Table 12. Change in Annual Operational Metrics in Bangladesh With Incremental Energy Storage Builds

	ES-100 MW	ES-300 MW	ES-500 MW	ES-1000 MW	ES-2000 MW	ES-5000 MW
Production Cost	-0.5%	-1.1%	-1.7%	-2.9%	-5.4%	-8.3%
Fuel Oil Generation	-1.2%	-3.1%	-5.4%	-11%	-22%	-34%
Energy Storage Share in Operating Reserves	0.4%	1.2%	1.9%	3.5%	11%	26%
Reserve Price	No significant change	No significant change	No significant change	-6%	-13%	-46%

Figure 44 shows the operation of energy storage in all scenarios of energy storage addition for Bangladesh. The pattern is similar in all where energy storage is discharging during the evening peak and charging at all other times.

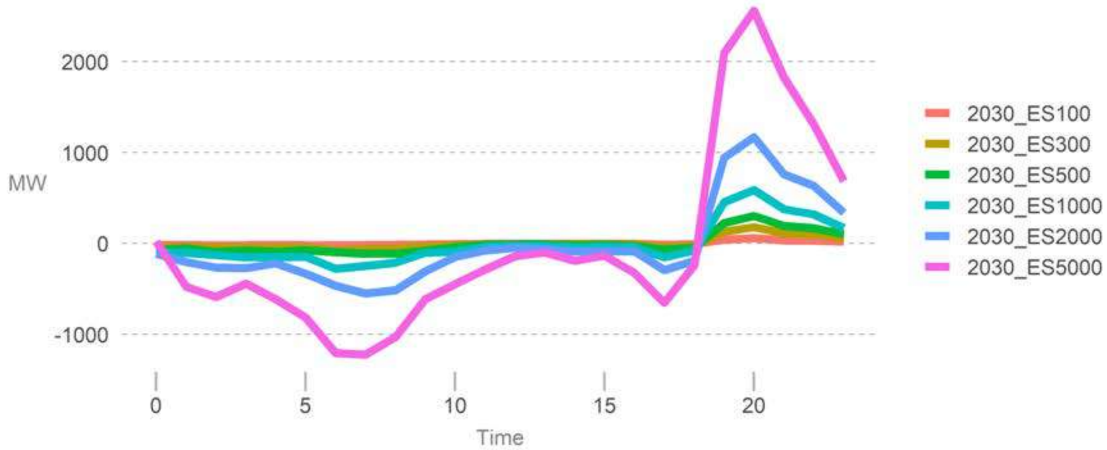

Figure 44. Average net generation pattern of energy storage devices in Bangladesh in the energy storage addition scenarios (ES100 = 100 MW, ES200 = 200 MW, etc.)

Note: Negative values indicate that the storage is charging from the grid.

3.6.2 Energy Storage in Bhutan Can Shift Exports to Times That Are Beneficial for Regional RE Integration

In present-day operations, all excess hydro generation from Bhutan is exported to India. The present contracts between India and Bhutan for various hydro projects located in Bhutan are based on total export potential rather than a specific power quantum. Therefore, in our modeling, exports from Bhutan to India were not associated with transmission wheeling or other charges. This ensured that all the excess power from Bhutan was exported to India. As shown in Figure 45, adding energy storage shifted exports more to the evening hours as well as increasing export during times of solar ramp up and down. This helps to balance the grid in India, allowing for ramping support and optimizing Bhutan's resources. Additionally, increasing amounts of energy storage in Bhutan lead to reduced daytime RE curtailment in India by reducing export during the middle of the day when solar is high and shifting it to the evening peak. Between the scenario with 500 MW and 1,000 MW energy storage in Bhutan, an additional 150 GWh of RE was accommodated on India's grid for the year.

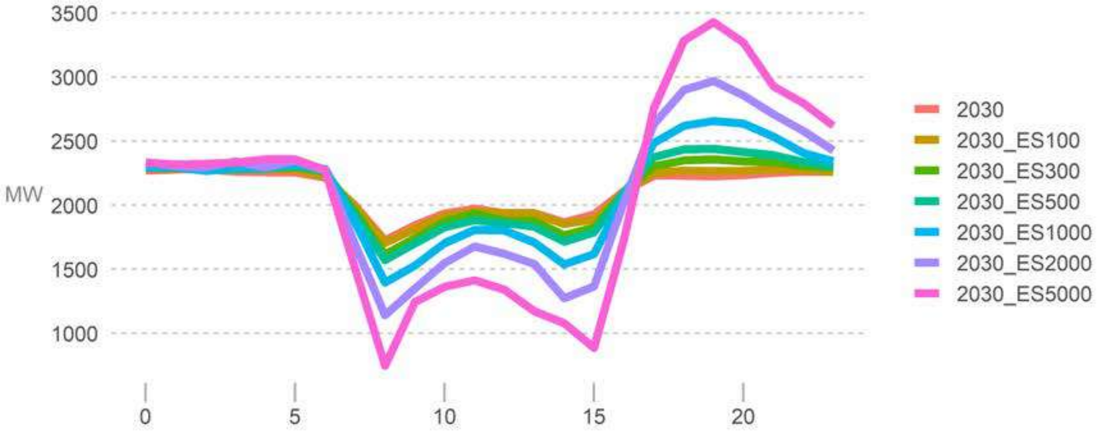

Figure 45. Average export pattern from Bhutan to India in 2030 without energy storage additions (2030) and with incremental energy storage builds in Bhutan (ES100 = 100 MW, ES200 = 200 MW, etc.)

3.6.3 Energy Storage Helps Nepal to Reduce Hydro Curtailment, Exporting More Energy to India and Providing Operating Reserves

Most of the existing and planned hydropower projects in Nepal are ROR type, except a few that have storage. Because ROR plants cannot modulate their output, Nepal may not be able to maximize the use of domestic hydropower resources during periods when domestic demand and exports to India are not sufficient to absorb the ROR generation. In our production cost modeling of hourly system operations in 2030, we observed that 0.6% of Nepal's hydropower generation was curtailed due to insufficient flexibility.[17] Adding 4-hour energy storage in Nepal helped shift hydro generation to periods when it is needed, reducing hydro curtailment, and increasing exports to India in 2030. Table 13 shows that adding up to 500 MW of 4-hour energy storage reduces curtailment substantially and increases the opportunities for exporting formerly curtailed power to India. We also tested scenarios with 1,000 MW, 2,000 MW, and 5,000 MW of storage capacity but did not see much further increase in exports to India.

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[17] ROR hydropower has very low or zero marginal costs to operate. Therefore, curtailing power, which is done by allowing water to flow past the dams, is wasting very low-cost energy that cannot be recovered.

Table 13. Change in Annual Nepal Export to India With Incremental Energy Storage Additions

4-hr Energy Storage Capacity	Change in Exports to India (GWh)	Hydro ROR Curtailment
0 MW	-	0.6%
100 MW	293	0.48%
300 MW	432	0.36%
500 MW	728	0.13%

Figure 46 shows the changes in the export of power to India for all scenarios of energy storage addition. Energy storage enables Nepal to shift daily exports to India to evening peak hours when India's demand is higher and solar generation in India is low or zero. Increasing the capacity of energy storage increases the export during evening peak.

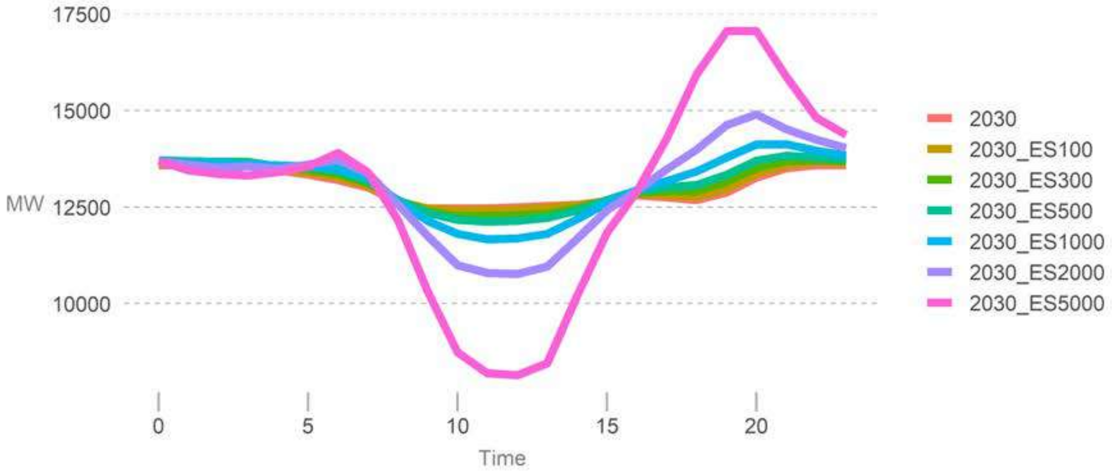

Figure 46. Average export pattern from Nepal to India in 2030 without energy storage additions (2030) and with incremental energy storage builds in Nepal (ES100 = 100 MW, ES200 = 200 MW, etc.)

We also studied the role of energy storage in providing operating reserves in Nepal.[18] Adding 500 MW of energy storage can provide 69% of total reserve requirements. Adding 100 MW of energy storage can provide 44% of total reserve requirements. The remainder of reserve requirements is fulfilled by reservoir-based storage hydro plants**.** This indicates that if energy storage with 4-hour duration is added to Nepal's power sector, it could increase reliability by contributing to operating reserves while having multiple value streams that it could access if the necessary regulations were in place.

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[18] Though there are no existing regulations related to operating reserves in the country, we assumed 5% of load as the reserve requirement for this analysis.

4 Summary

We found that grid-scale energy storage plays an important role in the development of a cost-effective power sector for India and is a key enabler for cost-effective solar PV deployment and reduced air emissions from India's power sector in the long term. Additionally, energy storage has the potential to increase efficiency and lower the costs of operations for Bangladesh, Bhutan, and Nepal. The system growth scenarios analyzed in this study, summarized in Figure 47, helped identify factors that lead to higher or lower energy storage deployment in India.

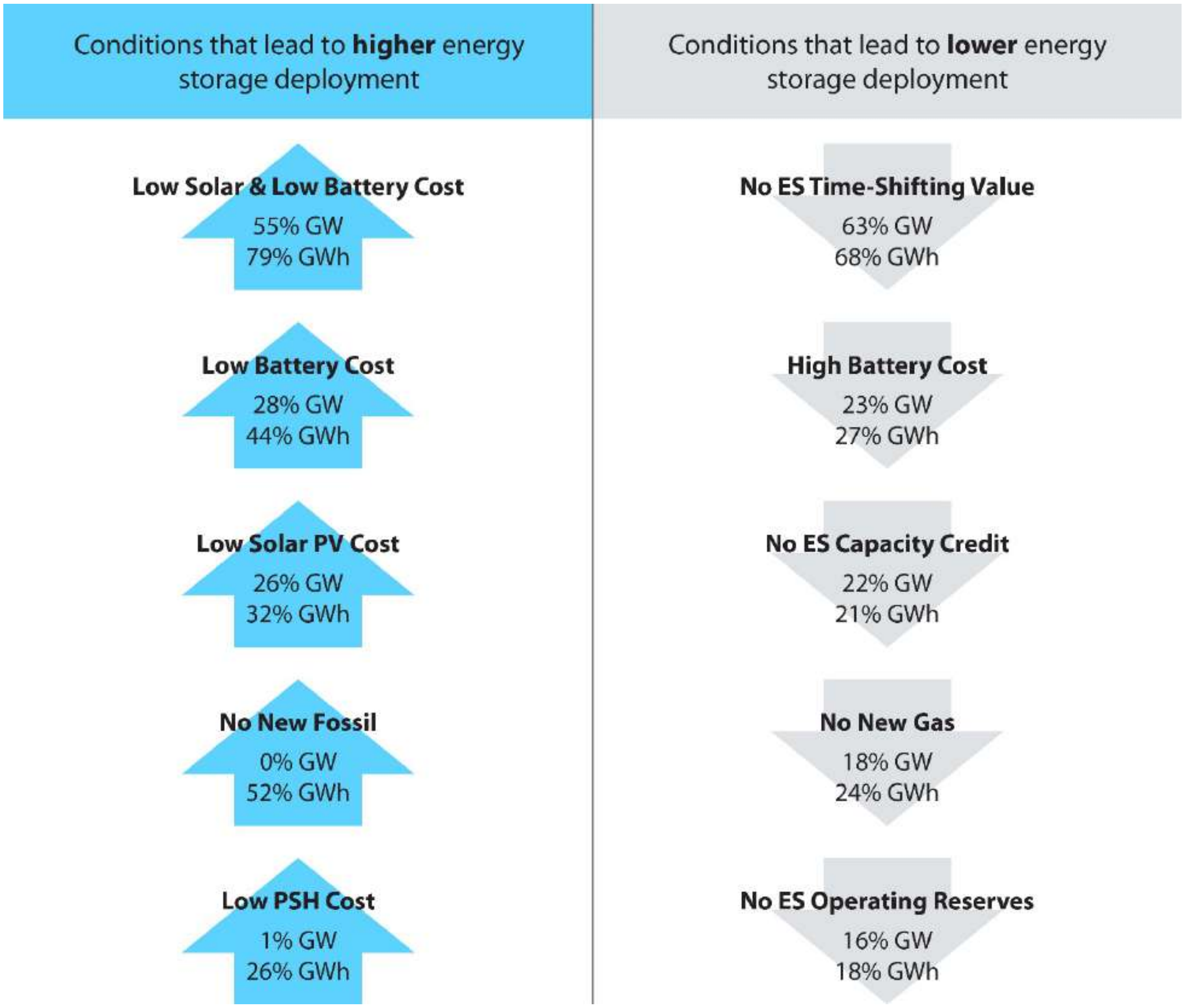

Figure 47. Conditions that lead to higher and lower energy storage deployment in India

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 spinning reserves.

The results point to several trends that can inform regulations, policies, and market rules for energy storage in South Asia:

- Establishing a level playing field for energy storage to compete with conventional technologies can lead to increased RE deployment and reduced air emissions from the power sector. Modeling results showed that when energy storage can compete directly with conventional resources to provide various system services, more energy storage becomes cost-effective, which results in increased solar PV deployment and reduced generation from fossil-fueled resources. Leveling the playing field can include new ways to value the performance of generating resources to meet system needs, such as ramp rates, response time, and minimum generation level.
- Energy storage systems can achieve their full economic potential if they are able to provide and monetize multiple system services. In the South Asia context, this means that new regulatory proceedings at the national and state levels may be needed to enable energy storage projects to participate as a source of both load and generation and to provide multiple grid services. For utility-owned energy storage devices, where costs are recovered under a cost-of-service regulation, utilities and regulators can establish agreed-upon methods to quantify and compensate the full system value that energy storage provides to the power system.
- Access to cost-reflective energy markets, with daily price fluctuations, is a key revenue stream that can enable energy storage to be cost-competitive with conventional resources. Regulators can consider allowing energy storage to participate in the wholesale and real-time energy market. In the absence of markets, tariff structures that reflect system value, such as rewarding energy storage for discharging during high-value periods, can help storage devices monetize the energy time-shifting value they provide to the system.
- Energy storage can be a significant source of reliable capacity for India's power system. Valuing the capacity contribution of energy storage, through tariff design or other mechanisms such as capacity auctions or capacity payments, can enable cost-effective energy storage to compete with fossil-fueled capacity resources. Regulators can begin by establishing clear and agreed-upon methods to quantify and compensate all resources (including energy storage devices) for contribution to reliable capacity.
- Energy storage can help meet operating reserve requirements and therefore reduce commitments of thermal generators. However, providing operating reserves is a relatively small portion of the full value of energy storage for the power system. Regulators can help ensure market rules governing operating reserves and other ancillary services enable energy storage to provide multiple grid services from the same device. In India, for example, CERC has issued draft regulations that explicitly allow energy storage to participate in the proposed ancillary services markets (CERC 2021).
- There is a strong synergy between energy storage and solar PV deployment. Policymakers can include energy storage in national energy policies and master plans and acknowledge the complementarity between solar PV targets and increasing opportunities for energy storage technologies.

The results also point to significant opportunities for energy storage in Bangladesh, Bhutan, and Nepal. In Bangladesh, energy storage can substitute costly thermal generation used for energy and operating reserves. With each incremental addition of energy storage in Bangladesh, we saw reductions in the annual production cost, as well as lower costs for operating reserves. In Bhutan, energy storage can be used to shift hydropower generation from the middle of the day, when solar generation in India is highest, to evening hours when exports are most valuable. In Nepal, energy storage can help reduce hydro curtailment, help maximize energy exports to India, and provide operating reserves.

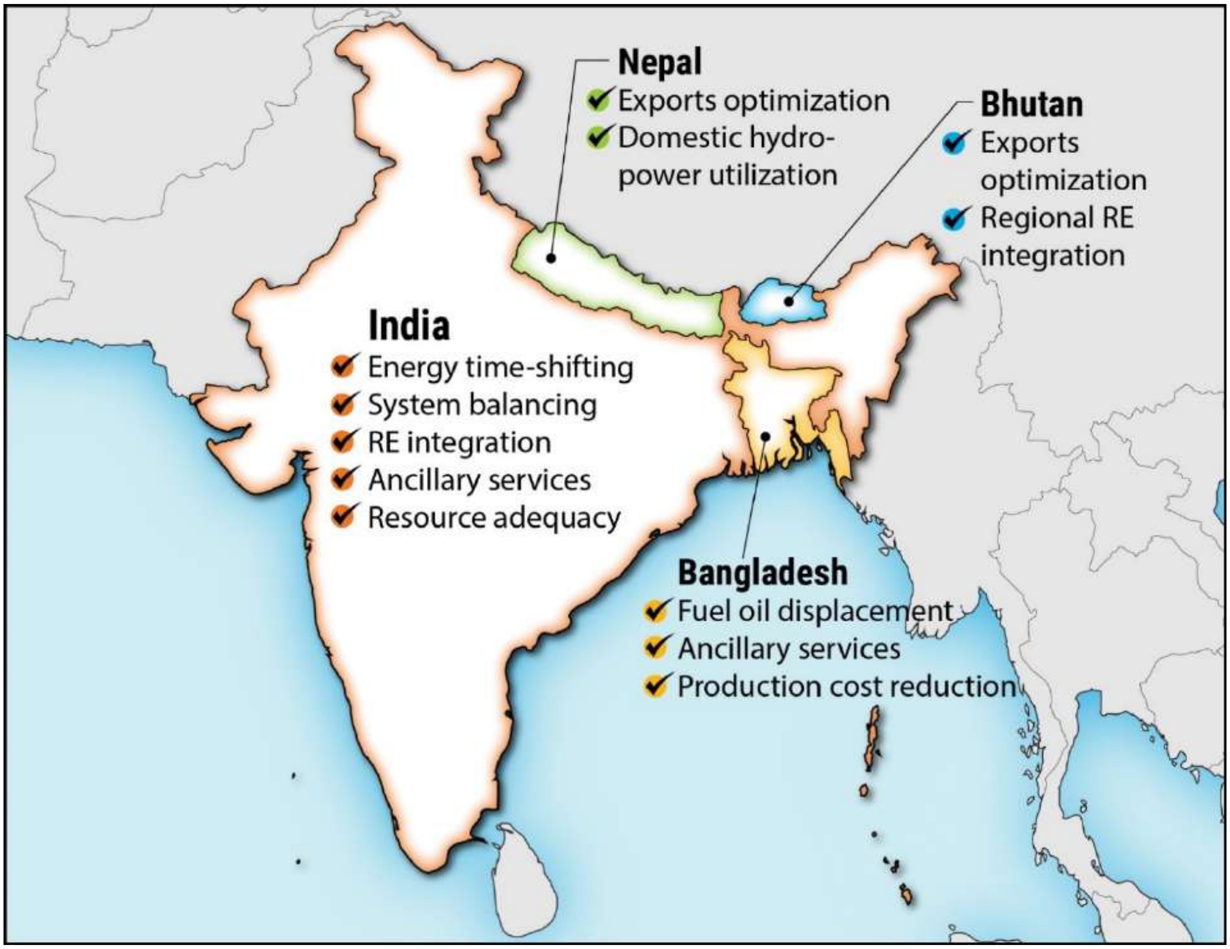

Figure 48. Summary of potential energy storage services in South Asia

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