The Limits of Sunshine

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By day, Pakistan runs on the sun. By night, it runs short.

I. Executive Summary

Pakistan is in the middle of one of the world's fastest solar booms, yet the load-shedding that hurts most has slipped beyond solar's reach. This brief asks where added solar stops cutting load-shedding, and how much firm evening capacity would close what remains. It uses a zonal energy-balance model built from permissioned NTDC and ISMO data to test the FY25 summer peak province by province.

Peak demand now falls at 23:00, when solar output is zero, so against the evening peak more solar does not help at any level. Solar's daytime job is nearly done too, with only about 1,500 MW of useful room left, almost all in Punjab, before further panels are wasted at midday. What the country is actually short of is firm evening capacity, roughly 1,700 MW that can run at 23:00, about 4,000 MWh across a six-hour window, needed in Punjab, Sindh, and the Islamabad-Rawalpindi region. Neither more solar nor more transmission closes that gap, and the household batteries now selling fast are too small and too scattered to reach it; only firm capacity built for the grid can, and the large hydro that would close it is years away.

The most important step concerns the battery rule Pakistan proposed this month. New solar projects must add storage worth ten percent of their size, but that sets the battery's power, not how long it lasts, so it can run flat before the 23:00 peak. The requirement should instead be sized to the six-hour evening shortfall. Alongside it, the country should stop subsidising solar past the point it helps and start buying night-capable capacity now, ahead of the delayed hydro.

II. Introduction

In 2024 Pakistan imported 17 gigawatts of solar panels, twice the year before and enough to make it the world's third-largest importer (Ember, 2025). Almost none of it was planned. The boom came rooftop by rooftop, households and businesses buying their own supply as grid power grew too costly and unreliable to trust. It grew fast enough to unsettle the state, which in February 2026 rewrote a decade of rules to slow it down. And yet the load-shedding that hurts most is the one thing that solar cannot fix. It strikes after sunset, on a still summer night when every household reaches for the air conditioner at once, hours after the last panel has gone dark.

What changed in February was the economics of a rooftop solar system. For ten years, net metering had let a household with solar panels sell its daytime surplus to the grid and buy power back after dark at the same price, unit for unit. The new system, net billing, ended that one-for-one trade (NEPRA, 2026). A home is now paid only about Rs 11 for a unit it sends out at midday, but still pays the full retail rate, between Rs 40 and 60, for a unit it draws back at night. Almost overnight, owning a rooftop solar setup became worth far less. NEPRA's reasoning mostly rested on cost. Solar homes, it argued, had been treating the grid as a free battery, and the consumers without panels were footing the roughly Rs 159 billion it cost to keep that grid running. Rooftop solar has grown so fast that the grid now sells about a tenth less power than it did three years ago, and the oldest thermal plants are being shut down as the need for them fades.

Despite all the arguments about who pays for solar, no one has answered a simpler question with open data. Does the solar Pakistan keeps installing actually reduce the load-shedding people live with? The answer depends on when the shortage hits, and the timing has shifted. Because demand here is driven by air conditioning, it climbs highest in the summer heat (NTDC, 2024). As rooftop solar spread, it flattened the old midday peak (Renewables First, 2026a), and on Pakistan's own FY25 demand record the worst hour of the day has slipped into the evening, to a time when the panels have already gone dark.

The published record establishes the shape of this problem, but not really its size. NEPRA's State of Industry reports show the system falling short of demand at peak (NEPRA, 2024). Renewables First documents the rooftop boom and the flattened midday peak (Renewables First, 2026a), and the IGCEP projects demand and capacity a decade ahead (NTDC, 2024). None of them fixes the point at which more solar stops easing the evening shortage, or how much firm capacity each region would then need. That is the gap this brief fills, and the question has a precise form. At what point does adding more solar stop reducing a province's load-shedding, and once it does, how much firm capacity that can run at night would be needed to close what is left? The policy fight is over rooftop solar; this analysis models the larger utility-scale kind. But both make their power in daylight and both fall silent at the evening peak, so what holds for one holds for the other.

III. Methodology

This analysis runs on a zonal energy-balance model of Pakistan's power system, built from permissioned operational data. It works at the province level, computing an hourly supply-demand balance across the FY25 summer peak day and splitting each result into daytime and evening hours. The model, though, is not a power-flow solver. It reports the direction and size of shortfalls rather than exact line-by-line dispatch, and its results are given as labelled ranges.

The demand signal is measured by National Power Control Centre (NPCC) hourly data supplied through the Independent System and Market Operator (ISMO). Transmission ratings come from the National Transmission and Despatch Company (NTDC) PSS/E case (SP-2025), backbone substation coordinates from the NTDC KMZ dataset, the generation fleet from OpenGridPK, and solar and wind capacity factors from the Global Solar Atlas and Global Wind Atlas. To locate the saturation point, utility-scale solar is added to each province in fixed increments, and its effect on unserved demand is tracked at each step, split into daytime and evening hours, up to the point where more solar changes nothing. Whatever evening gap remains is then measured as the firm capacity the province would still need.

Provincial demand is split by a city-population proxy rather than measured per-province metering, so national figures are firm while province-level figures are indicative. The distributed-solar totals cited for context are third-party modelled estimates rather than metered capacity.

The model treats solar as bare panels by design, because almost none of Pakistan's installed fleet has storage; batteries are handled separately, as firm capacity to be sized against the evening gap.

IV. Key Findings

The afternoon is already covered, and the shortage is now an evening event

The familiar picture of Pakistani load-shedding is a hot afternoon with too little power. For FY25, however, that picture is out of date. National demand now peaks at 29,201 MW at 23:00 (measured, NPCC via ISMO, 20 June 2025), and the concentration is not a one-night fluke: of the year's fifty highest-demand hours, 47 fall between 19:00 and 01:00 (measured). This is a residential peak, driven by households running air conditioning late into the night, long after the working day has ended. The afternoon, by contrast, is fully served. Summed across the country at the 16:00 peak, generation covers demand with about 2,000 MW to spare (derived), as the northern surplus in KPK, Balochistan, and AJK/GB carries the daytime deficits of Punjab, Sindh, and the Islamabad-Rawalpindi region. All of the unserved energy at the peak now falls after dark. That distributed solar flattened the old midday peak is already on the record (Renewables First, 2026a). The shift to a night-time peak is this analysis's own finding. On the measured FY25 data the worst hour is now 23:00, and even with unlimited transmission the country still falls about 1,673 MW short at that hour (derived).

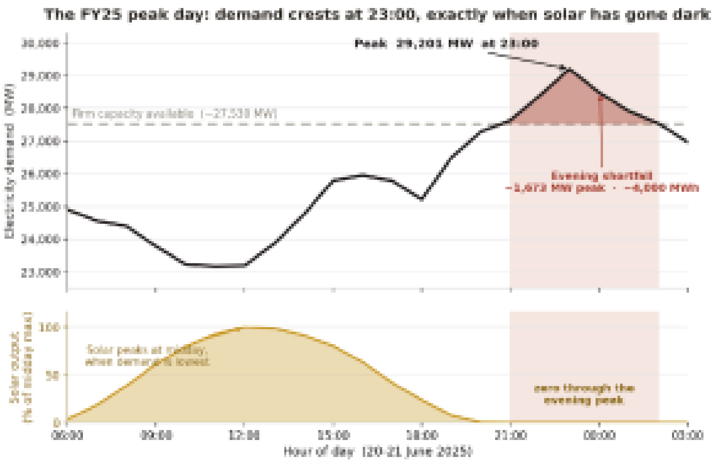

Figure 1. Demand crests at 23:00, when solar output has already fallen to zero.

Against the evening peak, more solar changes nothing at all

To test this, the model adds utility solar province by province, from zero up to 4,000 MW. The evening shortfall does not budge. Punjab sits at 4,264 MW of unserved evening demand at the first megawatt of solar, and at exactly the same 4,264 MW after four thousand (derived). Solar does not simply reach a point of diminishing returns against the evening peak; it never helps at all, because its output at 23:00 is zero. This is simply a fact about the fleet. Of the roughly 45 gigawatts of panels Pakistan imported over five years, cumulative battery storage stood at just 7.6 gigawatt-hours at the end of 2025, and near zero before 2024 (Renewables First, 2026b). Until this year, net metering paid households full retail to use the grid as their store, so almost no one bought a physical battery. The solar already on the roofs produces nothing at 23:00. Raising the assumed solar capacity factor by 15% leaves the gap where it was, and even unlimited transmission leaves the same 1,673 MW, because at the ordinary evening peak the northern surplus already reaches the southern deficit without congestion.

Against the daytime, solar's useful room is small and nearly spent

Where solar does work is during the daytime, and there the limit arrives fast. Nationally the afternoon is already covered, so little daytime shortage is left to close. Four provinces, Sindh and the entire north, already over-generate at midday with no added solar at all: midday is the demand trough, their fleets are unchanged, so any panel added there spills at once. Only Punjab has real room, and even there it runs out fast. Beyond about 1,500 MW of added solar its output spills at midday, while the mornings and late afternoons stay short for longer, when the sun is weaker and demand higher (derived). The Islamabad-Rawalpindi region crosses into midday surplus at about 2,000 MW. So the country's remaining useful utility-solar room is on the order of 1,500 MW, almost all of it in Punjab. Solar keeps genuine daytime value as it fills that room, collapsing Punjab's unserved daytime energy from about 9,900 to 1,350 MWh and displacing imported fuel (derived). But the room is nearly full, and past it more solar becomes the midday over-generation that NEPRA itself cited to justify net billing.

What closes the gap is firm evening capacity, in three provinces

The evening gap is about 1,673 MW of capacity able to run at 23:00, all of it in Punjab, Sindh, and the Islamabad-Rawalpindi region; the rest of the country is in surplus at every hour. On a shared-grid basis the shortfall is roughly 1,018 MW in Punjab, 332 MW in Sindh, and 323 MW in the Islamabad-Rawalpindi region. If each zone had to stand alone the figures rise to 4,264, 1,389, and 1,353 MW; the capital region's figure is large not because its demand is large but because it generates almost none of its own power and imports nearly all of it (derived; the split is indicative, resting on a city-population proxy, while the national total is firm). Bare solar supplies do none of this. What can is firm capacity, meaning storage, dispatchable thermal, or wind that runs into the evening. Storage is the natural fit, and solar is its cheapest fuel, since the midday surplus that solar already produces is exactly what a battery would store for the evening. Paired that way, the capacity credited to the evening peak is the storage's, measured by what it can discharge. Storage is now arriving fast, with battery imports up 220% in 2025. But it is household-scale and behind the meter, and only about one solar home in twenty-six has one (Renewables First, 2026b), so the grid cannot dispatch a home battery to the 23:00 peak. Closing a 4,000 MWh window every night takes storage built and sized to serve the grid, not batteries accreting one rooftop at a time.

V. Recommendations

The evening shortfall in this analysis measures, roughly 1,700 MW at the FY25 peak and sitting almost entirely in Punjab, Sindh, and the Islamabad-Rawalpindi region, needs firm capacity that can run after dark. It should be treated as a target in its own right, separate from the solar and tariff arguments around it.

NEPRA should measure "enough power" by what can run at the evening peak.

NEPRA's State of Industry Report shows a comfortable surplus at peak, about 6,000 MW in FY24 (NEPRA, 2024). But that surplus counts panels that produce nothing at night and plant now being retired. At 23:00 the capacity that can actually run falls about 1,673 MW short of demand (derived). NEPRA should publish, each year, how much capacity can run at the evening peak and how far short of demand it leaves the system, a number the surplus headline hides.

NEPRA and ISMO should write the battery rule around the evening, not as a share of plant size.

This month the government proposed that new solar projects in one 800 MW auction add batteries equal to 10% of the plant's size, a rule now before NEPRA (ISMO, 2026). Requiring storage is the right call. Setting it at ten percent of plant size is not, and the reason is physical. That share fixes how much power a battery can push out at once, not how long it can keep running, so a battery can meet the rule and still be empty within an hour, before the shortage even peaks. And the shortage lasts for hours. On the peak day it builds from 21:00, tops out at 1,673 MW at 23:00, and does not clear until 02:00, six hours and about 4,000 MWh in all (measured demand against firm capacity). The rule should set a minimum discharge duration to cover that window, and apply to all new utility solar, not one auction.

CPPA-G and PPIB should buy the fix now, and put it where the shortage is.

The lasting answer is large hydro, Dasu and Diamer Bhasha above all, which can run at night. But those dams are due between 2026 and 2030 (NTDC, 2024), Pakistani dams routinely run years late, and the plants covering the evening are being retired in the meantime. The battery boom now underway will not fill the gap either, since it is household-scale and behind the meter, invisible to the system operator at the evening peak. Rather than wait, buy fast-to-build firm capacity batteries first, on the order of 1,000 MW in Punjab, 300 in the Islamabad-Rawalpindi region, and 300 to 1,400 in Sindh. The wide Sindh range reflects how much it can lean on the national grid. The national total is firm; the province split is indicative, enough to say where to begin but to be confirmed with per-DISCO metering before procurement.

The Power Division and NEPRA should not retire an evening plant before its replacement is running.

Pakistan is retiring its old furnace-oil fleet to cut capacity payments, which is sound where the plants sit idle. Around 4 GW of furnace-oil capacity is being retired by 2030 as contracts expire, from plants such as the 362 MW Lalpir unit in Muzaffargarh (IEEFA, 2024). But furnace oil is the costliest fuel in the merit order, so the plants still in service run mainly at the peak, the evening hours where the gap sits. Retiring those before storage or the delayed hydro can replace them would widen the very gap this brief identifies. Each retirement should be tested against the 23:00 peak, and any plant that serves it is kept until its firm replacement is running.

The Power Division and AEDB should cap incentivised utility solar near its useful ceiling, and move the spend to firm capacity.

Solar's remaining room to cut load-shedding is small, about 1,500 MW of useful daytime headroom, almost all in Punjab, and nothing in the evening (derived). Past that, more panels only spill at midday, the over-generation net billing was written to curb. Net billing is already curbing the roughly Rs 159 billion cross-subsidy that rooftop solar drew from other consumers. The incentives and attention still pushing solar past its useful point should turn instead to firm evening capacity, the only thing that reaches the peak.

VI. Conclusion

Pakistan has bet its energy future on the sun, and in daylight the bet is paying off. But the shortage that wears a household down arrives after the sun is gone, and no amount of solar, however cheap or well-placed, reaches that hour. The gap left behind is small enough to close, roughly 1,700 MW across three regions, and firm capacity is the only thing that will close it. Yet almost everything Pakistan is now doing about power, the solar subsidies, the tariff battles, the batteries filling private rooftops, sails past this one hour. The neglect, not the size, is what makes it urgent. The country has spent three years learning to harvest the day. The task now is to keep some of it for the night.

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