

Co-locating Solar and Battery Storage for Reliable Power Supply

A techno-economic assessment



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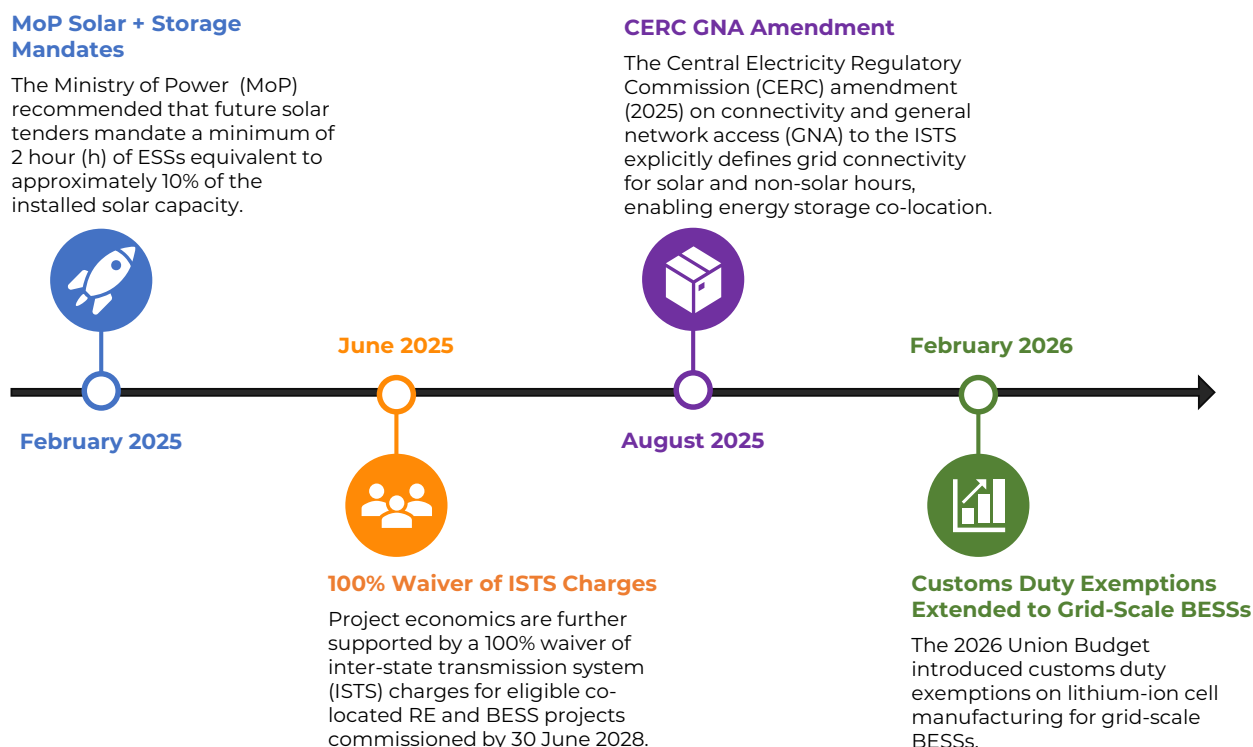
Introduction

India is moving from a phase of rapid renewable capacity addition to one focused on the quality of renewable power, i.e. its reliability, flexibility, and ability to meet system needs (Ministry of New and Renewable Energy, 2025). Energy storage, therefore, is central to this transition as it enables renewable energy (RE) to be delivered when needed, rather than only when generated. With this in view, India has installed approximately 9 gigawatt-hour (GWh) of battery energy storage systems (BESSs) as of July 2026, with around 59.4 GWh being under construction (Central Electricity Authority [CEA], 2026).

At the same time, India's RE procurement is increasingly incorporating products with defined delivery obligations, including round-the-clock (RTC) supply, assured peak-power blocks of different durations, and more recently, thermal-mimic tenders designed to replicate the delivery characteristics of conventional thermal generation.

As these differentiated delivery profiles become more common and ESS deployment increases, how RE and storage are configured becomes important for meeting supply obligations efficiently. Co-locating RE and BESS can improve the economics of such projects by enabling shared use of land and grid evacuation infrastructure, while also improving utilisation of transmission assets. Figure 1 depicts the evolution of policies that support co-located solar and BESS projects.

Figure 1: Current policy landscape for co-located solar and BESS projects (CEA, 2025; CERC, 2025; MoP, 2025; Sitharaman, 2026)

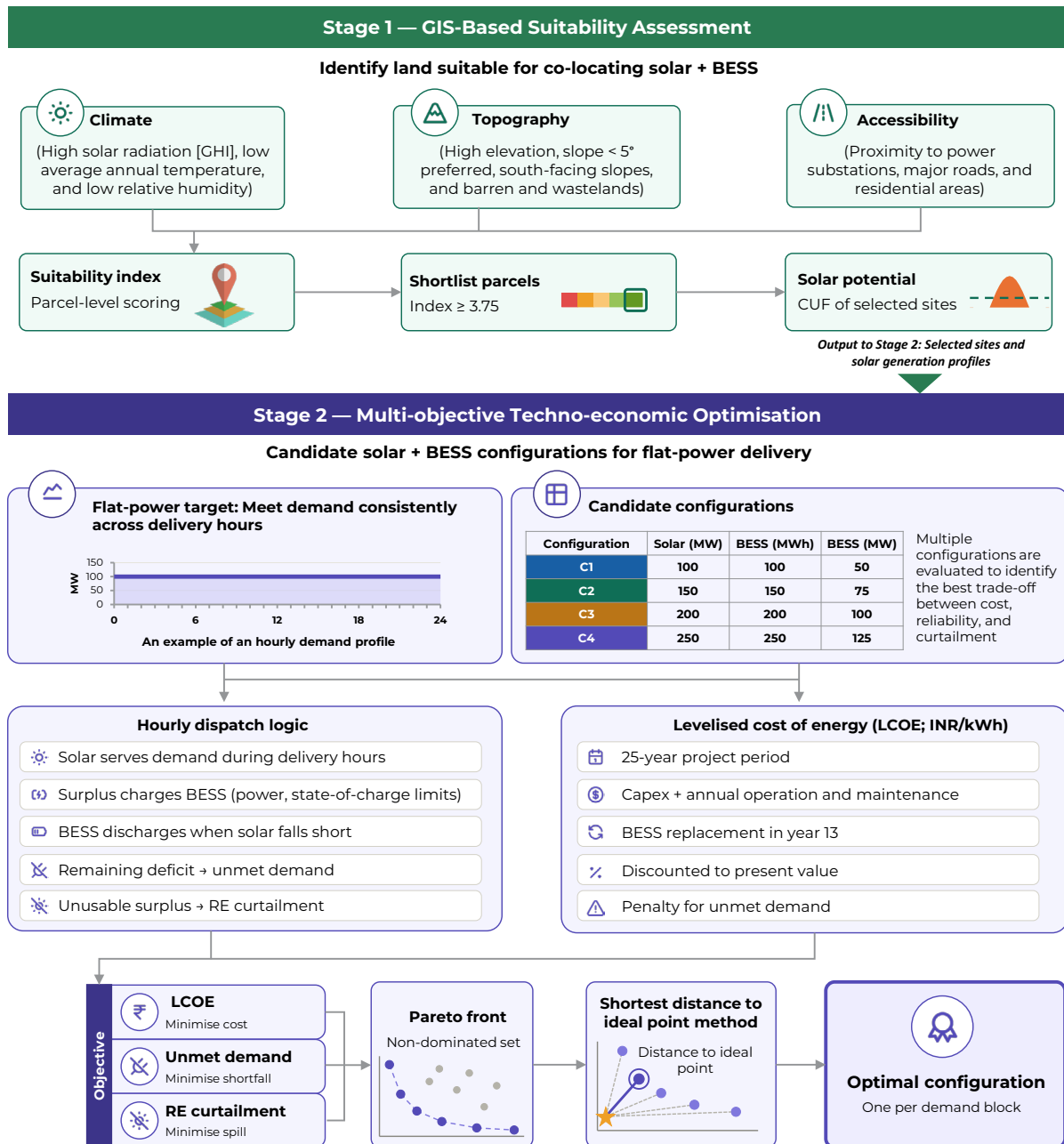


In this context, the Center for Study of Science, Technology and Policy (CSTEP) developed an integrated framework based on the Geographic Information System (GIS) and techno-economic planning for co-located solar and BESS projects. As a case study, the framework was applied to a 100 MW flat-power block (continuous 1 h block) across delivery durations ranging from 2 h to 24 h and different time-window placements in Karnataka.

Analytical Framework

The framework addresses where to co-locate solar and BESS projects and how to size them to meet different flat-power delivery requirements. It combines GIS-based site-suitability assessment and multi-objective techno-economic optimisation to evaluate trade-offs between reliability, RE curtailment, and cost (Figure 2).

Figure 2: Integrated framework based on GIS and techno-economic planning for co-locating solar and BESS (GHI – Global horizontal irradiance; CUF – Capacity utilisation factor; MW – Megawatt; Dimas de la Fuente et al., 2018; Jacob et al., 2026)¹

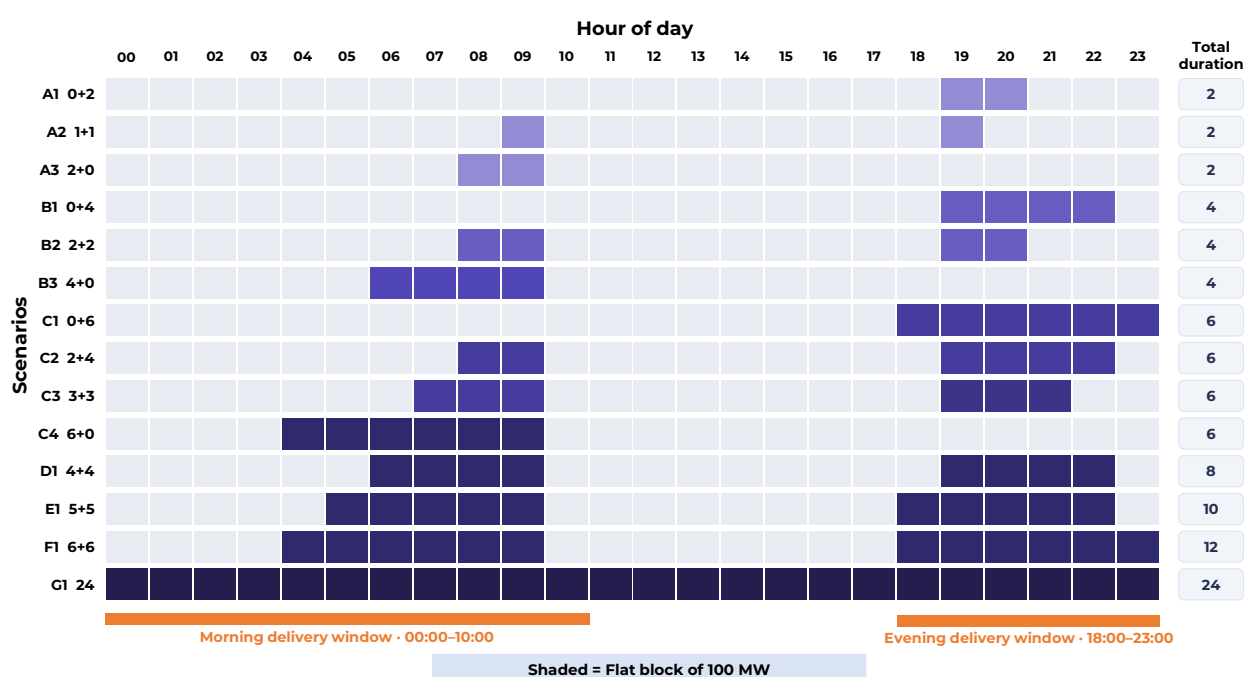


¹ Pareto front in the space of objective functions is the set of pareto-optimal solutions, which refer to a set of 'non-inferior' solutions in the objective space. Here, improving one objective would come at the expense of at least one other objective, thereby defining a boundary beyond which none of the objectives can be improved. Out of these set of solutions, the optimal solution that gives the best trade-off for the defined objectives is selected.

The Karnataka Case Study

The case study evaluated a 100 MW flat-block clean-power requirement across 14 scenarios with delivery durations of 2, 4, 6, 8, 10, 12, and 24 h. For the 2, 4, and 6 h scenarios, multiple delivery-window placements were considered to assess how distributing the supply obligation between the morning delivery window (00:00–10:00) and the evening peak window (18:00–23:00) affects solar and BESS sizing, reliability, RE curtailment, and cost (Solar Energy Corporation of India Limited, 2026). The 8, 10, and 12 h scenarios span both morning and evening delivery periods. The 24 h scenario was treated as an RTC case, where the entire day—not only selected peak periods—is supplied continuously by the solar-BESS system through a 100 MW flat block (Figure 3).

Figure 3: 100 MW flat-block timings for different scenarios

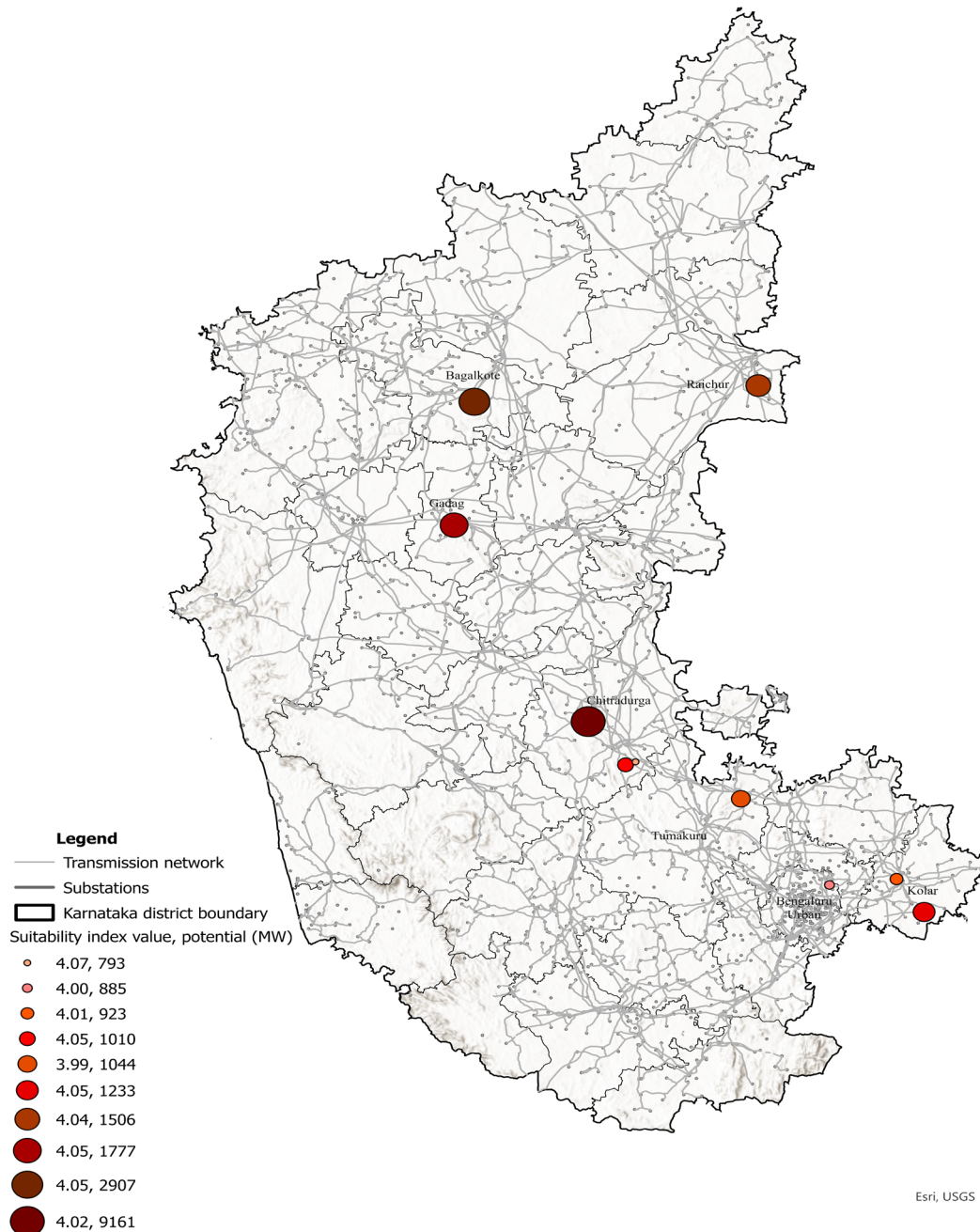


GIS-based site screening

To prioritise the best sites in terms of solar generation potential and lower associated infrastructure costs, we analysed land parcels in Karnataka with a higher range of suitability index, from 3.99 to 4.07. This range is specific to the 24 h scenario used in this case study and is sufficient to accommodate the demand requirements for 2–12 h scenarios. However, we may achieve a higher suitability index for other locations if we consider individual flat blocks in the 2–12 h range.

The case study excluded parcels having an area of less than 3.5 acres, as they are generally insufficient to accommodate a minimum of 1 MW solar installation. The BESS area requirement was considered as 1.5 acres/100 MWh, consistent with the Central Transmission Utility of India Limited (CTUIL) benchmarking (CTUIL, 2025). This would offer technical feasibility for utility-scale solar and BESS development. Figure 4 shows the top ten highly suitable sites shortlisted through dual screening: a GIS-based suitability index and the CUF for solar generation performance. Accordingly, an optimal site of 30,202 acres was selected on the border of Nandipura and Kenne Hadlu villages in Chitradurga Taluk, Karnataka.

Figure 4: Top 10 suitable sites for co-locating solar and BESS in Karnataka



Multi-objective techno-economic assessment

For the selected site, the case study evaluated how different solar and BESS energy capacity configurations can meet the demand requirement under each scenario. The solar generation profile corresponding to the selected site was used as input for the system simulations.

For each of the 14 scenarios, multiple configurations of solar and BESS energy capacity were modelled. Each configuration was simulated hourly over a full year (8,760 h) using the optimisation framework developed in Python. The Appendix (Table A1) provides the economic parameters for the LCOE calculations.

For each flat-block scenario shown in Figure 2, the optimal configuration—the solar and BESS combination representing the most favourable trade-off among LCOE, unmet demand, and RE curtailment—was compared with the least-cost, lowest unmet demand, and lowest curtailment configurations.

Key Insights

The optimal configuration across scenarios

Substantial variation in the solar-BESS sizes and associated costs was observed across the 14 scenarios. BESS energy and solar capacity requirements increase with demand. Solar capacity remains within 21%–25% of the daily energy requirement, indicating a consistent solar-sizing pattern across the different scenarios. BESS energy capacity requirements are more sensitive to the timing of the delivery block. With a larger share of non-solar-hour delivery, BESS energy capacity needed typically ranges between 75% and 125% of the daily energy requirement for the optimal configuration across different scenarios. For instance, at the lower end, the 2 h scenarios (A1, A2, and A3) require around 220–250 MWh of BESS and 47 MW of solar. In contrast, the 24 h RTC scenario requires 1,300 MWh of BESS and 515 MW of solar in the optimal configuration, as shown in Figure 5. Lower BESS energy capacity requirements are observed where a greater share of demand can be met directly by solar generation.

For the 2–10 h scenarios, demand coverage for the optimal configurations remains around 87%–91%, despite differences in system size and delivery-window placement. Coverage declines to 80.4% for the 12 h scenario and further to 76.4% for the 24 h RTC scenario. LCOE across the optimal configurations ranges from approximately INR 5.73/kWh to INR 6.79/kWh (Figure 6). The detailed results of the analysis are provided in the Appendix (Table A2).

Figure 5: Optimal solar and BESS energy capacities for different scenarios

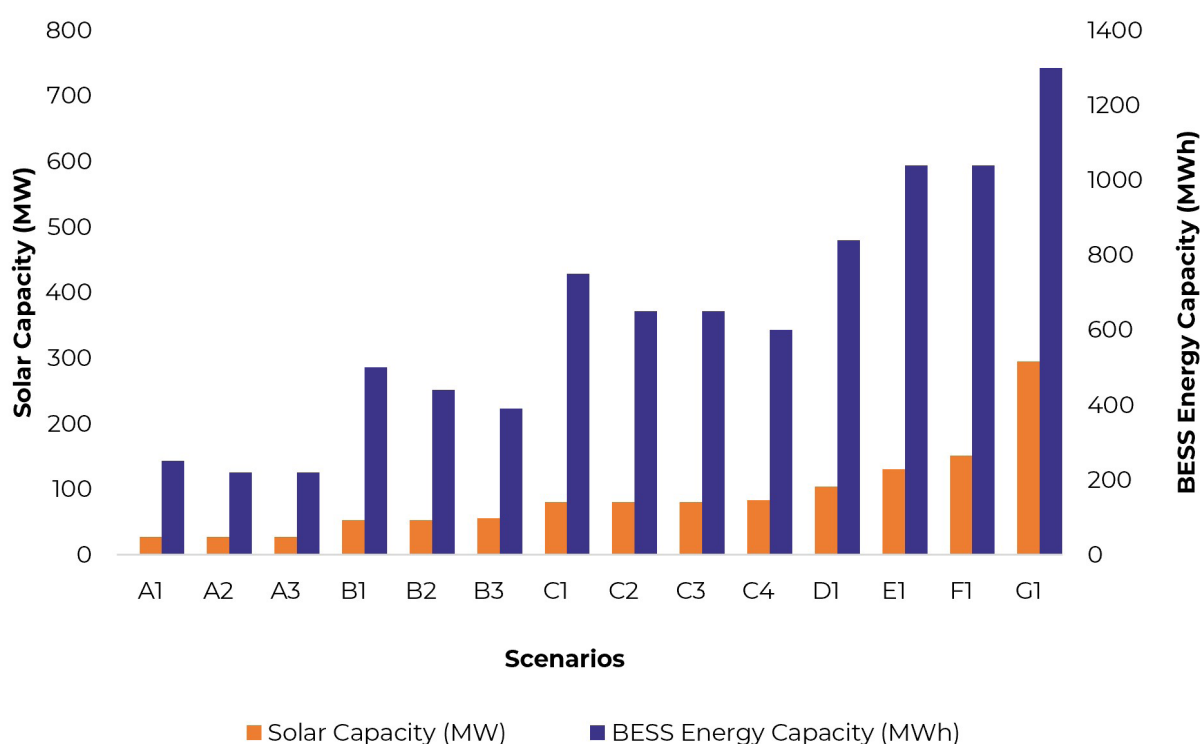
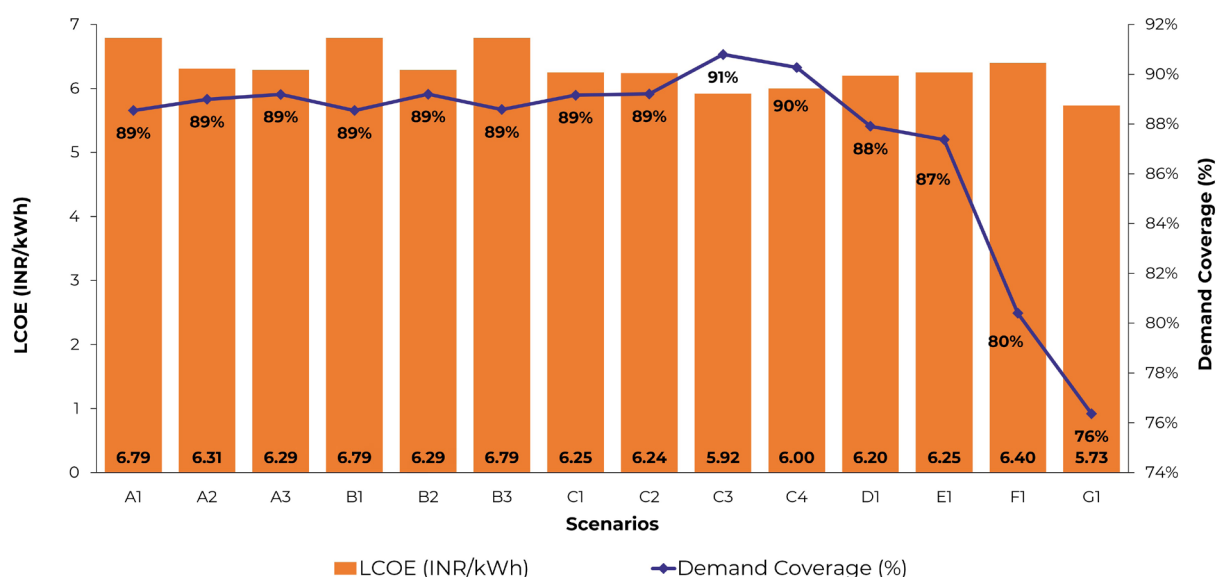


Figure 6: Optimal LCOE and demand coverage for different scenarios



Inferences: 2–12 h scenarios

- The preferred solar–BESS configuration is influenced by both the duration and timing of the delivery obligation.
- A clear reliability–cost–curtailment trade-off is observed across the scenarios. Reducing unmet demand requires additional solar and BESS energy capacity, which improves demand coverage but raises LCOE and, in most cases, RE curtailment.
- Minimising RE curtailment alone does not lead to better system performance. The lowest-curtailed configurations generally have significantly lower demand coverage and higher LCOE.

Inferences: 24 h RTC scenario (G1)

Table 1: Inferences for RTC scenario

Objective	BESS Energy Capacity (MWh)	Solar Share (MW)	Demand Coverage (%)	Total RE Curtailed (GWh)	LCOE (INR/kWh)
Optimal	1,300	515	76.36	143.86	5.73
Least cost	1,040	495	74.23	131.27	5.48
Least unmet	3,120	768	85.82	470.61	8.32
Least curtailment	3,120	320	57.88	2.24	10.36

When the flat block obligation increases from 12 h to 24 h, the optimal configuration comprises 515 MW of solar and 1,300 MWh of BESS, delivering 76.4% of annual demand at an LCOE of INR 5.73/kWh. Improving reliability to 85.8% requires 768 MW of solar and 3,120 MWh of BESS, increasing both LCOE and curtailment significantly (Table 1). This highlights the strong trade-offs between reliability, cost, and curtailment.

This case study did not account for battery degradation over the project lifetime, potentially affecting estimates of storage capacity, performance, and long-term project economics.

Recommendations

1. Include RE curtailment as an explicit parameter in RE-plus-storage procurement



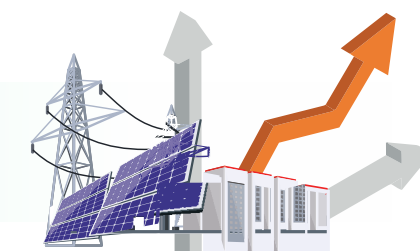
For products such as RTC, assured peak power, and other firm and dispatchable RE tenders, procurement frameworks typically focus on cost and demand-fulfilment requirements. However, as per our analysis, these metrics alone do not fully capture how available RE is utilised. RE curtailment should therefore be considered alongside least cost and demand fulfilment when evaluating RE-plus-storage configurations.



2. Integrate GIS-based site suitability into RE-plus-storage procurement

Site selection for co-located solar and BESS projects should consider factors other than generation potential. A GIS-based suitability index that incorporates climatic, topographic, and infrastructure-related parameters—such as proximity to substations, roads, and residential areas—can help identify locations that are both resource-rich and practical to develop.

3. Design delivery blocks based on the system need



Both the duration and timing of the delivery obligation materially affect solar and BESS sizing, reliability, RE curtailment, and cost. For the same block duration, shifting delivery from daytime towards non-solar hours increases storage requirements and LCOE.

Delivery windows for RTC, assured peak power, and other firm RE products should therefore be designed around actual power system requirements of defined peak windows, rather than using generic or standardised power delivery windows.

Benefits



- Considering RE curtailment as a parameter would help identify solutions that not only meet the delivery obligation reliably but also avoid excessive RE dumping.
- Integrating GIS-based suitability with generation metrics such as CUF can support better long-term project economics, more effective planning, and more efficient procurement of co-located RE and BESS projects.
- Designing delivery blocks based on the system need can help avoid unnecessary storage oversizing and improve the cost-effectiveness of firm renewable power procurement.

Barriers



- Grid import and export constraints could materially affect RE curtailment, battery utilisation, and project economics.
- Dependence on imported battery cells may expose projects to supply chain risks, price volatility, and procurement uncertainties.
- A lack of clarity around long-term revenue streams and revenue-stacking opportunities remains.

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Appendix

Table A1: Cost parameters for LCOE computations

Parameter	Value
BESS round-trip efficiency (%)	90%
Solar capex (INR/MW)	3,50,00,000
Solar operation and maintenance (O&M; INR/MW/year)	1% of solar capex (INR per MW)
Solar O&M growth rate (%)	1%
System life (years)	25 years
Discount rate (%)	10%
USD-to-INR conversion rate	USD 1 = INR 96 (approx.)
BESS capex with balance of plants (USD/kWh)	USD 80/kWh
BESS O&M cost (%)	1% of BESS capex with balance of plants
BESS O&M growth rate (%)	2.5%
BESS replacement cost	50% of BESS capex without balance of plant
Unmet demand penalty in LCOE (INR/kWh)	INR 3/kWh

Table A2: Comparison of the optimal configuration with least cost, least unmet, and least curtailment for different scenarios

	Objective	BESS Energy Capacity (MWh)	Solar Capacity (MW)	Demand Coverage (%)	Total RE Curtailed (GWh)	LCOE (INR/kWh)
A1	Optimal	250	47	88.54	5.04	6.79
	Least cost	220	52	91.27	11.04	6.37
	Least unmet	260	64	97.88	25.93	6.93
	Least curtailment	260	27	54.12	0.16	11.29
A2	Optimal	220	47	88.99	5.30	6.31
	Least cost	210	52	92.5	10.74	6.11
	Least unmet	260	64	98.38	26.42	6.88
	Least curtailment	260	27	54.76	0.05	11.12
A3	Optimal	220	47	89.19	5.40	6.29
	Least cost	190	52	92.21	11.28	5.86
	Least unmet	260	64	98.44	26.77	6.87
	Least curtailment	260	27	54.95	0.00	11.07
B1	Optimal	500	93	88.54	10.09	6.79
	Least cost	440	108	92.72	27.93	6.37
	Least unmet	520	128	97.88	51.86	6.93
	Least curtailment	520	53	54.12	0.32	11.29
B2	Optimal	440	93	89.2	11.00	6.29
	Least cost	360	103	91.29	24.28	5.81
	Least unmet	520	128	98.46	53.75	6.87
	Least curtailment	520	53	55.02	0.10	11.05
B3	Optimal	390	98	90.79	16.69	5.92
	Least cost	360	103	91.36	24.10	5.80
	Least unmet	520	128	98.48	53.70	6.87
	Least curtailment	520	73	75.51	0.00	7.94
C1	Optimal	750	140	88.58	15.15	6.79
	Least cost	660	160	92.58	38.28	6.33
	Least unmet	780	192	97.92	77.87	6.92
	Least curtailment	780	80	54.14	0.47	11.28

	Objective	BESS Energy Capacity (MWh)	Solar Capacity (MW)	Demand Coverage (%)	Total RE Curtailed (GWh)	LCOE (INR/kWh)
C2	Optimal	650	140	89.16	16.73	6.25
	Least cost	550	160	92.84	41.08	5.80
	Least unmet	780	192	98.46	80.72	6.87
	Least curtailment	780	80	54.99	0.26	11.06
C3	Optimal	650	140	89.21	16.71	6.24
	Least cost	550	160	92.91	41.07	5.80
	Least unmet	780	192	98.48	80.87	6.87
	Least curtailment	780	80	55.08	0.15	11.04
C4	Optimal	600	145	90.27	22.15	6.00
	Least cost	550	160	92.91	40.74	5.80
	Least unmet	780	192	98.48	80.53	6.87
	Least curtailment	780	110	75.51	0.00	7.94
D1	Optimal	840	182	87.91	18.15	6.20
	Least cost	720	212	92.1	54.50	5.80
	Least unmet	1,040	256	98.45	107.51	6.87
	Least curtailment	1,040	107	55.08	0.20	11.04
E1	Optimal	1,040	228	87.37	27.00	6.25
	Least cost	910	263	91.71	67.46	5.85
	Least unmet	1,300	320	97.81	136.60	6.93
	Least curtailment	1,300	133	55.1	0.25	11.03
F1	Optimal	1,040	265	80.4	51.10	6.40
	Least cost	1,040	310	85.68	99.90	6.29
	Least unmet	1,560	384	93.16	186.25	7.43
	Least curtailment	1,560	160	55.1	0.30	11.03
G1	Optimal	1,300	515	76.36	143.86	5.73
	Least cost	1,040	495	74.23	131.27	5.48
	Least unmet	3,120	768	85.82	470.61	8.32
	Least curtailment	3,120	320	57.88	2.24	10.36



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