Co-location of solar with batteries and the impact of market volatility

June 2025

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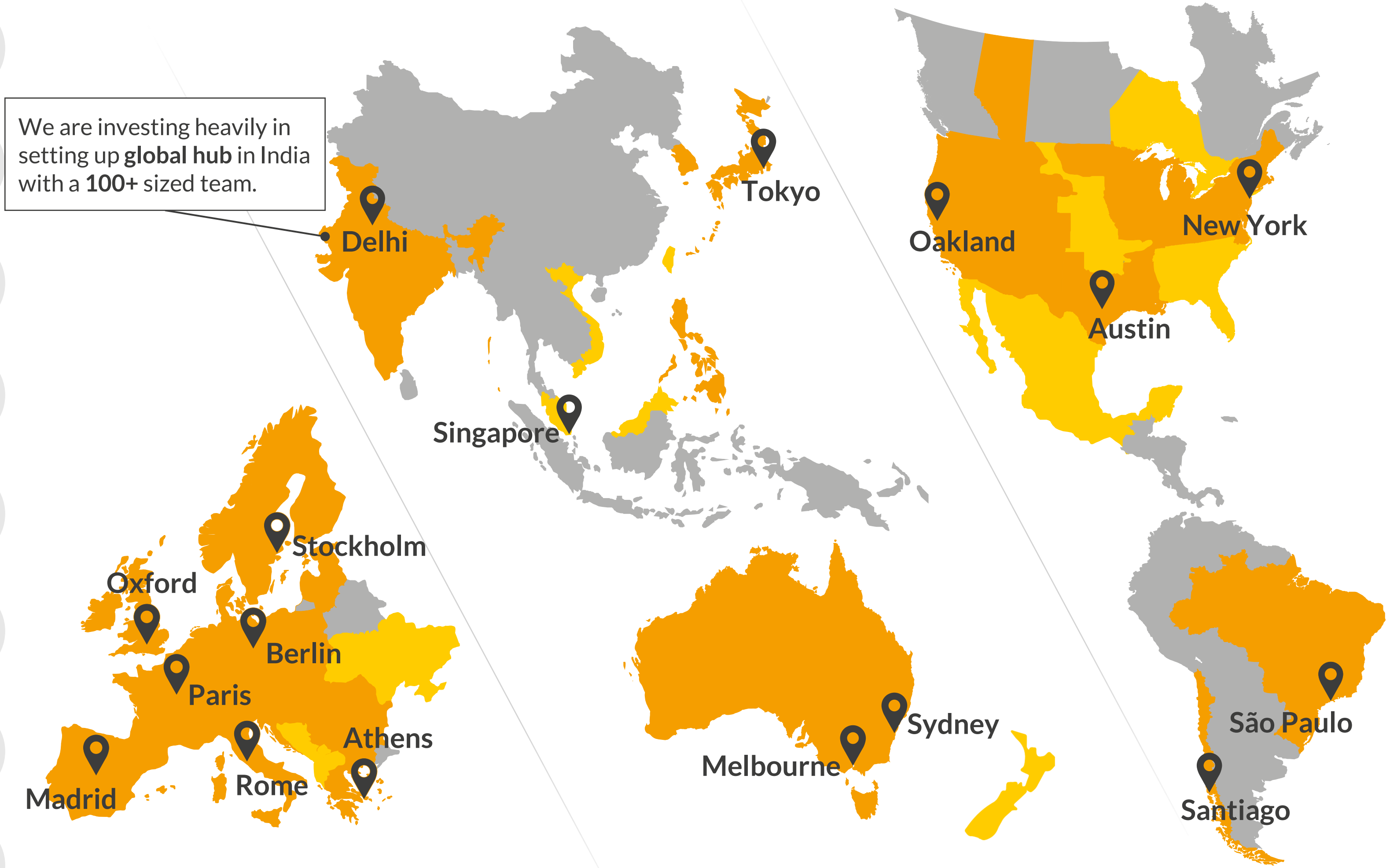

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250+ transactions supported in 2024

Sources: Aurora Energy Research

Aurora thanks the registrants for this session for their attendance and contributions to the discussion

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Sources: Aurora Energy Research

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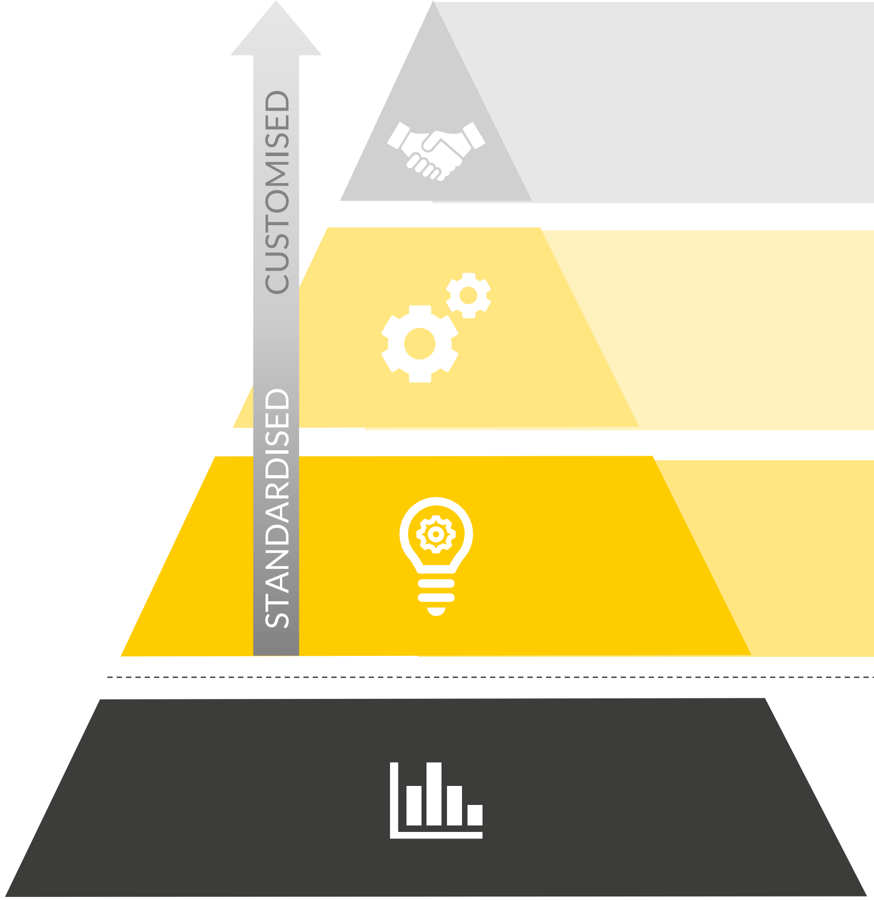

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Sources: Aurora Energy Research

Indian Power & Renewables Service:
Dive into key market analysis and forecasts for the Indian power and renewables markets

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Power & Renewables Service

Forecast Reports & Data

Quarterly forecast reports and data updates

- Detailed forecast data for India's capacity and generation mix out to **2060**, along with annual and monthly time-weighted average prices across the 13 main Indian price zones (DAM).
- A comprehensive databook containing half-hourly wholesale price forecasts in Central, High, Low, Accelerated Decarbonisation and Messy Transition scenarios.
- Renewable capture price forecasts and power sector emissions projections, offering insights into both profitability and environmental impact of renewable assets.
- Price distribution analysis and scenario-based modelling (High and Low scenarios) to help understand potential market variations and uncertainties around Aurora's Central forecast.
- Copies of Aurora's Global Energy Markets Forecast, published quarterly, providing a broader context of global energy trends alongside India-specific insights.

Strategic Insights

Strategic Insight Reports

In-depth thematic reports on topical issues, such as the economics of batteries, and the Portfolio design for FDRE auctions

Policy Updates

Timely research notes on recent changes to policy and regulation, demonstrating the impacts and opportunities for market participants

4 Group Meetings

Four Group Meeting roundtable events **in New Delhi** with key market participants such as developers, investors, financiers, utilities, grid operators, and government officials

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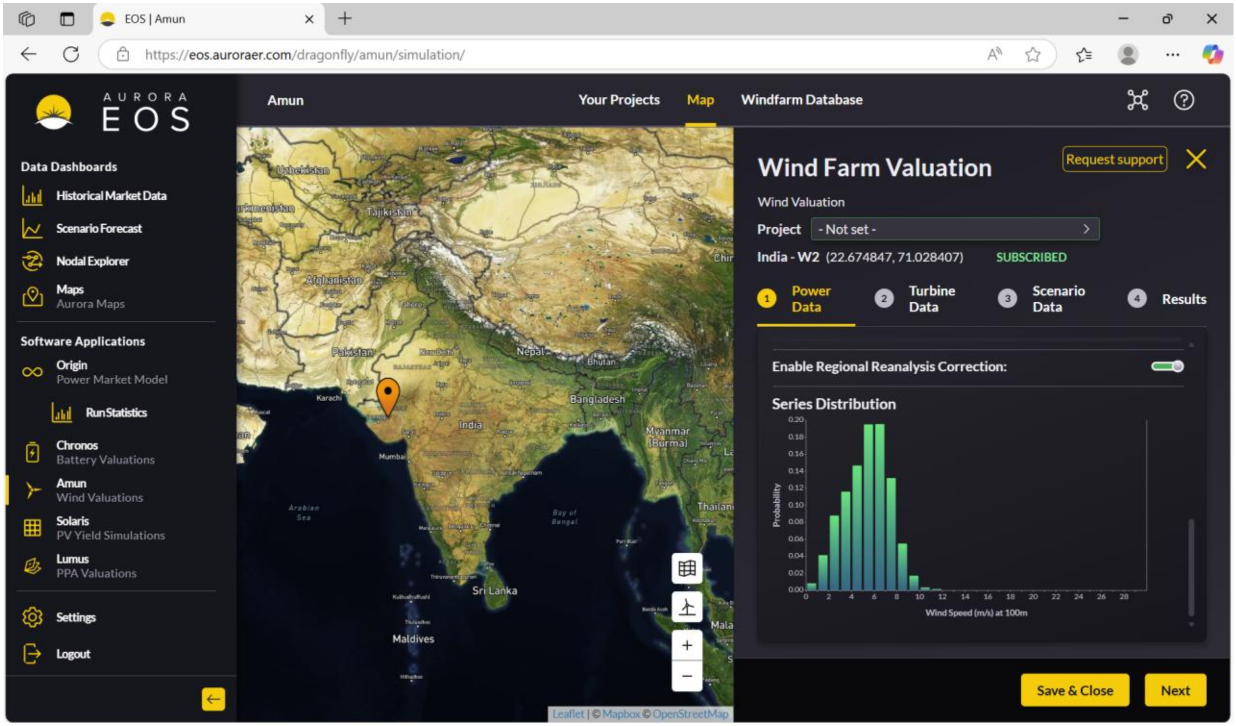

Transactions

Site Selection and Optimisation

Portfolio Valuation

PPAs

This session will present Aurora's co-located solar and battery investment cases for India, followed by portfolio design and economics of FDRE assets in July

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Dec 2024

- **First full, detailed Power & Renewables market report**

Aurora's detailed, long-term view on the power market in India, containing:

- Aurora's central scenario

Alternative scenario analysis to explore sensitivity to:

- Lower GDP growth

Feb 2025

- **Batteries Group Meeting: the economics of Standalone BESS in India**
  - Economics of battery storage
  - Business models for batteries
  - Impact of the expected policy changes like de-regulation of ancillary markets, DAM price caps

May 2025

Today's session

- **Messy Transition Group Meeting: Potential impact of unforeseen shocks**
  - Supply chain constraints, fuel shortages, or commodity price spikes
- **Economics of Co-located Batteries**
  - Analysis of hybrid tenders in Aurora Central and Messy Transition scenarios

Jul 2025

- **Peak Power/FDRE[1] & other complex tenders or contracts:**
  - Economics of FDRE or Peaking Power assets
  - Portfolio design for FDRE or Peaking Power auctions
  - Business models, key policies and regulations and their impact on FDRE or Peaking Power auctions

Nov 2025

- **Complex hybrid and storage portfolio optimisation 2.0** *(tbc)*:
  - Can batteries replace wind in a portfolio?
  - Peak Power technology choice
  - Weather years
  - Security of supply

Key releases

Reports

Power market forecast update
April

Update of Central and Low scenarios, with new Messy Transition scenario

- Additional sensitivity analysis of the forecast to low wind speeds

Power market forecast update
July

1st flexible energy report
August

First full, detailed Flexible Energy Report

- Battery economics in India, impact of location, duration, cycle target, and entry years on battery IRRs

Power market forecast update
October

Software

Amun

1) Firm and Dispatchable Renewable Energy.

Sources: Aurora Energy Research

India advisory - Our modelling capability, blended with deep analytical prowess and real-time on ground validation differentiates our solutions

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Services		Deliverable
1	**Debt transaction support**	▪ Lender's advisor on hybrids, FDRE, RTC, and solar-BESS projects. ▪ Covers regulatory landscape and merchant market outlook analysis.
2	**Asset portfolio optimisation (pre-bid and post-bid)**	▪ Optimal asset sizing for complex constructs: FDRE, RTC, and merchant BESS. ▪ Sensitivity analysis for investment returns – Project IRR and Equity IRR. ▪ Merchant nose and merchant tail assessment.
3	**Standalone and co-located BESS investment cases**	▪ Report evaluating BESS scenarios: variation in duration, location and cycling rate. ▪ Modeling scenarios of market participation (DAM,GDAM,RTM) & seasonal planning. ▪ Revenue upside of co-locating a battery with wind or solar assets.

4	**Battery revenue assessment**	▪ Bespoke, site-specific forecast of key revenue streams for batteries (2025-50) basis:
		    ▪ **Battery specifications:** Duration, efficiency, RtE and cycling rate.
		    ▪ Generation profile of solar power plant.

5	**Buy-side support for assets**	▪ Conducts VDD and provides market analysis, long-term volume forecast. ▪ Provides regulatory overview along with transfer sheet.
6	**C&I transaction support**	Strategic asset-specific report offering detailed insights into: ▪ Comprehensive analysis of regulatory frameworks and PPA price evaluation. ▪ Asset optimisation strategies, supplier growth, and PPA red flag support.
7	**Location prioritisation**	▪ Strategic site selection to maximise target IRR and penalty optimisation. ▪ Optimise grid connection and enhance merchant revenue potential efficiently.

10+

Transactions supported **mobilising $300 mn of debt**, **bankable forecasts across 8 banks** (ongoing with additional 6 banks).

10% +

Net savings modelled (in-house optimization tools for FDRE, RTC and solar-BESS constructs).

85+

sites with **200+ capacity configurations** for optimal sizing of hybrids.

12+

Battery investment cases covered.

Agenda

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Context for today's session	Standalone solar economics	Co-located solar and battery economics	Modelling non-equilibrium events	Asset impacts of non-equilibrium events
▪ How have returns for standalone solar evolved historically? ▪ Why are solar and batteries well-suited for co-location? ▪ What has driven price fluctuations in the power market in recent years?	▪ What is the effect of oversizing a solar asset relative to the grid connection? ▪ What is the optimal oversizing ratio for a solar asset for maximising returns?	▪ What are the economics for adding a battery on an existing solar asset? ▪ What is the optimal sizing configuration for a new-build co-located solar and battery asset? ▪ How do returns vary based on location?	▪ What effect can non-equilibrium events have on asset returns? ▪ How does Aurora model a Messy Transition scenario and how is it different from an equilibrium scenario?	▪ What is the potential upside for standalone solar assets in the event of unexpected shocks? ▪ How does the optimal configuration for a co-located asset change in the Messy Transition scenario?

Returns from standalone solar assets have stagnated for both tender-backed and merchant projects

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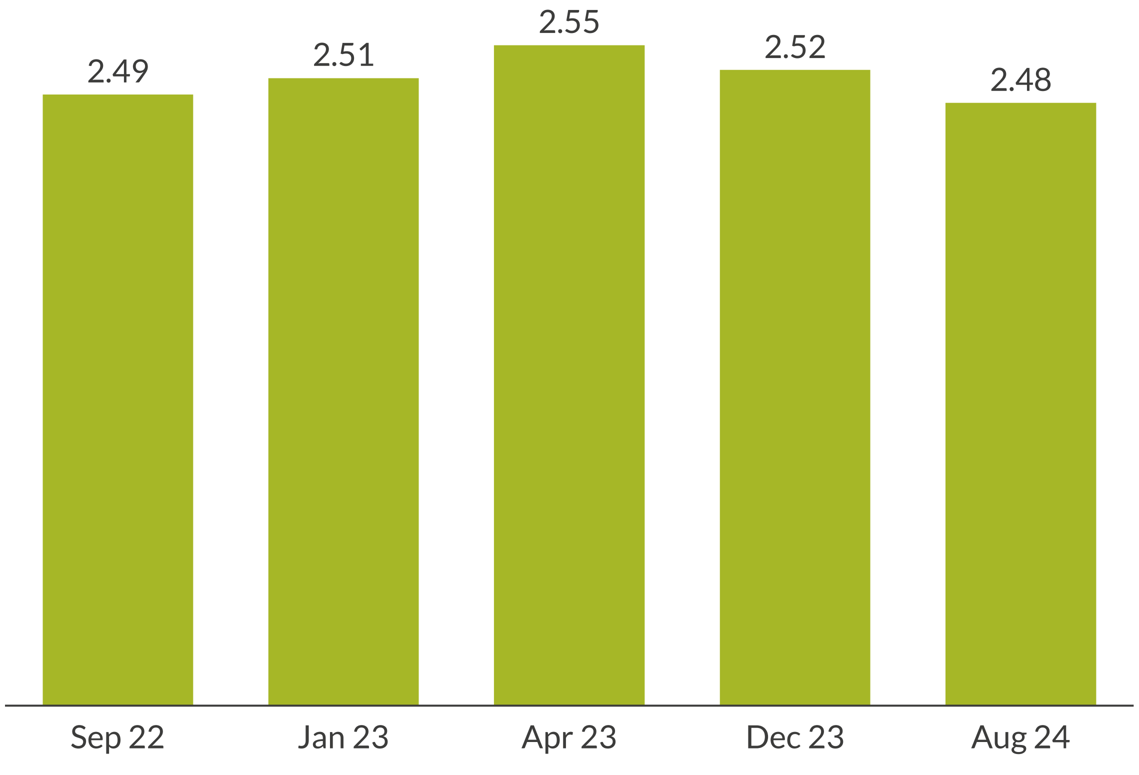
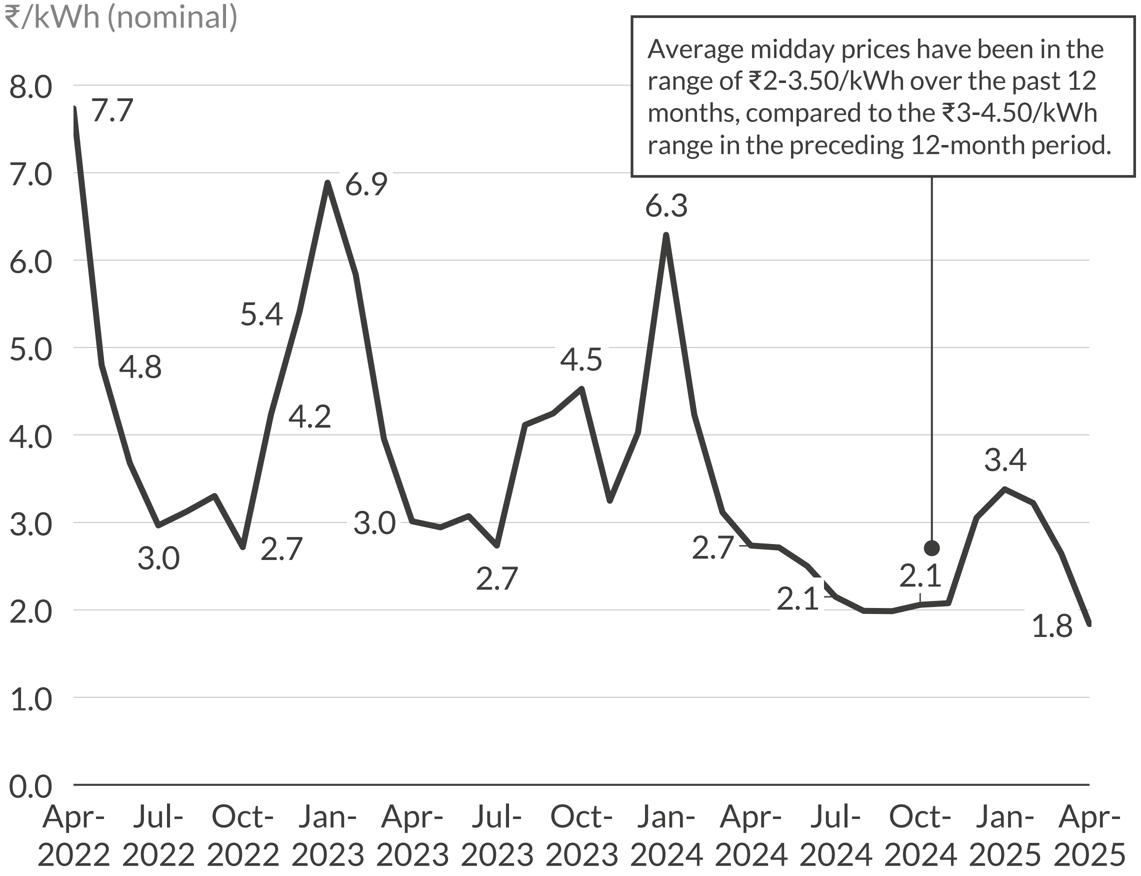
Standalone solar tariffs[1] from recent tenders by completion month
₹/kWh (nominal)



Average midday[2] DAM prices by month
₹/kWh (nominal)



Yearly average midday price[2,3]
₹/kWh (nominal)

2022	2023	2024	2025
4.21	4.04	2.91	2.77

For more information about our subscription analytics in India, reach out to: Mrunal.karnik@auroraer.com

1) Lowest winning tariff; 2) Average DAM price for the settlement blocks from 10:00 to 14:00; 3) 2022 data from 1st April onwards, 2025 data until 30th April.

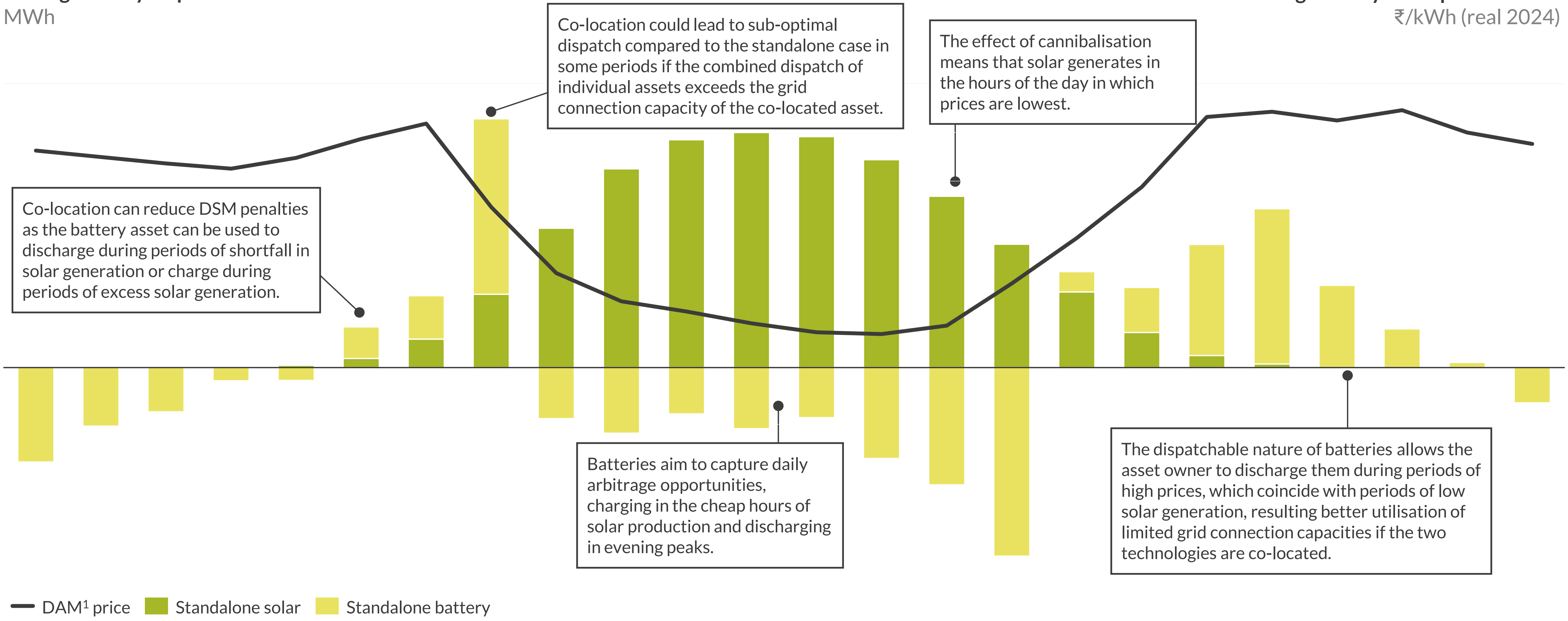
Sources: Aurora Energy Research, JMK Research & Analytics

Co-locating solar with batteries can boost returns, reduce curtailment, and maximise the potential of limited grid connection capacities

The dispatchable nature of batteries allows them to be charged during low price periods when solar is generating and discharged during high price periods, enabling effective utilisation of grid connection capacities while also reducing DSM penalties by charging or discharging during periods of excess or shortfall in solar generation.

Average hourly dispatch of a standalone asset in 2030
MWh

Average hourly DAM price in 2030
₹/kWh (real 2024)



1) Day Ahead Market.

Sources: Aurora Energy Research

Over the last 3 years, we have observed significant volatility of DAM prices on a month-on-month basis driven by shock events

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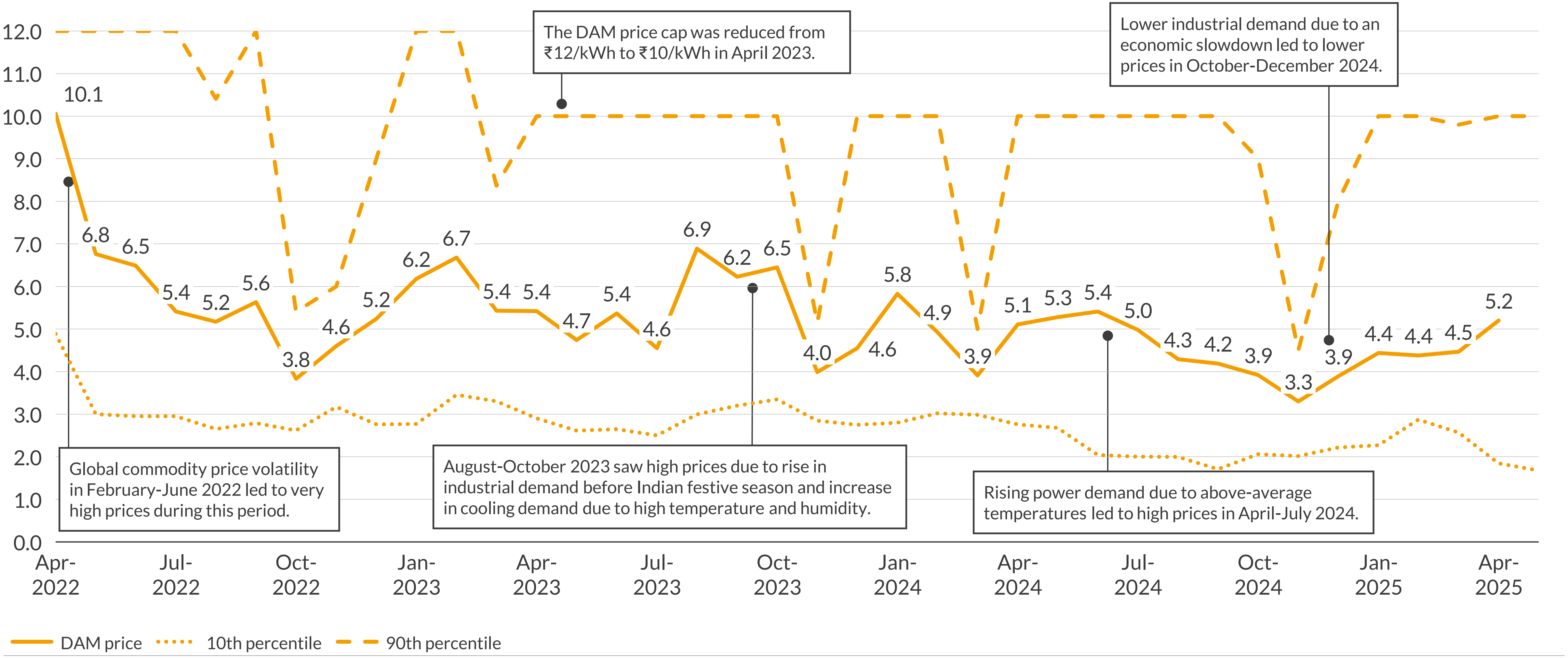
IEX monthly average DAM price and top and bottom percentiles
₹/kWh (nominal)



Sources: Aurora Energy Research, IEX

Returns from a solar asset can be boosted by co-locating it with storage, and potential upsides exist in case of market volatility

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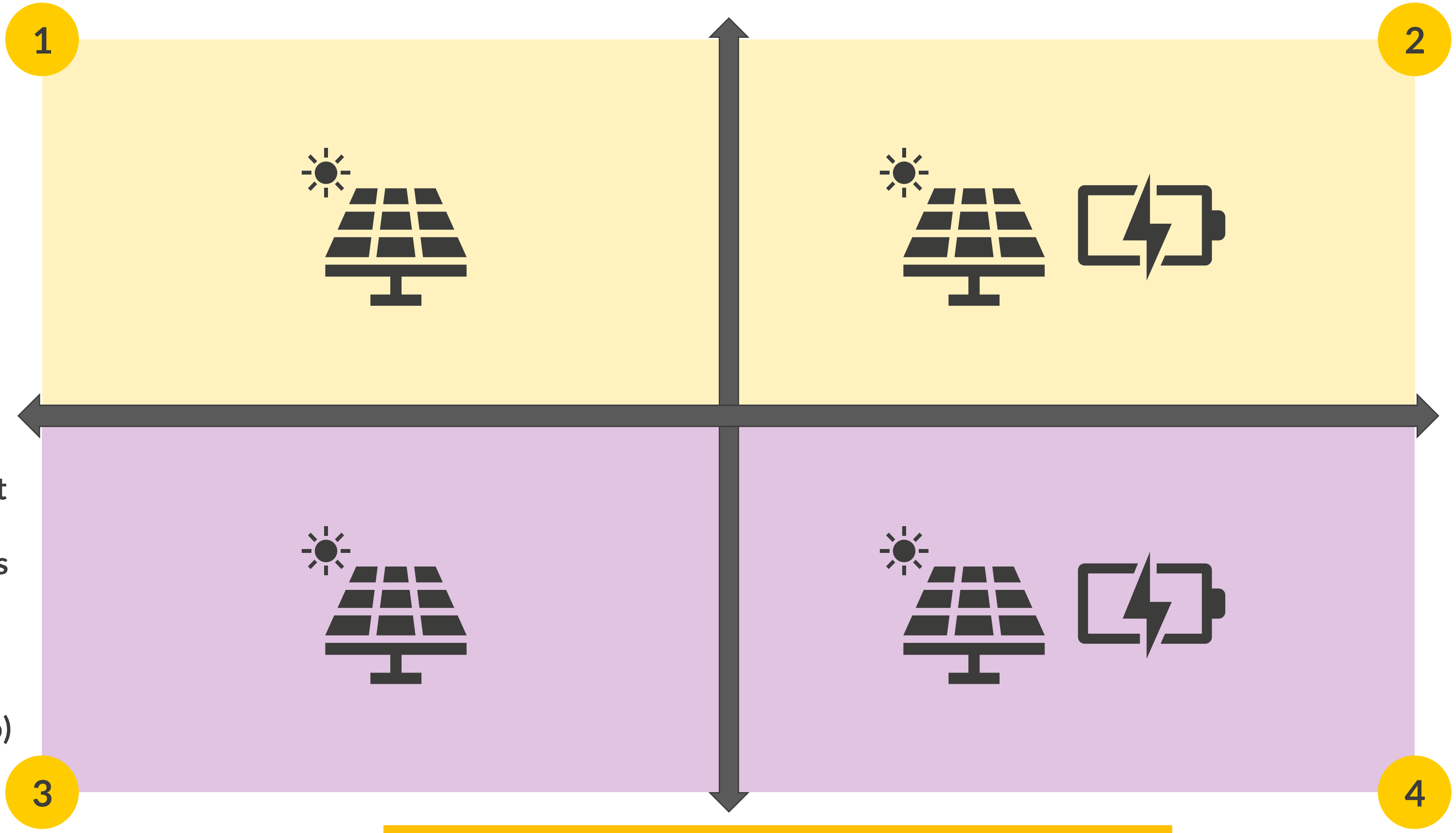
Standalone solar

Solar co-located with a battery

Asset returns under an equilibrium case

(Aurora Central scenario)



Potential impact of market shocks like supply chain squeeze, commodity prices and transmission deployment on the economics of assets

(Messy Transition scenario)

If you are interested in finding more about our analysis in India, reach out to: Mrunal.karnik@auroraer.com

Sources: Aurora Energy Research

Unique, proprietary, in-house modelling capabilities underpin Aurora's superior analysis

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Commodities (AER-GAS) ↔ **Power markets (AER-ES)** → **Battery asset dispatch (Chronos)**

INPUTS

- Technology
- Policy
- Demand
- Commodity prices[1]
- Weather patterns

Dispatch model

- 30-minute granularity
- Iterative modelling
- Dynamic dispatch of plant
- Endogenous interconnector flows

Continuous iteration until an equilibrium is reached

Investment decisions module

- Capacity market modelling
- Capacity build / exit / mothballing
- IRR / NPV driven
- Detailed technology assessments

OUTPUTS

- Capacity mix
- Generation mix
- Wholesale market prices
- Electric vehicle charging
- Profit / Loss and NPV

INPUTS

- AER-ES modelled half-hourly prices, including:
  - Day Ahead Market
  - Green Day Ahead Market
  - Real Time Market
- Battery configuration and operating constraints.

OUTPUTS

- Half-hourly dispatch decisions based on imperfect foresight.
- Margins and trading volume in each of the key markets.

1) Gas, coal, oil and carbon prices fundamentally modelled in-house with fully integrated commodities and gas market model.

Sources: Aurora Energy Research

Chronos dispatches battery through a two-stage process, a reflection of the market's operation across day-ahead and intraday markets

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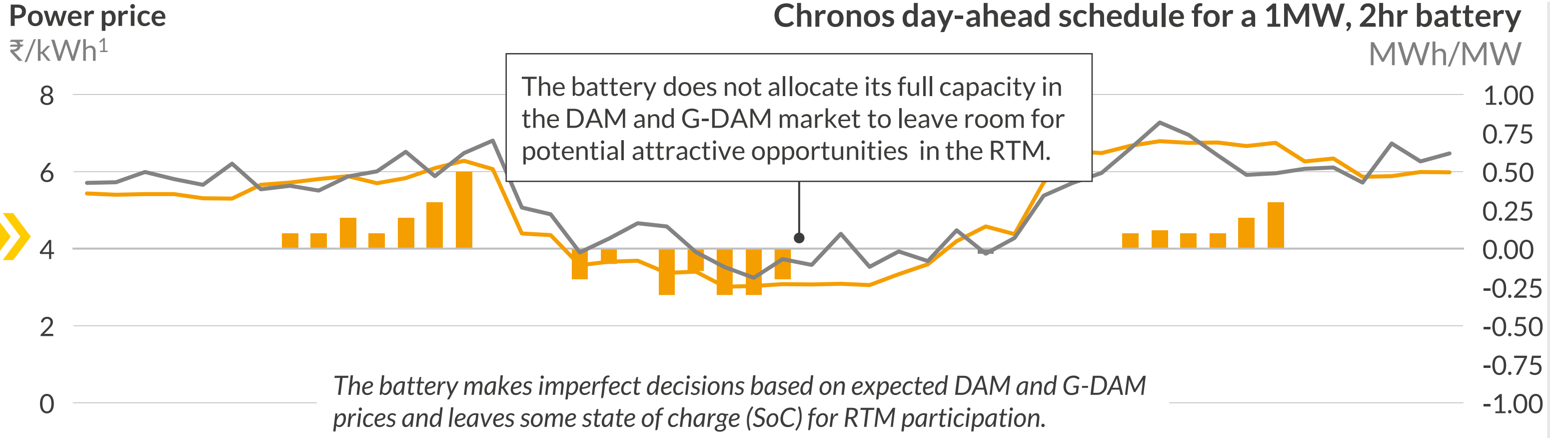
Stage 1: Scheduling phase

INPUT

- AER-ES half-hourly expected Day-Ahead Market price.
- AER-ES half-hourly expected Green Day-Ahead Market price.
- Chronos previous day's end-of-day state of charge.



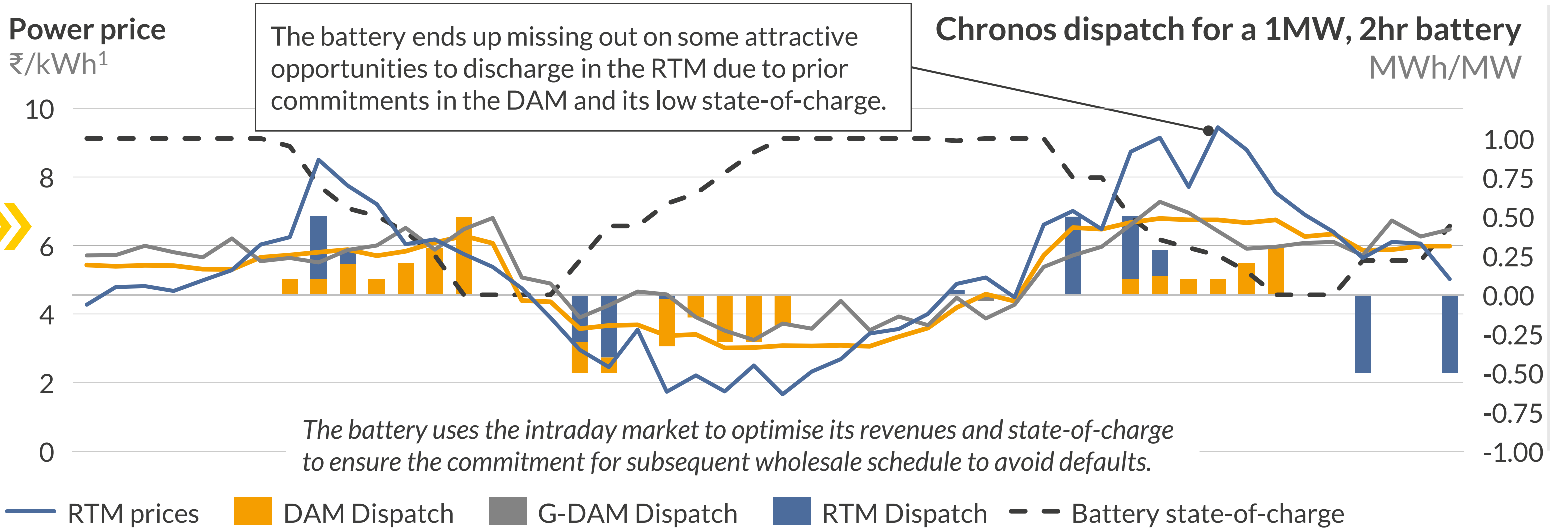
OUTPUT

- Energy schedule for the wholesale, Day-Ahead and Green Day-Ahead Markets.

Stage 2: Dispatch phase

INPUT

- Energy schedule for the wholesale, Day-Ahead and Green Day-Ahead Markets.
- AER-ES half-hourly Real Time Market price.
- Chronos previous day's end-of-day state of charge.



OUTPUT

- Energy revenue settlement for wholesale Day-Ahead, Green Day-Ahead, and Real Time Markets.
- End-of-day state of charge.

Stage 1 begins for the next day

1) Discharging/export actions are shown as positive, while charging/import actions are shown as negative.

Sources: Aurora Energy Research

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Introduction to today's session	Standalone solar economics	Co-located solar and battery economics	Introduction to the Messy Transition scenario	Upsides to assets due to market volatility
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Oversizing a standalone solar asset can improve returns by 0.9p.p. by increasing generation while saving on inverter and grid connection costs

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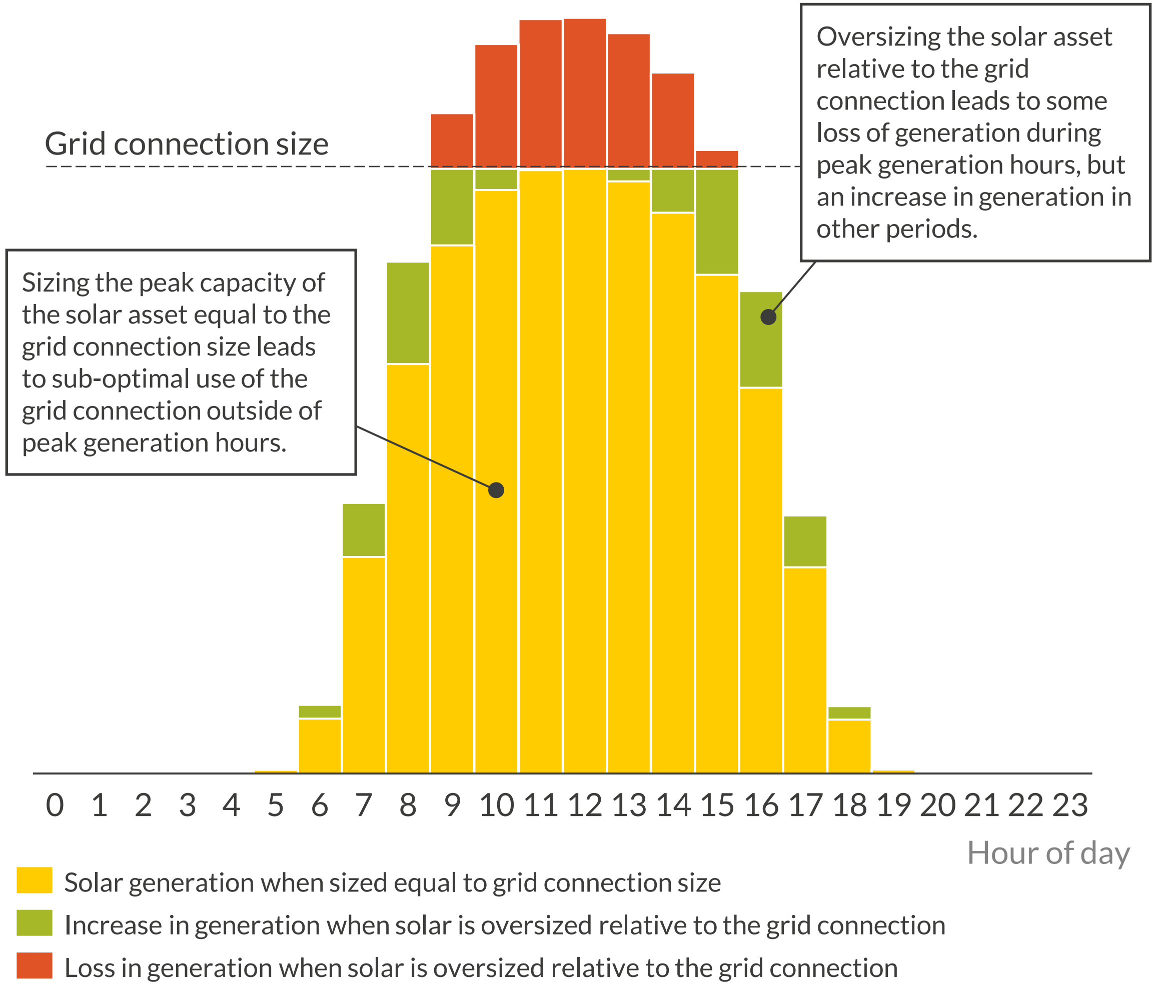
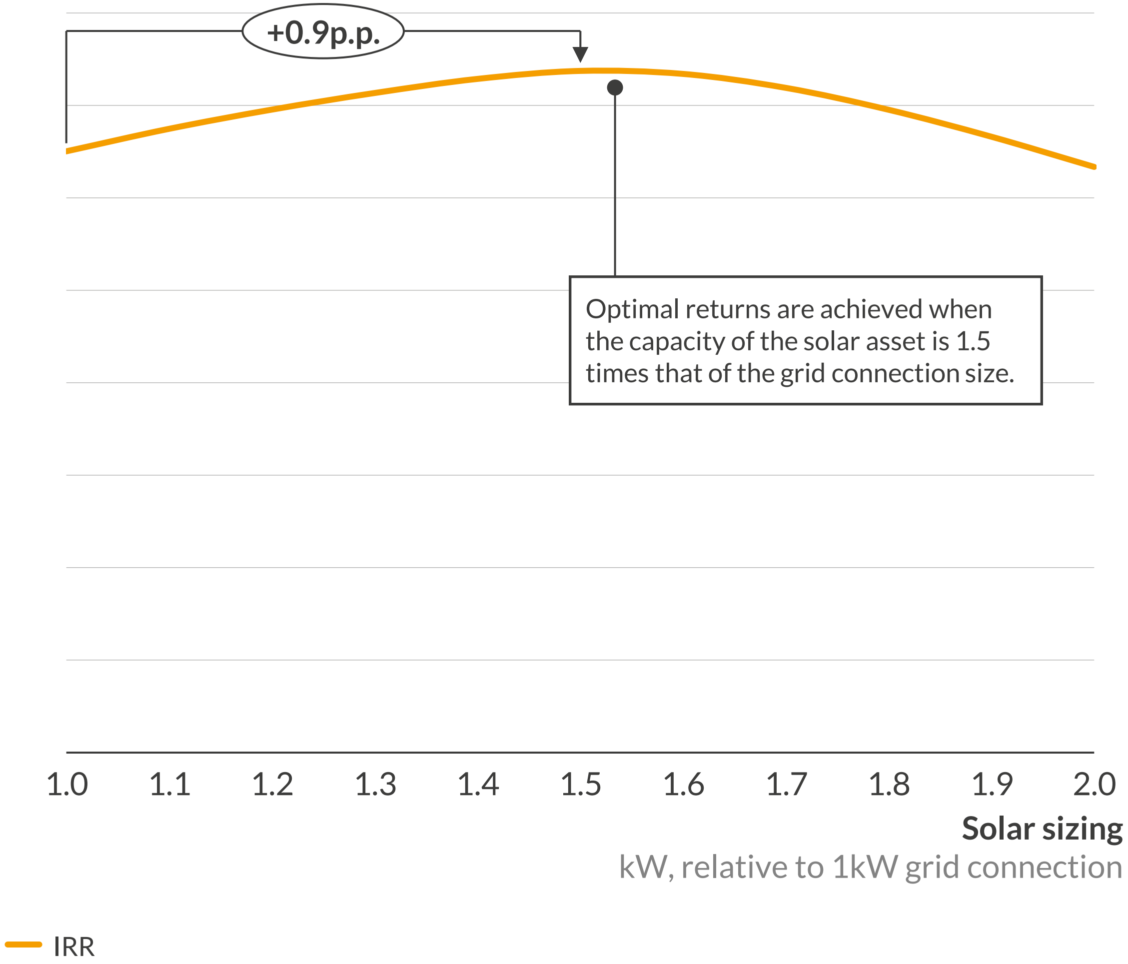
Solar generation profile by hour of day for different solar capacities relative to the grid connection capacity



Standalone solar IRRs by oversizing ratio in W2 for 2027 commissioning year

% (unlevered, pre-tax, real)



Sources: Aurora Energy Research

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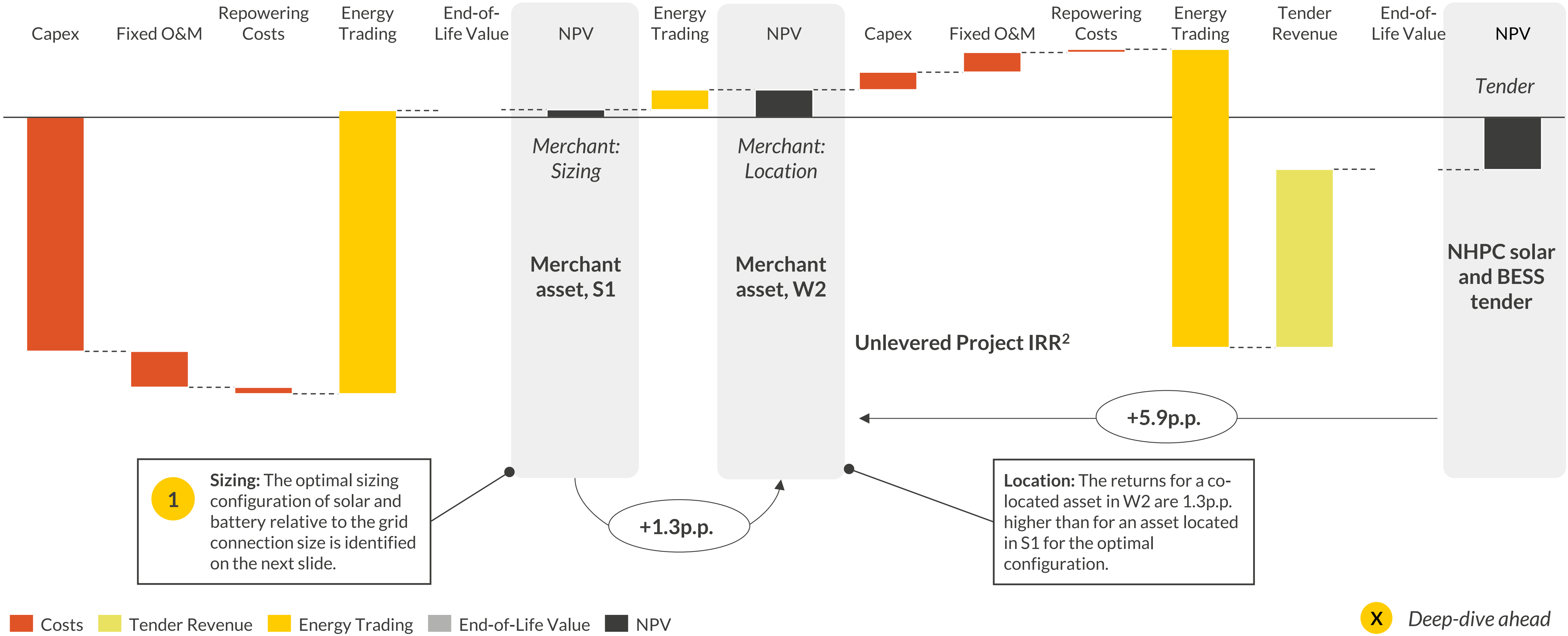
Returns for a merchant new-build co-located solar and battery materially exceed those based on recent tenders for co-located assets

Economics for a merchant co-located asset commissioning in 2027 in comparison to an asset commissioned under NHPC's solar and BESS tender
Present value[1,2], ₹/kW (real 2024)



1) Discount rate of 12.5%; 2) Pre-tax, in real terms.

Sources: Aurora Energy Research

1 Unlevered IRRs exceeding 14% can be achieved for 2- and 4-hour batteries respectively, but the latter offers less flexibility in configuration

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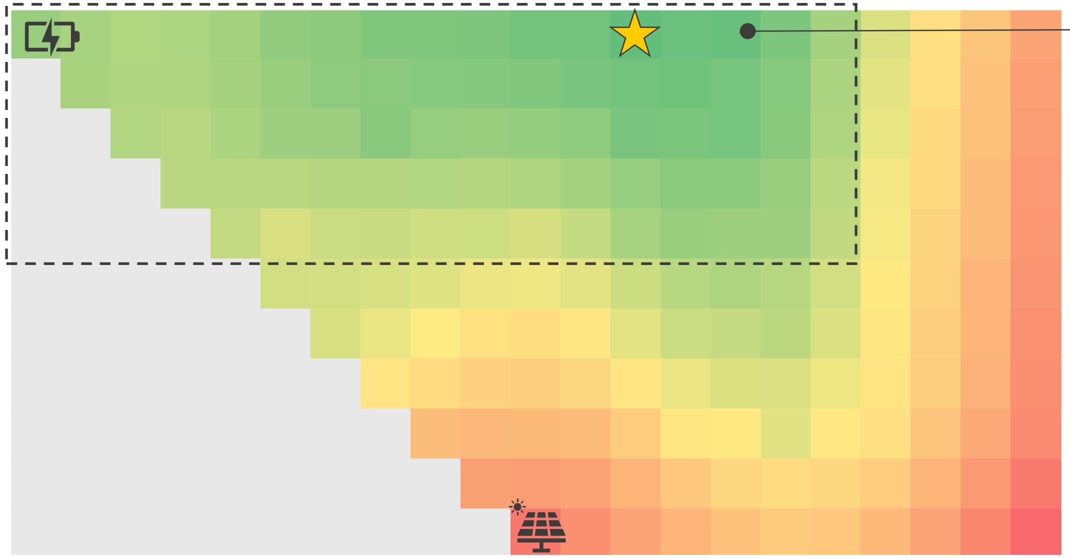
IRR[1], solar and 2-hour[2] battery, 2027 entry

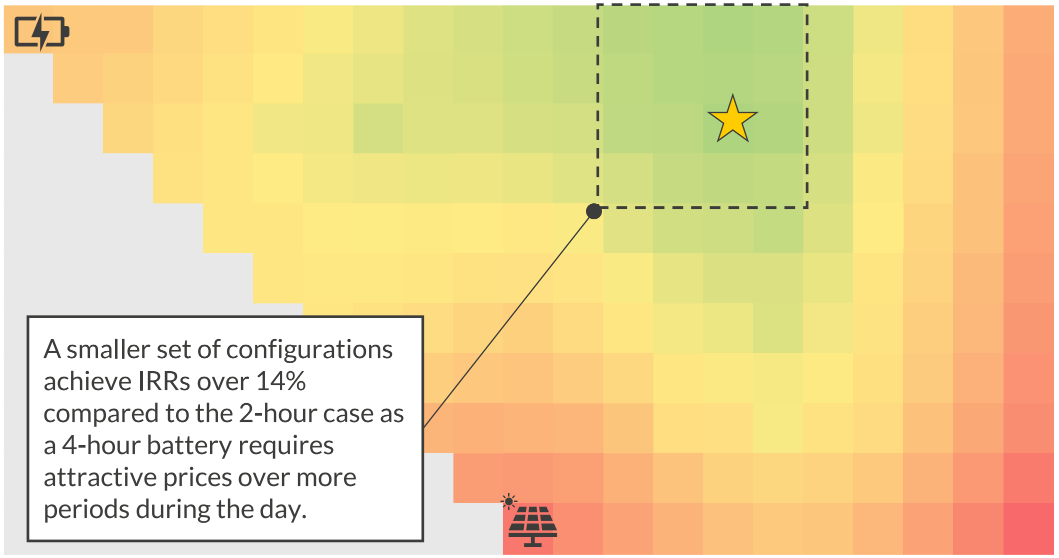
Battery sizing
kW, relative to 1kW grid connection



Solar PV sizing
kW, relative to 1kW grid connection

IRR[1], solar and 4-hour[3] battery, 2027 entry

Battery sizing
kW, relative to 1kW grid connection



A smaller set of configurations achieve IRRs over 14% compared to the 2-hour case as a 4-hour battery requires attractive prices over more periods during the day.

Solar PV sizing
kW, relative to 1kW grid connection

Optimal returns are achieved for a 20% oversized solar asset and battery size equal to the grid, further oversizing results in sub-optimal dispatch during periods when both assets want to utilise the grid connection.

IRR[1] of RES and battery, %

Key:

Standalone battery | Standalone solar PV | Highest IRR with solar >= 1 kW | Configurations with IRR >= 14%

1) Real, pre-tax, and unlevered; 2) Considering 1.5 cycles per day; 3) Considering 1.2 cycles per day.

Sources: Aurora Energy Research

Agenda

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Introduction to today's session	Standalone solar economics	Co-located solar and battery economics	**Introduction to the Messy Transition scenario**	Upsides to assets due to market volatility

Introduction to today's session

- How have returns for standalone solar evolved historically?
- Why are solar and batteries well-suited for co-location?
- What has driven price fluctuations in the power market in recent years?

Standalone solar economics

- What is the effect of oversizing a solar asset relative to the grid connection?
- What is the optimal oversizing ratio for a solar asset for maximising returns?

Co-located solar and battery economics

- What are the economics for adding a battery on an existing solar asset?
- What is the optimal sizing configuration for a new-build co-located solar and battery asset?
- How do returns vary based on location?

Introduction to the Messy Transition scenario

- What effect can non-equilibrium events have on asset returns?
- How does Aurora model a Messy Transition scenario and how is it different from an equilibrium scenario?

Upsides to assets due to market volatility

- What is the potential upside for standalone solar assets in the event of unexpected shocks?
- How does the optimal configuration for a co-located asset change in the Messy Transition scenario?

The Messy Transition scenario reflects the potential impact of unforeseen and unpredictable events or shocks on the power market

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Aurora's Central and Low scenarios are equilibrium market models. These models are important for understanding the value of investments but can miss out on the impacts of real-world volatility. **The Messy Transition scenario quantifies the potential impact of unpredictable market events on key forecast results.**

Equilibrium model feature	Advantages of equilibrium feature	Examples of real-world deviations
1 **Perfect foresight over capacity decisions**	• Build decisions are governed by **economic viability**. • **Avoids over- or under-supplying the market**, thus preventing extreme outcomes. • Over the long run, prices reflect the cost of new technologies[1].	• Unforeseen events can result in **plants exiting earlier or later** than planned. • **Supply chain issues** cause delays to pre-planned projects.
2 **Modelling takes place under 'normal system' conditions**	• Produces market results that represent an **average outcome.** • Note: Aurora's Central scenario captures an average level of volatility	• Modelling does not account for **random events** such as sudden plant outages which can result from unpredictable **weather events, plant ageing / failure** or **fuel shortages**.
3 **Commodity prices are in equilibrium, based on long term fundamentals**	• Creates coal and gas (and consequently power prices) that are based on average, **equilibrium outcomes.** • **Short-term volatility is captured** through blending of futures.	• **Non-equilibrium events**, such as geopolitical conflicts, can lead to unpredictable commodity prices which in turn **drive unpredictable power prices**.

Captured within the Messy Transition scenario

1) i.e. the average wholesale electricity price will often align with the cost of adding new firmed renewables (renewables with backup systems for reliability).

Sources: Aurora Energy Research

Aurora defines three classes of non-equilibrium factors that can affect asset performance relative to our Central scenario

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Included in Aurora Central

Typical volatility

Historical volatility, generally under system-normal conditions, in which ₹10/kWh+ prices occasionally occur

Drivers

- Market scarcity, particularly when renewable load factors are low
- Cost un-reflective pricing from generators in response to this market power

Direction and nature of impacts

- Generators taking advantage of market scarcity tend to raise prices above their short-run marginal costs, so these effects are generally positive for generator cashflows

Included in weather year sensitivites

Weather risks

Weather variation is a natural phenomenon which has substantial impacts power market outcomes; it is both seasonal and climate-driven

Drivers

- Temperature is a key driver of gas and power demand, leading to fluctuations in power prices
- Variable renewable load factors are highly dependent on weather

Direction and nature of impacts

- Weather impacts cashflows in both directions, with low/high demand, low/high renewable load factors, etc. broadly having opposing impacts on pricing

Included in Messy Transition

Market shocks

Market 'shocks' represent unexpected moves in supply and demand that take time to correct

Drivers

- Unexpected accidents at generators or interconnectors
- Significant commodity price shocks

Direction and nature of impacts

- Shocks rarely lower energy prices, so these events are generally positive for generator cashflows
- Extent of the upside depends on the market

Transitional risks

Long-term structural risk arising from the inherent uncertainty of an energy transition and the associated pivots in technology mix

Drivers

- Aging plants can malfunction, leading to unplanned outages
- Large new-build generators/interconnectors are prone to delays
- Policy risks associated with the energy transition

Direction and nature of impacts

- Plant availabilities and new-build delivery timelines are rarely better than expected, and often worse
- Provides prolonged, structural upside
- Transmission disruption can impact revenues in both directions

Sources: Aurora Energy Research

Aurora's Messy Transition scenario sees commodity price spikes, a sudden slowdown in renewable capacity, plant outages, and transmission disruption

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These events take place in three major shocks occurring between 2025 and 2035

Delays to renewable capacity

- Solar and wind installation is unexpectedly constrained for 2 years[1].
  - Solar[2] is limited to 10GW per year and onshore wind stalls (0GW added), driven by supply chain disruption, import restrictions, grid connection issues, and land constraints.
- Imported coal, and gas prices spike.

Transmission disruption

- Transmission capacity out of N2 and W2 (including renewable-rich states Rajasthan and Gujarat) is unexpectedly constrained.
  - Transmission capacity stagnates and some lines face outage, out of N2 and W2, driven by land and compensation disputes, environmental clearance.
- Imported coal, and gas prices spike.

Fall in baseload generation

- Several large baseload (coal and hydro) plants face unexpected closure or outage.
  - India's oldest coal plants face age-related maintenance issues resulting in plant outage and reduced coal availability[3].
  - Hydro generation unexpectedly declines due to plant outage.
- Imported coal, and gas prices spike.

Additional feature (applies in all years, not just shock years).

- Coal assets experience faster than expected (i.e., faster than Central) age-related deterioration.

1) Solar capacity additions are limited across India, proportional to current installed capacity (mostly N2, W2, and S1); 2) Fixed, tracking and BtM solar combined; 3) Coal outages occur across India with the oldest plants facing outage.

Sources: Aurora Energy Research

The Messy Transition scenario reflects the potential upside for equity investors arising from market shocks

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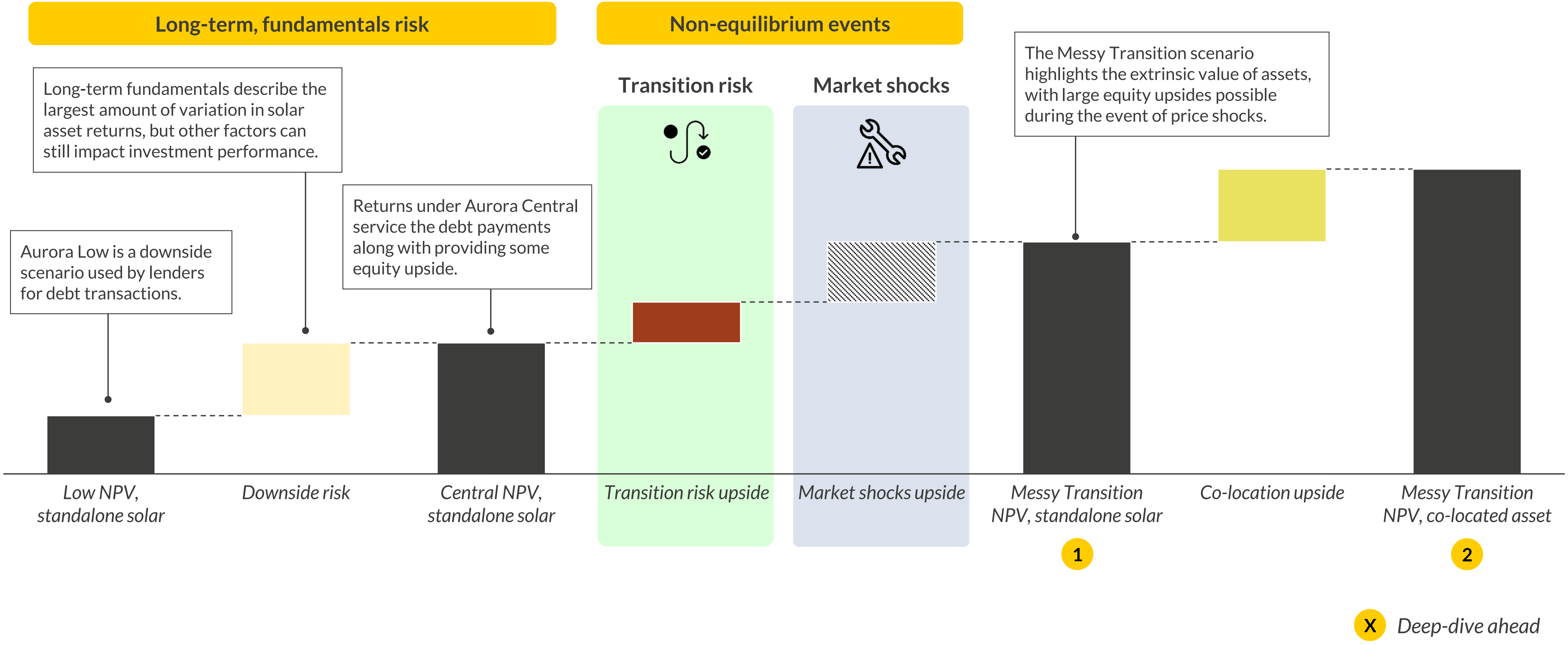
Illustrative economics for a typical standalone solar and co-located asset
Net present value, ₹/kW (real 2024)



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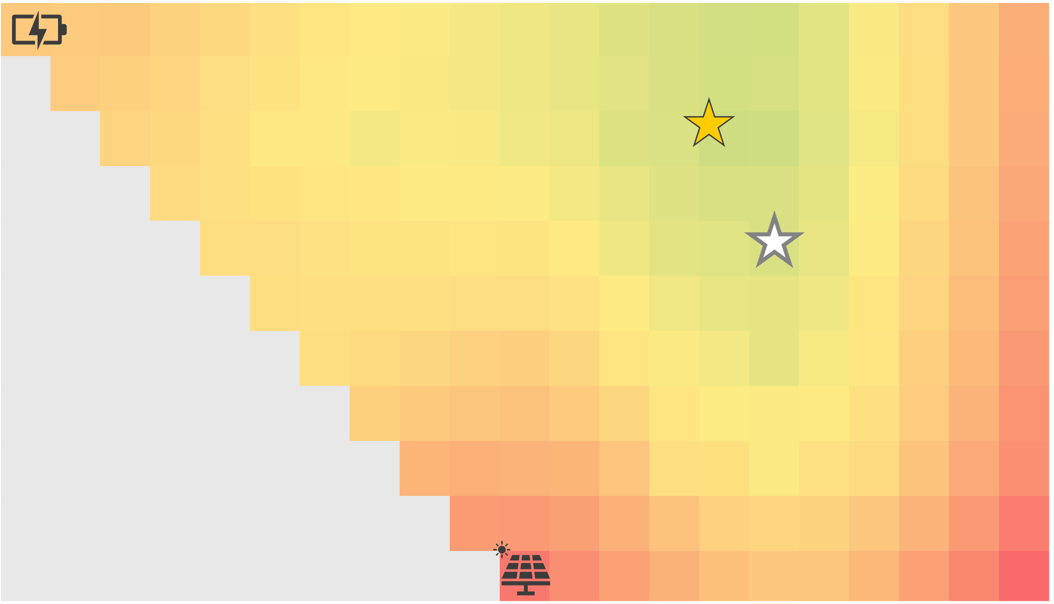
2 Returns for co-located solar and battery are 0.7p.p. higher in Messy Transition, but the Central configuration captures most of this upside

IRR[1], solar and 4-hour[2] battery, 2027 entry, Aurora Central

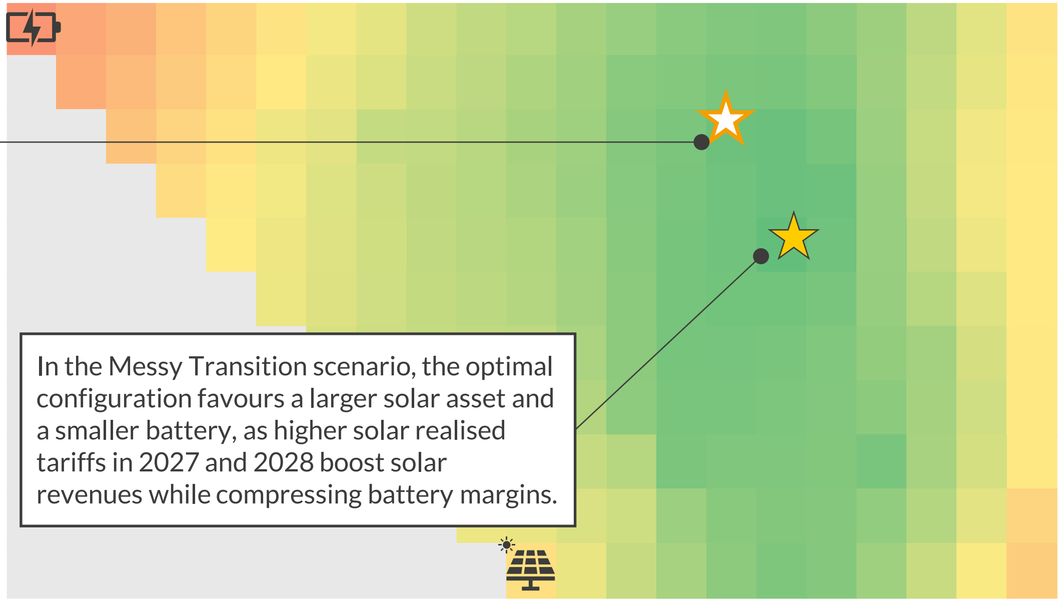
Battery sizing
kW, relative to 1kW grid connection



Solar PV sizing
kW, relative to 1kW grid connection

IRR[1], solar and 4-hour[2] battery, 2027 entry, Messy Transition

Battery sizing
kW, relative to 1kW grid connection



In the Messy Transition scenario, the optimal configuration favours a larger solar asset and a smaller battery, as higher solar realised tariffs in 2027 and 2028 boost solar revenues while compressing battery margins.

Solar PV sizing
kW, relative to 1kW grid connection

The optimal configuration in Central retains the potential for equity upside in the event of market shocks.

IRR[1] of RES and battery, %

Key:

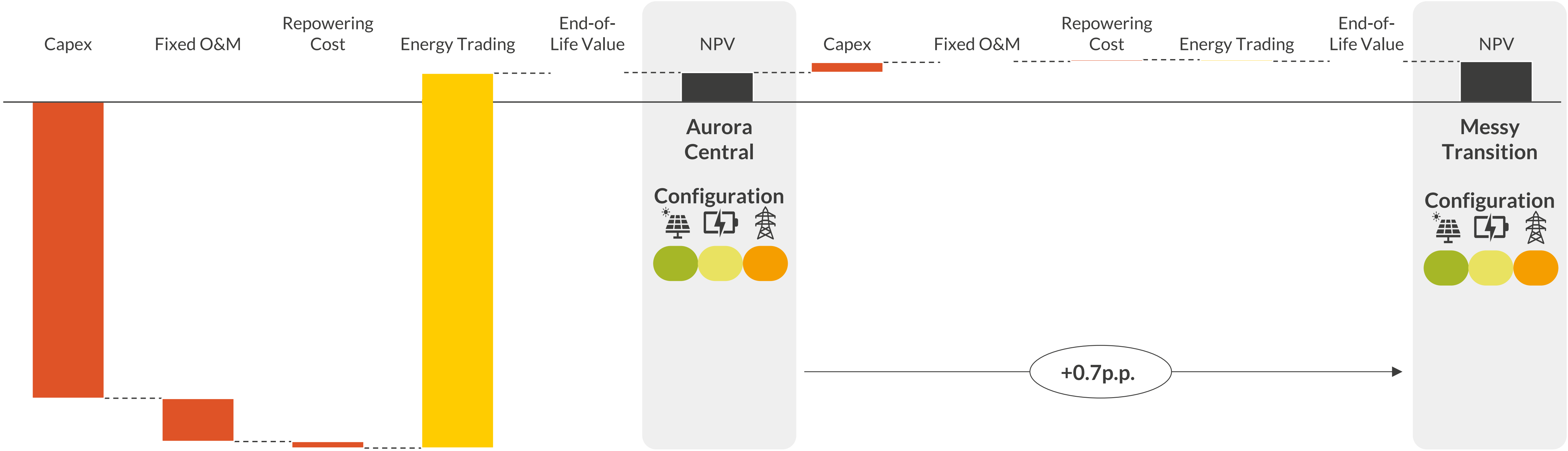
Standalone battery | Standalone solar PV | Highest IRR with solar >= 1 kW | IRR in Central for the optimal configuration in Messy Transition | IRR in Messy Transition for the optimal configuration in Central

1)) Real, pre-tax, and unlevered; 2) Considering 1.2 cycles per day.

Sources: Aurora Energy Research

2 For the optimal sizing configuration of solar and a 4-hour battery, returns in Messy Transition are 0.7p.p. higher than in Aurora Central

Economics for a new-build co-located solar and 4-hour battery asset, commissioning in 2027 in W2 (Gujarat or Maharashtra)
Present value[1], ₹/kW (real 2024)



- For the optimal configuration, returns in the Messy Transition scenario are 0.7p.p. higher than Aurora Central, driven by higher prices during the shock years.
- The solar deployment slowdown in 2027-28 increases prices during solar hours relative to Aurora Central, providing an upside to the solar asset.
- As a result, the optimal configuration shifts towards a larger solar asset, with a 50% oversizing of solar and 40% under-sizing of the battery relative to the grid connection size having optimal returns for a co-located asset entering the system in 2027.

If you are interested in finding more about our analysis in India, reach out to: Mrunal.karnik@auroraer.com

Costs | Energy Trading | End-of-Life Value | NPV

1) Discount rate of 12.5%; 2) Pre-tax, in real terms.

Sources: Aurora Energy Research

Key takeaways

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1. For co-located assets, a merchant route-to-market yields materially higher returns relative to SECI or DISCOM tenders, which have declined or stagnated in tariff levels.

2. The optimal configuration that yields the highest returns varies by site and duration of the BESS system and must be identified through bespoke granular analysis.

3. While investment cases are typically structured around an expectation of returns consistent with little market volatility, in practice any market shock can offer a significant upside or downside to equity investors.

4. In the context of co-located solar-BESS assets, the most likely shocks are associated with supply chains, the operability of ageing assets, and the deployment of transmission network – all of which offer a material upside.

5. For existing standalone solar assets, retrofitting a co-located BESS can help improve the overall value from the portfolio, but also offers a hedge against the tightening Deviation Settlement Mechanism (DSM) penalties for renewables.

Sources: Aurora Energy Research

Details and disclaimer

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