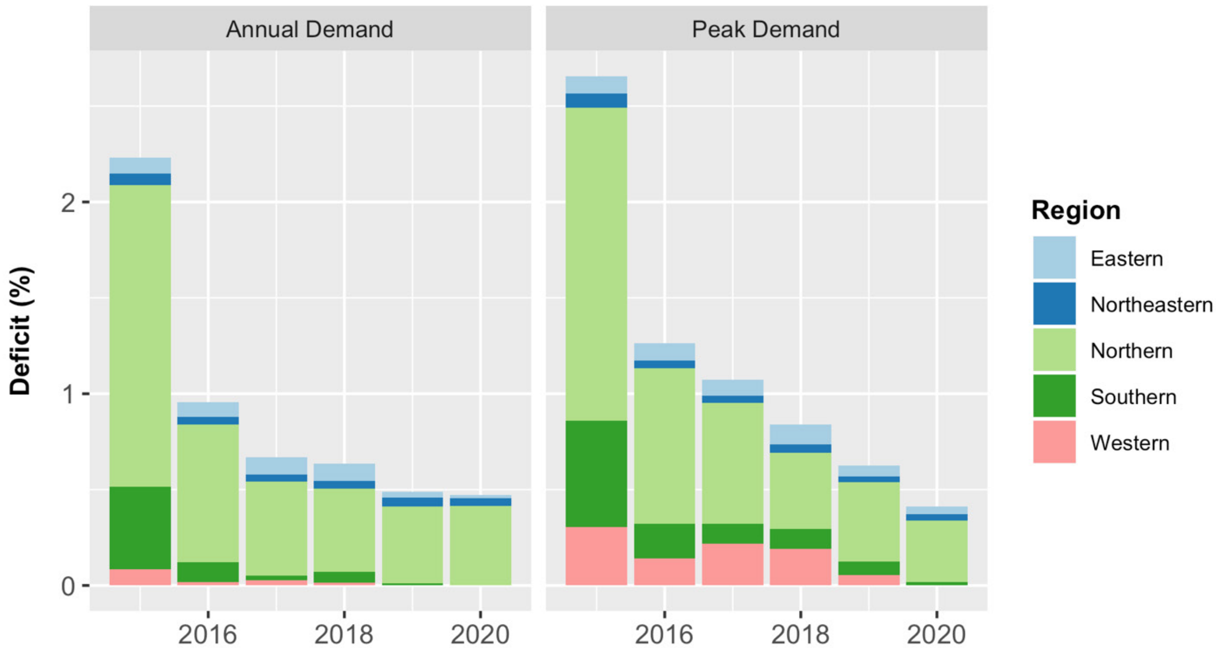


**Figure 4. Annual and peak demand deficits by region, 2015–2020**

Source: CEA Monthly Reports Archive

Generation deficits follow a seasonal pattern, with higher instances of unmet demand during the June–October months (Figure 5).

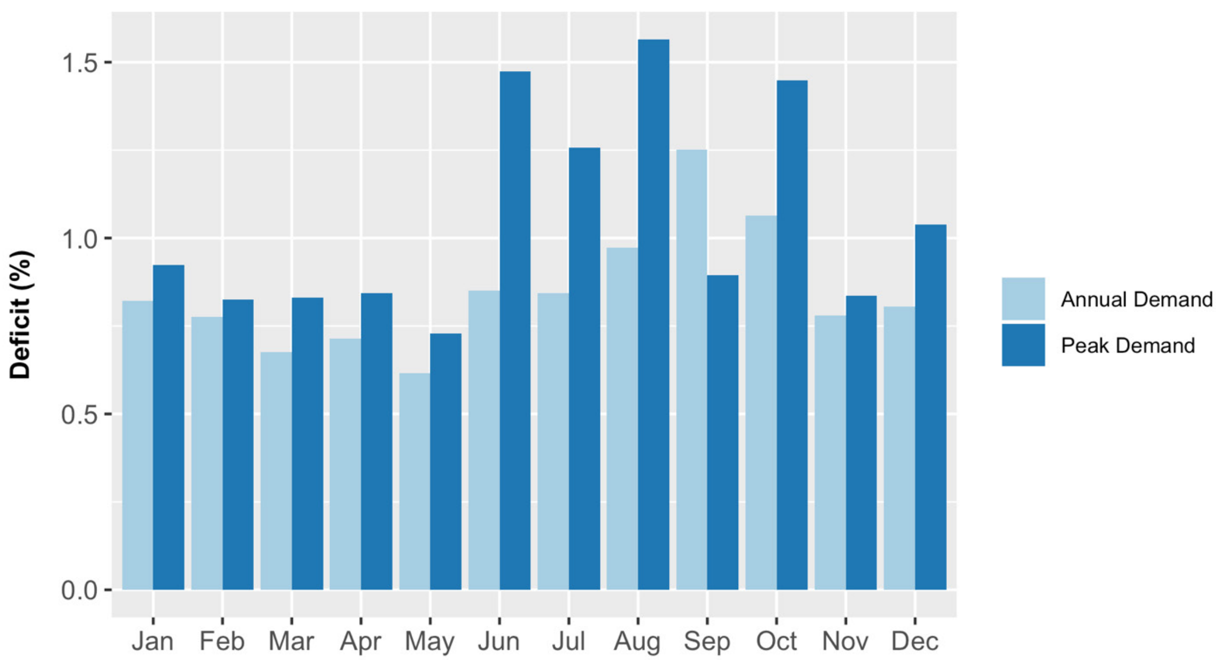


**Figure 5. Percentage of annual peak demand not met by month, averaged over 2015–2020**

Source: CEA Monthly Reports Archive

The COVID-19 pandemic has affected the outlook for energy demand and supply in India. Recently published CEA projections forecast an energy surplus of 3% and a peak surplus of 9% for the year 2020–2021 (CEA 2020e). According to the forecast, only the Eastern region is forecast to experience an energy deficit; however, as economic activity increases in the coming months and years, growing demand may once again strain existing supplies.

Currently, many distribution utilities purchase power from short-term energy markets to meet peak demand (BNEF 2019). In June 2019, the average market clearing price during peak demand periods reached as high as Rs[6] 8.89 per kWh. The price for the top 10% of peak demand hours was above Rs 4.6 per kWh for the same month. Long-term power purchase agreements with thermal generators are generally a less expensive option to meet peak demand. The average tariff for gas- and coal-based power stations is Rs 3.85 per kWh and Rs 3.55 per kWh, respectively (POSOCO 2020c). However, investing in new thermal power stations to meet demand during only a few hours or months of the year may not be economically strategic over the long term. By the end of 2019, India had Rs 3-4.5 trillion ($40-60 billion) in stranded generation assets due to low levels of utilization, fuel shortages, and lack of profitability (IEEFA, 2019).

Energy storage presents an increasingly cost-competitive alternative to meet existing and future peak demand needs. BNEF estimates a 4-hour lithium-ion battery could already displace poorly utilized open-cycle gas turbines in India and will be competitive with combined-cycle gas turbines with low utilization by 2025 (BNEF 2019). Energy storage could also bolster the ability of renewable generators to displace conventional technologies as peaking resources through hybrid projects. Researchers at Lawrence Berkeley National Laboratory estimate the cost of a solar plant plus a battery storing 25% of the solar energy is Rs 3.94 per kWh in 2020 and could decline to Rs 2.83 per kWh by 2030 (LBNL 2020). BNEF estimates a new PV or wind power project with 1-hour battery storage is already competitive with gas power plants in India. Falling battery prices could make longer-duration hybrid projects competitive by 2030. In fact, some of these prices are already being achieved. The first centralized auction for renewable energy paired with energy storage to provide “round-the-clock” renewable power[7] in May 2020 achieved a tariff of 2.9 rupees ($0.039) per kWh, 25% lower than the average tariff for coal-based power stations (Gupta 2020; POSOCO 2020c).

Energy storage technologies with one- to four-hour discharge could contribute to peak demand management and avoid the need for investments in new generation capacity with low anticipated utilization.

### 4. Increasing Levels of Transmission Congestion

Review

India experiences limited instances of congestion on the ISTS but instances of localized congestion may present a growing concern. Over the 2017–2020 period, POSOCO reports monthly violations of total transfer capacity (TTC) in 3% of hours. TTC violations are highest June–October and are more pronounced over import corridors into the Northern and

[6] Rs indicates Indian Rupee, equivalent to 0.014 U.S. dollar as of October 2020 (or roughly 73 Rupees per dollar).
[7] The winning bidder can use any combination of wind, solar, and energy storage and is required to maintain a minimum capacity utilization factor of 80% annually and 70% monthly.

Northeastern regions (Figure 6). It is also notable that, in most cases, instances of TTC violations are not increasing over time. In cases where transmission congestion is intermittent and not increasing, energy storage may be a viable alternative to building new transmission infrastructure.

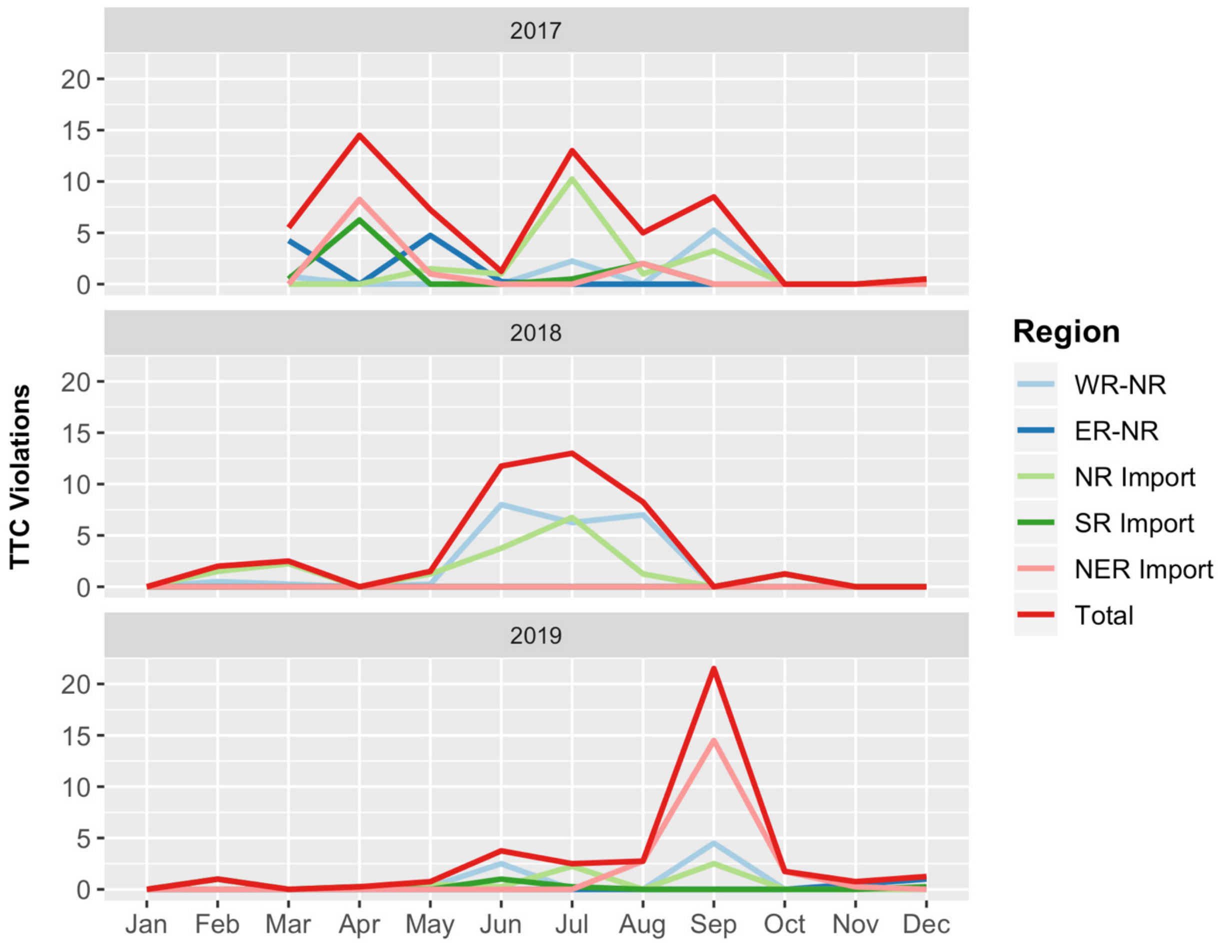


**Figure 6. TTC violations by month, March 2017–December 2019**

ER: Eastern Region; NER: Northeastern Region; NR: Northern Region; SR: Southern Region; WR: Western Region;

Source: POSOCO Monthly VDI/TTC/ATC

Localized transmission congestion due to injections of RE are a growing concern. For example, POSOCO reports output from the Bhadla Solar Park in Rajasthan has resulted in overloaded lines for the last five quarters (POSOCO 2020a). Similarly, Gujarat has experienced overloading transmission lines during high wind generation periods due, in part, to the remote location of the wind farms (MoP 2019). Storage co-located with renewables can improve transmission operations by absorbing excess generation and providing frequency and voltage support.

**5. Proposed Network Upgrades with Low Anticipated Utilization**

Monitor

India has made significant investments in new transmission capacity, reaching 19,500 MW of carrying capacity over the ISTS by the end of 2017. A further 14,000 MW of additional network capacity is expected to be added over the 2017–2022 planning period to ensure reliable power supplies during peak demand conditions. The anticipated cost of these additions total Rs 269,000 crore,[8] including Rs 30,000 crore for transmission reinforcements below 220 kV voltage level (CEA 2019b).

Energy storage can potentially delay, reduce, or avoid the costs of transmission investments by providing extra capacity to meet peak demand needs. NREL's production cost modeling[9] of India's planned 2030 power system reveals that 71% of the ISTS transmission corridors (out of 663 modeled) may experience an average annual utilization rate of 30% or less (Palchak et al. 2019). Further, 9% of lines are anticipated to have zero power flow for over a quarter of the year. Low levels of utilization tend to occur during the night and middle of the day when net electricity demand is low. These results suggest that, for certain underutilized transmission corridors, energy storage may be an economic alternative to transmission upgrades.

### 6. Low Flexibility in the Generation Mix — Monitor

India's growing penetration of renewable energy will increase the flexibility needs of the rest of the generation fleet to balance supply and demand. POSOCO reports that the daily variation in output from the thermal fleet has increased from 8%–10% in 2009 to 15%–18% in 2019 (POSOCO 2020d). On average, the daily change in net load that must be met by the thermal fleet is 15–17 GW. However, this requirement is increasing rapidly at a rate of 5–7 GW per year, reaching as high as 56 GW during the winter of 2019–2020.

India relies primarily on thermal generators to meet load following needs, but these units are ramp-limited resources and cannot respond quickly to control signals to change their output. CEA requires a 3% per minute ramp rate for thermal generators operating above the 50% Maximum Continuous Rating (CEA 2010). However, analysis by POSOCO found that only 35% of thermal generators in India are providing at least 1% per minute ramping capability; the majority of coal-fired central generating station are declaring a ramping capability of 0.5%–0.7% per minute (POSOCO 2019b). Similarly for minimum loading, CERC requires a minimum generation level of 55% for interstate generators but a recent report by POSOCO reveals only 6% of central generating stations are reaching a minimum generation level below 60% (CERC 2016; POSOCO 2020d). On an all-India basis, about 60% of units are flexing their output by 20%–30% of installed capacity (POSOCO 2020d).

Fast-ramping hydropower and gas units are also contributing to meet ramping needs. During the "Lights Off" event on April 5, 2020, system operators managed unprecedented ramp rates on the order of 3 to 4 GW per minute during the 9 p.m. 9-minute event (Figure 7). In preparation for the

[8] A crore denotes 10 million rupees.

[9] This model uses a linearized DC optimal power flow representation of transmission flows and does not replace the need for detailed transmission planning supported by AC power flow analysis.

event, system operators adjusted the droop settings[10] of some hydro generators to 1%–2% from the normal range of 4%–5% to allow faster response to frequency changes.

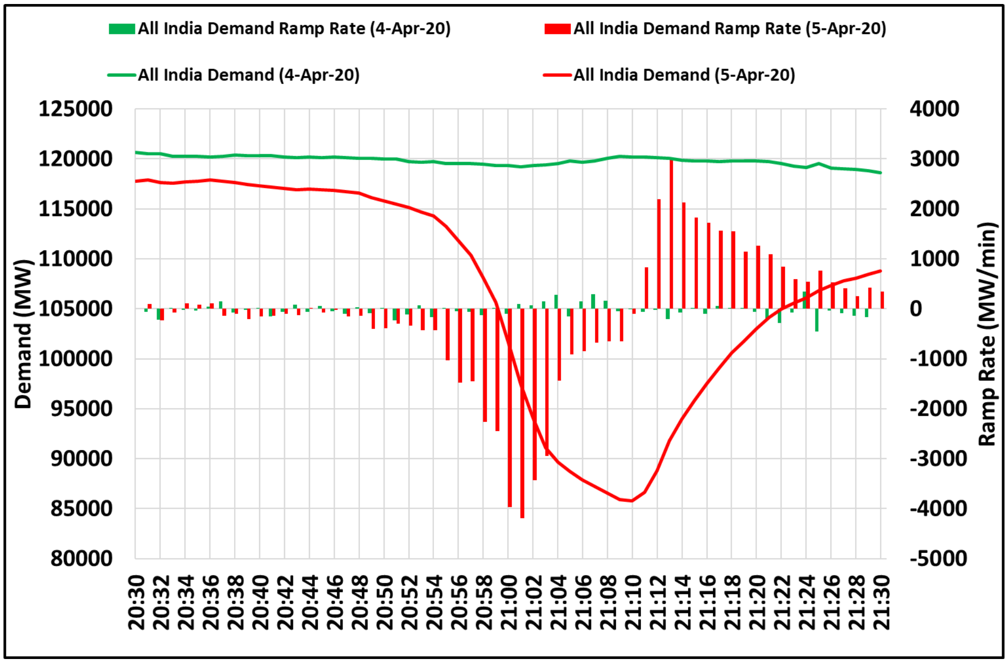


**Figure 7. Demand and ramp rates trend during the "Lights Off" event**

Source: POSOCO 2020e

The increase in variable renewable generation, particularly solar, is anticipated to increase the net ramping requirements of the remaining generation sources to turn down in the early morning and ramp up in the evening as solar generation declines and evening peak demand increases. Figure 8 shows the anticipated load and net load curves on the days with the highest ramping requirements and highest renewable generation in 2022 and 2030 (Palchak et al. 2019). On the day with the highest ramps, the total ramping requirement from the lowest point on the net load curve to the highest is expected to increase from 118 GW in 2022 to 286 GW in 2030, a quantum that exceeds India's entire 2020 thermal capacity. The day with the highest renewable generation is expected to see more than a doubling of renewable generation over this period resulting in larger turn-down of the generation fleet during the day and larger ramp up during the evenings.

[10] The droop speed control is a control mode used for AC generators to adjust the power output of a generator in response to frequency changes. The droop setting is represented as the percentage change in speed required for 100% governor action.

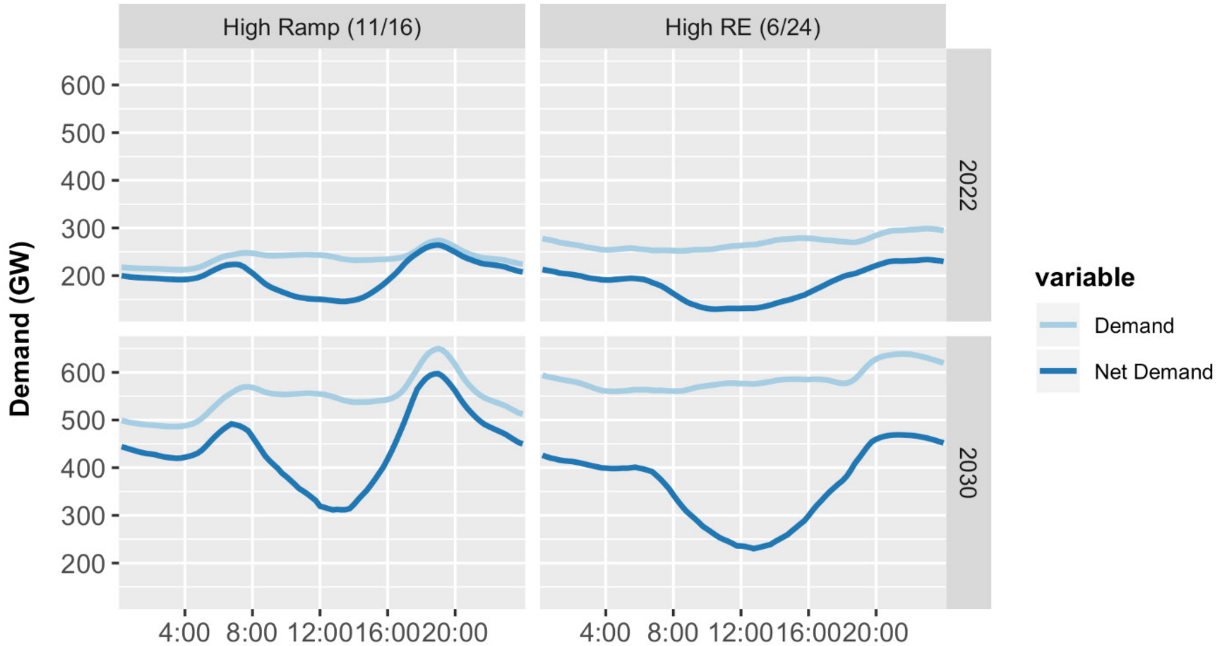


**Figure 8. Changes in the load and net load curves for the day with the highest ramping requirements (left) and highest renewable generation (right) for 2022 and 2030, respectively.**

Source: Palchak et al. 2019

The hourly ramping requirements are also anticipated to increase significantly. Figure 9 shows the maximum and 90$^{th}$ percentile 1-hour net load requirements for ramping up and down for the years 2022 and 2030 based on NREL's operational modeling.

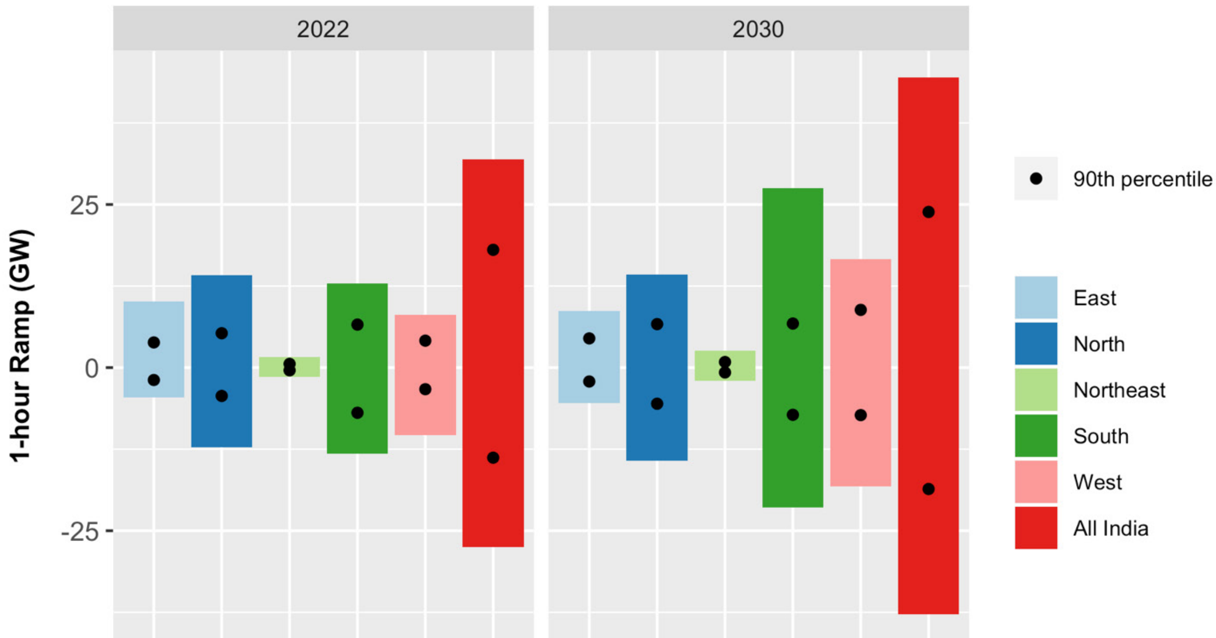


**Figure 9. Anticipated 1-hour ramping requirements by region and all India, 2022 and 2030, respectively**

Source: Palchak et al. 2019

Nationally, the maximum 1-hour ramp up could reach 32 GW by 2022 and 44 GW by 2030. The Southern and Western regions are expected to see the largest increases in net-load ramping as investments in new renewable energy capacity are expected to be concentrated in these areas.

Under higher penetrations of renewables, India's power system will need more fast-responding resources for system flexibility. Recent estimates suggest the additional costs of refurbishing India's thermal units to operate more flexibly could reach 5%–10% of the total project cost (Sen et al. 2018). The fast response of the hydropower fleet during the Lights Off event, while successful, does not present a long-term solution, as this requires advanced knowledge that the event would occur and running the plants outside of their normal operating range. Energy storage, particularly battery storage that is not subject to the droop setting limits faced by hydropower plants could be a cost-effective solution to meet increasing needs for system flexibility.

## 7. Increasing Curtailment of Variable Renewable Energy

Review

Data on renewable energy curtailment in India is limited but available data from select states suggest that curtailment is limited to specific locations and time periods. We analyzed curtailment data from Rajasthan and Andhra Pradesh, two states with high penetrations of renewable energy. From September 2019 to May 2020, 61.9 GWh of wind was curtailed in Rajasthan, equivalent to 1.6% of total wind generation in the state (Rajasthan Transco; CEA 2020c). In Andhra Pradesh, 0.3% (10 GWh) of wind and 4% (185 GWh) of solar was curtailed from August 2019 to May 2020 (AP Transco; CEA 2020c). In both cases, curtailment is infrequent. The number of dispatch periods with curtailment in Rajasthan and Andhra Pradesh is 4% and 6.5%, respectively. The low levels of curtailment indicate that reducing curtailment alone may not drive investments in energy storage; however, increased reporting of curtailment at the national and state level is required to better understand potential opportunities.

One reason curtailment rates are low and infrequent is India's must-run policy, which requires system operators to first redispatch other generators to avoid backing down renewables. In the first half of 2020, thermal generation from state and central generators in Rajasthan was backed down in 89% and 100% of dispatch periods, respectively, totaling 5690 GWh. Increased unit cycling and operating at lower generation levels can increase operating and maintenance costs for thermal generation units as well as decrease the plant's operating life and increase per unit emissions. Therefore, by smoothing the output from renewable generators, energy storage can help to minimize curtailment of renewable generation and improve the operating efficiency of the rest of the generation fleet.

## 3.4 Policy

India's energy policy framework largely excludes energy storage from key programs and initiatives. The lack of policy guidelines and supporting programs to direct the scope and scale of energy storage deployment present a barrier for investments.

| **8. Inclusion of Energy Storage in Energy Policy and Master Plan** | Revise |
|---|---|

Energy storage has received limited attention in India's existing energy policies. The two primary policy documents for the power sector are the 2003 Electricity Act, which covers major issues involving generation, distribution, transmission, grid operation and trading in power, and the 2006 Integrated Energy Policy, which provides a roadmap to develop the broader energy sector and increase the uptake of renewable energy sources (CERC 2003; NITI Aayog 2006). Under the 2003 Electricity Act, the MoP, in consultation with CEA and State Governments, is required to prepare a National Electricity Policy and Tariff Policy for the development of the power sector (CERC 2003). These policies are revised from time to time in response to changing system needs. Energy storage is not explicitly mentioned in the 2003 Electricity Act, the National Electricity Policy 2005, or the Tariff Policy 2016. Organizations such as the India Energy Storage Alliance (IESA) have called for future amendments to include a "clear policy framework regarding energy storage" (IESA 2020a). Recent amendments proposed earlier this year to the National Electricity Policy do not mention storage but include an amendment targeting renewable energy, which may also include storage-friendly components (ET Energy World 2020a). Proposed amendments to the Tariff Policy include measures to promote PSH only through regulated tariffs (MoP 2018).

In the 2006 Integrated Energy Policy and 2017 proposed revision (NITI Aayog 2017), storage is mentioned several times as an opportunity to supplement the rapid growth in variable renewables and smooth load curves. NITI Aayog surmises that renewables paired with storage, once cost-competitive, will lead to the widespread phase-out of coal across India. To this end, NITI Aayog proposes that all renewable energy installations in the future could be required to be co-located with some form of balancing capacity, either gas-burning power plants or energy storage, to maintain a steady and reliable electricity supply. India's recent round-the-clock power auction, discussed in subsequent sections, seems to be fulfilling this proposal.

Power Minister Singh has proposed introducing a renewable purchase obligation for round-the-clock power as a mechanism to promote energy storage (ET Energy World 2020b). Under the proposed scheme, increased demand for energy storage would drive investments in storage manufacturing facilities, driving down storage costs, and accelerating the transition to renewable energy. The IESA has also proposed specific policy changes, including allowing storage to provide ancillary services and frequency regulation and adding a storage purchase obligation (IESA 2020a) similar to the existing Renewable Purchase Obligation and proposed Hydropower Purchase Obligation (CEA 2019c).

Energy storage is also receiving more attention in national planning activities. The CEA, responsible for producing India's long-term plan for the power sector, has historically only considered PSH as the sole energy storage technology in its National Electricity Plan. In the latest Report on Optimal Generation Capacity Mix for 2029–2030, the candidate technologies included 4-hour battery storage, along with PSH (CEA 2020d). Base scenario results show 27 GW (108 GWh) of battery storage along with 10 GW of PSH would be needed by 2029–2030. CEA's analysis considers a variety of applications for energy storage, including providing ancillary services, load smoothing from renewables, and spinning reserves. This demonstrates an expansion on the singular application to the integration of renewables mentioned by NITI Aayog.

Including clear policy guidelines in the upcoming amendments to the National Electricity Policy, Tariff Policy, and in the final version of NITI Aayog's 2017 Draft National Energy Policy on energy storage can provide a market signal to spur development and direct regulatory authorities to begin implementing targeted regulations. These should address the many services that storage can provide as well as the full range of technologies available.

## 9. Targets for Storage Deployment

Review

The Government of India has a number of programs and targets aimed at catalyzing investments and transformation in the energy sector, but none of these include a specific target for energy storage deployment. In some cases, such as India's 450-GW renewable energy targets or auctions for round-the-clock power, energy storage is expected to play a key role in achieving these targets, but there is no accompanying policy or program to stimulate the necessary level of storage investments. The National Mission on Transformative Mobility and Battery Storage aims to coordinate research activities on advanced batteries and establish integrated battery- and cell-manufacturing giga-factories. While the outcomes of this program will likely impact investments in battery storage for grid applications, this primary objective is focused on the needs of the transportation sector rather than the power sector.

There is a growing body of analysis that could be used to inform future targets for utility-scale energy storage. The CEA has identified 96 GW of PSH capacity across 63 sites that could be developed in India (CEA 2017). In its Optimal Generation Capacity Mix for 2029–2030, CEA estimates the system could achieve 27 GW (108 GWh) of battery storage and 10 GW of PSH by 2029–2030 (CEA 2020d). The IESA has also released projections for energy storage in its 2019

Energy Storage Systems roadmap for the period 2019–2032. The report found that total demand for storage in grid support could reach 17 GWh by 2022 and 212 GWh by 2032. Total demand for storage across all sectors—including electric vehicles and data centers—could exceed 2,700 GWh (IESA 2019). Ongoing efforts to better capture the unique features of energy storage technologies in power sector planning models can further inform policy targets for energy storage. NREL is currently combining our flagship capacity expansion model, ReEDS, with a detailed production cost model of the Indian power system to better understand the techno-economic potential for energy storage in India. The results of this forthcoming work will inform where and when utility-scale energy storage is cost-effective and the drivers for energy storage investments.[11]

### 10. Energy Strategy Promotes Operational Flexibility

Review

India has been promoting greater flexibility in the generation fleet in part to facilitate the integration of renewable energy. CERC amended the electricity grid code to lower the minimum generation threshold for thermal generators from 70% to 55%. This change is expected to reduce renewable curtailment from 3.5% to 1.4% nationwide and reduce operating costs by 0.9% (Palchak et al. 2017). CEA is currently studying the effects of lowering this threshold further to 40%, which could decrease curtailment further to 0.73% (CEA 2020d; Palchak et al. 2017).

India is also expanding its ancillary services offerings. POSOCO piloted the use of secondary reserves to provide AGC, which involves changing generators' outputs based on commands from the NLDC. The end goal is to expand AGC to all generating units for secondary reserves. To improve the speed and accuracy of response, POSOCO introduced another pilot in 2019 for fast tertiary ancillary service comprising 20 hydropower generating stations with faster response times than thermal generators (POSOCO 2019c). Adding energy storage to the pilot could be beneficial for enhancing flexibility, as several energy storage technologies have comparable or faster response times.

CERC has also written a discussion paper on the creation of a market-based system for its RRAS tertiary response service, which would increase reliability and dispatch speed (CERC 2018a). Whether through a market or amendments to regulated services, promoting greater operational flexibility through requirements for fast-responding assets improve system reliability. And expanding the range of storage technologies eligible to meet flexibility needs beyond PSH can increase the total amount of fast-responding assets available for balancing.

### 11. Support Organized Knowledge Sharing and Delivery for Scale Up and Replication

Review

There are a multitude of initiatives focused on energy storage in India and a general need for greater coordination among the agencies involved. Coordination efforts to advance energy storage deployment are currently driven by industry-led organizations. The IESA is leading these

[11] Results will be available on www.nrel.gov.

efforts and has several initiatives aimed at disseminating information to catalyze growth in energy storage, including an India Energy Storage Database and Energy Storage Standards Taskforce, as well as targeted training and discussion forums that bring together experts from across the power sector.

The Indian government has several programs to support energy storage, but no central agency is responsible for coordinating these activities. NITI Aayog is the primary arm of the government working on fostering growth in new storage technologies. In parallel, India's Department of Science and Technology has provided research funding for energy storage since 2009 through its Clean Energy Research Initiative (IEA 2020b). India has also grown its international partnerships to secure more funding for storage research, such as the Indo-US Joint Clean Energy Research and Development Center (IUSSTF) and its equivalent with the UK (JUICE). Both of these centers research the potential for storage to improve grid stability. In addition, the MoP is promoting energy storage pilots through the joint Greening the Grid initiative with USAID and the World Bank is promoting battery storage through its Accelerating Battery Storage for Development program.

With so many separate initiatives, there is a need for greater coordination through the establishment of a government agency or privately led forum. The Association of Renewable Energy Agencies of States (AREAS) could serve as a useful example of what such an entity could look like. AREAS is an MNRE initiative to provide knowledge sharing platform focused on RE where state nodal agencies can "learn from each other's experiences and also share their best practices and knowledge regarding technologies and schemes/programmes" (AREAS 2020). In the United States, the state of New York has gone further in creating the New York State Energy Research and Development Authority (NYSERDA), a state agency tasked with, inter alia, promoting the energy storage market (NYSERDA 2020). NYSERDA is responsible for allocating state funds to implement storage incentive programs and also serves as the clearinghouse for information on incentives and technical resources for installing and operating energy storage facilities, opportunities for researchers and manufacturers to develop new energy storage technologies, and the state's progress toward its clean energy goals. NYSERDA also connects technical experts through one-on-one consultations for developers and contractors to help with project siting, sizing, and economics.

### 12. Domestic Industrial Policy Supports Storage Manufacturing

Review

Policies to promote domestic manufacturing of energy storage have been limited to the use of batteries in the transportation sector. In January 2019, Prime Minister Modi announced a National Mission on Transformative Mobility and Battery Storage to develop more factories to produce batteries and electric vehicles (GOI 2019c). As part of this goal, 25%–40% of the batteries for electric vehicles would be met through domestic manufacturing initiatives. The mission includes a 5-year phased manufacturing program to set up large-scale battery giga-factories. In the state of Andhra Pradesh, Urja Global, a solar and battery manufacturing firm, is investing in production centers (Deign 2019). Expanding this program to include a diverse range of energy storage applications or developing a similar initiative focused on power sector applications could accelerate the deployment of non-hydropower storage technologies.

#### 13. Targeted Support to Early Adopters

Revise

New technologies often face a funding gap between research and development and full commercial deployment. This is particularly true for technologies, such as energy storage, that can provide a range of system benefits, some of which are not monetized through existing markets or tariffs. CERC notes that the high cost of setting up a new storage facility poses a barrier for new investments in India (CERC 2017).

Existing financial incentives for storage are limited. PSH, the only established storage technology in India, received a recent boost from measures adopted in 2019 declaring large hydropower plants as renewable energy resources (GOI 2019d). Additional support is proposed in the form of hydropower purchase obligations for these resources. Establishing similar purchase obligations for all storage technologies could be one way to incentivize nascent technologies.

The main way in which non-hydropower storage facilities are being installed is in combination with renewable energy projects. SECI's auctions for solar plus storage installations and round-the-clock renewable power projects have promoted the inclusion of storage as a way to smooth output from renewable energy facilities and reduce curtailment. Extending existing renewable energy financing tools to storage could also encourage its growth. For instance, renewable energy projects, as well as electric vehicles, have access to an accelerated depreciation tax benefit at a higher rate of 40% (IEA 2020b). Direct assistance of this kind can promote storage projects for a wider range of applications beyond RE integration.

Other support mechanisms could include targeted pilot programs for emerging storage technologies, joint ventures, or special purpose vehicles funded by the Indian government. These have been popular policy approaches in the United States, including Massachusetts's $10 million Advancing Commonwealth Energy Storage competitive grant program and New York's $150 million in funding for utility-scale storage installations under its Market Acceleration Bridge Incentive Program (Power Line 2019).

Targeted government support can help bridge the funding gap and reduce risk for new storage technologies to reach commercial maturity. Support programs that are technology agnostic, focused on desired capabilities rather than specific technologies, can encourage a wider range of possible storage solutions.

## 3.5 Regulation

India's existing regulations present a useful framework for enabling energy storage deployment; however, current regulations that explicitly restrict storage from providing services or earning revenue for those services present a barrier to maximizing the cost-effective value of storage investments.

#### 14. Utilities and Private Developers Allowed to Make Storage Investments

Review

Energy storage ownership rules are not clearly defined by CERC. The commission has outlined potential ownership models for transmission, generation, and distribution companies, all for different purposes (CERC 2017). Under this scheme, transmission-owned storage would be able to provide multiple services, including renewables integration by firming renewable energy output, peak demand management, congestion relief, and providing frequency or voltage support. Transmission operators could recover storage costs through transmission charges, but they would not be allowed to lay claim to the actual energy stored within the system. For generator-owned storage assets, the costs could be recovered by including the tariff from the storage component in the total annual fixed charges or issuing a supplemental charge for the times of year when the storage is in use. Alternatively, the generator could sell power in the market as an energy arbitrage resource. Distribution companies would be allowed to own storage for the purposes of reliability, sale of power to other generators, or demand management.

Formalizing the roles and ownership models for energy storage investments from different segments of the power sector through CERC regulations can reduce uncertainty for investors.

### 15. Interconnection Processes Give Storage the Right to Interconnect and Obtain Transmission Service

Monitor

CERC regulations allow for the connection of storage both as a stand-alone asset and in combination with renewables in hybrid projects (CERC 2019a). As part of a hybrid project, applications for interconnection are based on the aggregate power supplied by the project. For stand-alone storage facilities greater than 50 MW, applications for connectivity are based on the larger of the intended maximum injection or maximum withdrawal amount and these facilities must sign separate agreements for injection and withdrawal. Stand-alone storage projects under 50 MW can apply for interconnection if they are operated in aggregate. CEA has also amended its Technical standards for Connectivity to the Grid, enabling storage devices as well as charging infrastructure to be connected to the grid (CEA 2019d).

These regulations support a range of possible storage solutions, including mechanical, electrochemical, and thermal storage technologies. Additional steps could further expedite interconnection approvals for energy storage projects. For example, publishing a network map of preferred storage locations or allowing expedited approval for projects with low anticipated negative impacts on the grid can incentivize storage investments in areas that support the grid.

### 16. Promotion of High-Quality Standardized Technologies Through Safety Standards for Energy Storage Technologies

Review

In a 2017 staff paper, CERC asserted that establishing proper "safety standards and procedures" are necessary for storage to be deployed (CERC 2017). The Bureau of Indian Standards is now pursuing this task through is Energy Storage Sectional Committee. The committee's efforts are focused on standardization in the field of grid integration of electrical energy storage systems (IESA 2020b). The IESA is actively involved in this area as a member of the Bureau of Indian Standards committee and also through a collaboration with UL to create an Energy Storage Standards Taskforce. The taskforce is working on raising awareness on the standards development process, identifying gaps in existing standards, and serving as a leader in forming new standards to fill these gaps.

As interest in energy storage technologies in India grows, increased education, training, and technical support for the development of new codes, standards, and regulations will be critical for the safe and timely deployment of these technologies.

## 17. Operating Requirements for Fast-Responding Assets

Revise

The need for fast-responding assets and power system flexibility has taken on increased importance as the share of variable generation has grown in India. Existing provisions of CEA Technical Standards for Construction of Electrical Plant and Electrical lines requires thermal generators to be capable of providing 3%–5% per minute ramp rate, while the Indian Electricity Grid Code (IEGC) recommends 1% per minute or as per manufacturer's limits (CEA 2010; CERC 2010b). The actual performance of the thermal generators has not met the 3%–5% requirement by CEA. Block-wise ramp rates declared to the system operator for scheduling purposes are generally in the range of 1%. To incentivize generators to provide more ramping capability, CERC updated its tariff to provide financial incentives for generators to provide ramping capability beyond the 1% and to penalties to those that fail to provide 1% ramping (CERC 2019b). The incentive would increase or decrease the allowed rate or return on equity for generators whose tariff is determined by CERC.

Other regulatory efforts to increase fast-moving assets have focused on ancillary service requirements. India's ancillary services sector is still in the development phase. Table 4 summarizes the various ancillary service products proposed by CERC.

**Table 4. Fast-Response Ancillary Services Under Development**

| | Inertial | Primary | Secondary | Fast Tertiary | Slow Tertiary |
|---|---|---|---|---|---|
| **Response Time** | Seconds | Seconds–5 min | 30 s–15 min | 5–30 min | >15–60 min |
| **Quantum** | ~10 GW/Hz | ~4 GW | ~4 GW | ~1 GW | ~8–9 GW |
| **Territory** | Local | Local | NLDC/RLDC | NLDC | NLDC/SLDC |
| **Control** | Automatic | Automatic | Automatic | Manual | Manual |
| **Code/Order** | IEGC/CEA Standard | IEGC/CEA Standard | Roadmap on Reserves | Ancillary Regulations | Ancillary Regulations |
| **Status** | Existing | Partly Existing | Pilot | Pilot | Existing |

Note: Table adapted from CERC 2018a

Inertial and primary response requirements are set out in the Indian Electricity Grid Code (IEGC) and CEA Technical Standards for Connectivity to the Grid (CERC 2010b; CEA 2019d). Generators are required to provide these services but are not explicitly compensated for doing so. Actual primary response has been lower than desired at times due to technical difficulties for units to respond in time and some generators not retaining adequate capacity on reserve (Shrivastava 2017).

Secondary response and fast tertiary response are both in the pilot phase and have not been fully implemented. Secondary reserves are met through AGC connected to generating units and controlled centrally. CERC has ordered further upgrades to equip units with AGC and set up communication between the control room and generating units to fully implement AGC response (CERC 2018b). Fast tertiary response is being piloted for hydropower projects under a CERC Order but this service has not been formalized in CERC regulations (CERC 2018c).

Finally, slow tertiary reserves, also referred to as RRAS, are provided by unscheduled capacity from inter-state generating stations and compensated through variable and fixed charges as outlined in CERC’s Ancillary Services Operations Regulations (CERC 2015a). Any imbalance between supply and demand is managed by dispatching RRAS. Similar to primary reserves, POSOCO has reported that actual RRAS available have been insufficient during some peak demand periods (POSOCO 2019a).

Despite recent advances promoting fast-responding ancillary services, two key barriers remain to achieving the desired amount of system flexibility. First, CERC has yet to mandate the amount of reserves required for each service. The 2015 “Roadmap to Operationalise Reserves in the Country” presents guidelines on reserve requirements but these have not been formalized (CERC 2015b). Second, current regulations exclude certain technologies from providing reserve services, including energy storage. In the 2020 review of the IEGC, the Expert Group recommended current ancillary services regulations be expanded to include energy storage technologies (CERC Expert Group 2020).

Updating current regulations to signal the desired amount of ancillary services required to maintain reliable power supplies can signal investment needs among project developers. And expanding the range of technologies eligible to provide these services to include energy storage technologies can increase the amount of fast-responding assets available to meet these needs.

### 18. Electricity Service Charges Reflect the Value of and Increase Price Transparency for Energy Services

Revise

Pricing mechanisms in India are increasingly capturing the value of different services to the grid. This is an important step toward incentivizing investments in technologies that best fit the needs of the system. For instance, wholesale market prices reflect the value of energy at different times and locations, indicating potential opportunities for energy arbitrage and peak demand management services. However, these opportunities are limited, as wholesale markets account for less than 10% of energy sales.

Recent tariff updates by CERC are improving the price signals from regulated tariffs to value generator availability. To improve system adequacy, CERC updated the fixed cost component of the tariff for pumped hydropower and thermal plants to include a capacity charge based on generator availability during high demand periods. PSH plants are required to pump water to an upper reservoir during off-peak hours and maximize available supplies during peak hours to receive capacity payments each day. For thermal plants, capacity payments are higher for peak hours and high demand months. Both of these approaches encourage generating units to be available when most needed (i.e., during high demand periods). To further incentivize greater reliability, thermal generators can earn an additional payment of Rs 0.65 per kWh for energy scheduled during peak hours and Rs 0.50 per kWh for energy scheduled during off-peak hours in excess of the normative annual plant load factor (CERC 2019b). Expanding these pricing mechanisms to be technology-agnostic could encourage greater availability and performance of the entire generation fleet.

Tariff reforms for ancillary services could also improve system performance. Ancillary services are currently provided from uncommitted centrally-owned thermal and hydropower plants. These units are dispatched based on merit-order criteria, favoring those low operating costs. However, these criteria and the payments for providing ancillary services do not consider the speed and accuracy with which these resources respond. Updating the price signals to reward fast-ramping resources, such as energy storage, could lower total ancillary service requirements.

### 19. Storage Able to Compete with Other Grid Assets to Provide Multiple Services

Revise

Under existing regulations, stand-alone energy storage facilities are allowed to compete as a grid-connected entity to provide energy through cost-of-service regulation or within India's power exchanges (CERC 2010a). However, current market and operating rules—designed for conventional grid assets—fail to capture the operational value and limitations of energy storage technologies (i.e., speed and accuracy of response, state-of-charge, duration). Energy storage can also provide grid support during outages and reduce variability in renewable energy generation for paired renewable energy-plus-storage systems (BNEF 2019).

Other services are restricted either explicitly by current regulations or due to a lack of compensation mechanisms. For example, energy storage is not considered a "generating station" and, as a result, cannot provide ancillary services or contribute toward India's resource adequacy requirements (BNEF 2019). Other services, such as improving power quality and reducing RE losses, are technically allowed for stand-alone storage facilities but are not economic under existing compensation mechanisms (BNEF 2019). Storage as part of hybrid projects can be used to reduce variability of power output and provide firm power, but there is no direct payment for these services.

Increasing access to multiple revenue streams can improve the economic viability of energy storage investments.

**20. Storage Able to Receive Revenue for Providing Multiple Services**

Revise

There are limited mechanisms for stand-alone storage projects in India to receive revenue. Compensation is primarily earned through long-term cost-of-service agreements directly related to the provision of power; however, this revenue may be insufficient to fully cover the costs of an energy storage facility (BNEF 2019).

There are multiple existing revenue streams that could be expanded to include energy storage. For instance, India's availability-based tariff compensates generators that can respond to changes in net load to maintain a balance of supply and demand. Energy storage, with its ability to rapidly respond to control signals to inject or withdraw power, could improve system operations and earn revenue through availability-based tariff payments (IEA 2020b). Frequency regulation presents another potential revenue source for energy storage. Generators that provide RRAS can earn additional payments in addition to their energy charges. Under current regulations, only thermal and hydropower plants can provide RRAS. Expanding the range of technologies eligible to provide ancillary services to include energy storage could improve the financial viability of storage projects and improve overall grid performance. For other benefits, new mechanisms are required to value the services that energy storage can provide and compensate owners for these services.

A related issue is how energy storage resources that provide multiple use applications can or should be compensated through both cost-based and market-based mechanisms. CERC's proposed guidelines involve separate service charges for each service energy storage provided at its time of use (CERC 2017). For instance, if the storage capacity is sold to other generators, the costs could be recovered with a markup price based on the cost of energy during the charging, holding, and discharging periods. If storage is used for voltage control or congestion reduction, costs can first be recovered from the reactive pool account or reliability charges. Further work is needed to define how to combine multiple revenue streams without resulting in double recovery of costs or distorting market outcomes.

# 4 Guidelines for Policymakers and Regulators

The application of the energy storage readiness assessment for India reveals multiple technical and economic opportunities for energy storage, including providing energy, load following, resource adequacy, ancillary services, and transmission support. However, significant barriers exist in existing policy and regulatory frameworks to enable storage projects to provide these services.

A critical first step is including energy storage in the national energy policy. By outlining the desired scope and scale of storage deployment, policymakers can accelerate the identification and implementation of appropriate energy storage solutions. National targets for storage deployment and support for energy storage development can promote investments that fulfill desired policy goals. India, like most countries, is in a familiarization stage with non-hydropower energy storage technologies. Establishing a forum for knowledge exchange through, for example a dedicated office within MoP or MNRE, where stakeholders can find resources and share best practices can help with scale-up and replication of successful projects.

Integrating energy storage into national energy policies also enables regulatory authorities to begin implementing necessary regulations to achieve these policy outcomes. Chief among these in India are regulations that enable energy storage to provide a wider range of grid services and accompanying compensation mechanisms—whether through regulated tariffs or markets—to earn revenue for those services.

The range of energy storage technologies for utility-scale grid applications is expanding quickly including multiple forms of mechanical, electrochemical, and thermal energy storage. Policymakers and regulators can encourage technology innovation through technology-agnostic policies, programs, and rules focused on desirable characteristics and operating requirements rather than specific technologies. A technology-agnostic approach will avoid creating artificial barriers for emerging technologies.

As the Indian power system continues to transform, energy storage technologies can contribute to meeting evolving system needs for flexibility and reliability. Comprehensive policy and regulatory frameworks can enable economically viable storage technologies to meet these needs.

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