Energy Storage in South Asia: Understanding the Role of Grid-Connected Energy Storage in South Asia's Power Sector Transformation

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National Renewable Energy Laboratory

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List of Acronyms

ATB	annual technology baseline
BESS	battery energy storage systems
CBET	cross-border electricity trade
CEA	Central Electricity Authority
CEM	capacity expansion model
CERC	Central Electricity Regulatory Commission
LCOE	levelized cost of electricity
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PCM	production cost model
PSH	pumped storage hydropower
PV	photovoltaic
RE	renewable energy
ReEDS-India	Regional Energy Deployment System India
reV	Renewable Energy Potential tool
ROR	run-of-river
VC	variable cost

Executive Summary

During the last decade, the cost of energy storage technologies, primarily lithium-ion battery energy storage systems (BESS), has declined rapidly and is projected to decline further over the next decade (BloombergNEF 2019). This comes at a time when electricity grid flexibility is being recognized as an essential resource for reliable operations and for integrating high amounts of renewable energy (RE). In India, flexibility has been referred to as the “new currency for the use of energy” (Soonee and Kumar 2020). Energy storage has the technical potential to provide some of this grid flexibility. However, questions remain about the opportunities for energy storage in India and other South Asia countries, including Bangladesh, Bhutan, and Nepal. Uncertainty remains about the technology costs, as well as rules governing energy storage operations, ownership, and compensation mechanisms.

Objective and Scope

This study provides a first-of-its-kind assessment of cost-effective opportunities for grid-scale energy storage deployment in South Asia both in the near term and the long term, including a detailed analysis of energy storage drivers, potential barriers, and the role of energy storage in system operations. We conducted scenarios-based capacity expansion modeling to assess when, where and how much energy storage can be cost-effectively deployed in India through 2050. The analysis relies on state-of-the-art modeling approaches to uncover and compare the value streams of battery storage with different durations, as well as pumped storage hydropower (PSH). We also ran hourly simulations of system operations in India, Bangladesh, Bhutan, and Nepal as a single South Asia interconnection with no institutional barriers to cross-border electricity trade (CBET). Simulations are run for 2030 and 2050 to understand how energy storage will be utilized by system operators to help integrate RE, reduce operating costs, optimize CBET, and optimize the use of domestic resources.

This study does not seek to identify a single optimal scenario for power sector growth and energy storage deployment. Instead, scenario analysis is used to assess the range of possible least-cost pathways for India’s power sector and the potential role for energy storage. Nor does this study consider the challenges that may be faced in scaling up energy storage from a manufacturing, materials, land-use, or supply chain perspective. Finally, this study does not evaluate the potential for future breakthroughs in long-duration energy storage technologies such as power-to-gas hydrogen applications or gravity energy storage.

Key Findings

Energy storage can provide a range of grid services and has the potential to play an important role in the development of a cost-effective power sector for India. Storage can also provide benefits to Bangladesh, Bhutan, and Nepal individually and collectively to the South Asia grid (see Figure ES-1). Energy storage in Nepal and Bhutan can help in optimizing exports to India, thereby helping the South Asia grid to accommodate more hydro and RE in the system. Energy storage in Bangladesh can help displace fuel oil generation, reduce the production cost, and provide balancing services.

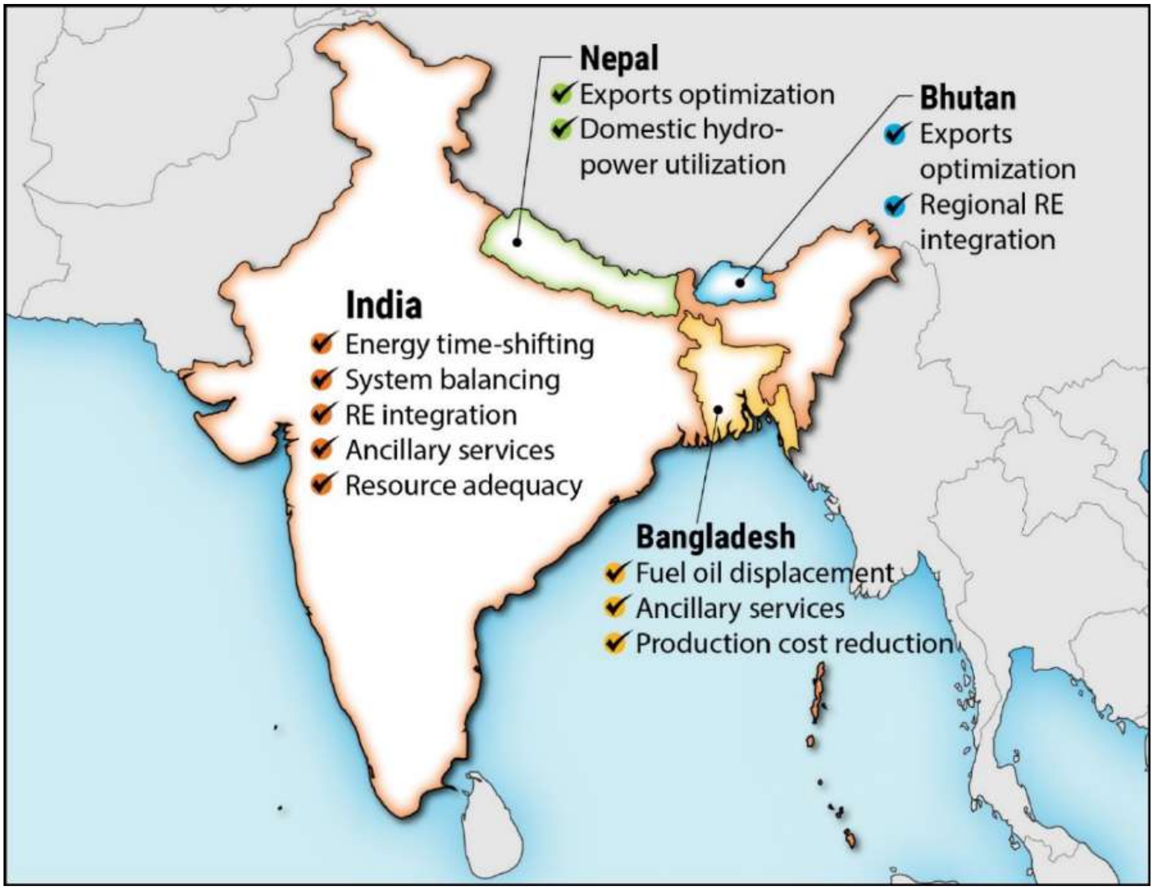

Figure ES-1. Primary sources of value of energy storage

Cost-Effective Energy Storage Opportunities for Various Grid Services Are Right Around the Corner

We find that energy storage becomes cost-competitive with other technologies due in part to projected cost declines through 2030. Results show that cost-effective energy storage capacity grows quickly with an average year-over-year growth rate of 42% between 2020 and 2030. Initial deployments are primarily 2-hour duration battery systems. Beginning in the mid-2020s, 4-hour battery storage deployments dominate the energy storage landscape. Pumped-hydro development is limited to those projects that are currently under construction or planned as per the Central Electricity Authority (CEA) (CEA 2021). Battery storage investments are found to be cost-effective in 26 of the 34 states and union territories by 2030. In the Reference Case, which represents the standard set of assumptions used in this study, three states have over 10 GW of battery storage capacity by 2030: Jammu and Kashmir, Gujarat, and Karnataka.

Across All Scenarios, Energy Storage Technologies Play an Increasing Role in India's Power System

We evaluate the investment potential for energy storage under several scenarios representing different trajectories for technology costs, regulatory rules, and policy changes. In all cases, energy storage grows to play a significant role in India's power system. The capacity of storage technologies reaches between 180 GW and 800 GW, representing between 10% and 25% of total installed power capacity by 2050. Energy capacity of storage reaches between 750 GWh and

4,900 GWh by 2050. Figure ES-2 shows the range of storage deployment results across all scenarios.

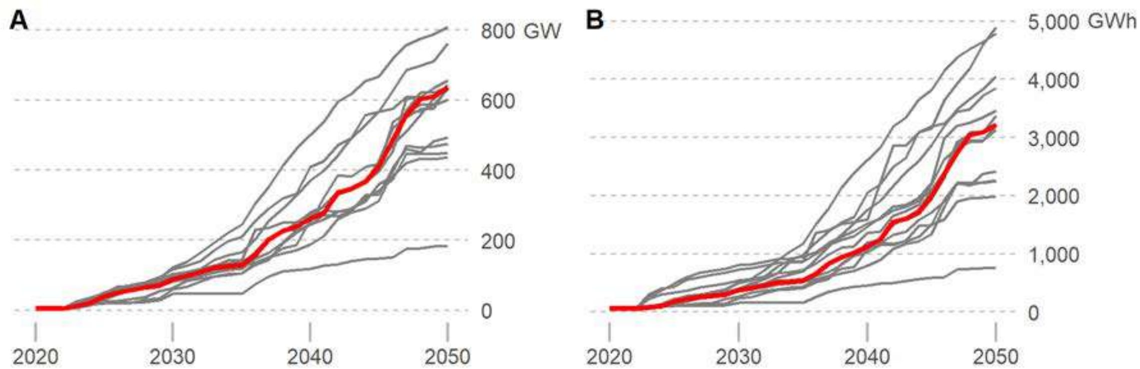

Figure ES-2. Energy storage power (A) and energy (B) capacity deployment in India to 2050

Note: Each line represents one modeled scenario. The Reference Case is highlighted in red.

The Reference Case is not designed to forecast what is most likely to happen. Rather, the Reference Case is designed as a launching point to examine the key drivers for energy storage deployment and allow us to examine these drivers through additional scenarios. The scenarios analyzed in this study, summarized in Figure ES-3, help identify conditions that lead to higher or lower energy storage deployment in India.

Figure ES-3. Conditions that lead to higher and lower energy storage deployment in India

No ES Time-Shifting Value: energy storage is not valued for shifting energy to different times of day; No ES Capacity Credit: energy storage is not valued for contributions to resource adequacy; No ES Operating Reserves: energy storage does not provide operating reserves.

Energy Time-Shifting and Capacity Services Are the Largest Source of Value for Energy Storage Both in the Near and Long Term

Energy storage can provide multiple services to the grid, and the value for providing these services changes over time as the generation mix and patterns of electricity demand change. Across all scenarios evaluated in this study, energy time-shifting and capacity services make up the lion's share of value for energy storage. We find that the ability for energy storage to provide diurnal energy time-shifting has the largest impact on both near-term and long-term storage deployment (Figure ES-3).[1] And the value of energy time-shifting is likely to increase over time as anticipated growth in electricity demand and RE deployment results in increased variability in daily net load patterns. In the scenario where energy storage cannot receive revenue for energy time-shifting, overall investments in energy storage technologies fall by 65%. This scenario

[1] We evaluate the time-shifting value of energy storage on an hourly timescale. Sub-hourly timescales are outside the scope of this study.

could happen in a contract structure in which there is a single tariff that does not correctly account for the changing price of energy throughout the day.

Valuing Energy Storage for a Range of Grid Services Helps Achieve a Least-Cost Power System

The Reference Case assumes that energy storage devices can receive revenue equal to the full value of grid services they provide. Scenario analysis is used to evaluate the impacts of removing certain revenue streams. Total systems costs are higher when energy storage does not provide certain grid services (Figure ES-4). In the scenario where energy storage cannot receive revenue for energy time-shifting, system costs are 4% higher compared to the Reference Case. This is due, in part, to differences in the capacity and generation mix, with less RE and more high-operations and maintenance (O&M) cost thermal investments. The No ES Capacity Credit scenario, where storage devices are not compensated for their contribution to capacity reserve requirements, also leads to a 4% increase in total system costs. In this scenario, more underutilized thermal capacity is needed to meet capacity reserve margins compared to the Reference Case. And when energy storage does not provide operating reserves, system costs are 3% higher. Increased system costs in this scenario are driven primarily by higher fuel consumption and O&M costs for conventional generators.

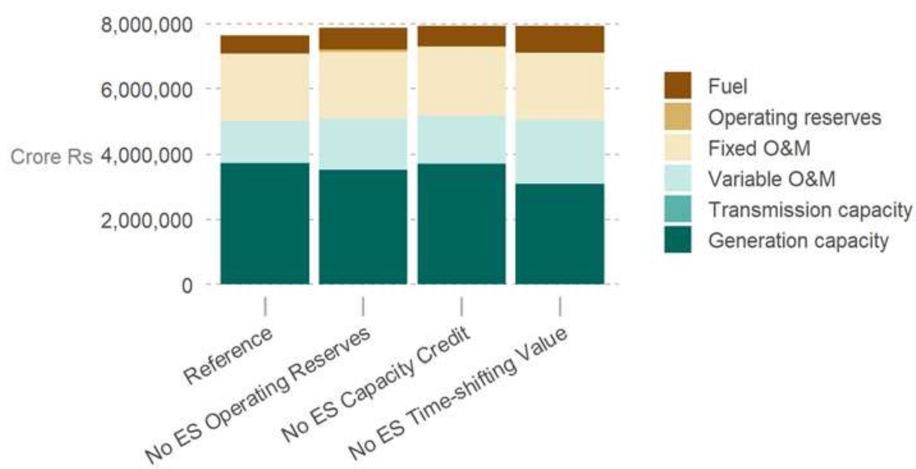

Figure ES-4. Present value of total system costs for 2020 to 2050 in Reference Case and energy storage regulatory scenarios

Note: The currency conversion rate for Indian Rupees (₹) to United States Dollars ($) is taken as ₹70.2 per $1.

Four-Hour Battery Storage has the Largest Potential to Provide Peaking Capacity for Long-Term Capacity Adequacy

Energy storage can provide a reliable source of peaking capacity, contributing to long-term capacity adequacy. However, the ability of storage to provide peaking capacity depends on the storage duration and the shape of the net demand curve. We find that 4-hour battery storage has the largest potential to provide peaking capacity with a 100% capacity credit (67 GW in 2030 and 140 GW in 2050) in the Reference Case. We also find the ability of energy storage to count towards long-term capacity adequacy requirements has the second-largest impact on overall storage deployment. In scenarios where energy storage cannot receive revenue for capacity adequacy, overall investments in energy storage technologies fall by 22%.