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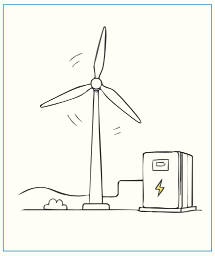
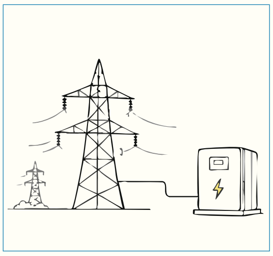
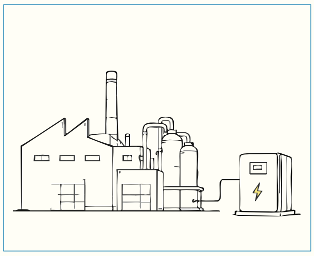


Energy Storage Systems Investment Opportunities in Pakistan 2026

August 2026

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About this publication

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Executive summary

Pakistan has deployed close to 38 GW of solar within a decade, saving more than USD 12 billion (B) in fossil fuel imports. Yet solar deployment has outpaced grid flexibility, producing a pronounced duck curve, Partial Load Adjustment Charges (PLAC) of PKR 46.39 B in FY2025, and curtailment losses of PKR 81 B between FY20 and FY25. This study quantifies Pakistan's battery energy storage requirement to 2045 and builds commercial cases for its deployment.

The IGCEP recognizes storage only as a grid-support tool for frequency response and intermittency management. It does not assess bulk energy shifting, renewable firming, or the evolving load patterns emerging from distributed solar and future electric vehicles (EVs) uptake. This study fills that gap by quantifying the scale of Battery Energy Storage System (BESS) Pakistan needs, mapping where value can be captured and grounding the numbers in the emerging Competitive Trading Bilateral Contracts Market (CTBCM).

The analysis applies TransitionZero's Scenario Builder to the IGCEP capacity pathway, layers in distributed solar and 4-hour BESS across 2030, 2035, 2040, and 2045, and tests four commercial applications on that base. Energy arbitrage captures the widening daytime-to-evening price spread, where a 100 MW / 400 MWh system yields a 7% Internal Rate of Return (IRR) that lifts to 10.8% once grid-support revenues are stacked. PLAC reduction targets thermal cycling under the duck curve, and a 200 MW / 800 MWh BESS at Bhikki smooths dispatch, cuts annual PLAC exposure by PKR 5.85 B, and returns a 16% IRR. Curtailment avoidance recovers wind output lost on the Jhimpir-Gharo corridor, where a 100 MW / 400 MWh grid-side battery at Jamshoro captures around 22% of yearly curtailment at a 12% IRR. Industrial firm capacity pairs solar PV with molten-salt thermal energy storage to serve a 20-hour continuous load, delivering clean power at USD 0.062/kWh, quite below prevailing industrial tariffs.

Taken together, the results give Pakistan clear visibility into the scale, timing, and location of its storage needs, showing 6.3 GW required by 2030 and 15.2 GW by 2045. They equip planners, regulators, and investors with an evidence base to shape procurement, market design, and compensation for flexibility services in future capacity plans.

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Distributed solar has created a new opportunity for BESS in Pakistan

Pakistan has experienced one of the most rapid solar buildouts among developing economies in the past decade. Close to 55 GW (as shown in Figure 1) of solar panels have been imported, of which an estimated 38 GW are now deployed across utility-scale projects, commercial and industrial rooftops, and behind-the-meter (BTM) residential installations.[1] This solar rush has already cushioned the economy through more than USD 12 B in avoided fossil fuel imports, demonstrating that indigenous renewable energy can deliver both environmental and macroeconomic benefits.[2]

However, the scale and pace of solar deployment have outpaced the grid infrastructure and planning frameworks originally designed around a centralized, thermal-dominated power system. As solar penetration continues to increase, Pakistan's power sector is entering a new phase characterized by changing demand patterns, growing flexibility requirements, and increasing reliance on mechanisms capable of shifting energy across time. These emerging system realities define the case for BESS in Pakistan.

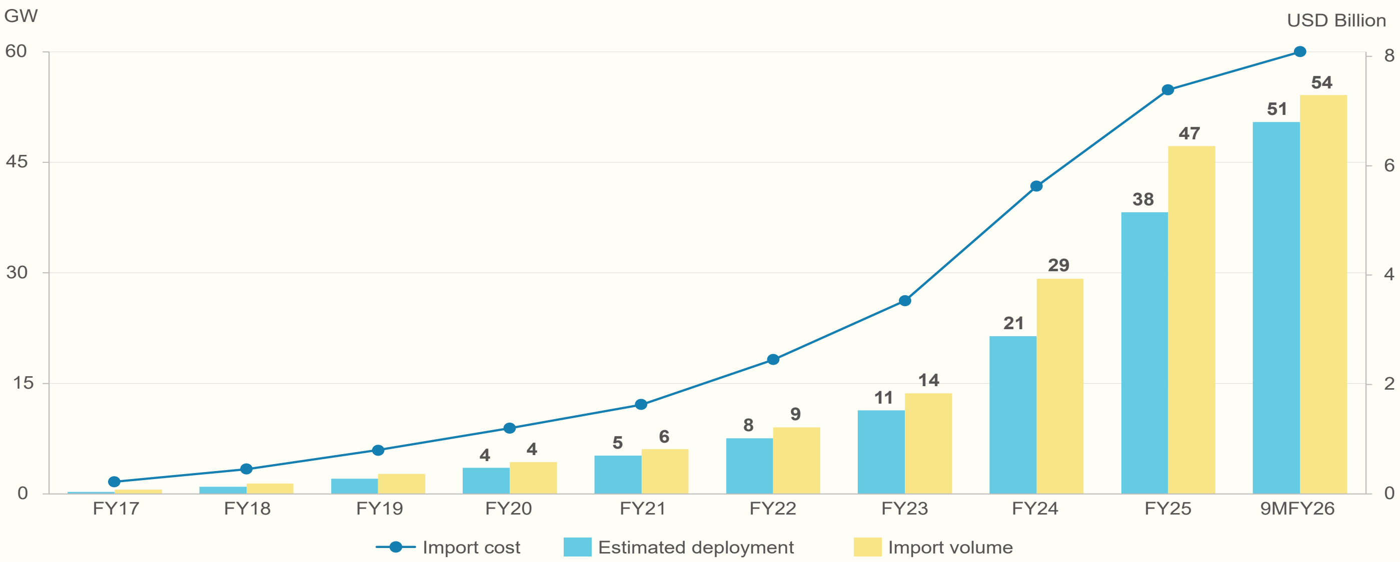

Figure 1: Cumulative volume, cost, and deployment of Chinese solar PV modules imported by Pakistan, FY17-9MFY26

Rapid solar deployment has disrupted electricity demand patterns, resulting in a duck curve

Solar generation is increasingly suppressing grid-supplied demand during the middle of the day, while demand rapidly returns to the grid in the late afternoon and evening as solar output declines. This creates a deeper midday demand trough, a steeper evening rebound, and a growing requirement for flexible resources during evening hours. The daily demand variation between the afternoon low and evening peak has already grown to around 4–6 GW, (as shown in Figure 2) increasing reliance on thermal generation to serve short-duration peaks. This is reflected in rising

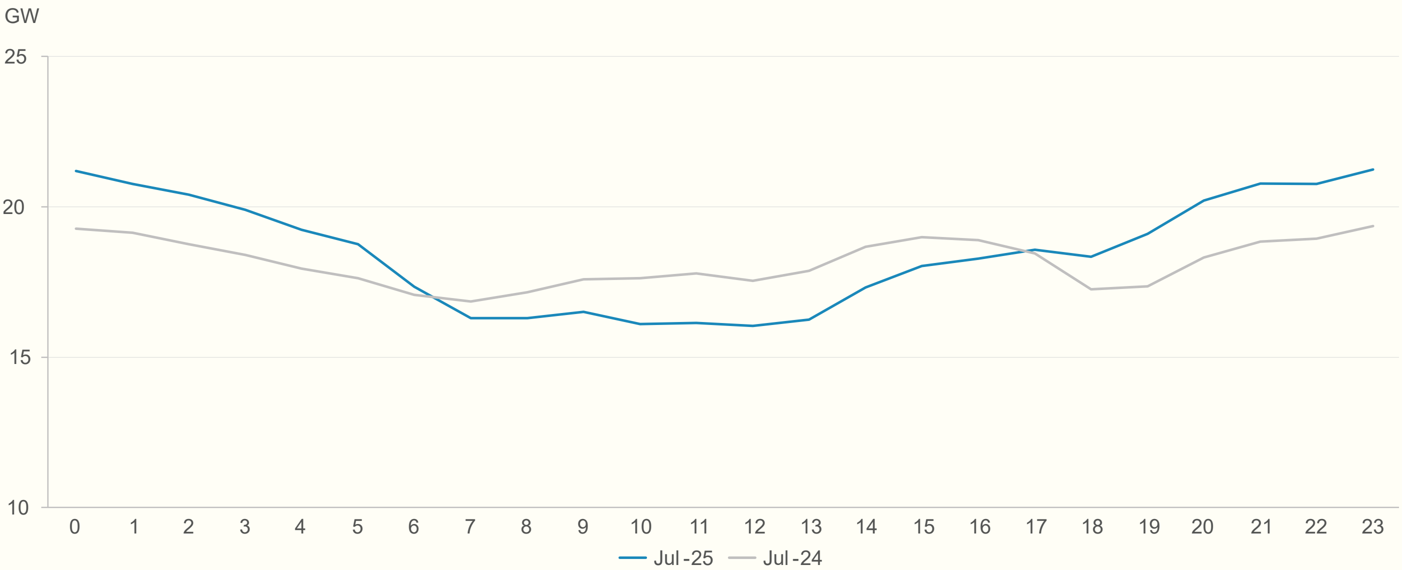

Figure 2: Hourly electricity demand profile - July 2025 vs. 2024

[1]Renewables First, "Customer Owned Renewable Electrification (CORE) Finance Mapping, 2026"

[2]Blog, "The hedge that paid off: How Pakistan's solar boom is shielding it from the Hormuz crisis"

PLAC, which compensate power producers when plants are dispatched below minimum stable load. Such operation reduces plant efficiency and ultimately feeds through to consumers, highlighting the growing cost of operating a thermal fleet that is increasingly being used for flexibility rather than steady generation.

The absence of adequate flexibility is also resulting in direct economic losses through renewable curtailment. Non-Project Missed Volume (NPMV) captures energy that could have been generated but was not delivered due to factors beyond the producer's control, including transmission constraints and other system limitations.

Together, PLAC and NPMV provide evidence that Pakistan is already incurring substantial costs due to insufficient system flexibility. In FY24-25, PLAC costs reached Rs. 46.39 B, while the combined NPMV and PLAC burden amounted to approximately Rs. 59.67 B. These costs represent only part of the broader economic impact associated with renewable curtailment, inefficient thermal operation, and the inability to align periods of high renewable generation with periods of peak demand.

Current Policy Recognises Storage but Only as a Grid-Support Tool

These operational and economic signals are increasingly being recognized within Pakistan's policy and planning framework. The IGCEP has, for the first time, incorporated BESS into its modelling scenarios, (as shown in Figure 3) acknowledging that storage will play an important role in managing variability from renewable generation. The plan identifies storage requirements for fast frequency response, renewable variability management, and support during the late-afternoon ramp as solar output declines.

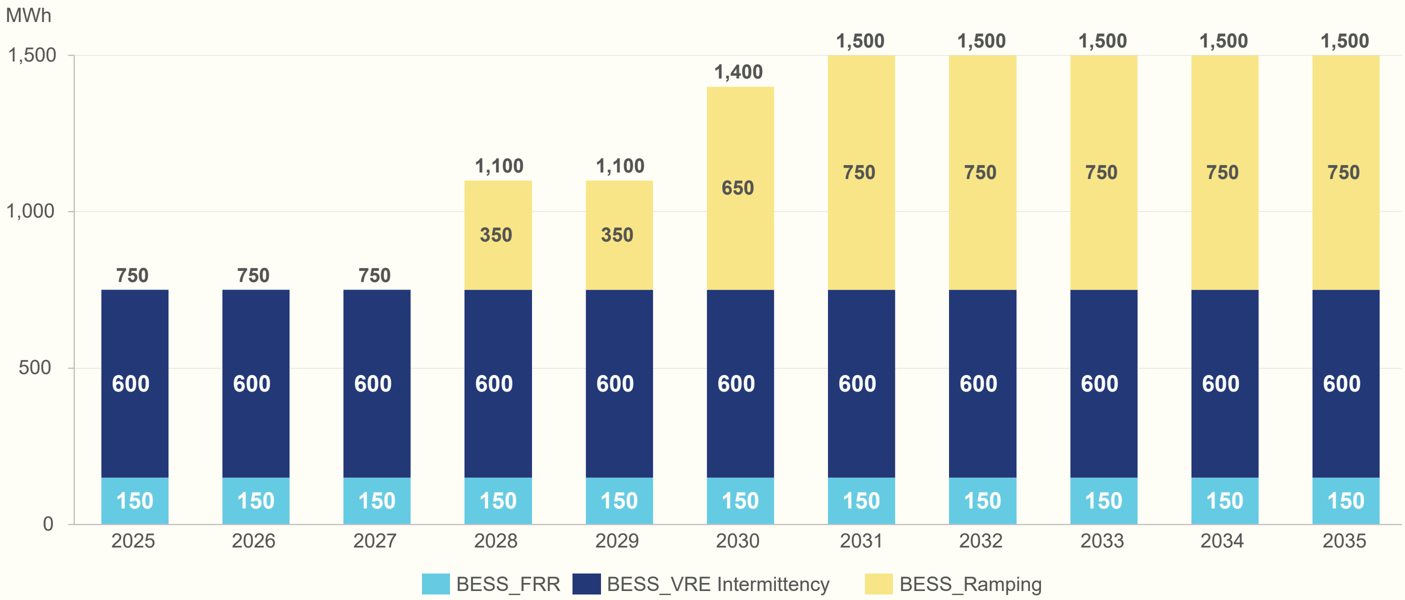

Figure 3: BESS MWh requirements under IGCEP

However, an important planning gap remains. Existing policy and planning documents primarily consider storage as a grid-support resource for system stability, frequency regulation, and operational balancing. They do not yet comprehensively assess storage requirements for large-scale energy shifting, renewable firming, peak demand management, or the evolving load patterns emerging from rapid distributed solar deployment.

The forthcoming implementation of the CTBCM further strengthens the commercial rationale for storage. As renewable energy projects increasingly compete in a market environment, developers will require greater control over the timing and firmness of electricity delivery. Furthermore, the anticipated uptake of electric vehicles will reshape the load profile, as residential charging concentrates additional consumption into nighttime hours. Without storage to bridge daytime renewable surpluses and nighttime demand, the system will require either expanded thermal capacity or higher fuel imports.

Pakistan power system modelling highlights a growing role for BESS through 2045

The analysis uses TransitionZero's Scenario Builder to assess least-cost generation and storage pathways for Pakistan's power system. The IGCEP optimized capacity pathway is used as the core reference for the model. Existing capacity, planned additions, and retirements follow the IGCEP trajectory. The analysis is carried out for four representative spot years: 2030, 2035, 2040, and 2045 (see Table 1). For each model year, the previously optimized system is carried forward, new additions and retirements are applied, and the model is then re-optimized for that year.

All core system assumptions are taken from IGCEP unless stated otherwise (see Table 3). The main addition made in this analysis is the inclusion of distributed solar capacity which is not fully captured in central planning, and the modelling of battery energy storage systems.

Battery Energy Storage Systems are modelled as 4-hour storage assets, reflecting the currently dominant commercial battery configuration. Demand projections up to 2035 are taken directly from the IGCEP 2025–35. Demand after 2035 is extrapolated using an annual growth rate of 2.8%. The resulting demand trajectory is shown in Table 2 below.

The single-node resolution means localised curtailment, sub-regional transmission bottlenecks, and project-level siting decisions are not captured. The results should therefore be interpreted as system-level aggregates rather than spatially resolved outcomes.

	2030	2035	2040	2045
Distributed PV (MW)	13,340	17,512	21,512	25,512

Table 1: Distributed solar capacity assumptions incorporated in the analysis

	2030	2035	2040	2045
Demand (TWh)	156	179	210	250

Table 2: Annual electricity demand inputs

Assumption area	Treatment in this analysis	Source / basis
Existing and new capacity	Taken from IGCEP pathway	IGCEP
Plant retirements	As per IGCEP and technical life of plants	IGCEP
Demand to 2035	Taken directly from IGCEP 2025–35	IGCEP
Demand after 2035	Extrapolated at 2.8% annual growth	RF analysis
Distributed solar	Added outside central IGCEP capacity	RF analysis
Battery storage	Modelled as 4-hour BESS	RF analysis

Table 3: Key modelling assumptions

The model confirms a storage requirement reflecting the system's need

Battery storage is optimized from the first spot year and expands steadily across the study period. The result is consistent with the direction of Pakistan's current capacity additions. Solar is being added faster than any other resource, and rising midday photovoltaic output produces the characteristic net-demand profile of a high-solar system, a midday trough followed by a steep evening ramp. Meeting that ramp from the existing fleet is increasingly costly, and the optimization responds by procuring flexibility. The optimized pathway shows BESS capacity increasing from 6.3 GW in 2030 to 15.2 GW by 2045 (see Figure 4). Since the model assumes 4-hour batteries, this is equivalent to an increase in energy storage capacity from around 25 GWh to 61 GWh. BESS also rises as a share of total installed capacity, from 9.3% in 2030 to 15.3% by 2045.

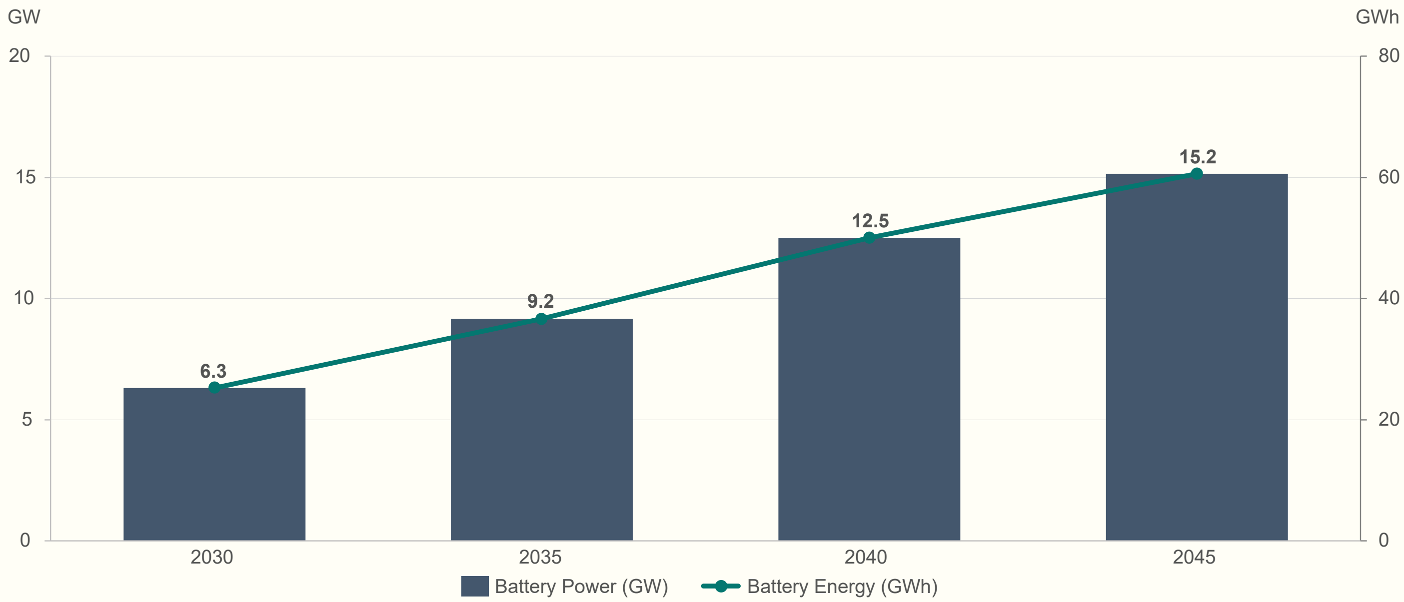

Figure 4: BESS capacity and energy growth trajectory

The result is significant because BESS grows alongside the changing structure of the power system (see Table 4 and Figure 5)). Solar and wind capacity increase from around 22 GW in 2030 to almost 40 GW by 2045, while Gas/RLNG capacity declines from 10 GW to 5.7 GW. In other words, the model is adding storage as the system becomes more renewable-heavy and less dependent on gas-based flexibility.

	Capacity (GW)			
	2030	**2035**	**2040**	**2045**
Hydro	17.56	22.06	22.06	25.97
Nuclear	3.29	4.41	4.41	4.41
Wind	5.96	6.08	6.94	10.73
Solar	16.17	20.19	24.94	28.94
Gas/RLNG	10.05	8.95	8.03	5.69
Imp. Coal	4.40	4.40	4.40	4.40
Local Coal	3.03	3.03	3.03	3.03
Biomass	0.38	0.38	0.38	0.24
Oil	0.96	0.80	0.41	0.20
Battery Storage	6.31	9.16	12.51	15.15
Total	**68.10**	**79.44**	**87.09**	**98.73**

Table 4: Technology-specific optimized capacity by study year

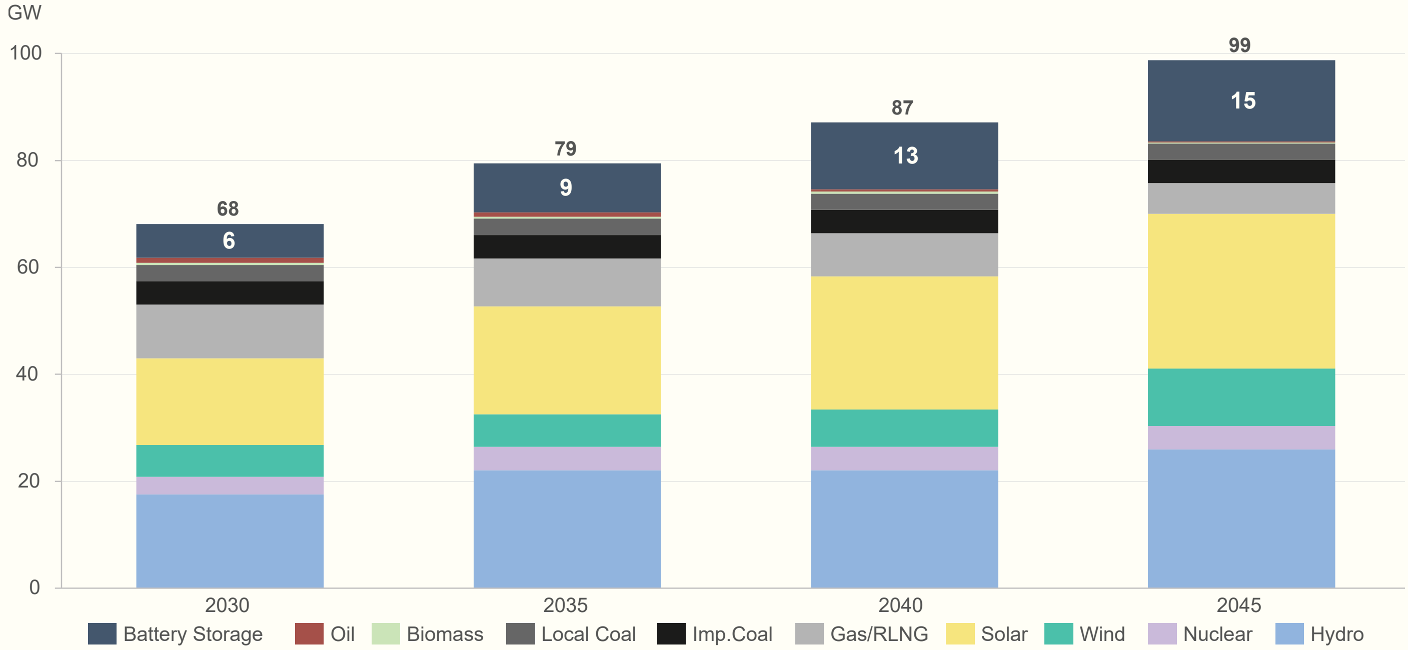

Figure 5: Installed capacity by technology, 2030-2045 (GW)

The generation mix provides the same signal from the operational side. Total electricity generation increases from 156 TWh in 2030 to 250 TWh in 2045 (see Table 5). Over the same period, solar and wind generation increase from around 52 TWh to 93 TWh. This rising share of variable renewable generation increases the need for short-duration flexibility, particularly for shifting energy across the day and managing residual demand during non-solar hours. This increasing need for flexibility is reflected in the growing role of BESS. Battery absorption increases from 1.33 TWh in 2030 to 3.54 TWh in 2045, indicating greater use of storage to absorb electricity during charging periods and shift it to periods of higher residual demand. The negative values reported for battery absorption in Table 5 represent electricity consumed by the BESS for charging rather than negative generation. As solar and wind generation increase, BESS can therefore absorb available electricity and subsequently discharge it during non-solar hours, reducing the need for thermal generation to provide short-duration flexibility.

Gas/RLNG generation remains very low throughout the modelling period despite the presence of installed capacity. Gas plants are retained mainly for backup or peaking purposes rather than bulk energy supply. In that context, BESS becomes important because it can provide flexibility without requiring thermal plants to operate inefficiently at low utilization.

	Generation (TWh)			
	2030	2035	2040	2045
Hydro	69.21	81.16	90.20	104.81
Nuclear	25.94	34.74	34.74	34.74
Solar + wind	52.0	59.4	71.9	93.3
Gas/RLNG	0.02	0.00	0.25	1.38
Imported .Coal	7.38	3.97	9.89	12.05
Local Coal	1.55	0.74	4.19	6.25
Biomass	1.52	0.99	1.74	1.13
Oil	0	0	0	0.00
Battery absorption	-1.33	-1.72	-2.84	-3.54
Total System	156.3	179.3	210.1	250.2

Table 5: Generation mix of specified technologies by study year

Overall, the results show a clear and consistent storage buildout. BESS capacity more than doubles between 2030 and 2045, while battery utilization also increases (see Figure 6). The planning implication is straightforward: Pakistan should treat storage as a core system asset, not as an optional technology to be considered later. The optimized pathway already requires around 6 GW of 4-hour BESS by 2030, increasing to more than 15 GW by 2045. This scale of deployment will require early decisions on procurement, grid connection, market participation, and compensation for flexibility services.

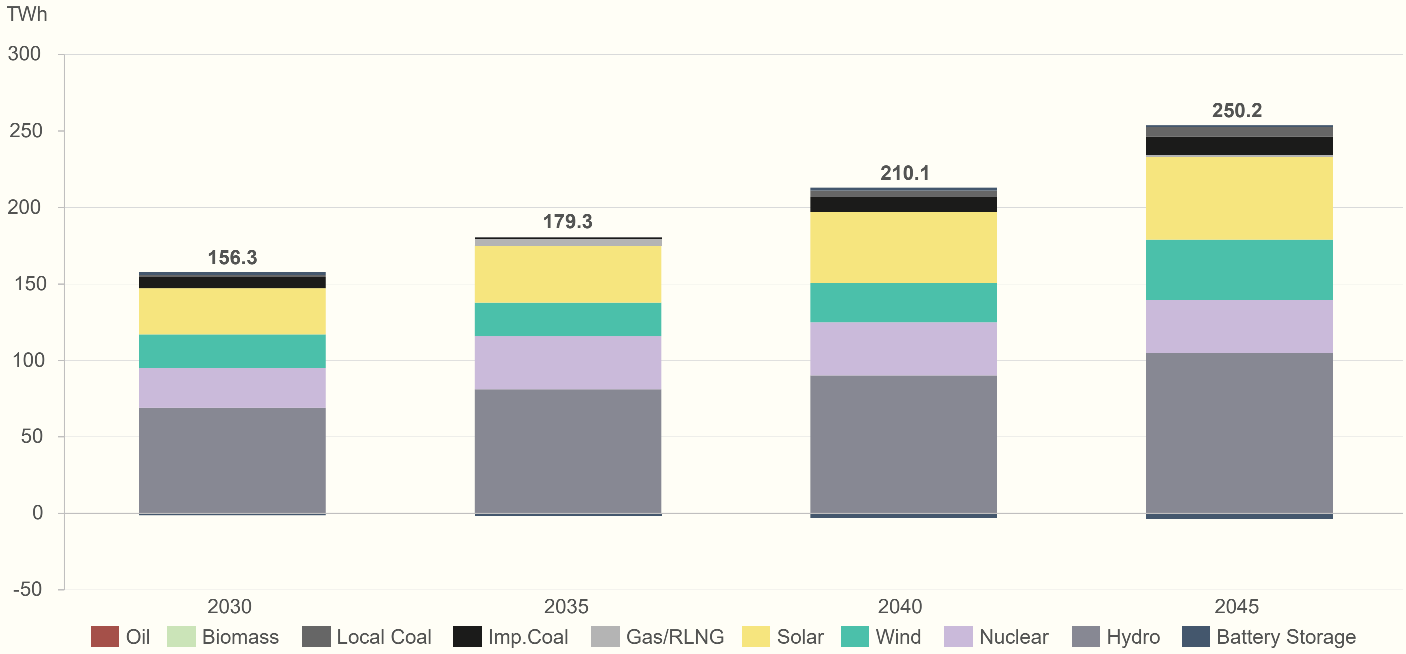

Figure 6: Generation energy mix (TWh)

Identified ready-to-invest storage applications support Pakistan's power system and offer commercial viability

- Pakistan's FY25 marginal price data shows a clear emerging arbitrage signal for storage. Across 8,760 hourly observations, marginal prices averaged PKR 17.72/kWh, ranging from PKR 3.07/kWh to PKR 36.21/kWh, with prices clustering around lower daytime bands and higher evening bands.
- The price signal also shows a clear intraday pattern: prices tend to fall during the daytime solar window and rise after sunset, creating a charge–discharge opportunity for BESS as solar penetration increases.
- Under the base case, a 100 MW / 400 MWh BESS generates positive operating cash flow from energy arbitrage, with Year 1 net cash flow of around USD 5.6 million (M), an effective arbitrage spread of about USD 55/MWh, and an estimated 7% IRR.
- Sensitivity analysis indicates that the gap to bankable returns is relatively narrow. Increasing the effective price spread by around PKR 3.5/kWh — from PKR 16.53/kWh to PKR 20/kWh — could move arbitrage-only returns toward the 10% IRR range.
- Alternatively, recognizing grid-support services through an additional revenue stream of around USD 1.5 M per year, equivalent to roughly USD 15,000/MW-year for a 100 MW system, could raise returns from 7% IRR to around 10.8% IRR.

Solar-driven price shifts are creating an energy arbitrage opportunity for BESS

Storage create value by charging during periods of low electricity prices and discharging during periods of higher prices. In Pakistan's context, these opportunities are increasingly linked to the emergence of the duck curve, where abundant daytime solar generation suppresses grid demand and system prices, while evening demand and thermal generation requirements increase after sunset. As solar penetration continues to rise, the ability to shift low-cost daytime energy into evening demand periods is expected to become an increasingly important value stream for storage.

The analysis draws on the complete set of 8,760 hourly marginal prices for FY25. Across the year, prices averaged PKR 17.72/kWh and ranged from PKR 3.07/kWh to PKR 36.21/kWh. The distribution, however, matters more than the average. Operating hours concentrate in two distinct zones: a daytime band around PKR 10–15/kWh and a larger evening band around PKR 20–25/kWh, which together account for roughly two-thirds of all hours (see Figure 7).

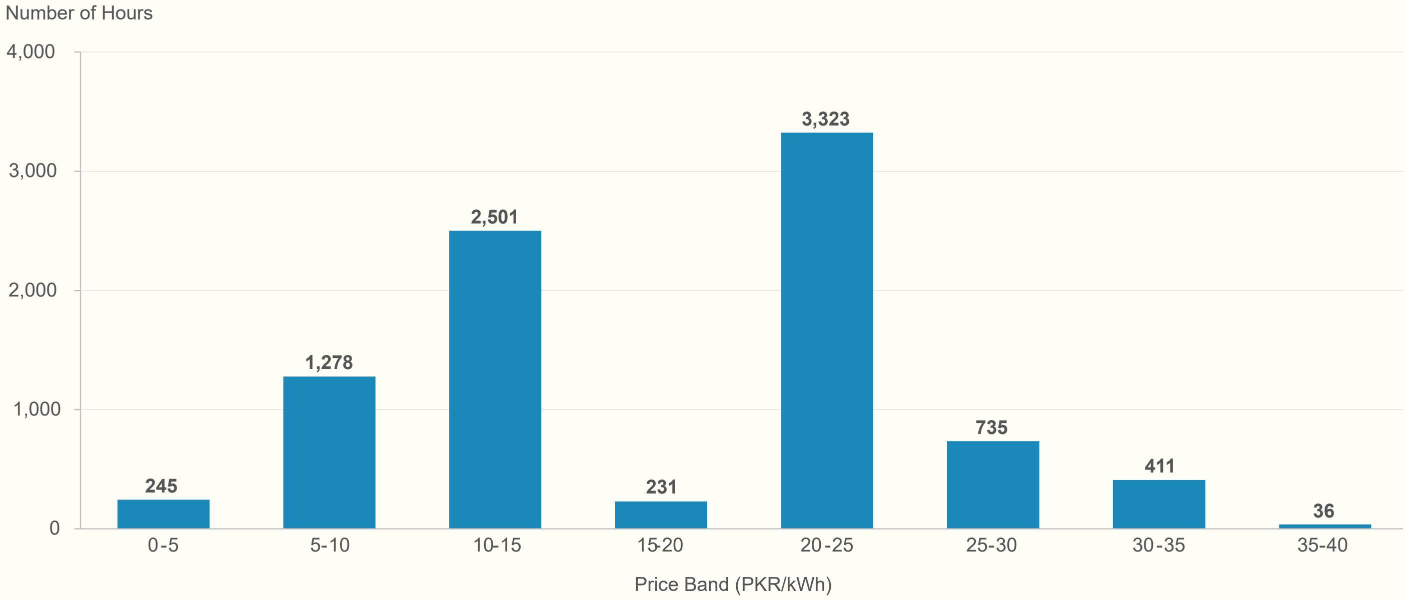

Figure 7: Distribution of hourly marginal price, FY25

The price signal shows a clear intraday structure. In summer and the shoulder months prices follow the expected duck-curve shape: they fall to a midday trough as solar floods the system, then rise to a peak after sunset when demand and thermal generation take over (see Figure 8).

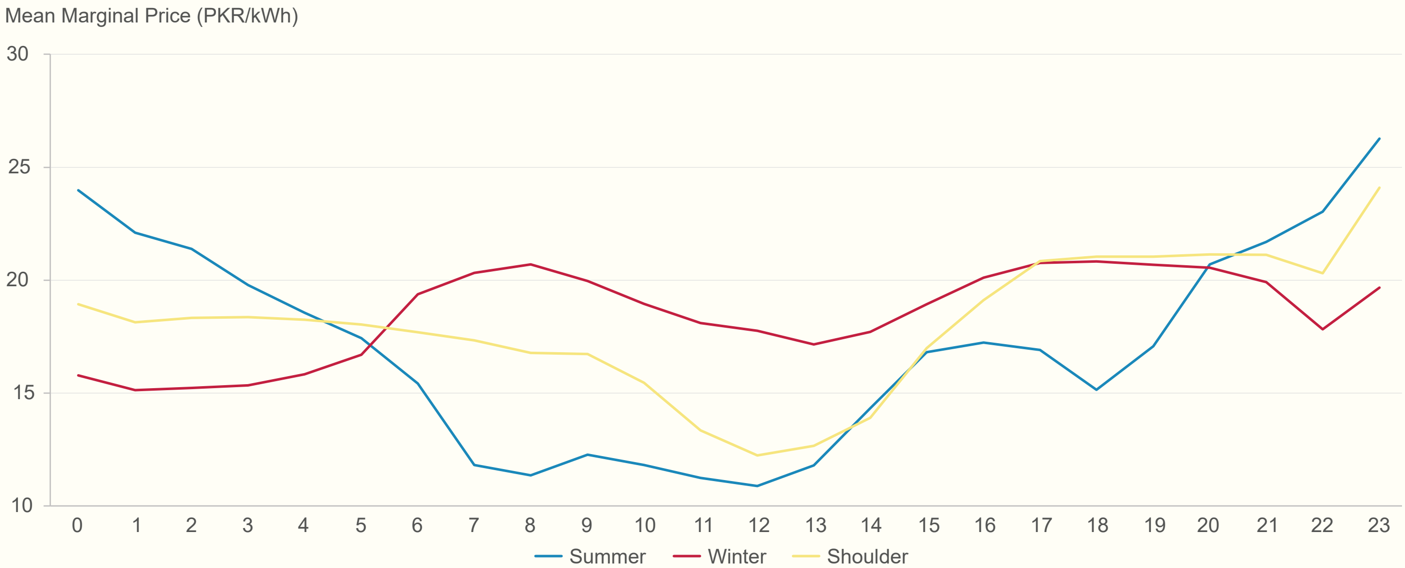

Figure 8: Average 24-hour price profile by season, FY25

Monthly daily spreads show how the strength of this arbitrage window varies across the year (see Figure 9). Spreads are generally wider in the warmer months, averaging around Rs 21/kWh from May to September, and narrower in winter, averaging around Rs 10/kWh from December to February. This suggests that storage would likely find stronger charge-and-discharge differentials in the warmer half of the year.

Building on the price signal, the analysis translates the daily charge–discharge differential into project-level economics for a representative 4-hour battery system. The model uses FY25 prices and applies standard commercial assumptions. The resulting cash flows reflect a realistic, single-cycle-per-day operating pattern.

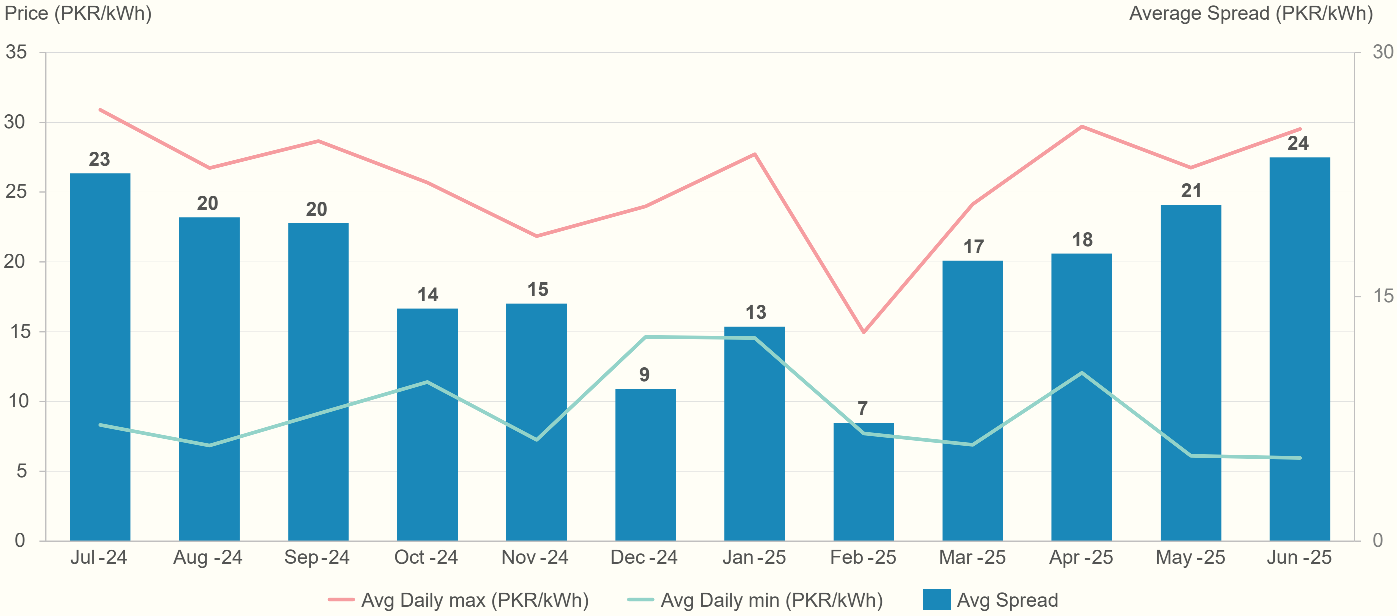

Figure 9: Monthly average spread available for arbitrage

The following Table 6 lays out key technical assumptions for the arbitrage business model and Table 7 lays out the key economic assumptions to evaluate the business case.

Parameter	Value
Power rating	100 MW
Energy capacity	400 MWh (4-hour)
Charge price	PKR 9.29/kWh
Discharge price	PKR 25.82/kWh
Round-trip efficiency	90%
Cycles per year	300
Installed Cost (CAPEX)	USD 125/kWh
Project Life	20 years
Discount Rate	10%
O&M (Annual)	2 %
Capacity degradation	2 %

Table 6: Key technical assumptions for the baseline arbitrage business model

Parameter	Value
Total CAPEX	USD 50 M
Year 1 net cash flow	USD 5.6 M
IRR	7.1%
NPV @ 10%	- USD 8.6 M
Simple payback	10 years
Discounted payback	N/A

Table 7: Key results for baseline arbitrage

As can be seen in Figure 10, the project demonstrates (under above assumptions) a positive operating case for BESS energy arbitrage, generating net cash flow from Year 1. However, the estimated IRR of roughly 7% indicates that energy arbitrage can support an emerging commercial case for storage, while additional value streams, improved market conditions, or targeted financing support could further strengthen project returns.

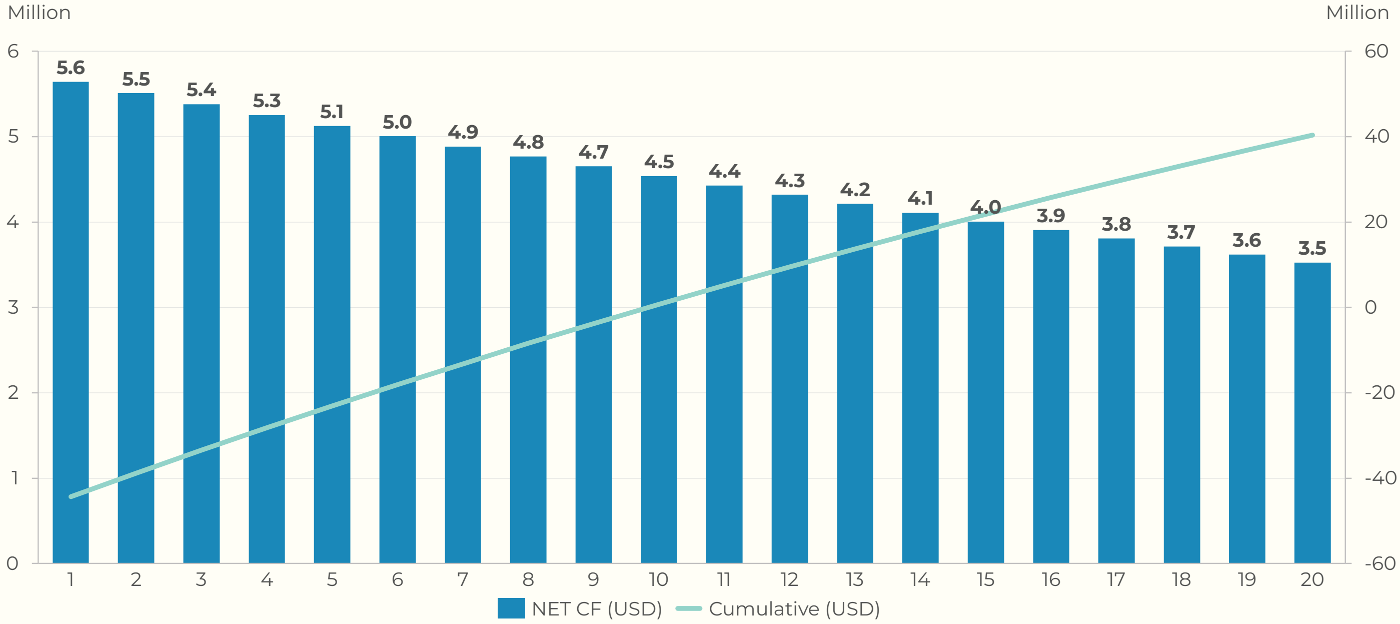

Figure 10: Annual net cash flow and cumulative cash flows in the baseline arbitrage scenario

Stronger Price Signals through Market Reforms

The financial outcome does not imply that battery storage lacks value within Pakistan's power system. Rather, it indicates that under present assumptions, energy arbitrage alone is insufficient to support investment-grade returns. Threshold analysis suggests that moderate changes in market conditions, revenue mechanisms, or capital costs could materially improve project economics.

The profitability of energy arbitrage depends directly on the spread between charging and discharging prices. Under current market conditions, the battery achieved an effective arbitrage spread of approximately PKR 16.53/kWh. As Pakistan progresses toward CTBCM implementation and broader electricity market reforms, stronger temporal price signals may emerge through more competitive market operation and increased renewable energy penetration.

Threshold analysis indicates that, for arbitrage revenues alone to support returns approaching the 10% IRR range, the effective arbitrage spread would need to rise to approximately PKR 20/kWh, an increase of roughly PKR 3.5/kWh from the base case. This would lead to results as shown in Table 8 and Figure 11

Parameter	Value
Total CAPEX	$50 M
Year 1 net cash flow	$7.1 M
IRR	10.8%
NPV @ 10%	USD 2.6 M
Simple payback	8 years
Discounted payback	17 years

Table 8: Summary of results for arbitrage with higher spread

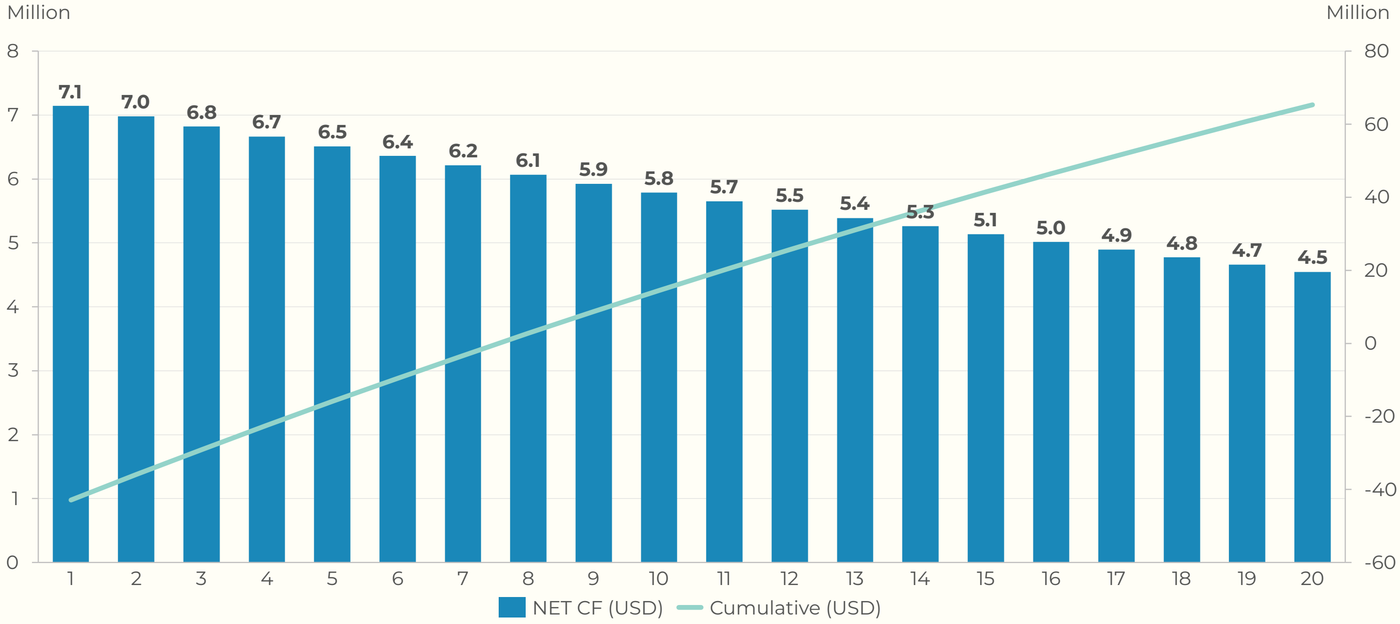

Figure 11: Annual net cash flow and cumulative revenues with higher spread arbitrage

Battery systems provide several operational benefits beyond energy trading, including reserve provision, frequency response, voltage support, ramping support, and broader flexibility services. These services create value for the power system but remain largely uncompensated under current market arrangements.

The analysis indicates that the battery project would require an additional annual revenue stream of approximately USD 1.5 M per year to move from a 7% IRR to around 10.8% under the existing assumptions. For a 100 MW / 400 MWh system, this corresponds to an availability or capacity payment of approximately USD 15,000/MW-year, or USD 15/kW-year.

Compensation mechanisms that recognize grid-support services could therefore materially improve project economics while also supporting broader system reliability objectives.

Bhikki case study shows how co-located storage dispatch can reduce PLAC charges and create system-wide value

- Pakistan’s duck curve is increasingly pushing thermal plants into deep part-load operation and steep daily ramps, increasing PLAC exposure for consumers.
- Bhikki illustrates this stress clearly: in FY25, the plant operated below 80% of dependable capacity for 4,638 hours and below 50% for 1,771 hours, including sharp swings and daytime shutdowns.
- A 200 MW / 800 MWh BESS can cover around 49.6% of Bhikki’s dispatch-smoothing requirement, reducing deep cycling and supporting more stable plant operation.
- Applying this coverage to Bhikki’s annual PLAC exposure gives an indicative avoided PLAC value of around PKR 5.85 B per year.
- The business case is attractive under base assumptions, with USD 100 M CAPEX, Year 1 net cash flow of USD 18.8 M, 16% IRR, USD 39.7 M NPV, and a simple payback of around 5.6 years.

Bhikki powerplant at a glance

Bhikki Power Plant is a 1,180 MW RLNG-based combined-cycle facility located in Punjab, Pakistan. The plant was developed to provide reliable, large-scale generation to the national grid. Beyond bulk energy supply, its operation is also important for system security, as continued dispatch of large thermal units helps maintain voltage stability, reactive-power sharing, and system response to changes in demand. NEPRA and the National Power Control Centre (NPCC) have documented cases where reduced dispatch of RLNG-based generation has produced these very constraints.

Retaining a plant of Bhikki's scale primarily for short-term operational flexibility, however, is inefficient. Combined-cycle generation carries inherent limitations in ramping, minimum stable generation, start-up and shutdown, and part-load operation. These limitations grow more binding as renewable variability increases and the system demands faster upward and downward adjustments. NEPRA's recent performance data further indicate that Bhikki's full installed capacity is not continuously required for energy delivery.

Due to the duck curve phenomena, thermal power plants are increasingly being dispatched below their minimum stable load during solar-rich hours and then rapidly ramped up to meet evening demand. This operating pattern is driving a significant increase in PLAC, which are ultimately borne by electricity consumers.

BESS offer an alternative flexibility resource. Rather than forcing thermal plants to absorb daily solar-driven variability, batteries can charge during periods of lower demand and discharge during the evening peak, allowing thermal units to operate closer to stable output levels. This creates an opportunity to reduce PLAC exposure while simultaneously improving operational efficiency and reducing thermal cycling.

Bhikki provides one of the clearest examples of how the duck curve is reshaping thermal dispatch in Pakistan. The power plant was designed to operate as a high-efficiency baseload or intermediate-load facility. However, FY25 dispatch data reveals a markedly different operational reality. On several days, the variation was significantly higher, including a swing of approximately 1,080 MW on 1 March, a complete shutdown during solar-rich hours on 13 May, and a near zero-to-full ramp on 8 July (see Figure 12).

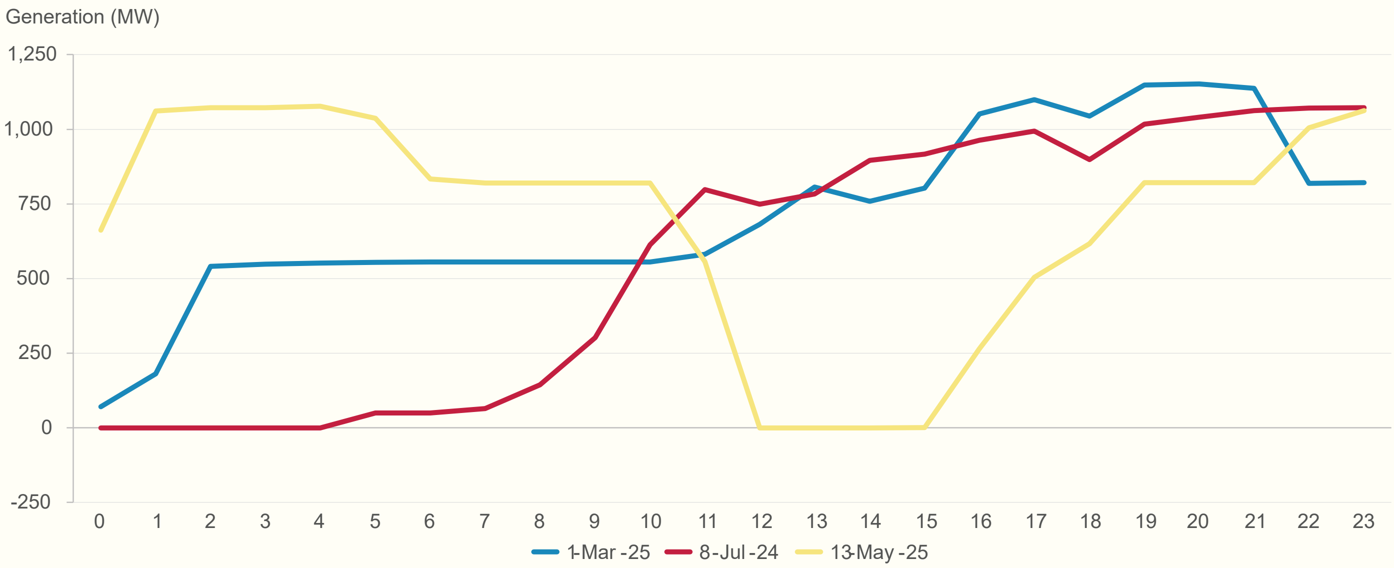

Figure 12: Bhikki case study - 3-day dispatch curve

These operating patterns demonstrate that Bhikki is increasingly being used as a flexibility resource rather than a conventional baseload or intermediate-load plant. In FY25, the plant frequently operated below efficient loading levels, including extended periods below 80% and 50% of dependable capacity (see Table 9).

Benchmark	Hours below threshold	Share of year
Offline / zero generation	1,337	15.2%
80% of dependable capacity	4,638	52.9%
50% of dependable capacity	1,771	20.2%

Table 9: Operational characteristics of Bhikki

The financial consequences of this operating pattern are reflected in recurring PLAC payments as shown in Figure 13.

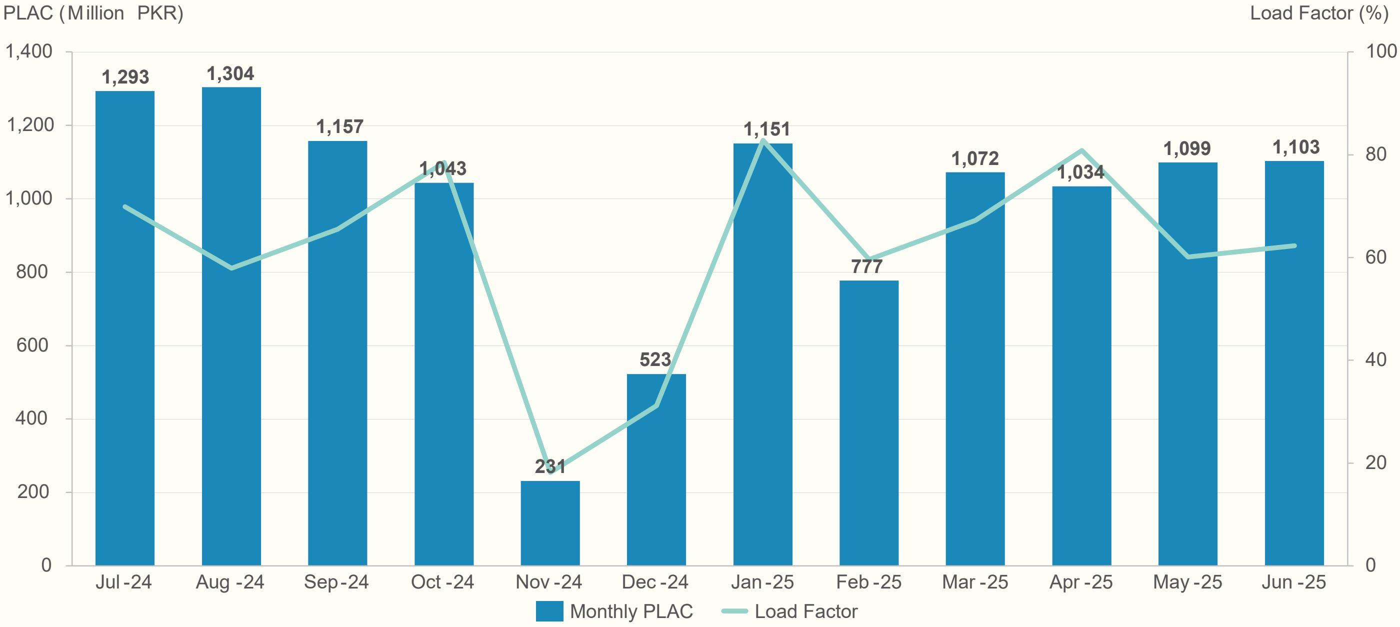

Figure 13: Monthly PLAC and load factor - Bhikki

A battery co-located with Bhikki, or located near the relevant load centre, can reduce the short-duration variability currently being imposed on the thermal plant. Rather than requiring Bhikki to follow sharp intra-day ramps, the battery can absorb part of the downward dispatch movement by charging and support upward movement by discharging. This allows the plant to operate on a smoother profile, reducing abrupt cycling, deep part-load operation, and the operating conditions that contribute to PLAC exposure.

The BESS case is therefore modelled as a dispatch-smoothing intervention. The objective is to reduce sharp ramps and avoid deep operating dips where feasible. We assumed 125 MW/hour ramp-smoothing constraint and a 50% minimum operating threshold of 565 MW, while keeping zero-generation/offline hours separate. A 200 MW / 800 MWh BESS is then simulated chronologically across the full 8,760-hour FY25 dispatch profile. The battery charges when smoothing require Bhikki to generate above actual dispatch and discharges when smoothing require support above the revised plant output. Figure 14 gives an example how this could be operationalized using March 1, 2025 as an example.

On this basis, the 200 MW / 800 MWh BESS is estimated to cover approximately 49.6% of the relevant dispatch-

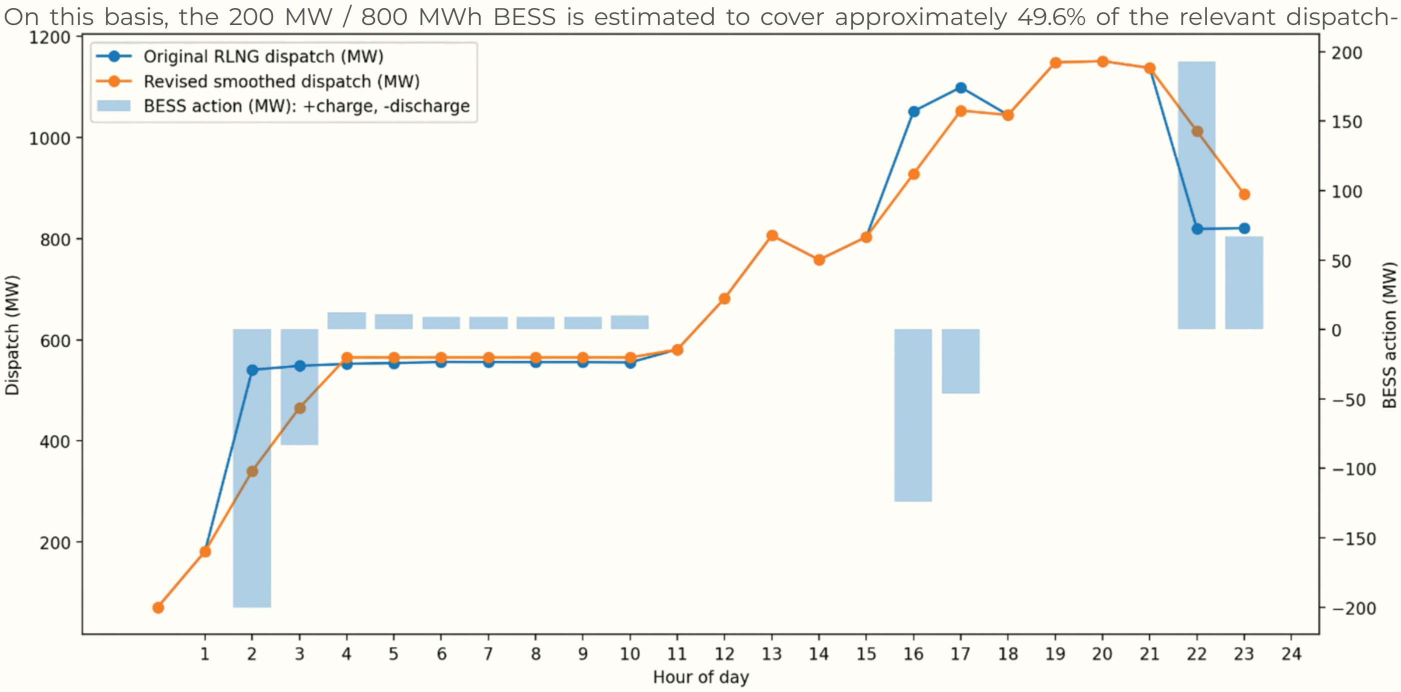

Figure 14: Bhikki dispatch smoothing with BESS - 1 March 2025

smoothing requirement (see Table 10). This coverage factor is used as a practical proxy for the portion of PLAC exposure linked to operational flexibility stress that could be reduced through storage. Applying this to Bhikki's annual PLAC exposure gives an indicative avoided PLAC value of approximately PKR 5.84 B per year. Actual PLAC recovery will depend on dispatch instructions, contractual treatment, heat-rate curves, start-stop costs, market settlement rules, and the operational availability of the BESS.

Parameter	Value
Dependable capacity	1,130 MW
Minimum operating threshold	565 MW
Ramp-smoothing limit	125 MW/hour
BESS power rating	200 MW
BESS energy capacity	800 MWh
Required smoothing adjustment	166,820 MWh
BESS-covered adjustment	82,690 MWh
Smoothing coverage	49.6%

Table 10: Key assumptions for BESS at Bhikki

The financial model evaluates PLAC avoidance as the primary value stream. The model is built on the following inputs (see Table 11):

Parameter	Value
Power rating	200 MW
Energy capacity	800 MWh (4-hour)
Round-trip efficiency	90%
Cycles per year	300
Installed Cost (CAPEX)	USD 125/kWh
Project Life	20 years
Discount Rate	10%
Annual PLAC Exposure	PKR 11,788 M / USD 42.1 M
PLAC Coverage	49.6%

Table 11: Key economic assumptions for BESS

Table 12 highlights the summary of the results for Bhikki – a USD 100 M layout with a final IRR of 16% and Figure 15 shows the annual and cumulative cashflows.

Parameter	Value
Total CAPEX	USD 100 M
Year 1 net cash flow	USD 18.8 M
IRR	16%
NPV @ 10%	USD 39.7 M
Simple payback	5.57 years
Discounted payback	8.86 years

Table 12: Summary of the business case for Bhikki

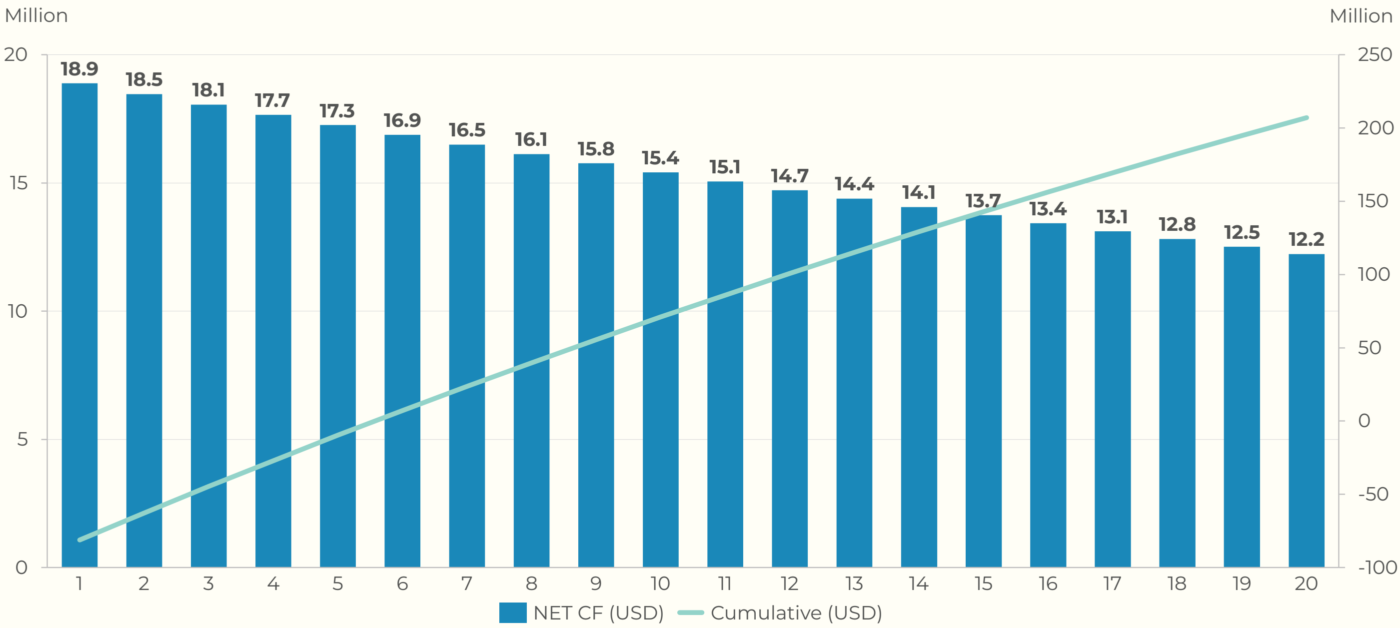

Figure 15: Annual net cash flow and cumulative cash flows - PLAC

To test the robustness of the results, a sensitivity analysis was performed under varying levels of PLAC recovery (see Table 13). Under the modelled base-case recovery of 49.6%, the project remains economically attractive, generating a positive NPV and an IRR above the assumed hurdle rate. The results show that project viability improves as the recovery rate increases. At 35% recovery, the project is marginal, with a negative NPV of USD 6.4 M and an IRR of 9.0%. The project becomes economically viable at around 40% recovery, with a positive NPV of USD 9.4 M and an IRR of 11.5%. At the base-case recovery of 49.6%, the project achieves an IRR of 16.0%, an NPV of USD 39.7 M, and a 5.6-year payback period. At higher recovery rates, the business case strengthens further, reaching an IRR of 38.0% and a 2.5-year payback period at full recovery.

PLAC Recovery Rate Sensitivity (% of annual PLAC exposure recovered)					
PLAC recovery rate	**Annual Gross saving (USD M)**	**Project IRR**	**NPV @ 10% (USD)**	**Payback (yrs)**	**Decision**
35.0%	14.74	9.0%	(6,420,774)	8.6	✗ Marginal
40.0%	16.84	11.5%	9,380,133	7.2	✓ Invest
49.6%	**20.88**	**16.0%**	**39,717,876**	**5.6**	**✓ Invest**
50.0%	21.05	16.2%	40,981,949	5.5	✓ Invest
60.0%	25.26	20.7%	72,583,764	4.5	✓ Invest
70.0%	29.47	25.1%	104,185,579	3.8	✓ Invest
80.0%	33.68	29.4%	135,787,394	3.2	✓ Invest
90.0%	37.89	33.7%	167,389,209	2.8	✓ Invest
100.0%	42.10	38.0%	198,991,025	2.5	✓ Invest

Table 13: PLAC recovery rate index

These results indicate that the business case is not dependent on perfect operational performance or full PLAC elimination. Rather, it remains viable across a range of realistic operating conditions.

The structural driver of PLAC is not unique to Bhikki. Similar operating conditions are increasingly affecting other major RLNG combined-cycle plants across Pakistan's power system. In FY25, PLAC exposure across Balloki, Haveli Bahadur Shah, Punjab Thermal and Bhikki reached approximately PKR 37 B.

Applying a similar operational methodology across this fleet suggests that coordinated BESS deployment could reduce a material portion of recurring PLAC exposure. The findings suggest that recurring PLAC payments may represent a more expensive long-term flexibility solution than targeted investment in battery storage. As solar penetration continues to increase, dedicated flexibility resources such as BESS may provide a more cost-effective approach to managing daily system variability while improving thermal fleet utilization and reducing costs for consumers.

Jamshoro case shows how grid-side BESS can help avoid curtailment and strengthen the system

- Renewable curtailment is becoming a material system cost in Pakistan, with around 2,942 GWh curtailed and approximately PKR 81 B in NPMV compensation between FY20 and FY25.
- Jamshoro is a strategic grid-side BESS location, acting as the main aggregation and evacuation point for around 1.8 GW of wind capacity from the Jhimpir-Gharo corridor.
- Curtailment events are often sustained rather than brief, with nearly half of curtailed energy coming from events longer than seven hours, making 4-hour storage a suitable pilot option.
- A 100 MW / 400 MWh BESS at Jamshoro can capture around 21–22% of annual curtailment while improving use of existing transmission infrastructure.
- The business case is viable under base assumptions, with USD 50 M CAPEX, Year 1 net cash flow of USD 7.7 M, 12% IRR, USD 7 M NPV, and a simple payback of 6.9 years.

As renewable penetration increases, periods are becoming more frequent where available wind generation cannot be fully absorbed by the power system. The result is renewable energy being curtailed due to transmission constraints, operational requirements, and system security considerations. Between FY20 and FY25, Pakistan's renewable fleet incurred approximately PKR 81 B in NPMV compensation. Annual losses fluctuated considerably, ranging from only 42 GWh in FY22 to 1,337 GWh in FY24, before declining to 523 GWh in FY25. The scale and volatility of these losses indicate that curtailment is not an isolated operational issue but an increasing material system cost (see Table 14.)

Fiscal Year	Energy Lost (GWh)	Financial Impact (PKR bn)	Implied Rate (PKR/kWh)
FY20	522	13.0	24.9
FY21	99	2.0	20
FY22	42	1.0	24
FY23	419	12.0	28.6
FY24	1,337	40.0	29.9
FY25	523	13.2	25.2
Total	**2,942**	**81.2**	—

Table 14: Yearly curtailment, financial impact, and implied rate

The Jamshoro 220 kV node represents one of the most strategic locations for grid-scale storage deployment in Pakistan. Approximately 1.8 GW of installed wind capacity is concentrated within the Jhimpir-Gharo wind corridor of Sindh. Generation from these wind plants converges through a network of collector substations before reaching the Jamshoro node. From Jamshoro, electricity can flow through three primary pathways (see Figure 16):

- North through the Matiari-Lahore HVDC transmission corridor;
- South toward Karachi through K-Electric;
- East into HESCO's distribution network.

This makes Jamshoro the principal aggregation and evacuation point for Pakistan's wind fleet.

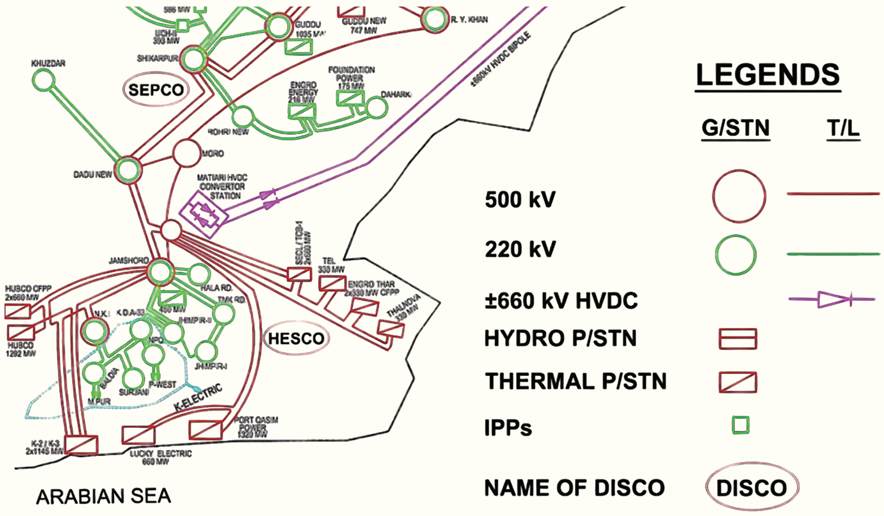

Figure 16: NGC's southern transmission network

The corridor also hosts a large concentration of thermal and nuclear generation. During periods of high wind output, renewable generation must compete with these plants for available transmission capacity and system operating headroom.

In some instances, curtailment occurs because available export capability is insufficient. In other cases, system operators may maintain conventional generation online to satisfy inertia and other system stability requirements. Battery storage offers a potential solution to both challenges. By absorbing renewable energy during constrained periods and discharging later, storage can improve utilization of existing transmission infrastructure while reducing the need to curtail low-cost renewable generation.

Analysis of hourly curtailment profile indicates that curtailment events are often sustained rather than short-lived. Nearly half of total curtailed energy originates from events lasting longer than seven hours, highlighting the importance of energy capacity in addition to power rating.

Based on the observed event duration and capture-rate analysis, a 100 MW / 400 MWh battery was identified as the most attractive pilot configuration (see Table 15 for key assumptions). The results in Table 16 indicate that the curtailment-avoidance investment is financially attractive. On a USD 50 M CAPEX, the project yields USD 7.7 M in Year 1 net cash flow, a 12% IRR, and a USD 7 M NPV at a 10% discount rate. Simple payback stands at 6.9 years and discounted payback at 13.4 years, both well inside the project lifetime. Figure 17 further highlights that annual cash flows remain consistently positive and cumulative returns rise steadily across the horizon, while the battery captures roughly 21% of annual curtailment.

Parameter	Value
Power rating	100 MW
Energy capacity	400 MWh (4-hour)
Average Discharge price	PKR 25.41/kWh
Peak Discharge price	PKR 36.21/kWh
Round-trip efficiency	90%
Cycles per year	300
Installed Cost (CAPEX)	USD 125/kWh
Project Life	20 years
Discount Rate	10%
Depth of Discharge	80%
O&M Cost	2%
Capacity Degradation	2%

Table 15: BESS technical parameters and assumptions for curtailment avoidance

Parameter	Value
Total CAPEX	USD 50 M
Year 1 net cash flow	USD 7.7 M
IRR	12%
NPV @ 10%	USD 7 M
Simple payback	6.9 years
Discounted payback	13.4 years
Curtailment captured	21%

Table 16: Key results for curtailment avoidance

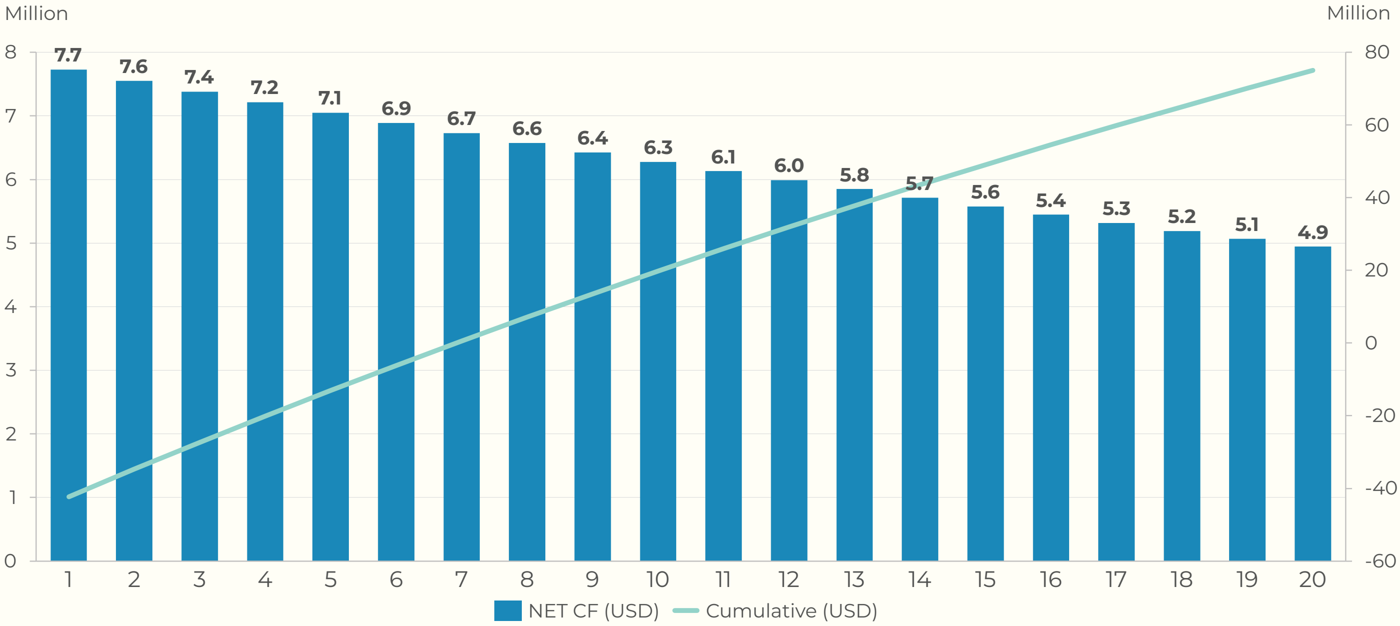

Figure 17: Annual Net Cash Flow & Cumulative - Curtailment

While curtailment reduction represents the primary value stream, a grid-side battery at Jamshoro may provide several additional system benefits.

1. It can provide fast frequency response, reserve support, and synthetic inertia, reducing the need to keep thermal generation online solely for system stability purposes.
2. By reducing congestion and improving transmission utilization, the battery may defer future network reinforcement investments.
3. The battery can improve renewable utilization without requiring major changes to existing generation assets.

Thermal energy storage converts surplus solar into firm industrial capacity and unlock new investment opportunities

- Pakistan's industry consumes 181 TWh of process heat annually, much of it above 1,500 °C and impossible to electrify economically. Unreliable gas, 2.1 GW of stranded captive RLNG capacity, and CBAM exposure on USD 8.8 B of EU exports make firm clean thermal supply a survival requirement.
- The modelled case pairs a 210 MW solar PV field with a 20 MW molten-salt TES block sized for 10 hours of discharge, delivering 20 MW of firm capacity across a continuous 20-hour window from 8 am to 4 am.
- TES dispatches stored solar as electricity or heat, capturing thermal efficiencies above 80% against 40% for an electric round-trip. It retrofits stranded captive plants by replacing only the combustion block, decarbonises power and heat together, and turns CBAM compliance into a procurable commodity under CTBCM bilateral contracts.
- At USD 145 M CAPEX the system delivers electricity at USD 0.062/kWh, structurally below industrial tariffs of 11 to 13 US cents/kWh, returning a 10% IRR over a 25-year life. Economics strengthen further in direct heat-supply mode where round-trip efficiency exceeds 80%.

Pakistan's industrial sector is among the most exposed segments of the economy to the twin pressures of unreliable grid supply and tightening international carbon accountability.

Continuous-process industries such as textiles, cement, fertilizer, food and beverage, and chemicals require firm, round-the-clock energy at predictable cost, and increasingly require that energy to be demonstrably clean if their output is to remain competitive in export markets. The underlying demand is overwhelmingly thermal. According to IEA analysis for 2023, Pakistan's total industrial process-heat demand stands at approximately 181 TWh, with a significant share occurring at temperatures of up to 1,500 °C in cement and certain chemical processes that cannot be economically electrified. Multi-shift operations across this fleet require firm supply across the full non-solar window of roughly 14 to 16 hours, placing the requirement squarely in the long-duration storage class.

Thermal Energy Storage (TES) using molten salt is uniquely suited to this profile because it can dispatch stored energy as either electricity or heat. Routing stored solar-thermal energy directly to thermal processes such as drying, boiling, bleaching, thermoforming, resin curing, and kiln firing bypasses the round-trip electrical conversion and captures thermal efficiencies above 80% against a 40% electric round-trip. TES therefore addresses both the electricity and the heat decarbonization fronts simultaneously, which no electrochemical technology can replicate at comparable cost.

Three policy and market shifts reinforce the commercial case.

- First, the European Union's Carbon Border Adjustment Mechanism (CBAM) enters its definitive phase in 2030 and will price the embedded carbon in Pakistani exports at the EU border. Pakistan's exports to the EU stood at USD 8.8 B in FY25, with textiles forming the dominant share, placing a material portion of national export earnings at direct carbon-cost risk.
- Second, under the USD 7 B IMF agreement, the authorities have raised gas prices for captive power plants from PKR 3,000 to PKR 3,500 per mmBtu to discourage self-generation, pushing an estimated 2.1 GW of captive RLNG capacity toward stranded status and onto an already constrained national grid. TES offers a practical conversion pathway for this fleet and for retiring coal-fired units, as the existing steam turbine, generator, and grid connection are retained, and only the combustion setup is replaced with a molten salt charging and storage block.
- Third, the imminent operationalization of the CTBCM will allow industrial consumers to procure directly from renewable and storage providers under bilateral contracts, converting clean firm power from a compliance burden into a procurable commodity.

The use case models a hybrid plant designed to supply a 20 MW industrial hub with firm capacity for a continuous 20-hour window, beginning at 8 am and running through to 4 am the following morning, covering the full working day and the evening and night shifts. The configuration combines a 210 MW solar PV field with a 20 MW TES block sized for 10-hour of discharge (see Table 17 for key assumptions).

Parameter	Value
Power rating (TES)	20 MW
Solar PV field size	210 MW
Firm Capacity Delivered	20 MW for 20 hours (8 am- 4 am)
Round-trip efficiency	40%
Cycles per year	300
TES Installed Cost (CAPEX)	USD 2092/kW
Solar Installed Cost (CAPEX)	USD 490/kW
Project Life	25 years
Discount Rate	10%
O&M Cost	USD 12000/ MW (annual)

Table 17: Key assumptions for industrial TES

The dispatch curve, shown in figure 18 below, confirms that the 20 MW firm capacity target is met across the full 20-hour delivery window. Solar generation between 9 am and 4 pm both charges the molten salt block and meets daytime industrial load directly, with output peaking near 100 MW around midday (see Figure 18). The TES block discharges from 7 pm until 4 am and bridges the entire evening and early-morning window in which the hub would otherwise depend on grid imports or captive thermal generation.

The midday surplus visible on the curve reflects the deliberate oversizing of the solar field to guarantee year-round charging under realistic irradiance variability, and it constitutes a monetizable revenue stream. The surplus can be sold to neighboring industrial loads through bilateral arrangements, used to expand the storage block in subsequent project phases, or sold into the wholesale market once CTBCM is operational. The cost-plus tariff structure under the Alternative and Renewable Energy Policy 2019 further compresses the levelized cost.

At a total capital cost of USD 145 M for 20 MW of firm 20-hour clean capacity, the configuration delivers electricity at USD 0.062/kWh (see Table 18), which is structurally below the prevailing industrial tariff in Pakistan i.e., 11-13 cents per kWh and well below the marginal cost of grid electricity during evening peak hours.

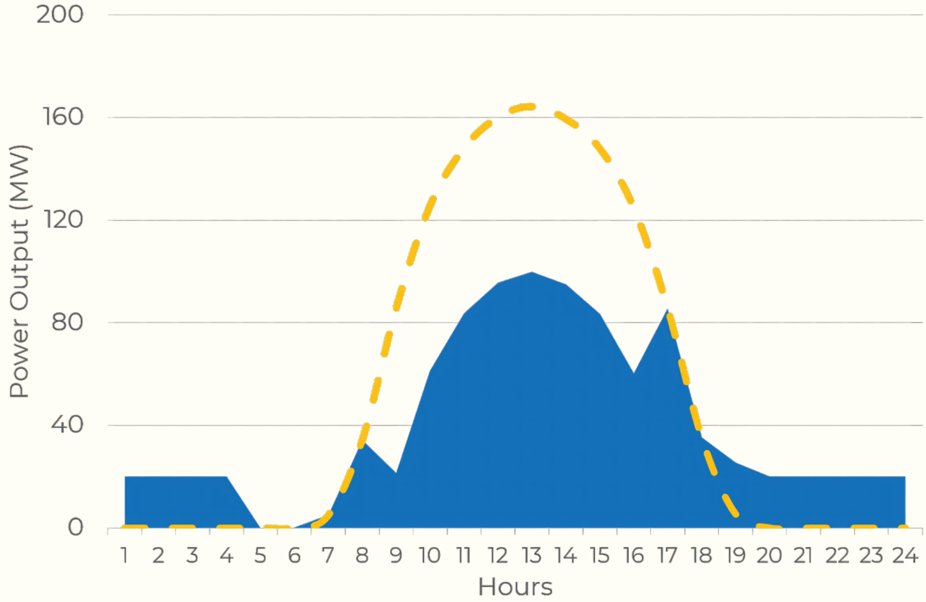

Figure 18: Hourly dispatch of PV + TES and solar alone

Parameter	Value
Total CAPEX	USD 145 M
IRR	10%
LCOE	0.062 /kWh

Table 18: Investment economic results for industrial firm capacity

The economics improve materially when the system is operated in heat-supply mode for thermal processes, because the 40% electric round-trip efficiency is replaced by a thermal-only efficiency exceeding 80%. The present analysis is conservative in modelling electricity supply only. Industrial estates, special economic zones, and export-oriented clusters in Punjab and Sindh are the natural early adopters, where the combination of dense thermal load, reliable solar resource, and CBAM exposure creates a clear commercial case for the technology.

Energy storage can reduce system costs, deliver system-wide value and open new investment opportunities

The matrices below summarize storage applications across Pakistan's power system and industrial sector. Table 19 shows how the results of the above analyses – highlighting that particularly PLAC and Industrial Firm Capacity generates IRRs 16% and 10% respectively. For case 1, energy arbitrage, this can only be achieved when either having wider spreads of buying-selling prices or by expanding revenue stacking and generating revenues through ancillary services.

Application	Value Stream	Best-Fit Tech	Power (MW)	Duration (h)	Addressable Quantum	CAPEX (USD m)	IRR (%)	Horizon
Energy Arbitrage	Intraday price spread capture	Li-ion	100	4	National wholesale market post-CTBCM	50	7	Near-term
PLAC Charges Reduction	Avoided part-load thermal dispatch cost	Li-ion	200	4	Annual PLAC Exposure (FY25): PKR 46 B	100	16	Near-term
Renewable Curtailment Reduction	Recovery of NPMV-linked lost generation revenue	Li-ion	100	4	PKR 39 B NPMV burden (FY24)	50	12	Near-term
Industrial Firm Capacity and Heat	Firm 20-hour clean supply plus process heat	TES (Molten Salt)	20	10	181 TWh industrial process-heat demand; 2.1 GW stranded captive fleet	145	10	Near-term

Table 19: Pakistan's energy storage business cases

About the Renewables First

Renewables First (RF) is a think and do tank for energy and environment. Our work addresses critical energy and natural resource issues with the aim to make energy and climate transitions fair and inclusive.

About the University of Queensland's Asia Pacific Industry Transitions Work

The Asia Pacific Industry Transitions work at UQ focuses on policy-oriented research to support decision-makers and communities across Asia, Australia, and the Pacific in successfully navigating major industry transformations.

We focus on four critical global trends:

- Energy transitions and climate change
- Artificial intelligence and digitalization
- Geo-economics and the role of China
- Heavy industry transitions, including iron and steel

We are dedicated to driving real-world sustainable impact through research excellence and global partnerships with industry, government, and communities in these areas. Our core deliverables include policy research, market analyses, industry reports, investment and trade databases, capacity building, executive education, and research exchanges.

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