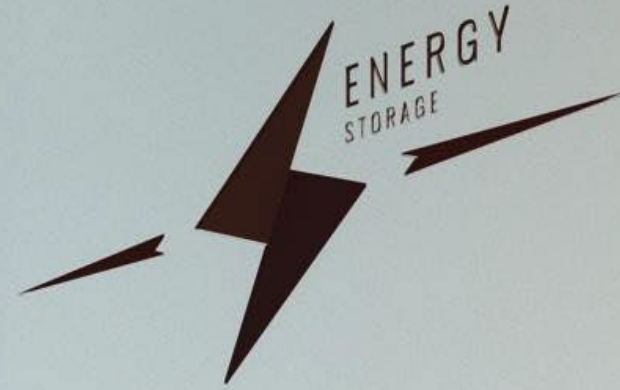


Challenges assessing the contribution and accreditation of long duration energy storage to resource adequacy

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Agenda

1. Growth in the deployment of batteries in wholesale electricity markets.
2. Overview of challenges to assess resource adequacy and capacity contribution and accreditation.
3. Challenge 1- Adopting a broader temporal perspective to reveal emerging resource adequacy needs and highlight the value of assets such as long-duration energy storage (LDES).
4. Challenge 2- Connecting system adequacy needs with resource functions and attributes.
5. Conclusions and questions to ESIG community.



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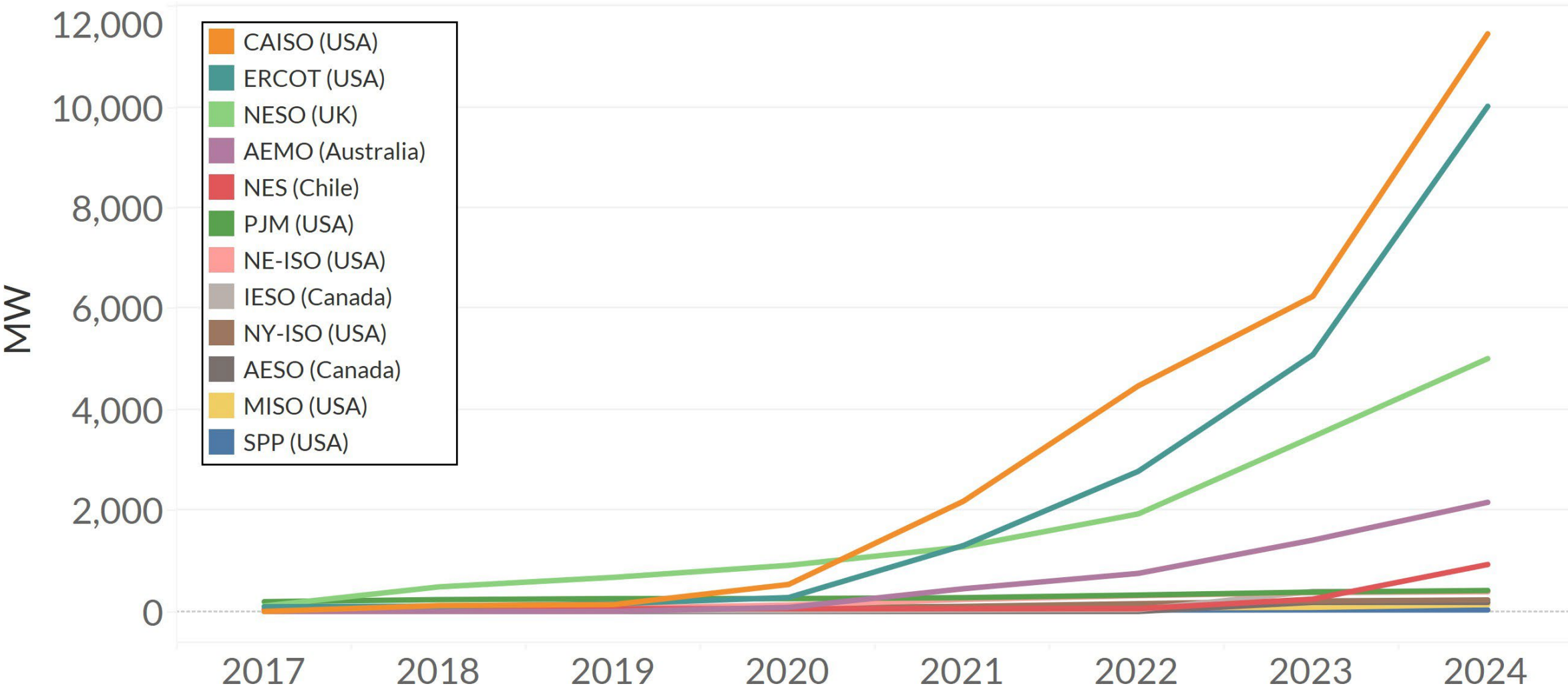
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1

Growth in the deployment of batteries in wholesale electricity markets

Installed BESS capacity in some wholesale electricity markets is growing rapidly, with the fastest expansion occurring in CAISO and ERCOT



The duration of installed BESS capacity in wholesale electricity markets has been between 2 and 5 hours

		Existing BESS Capacity by April 2025 (MW)	BESS capacity with at least IA with construction date set by 2026 (MW)
	CAISO	12,471	18,947
	ERCOT	12,227	12,629
	NESO	5,337	6,267
	AEMO	2,563	4,711
	Chilean ISO	1,290	3,535
	MISO	412	3,032*
	NE-ISO	403	1,075*
	PJM	399	1,137*
	NY-ISO	234	145
	AESO	190	898*
	COES	74	N/A
	IESO	30	2,166
	SPP	29	1,824*
	REE	25	N/A

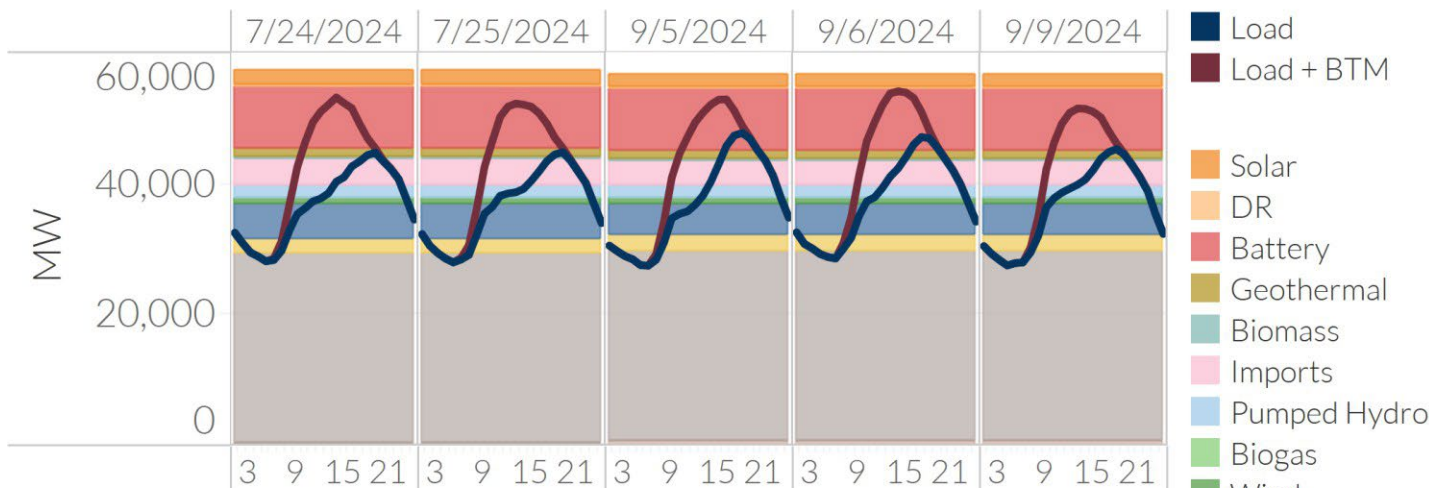
*In hybrid plants, BESS MW values are not distinguished from those of their renewable technology, therefore BESS capacity could be overestimated.

2

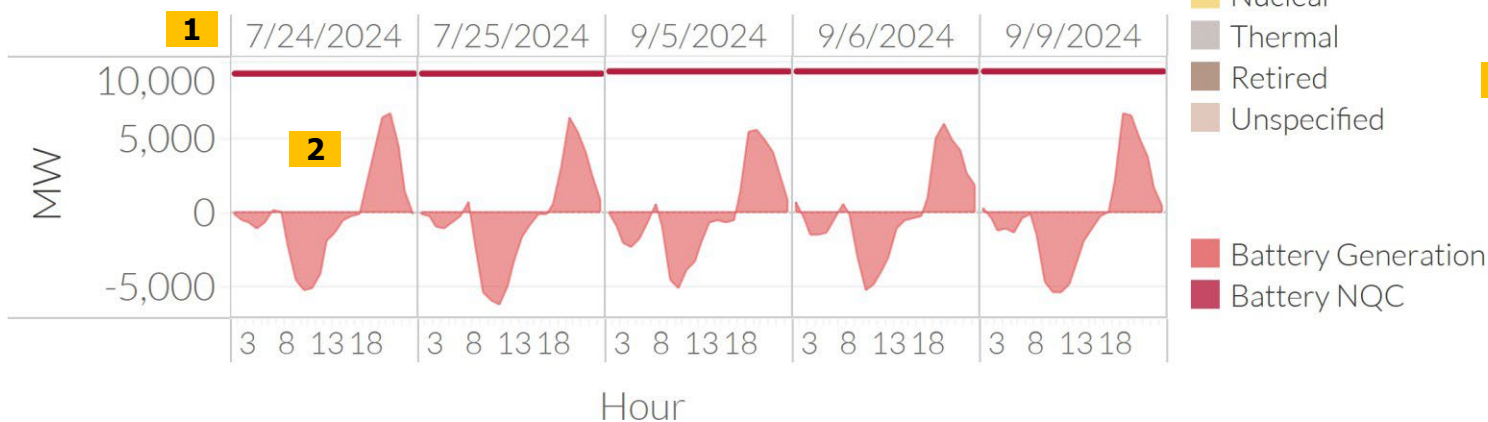
Overview of challenges to assess resource adequacy and capacity contribution and accreditation

CAISO's current accreditation process faces challenges in reflecting the temporal contribution of resources to system adequacy

NQC and load for 5 days of maximum demand in 2024



Real generation of batteries and NQC



Net qualifying capacity (NQC) definition*

- Qualifying capacity is the maximum resource adequacy capacity that a resource adequacy resource may be eligible to provide.
- Net Qualifying Capacity considers a reduction from testing, performance, and deliverability limits.
- An annual deliverability study with a focus on peak demand determines how much capacity is available for resource adequacy.

- Only dispatch data is available for BESS. State of charge and ancillary service participation data is not available for analysis.
- CAISO in an operational report shows that during July 24th, from hour 18 to 24 battery capacity was available to the market to meet resource adequacy requirement however the BESS were providing ancillary services or were not dispatched because their bids were out of merit order. Some BESS reported unavailability or outages.

*according to CAISO Tariff June 3, 2025

Challenges with resource adequacy contribution and accreditation are moving markets to test new approaches, including CPUC's Slice-of-Day

California Public Utilities Commission (CPUC) Decision 21-07-014 – Adoption of Slice of Day Proposal and Principles. The Decision identified five key principles, of which an “implementable” Resource Adequacy (RA) framework must address:

- Principle 1** To balance ensuring a reliable electrical grid with minimizing costs to customers.
- Principle 2** To balance addressing hourly energy sufficiency for reliable operations with advancing California’s environmental goals.
- Principle 3** To balance granularity and precision in meeting hourly RA needs with a reasonable level of simplicity, and transactability.
- Principle 4** To be implementable in the near-term.
- Principle 5** To be durable and adaptable to a changing electric grid.

Challenges identified

- 1** Need for simplicity – Leads to understanding and capacity to explain to stakeholders.
- 2** Alignment to system reliability needs
 - Accreditation reflects contribution of resource towards reliability needs.
 - Accreditation and efficient payment which aligns with reliability needs.
- 3** Ensuring hourly and temporal reliability needs are met with RA framework.
- 4** Ensures minimal cost, environmental goals and reliability.

Maintaining resource adequacy during the energy transition demands a broader perspective on system needs and future grid operations.

Broader perspective identified in ESIG Guides

- A significant limitation of the single adequacy metric approach is its failure to differentiate among the size, frequency, duration, and timing of shortfalls. This is a critical omission, as damages associated with power system shortfalls are nonlinear.*
- Early tools evaluated only single peak load periods and did not assess risk of shortfalls across an entire year**
- Establishing the appropriate level of power system adequacy requires the collective judgment of planners, regulators, customers, and other stakeholders.

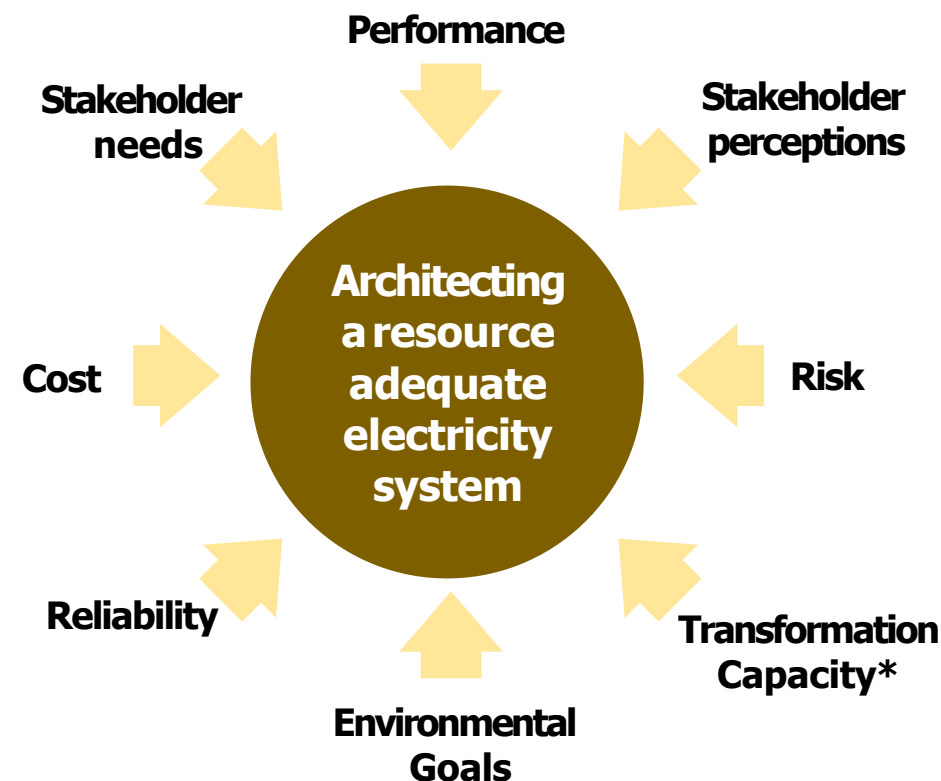
Perspective needs to be expanded to ensure adequacy across operational and temporal scales

- 1 System needs must be identified and assessed across a robust range of potential operational environments.
- 2 System and adequacy requirements must be met over a broad temporal spectrum—from immediate, short-term demands to long-term, year-over-year challenges.

*<https://www.esig.energy/wp-content/uploads/2024/03/ESIG-New-Criteria-Resource-Adequacy-report-2024a.pdf>

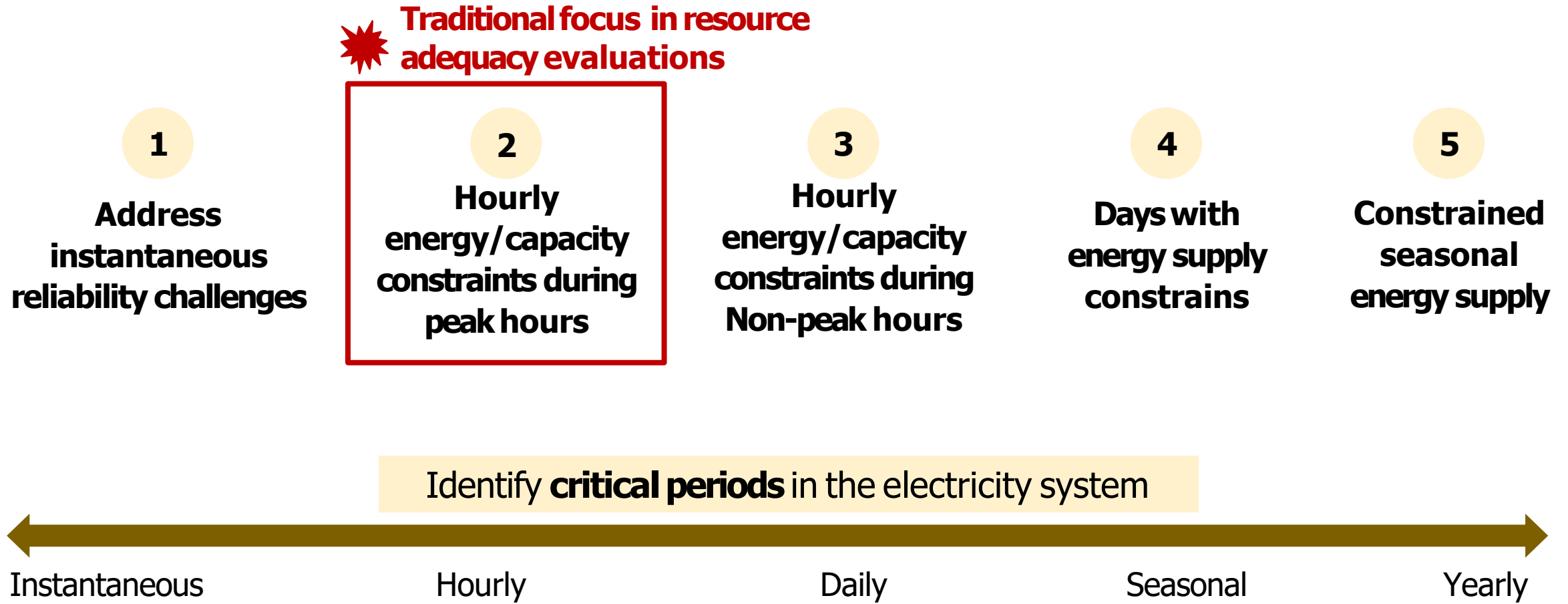
**<https://www.esig.energy/wp-content/uploads/2022/12/ESIG-Redefining-Resource-Adequacy-2021-b.pdf>

Broader drivers of a resource adequate system

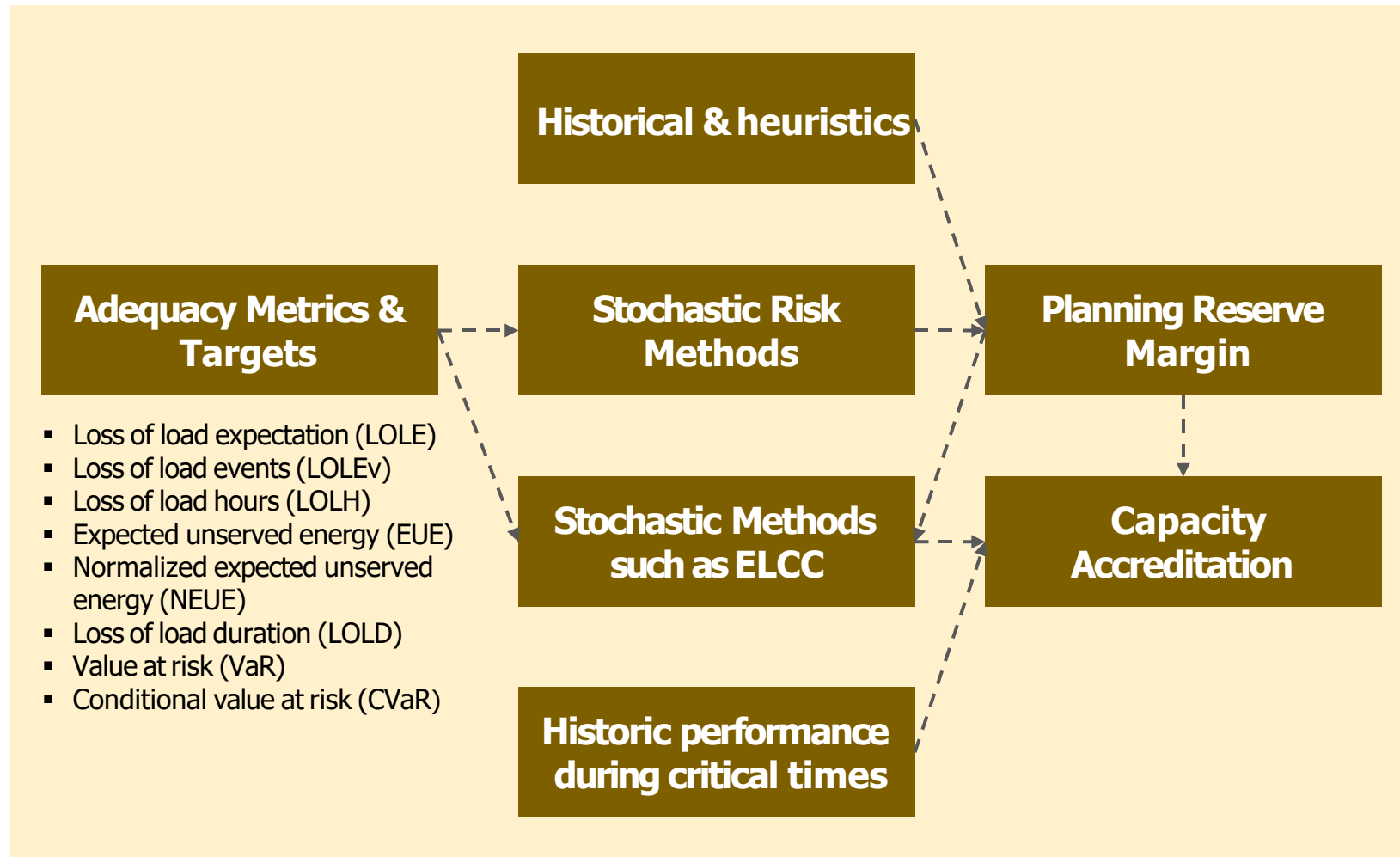


*Transformation capacity involves several components including ensuring the required resources are available, this involves attracting investment and sending the right market signals including transactability and transparency.

A broader temporal perspective is needed to reveal emerging resource adequacy needs and highlight the value of assets such as long-duration energy storage (LDES)



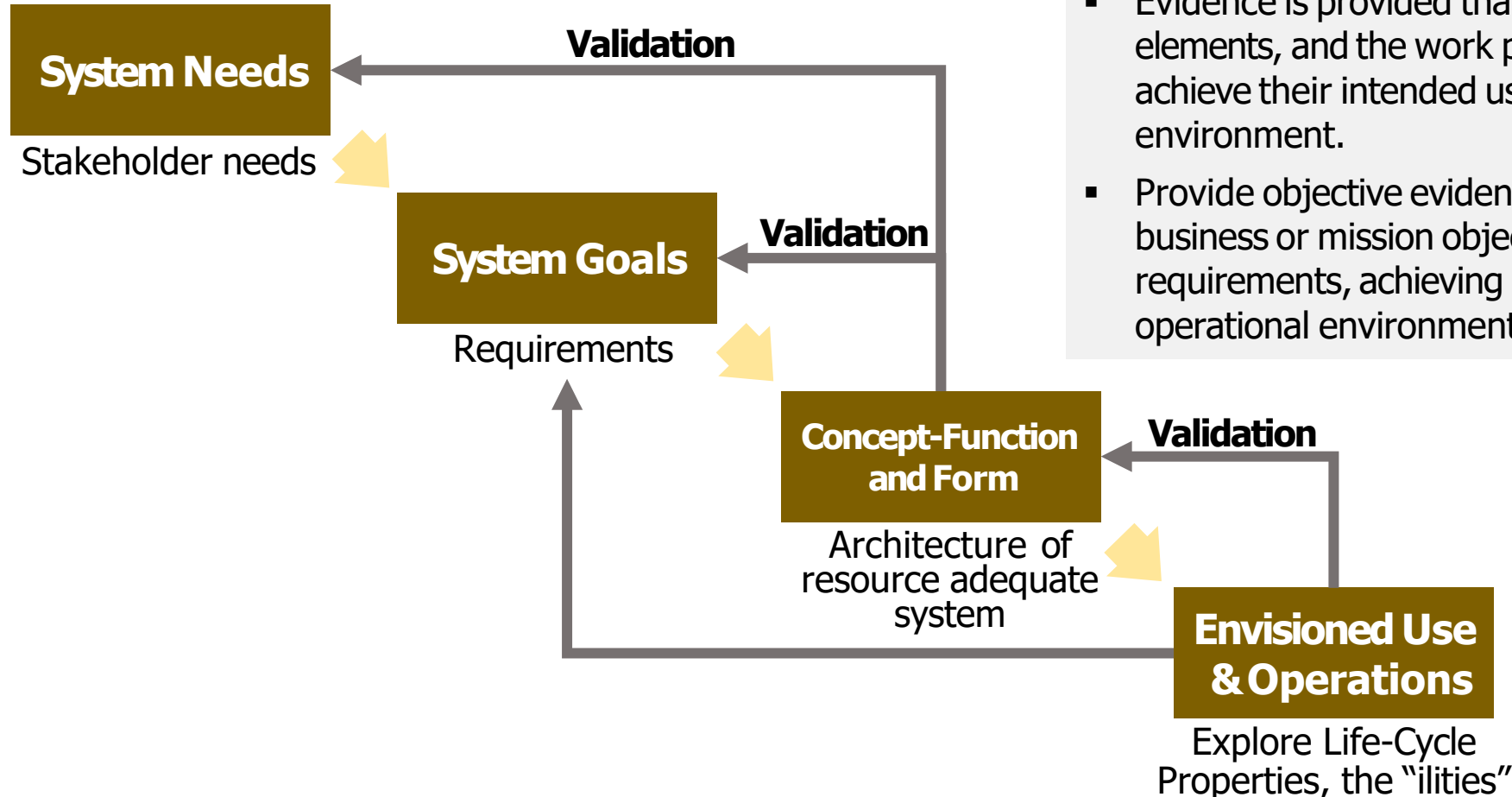
Resource contribution and accreditation methods need to be expanded, as they currently rely primarily on complex stochastic risk analysis and simpler historical performance metrics



Expand resource adequacy evaluation approach to uncover the value of resources such as LDES in the energy transition. This approach requires:

- 1 Broader temporal perspective to determine contribution and accreditation.
- 2 Concept analysis to ensure resource adequate electricity system meets needs, goals and critical envisioned operational scenarios, prior to stochastic risk methods.
- 3 Broader range of approaches and tools to uncover potential operational environments
- 4 Validation.

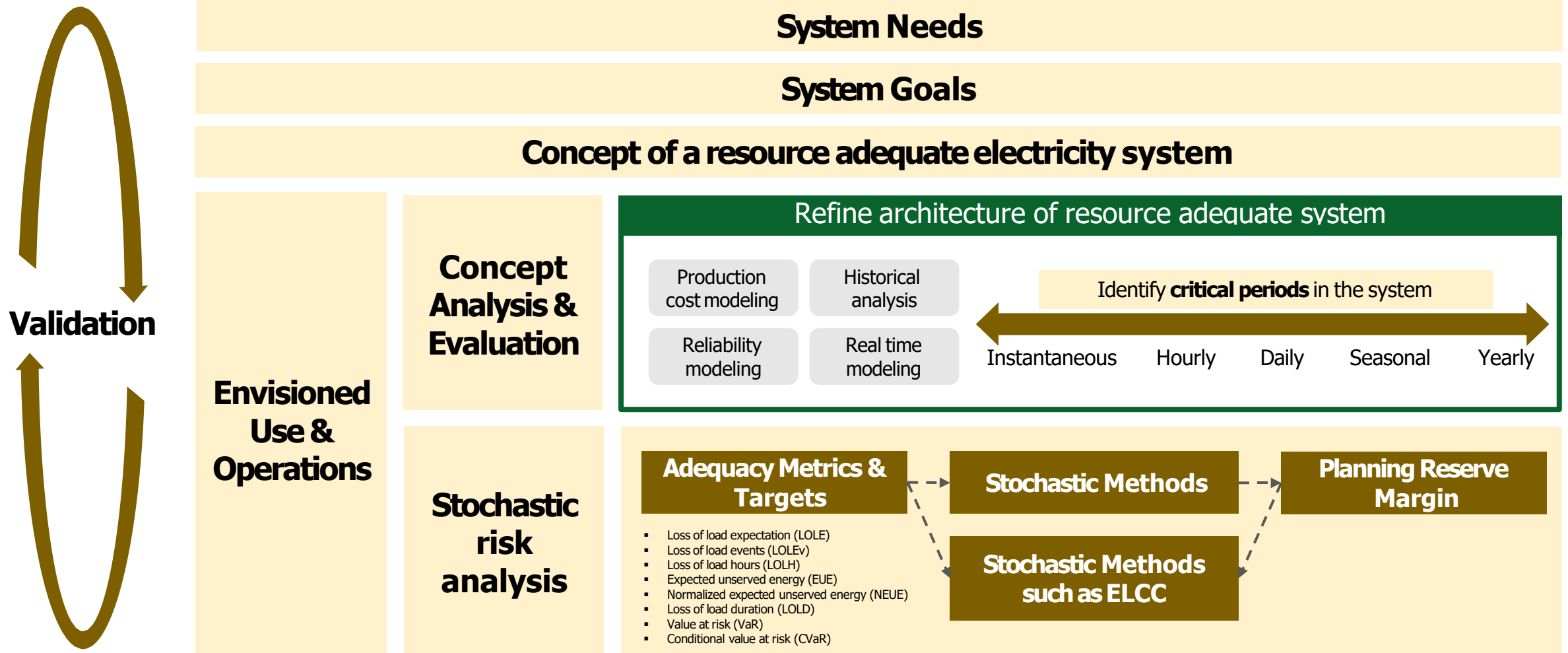
A validation process is key to meeting system and resource adequacy needs under diverse future scenarios and to clarifying the role of LDES



Validation process (INCOSE Handbook):

- Evidence is provided that the system, the system elements, and the work products in the life cycle will achieve their intended use in the intended operational environment.
- Provide objective evidence that the system fulfills its business or mission objectives and stakeholder requirements, achieving its intended use in its intended operational environment.

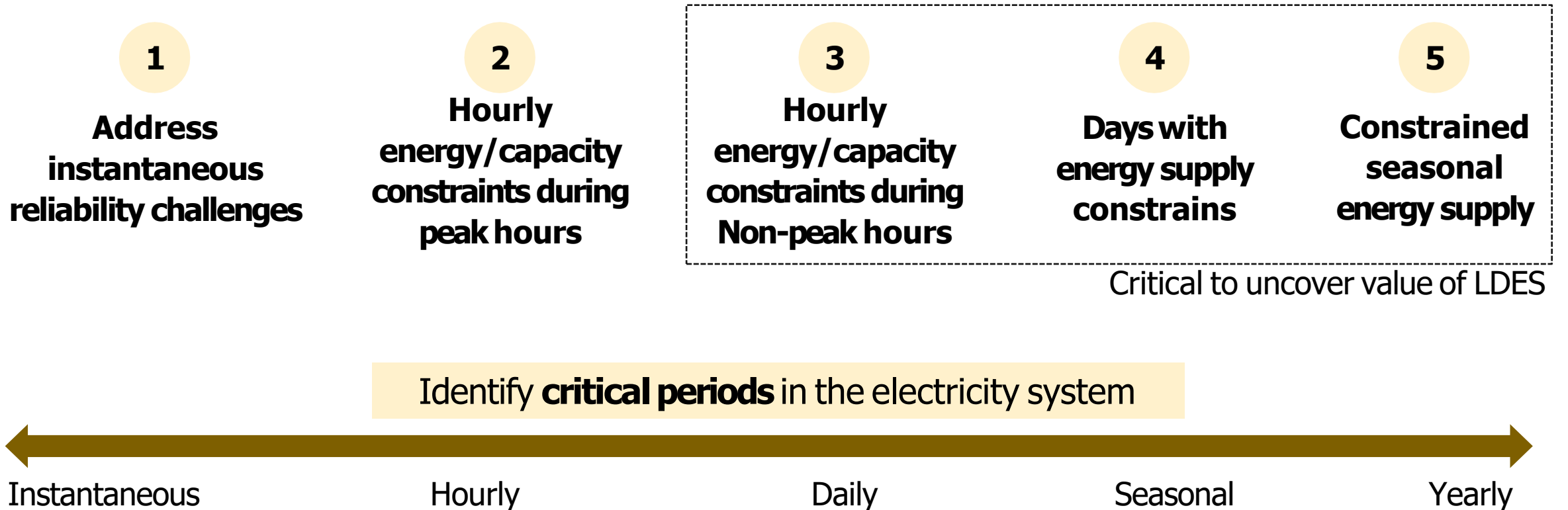
Expanding our approach to resource adequacy evaluation methods will ensure we architect a more robust electricity system that meets stakeholder needs & is more resilient against future operational conditions



3

Challenge 1 - Adopting a broader temporal perspective to reveal emerging resource adequacy needs and highlight the value of assets such as long-duration energy storage (LDES)

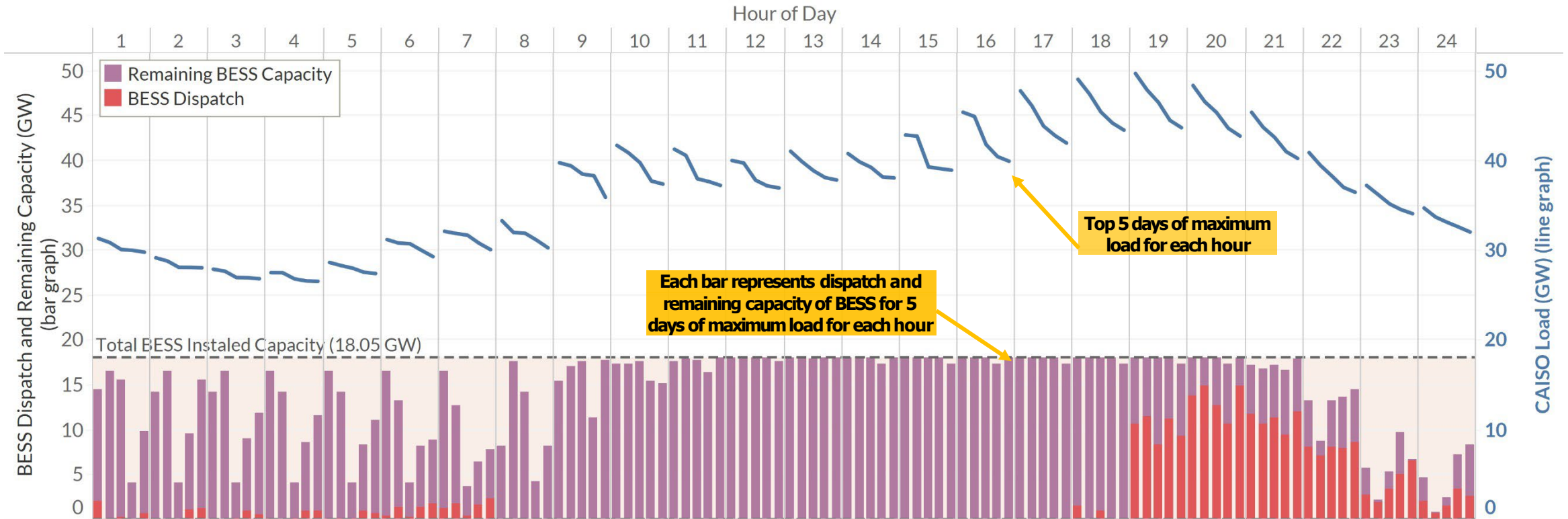
Adopting a broader temporal perspective to reveal emerging resource adequacy needs and highlight the value of assets such as long-duration energy storage (LDES)



3 Hourly energy/capacity constraints during non-peak hours

In CAISO, the capacity of short duration BESS to contribute declines significantly after 10 PM and overnight in September 2028, emphasizing the potential value of LDES. Assumptions from the Preferred System Plan (PSP) – 25 MMT Core scenario in the CPUC’s 2022–2023 IRP cycle were considered.

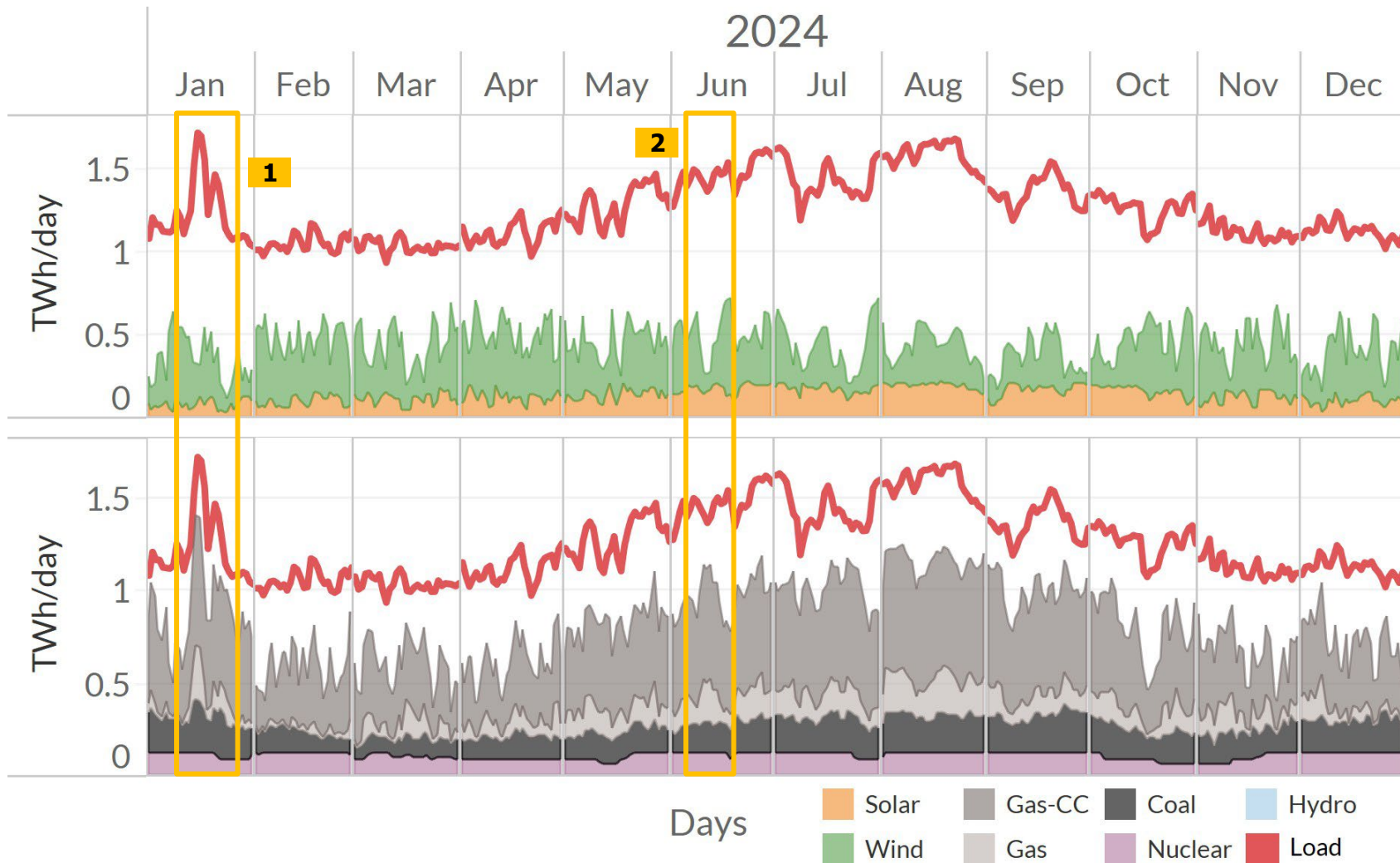
Projected Operation for the Top 5 days for each hour in September 2028



*Peak Load include battery charge

**The new installed capacity in CAISO from the 25 MMT Core scenario in the PSP IRP 2022-2023 cycle was used. The PSP IRP values in 2024 are different than in our model, since we used more recent starting point. For example, in the PSP IRP they consider 13 GW of energy storage in 2024 while we consider less than 12 GW which matches the available capacity in 2024. Therefore, for the whole scenario there is 1.2 GW less of energy storage than in the PSP IRP.

4 Days with energy supply constrains – Significant drop in wind supply and unusual high demand lead to daily energy challenges in ERCOT in 2024



1 January was the most critical month of the year, with a peak in electricity load occurring between the 15th and 16th, during extreme winter weather conditions.

Daily demand reached up to 1.7 TWh.

Sudden reductions in wind generation occurred simultaneously with the surge in demand.

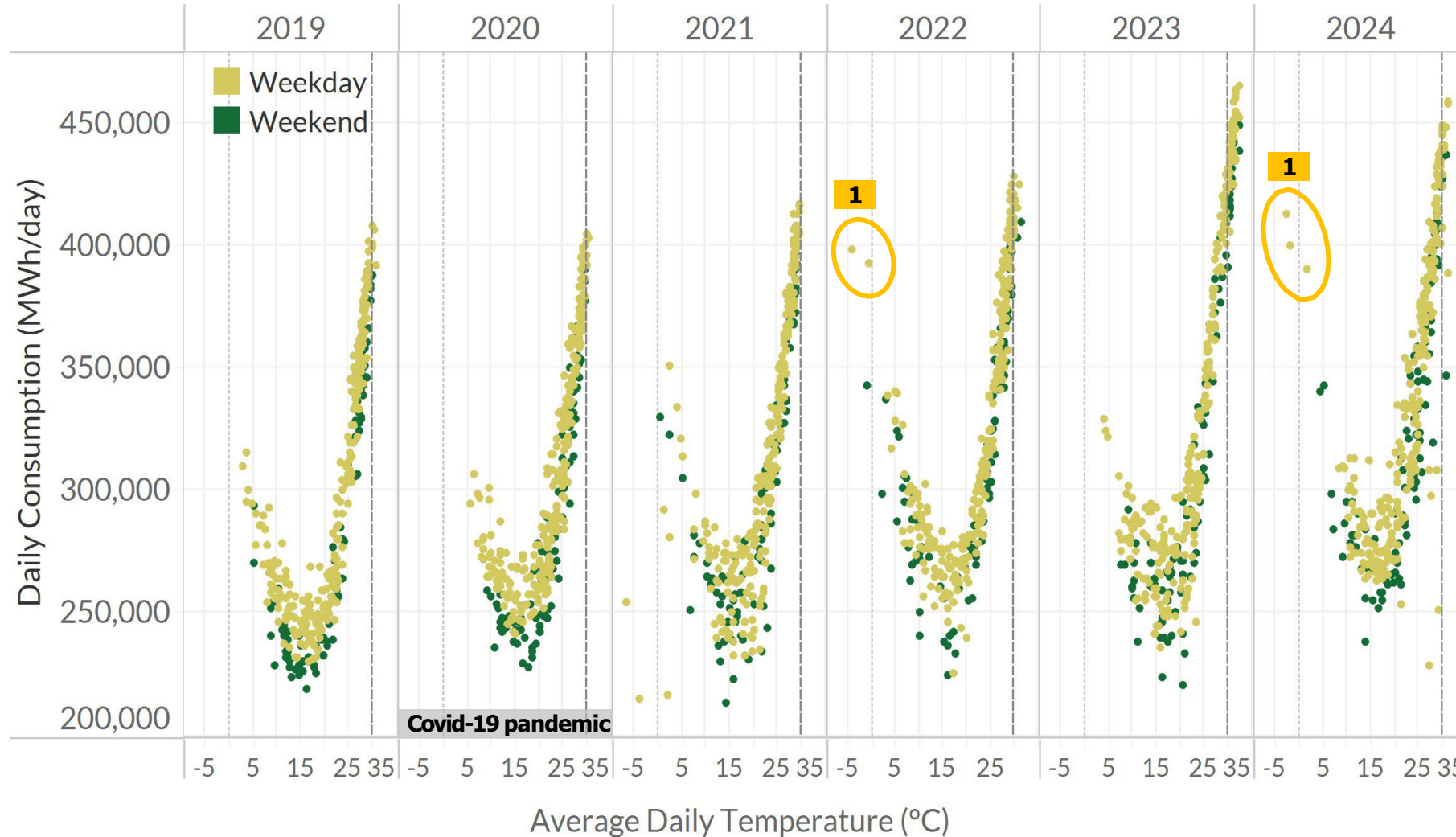
Wind generation dropped to as low as 0.07 TWh/day and coincided with limited solar output observed in winter months.

The days of energy shortfall had to be covered primarily by thermal generation, led by gas-fired combined cycle (Gas-CC) and coal, followed by nuclear and conventional gas sources.

2 In June, despite higher solar generation due to summer conditions, there were a few days with nearly no wind output, requiring the gap to be filled by thermal generation.

4 Changing weather conditions are causing shifts in high load periods in Houston (ERCOT), which can coincide with constrained energy supply

Impact of average daily temperature on daily consumption



1 Extreme winter weather in 2022 and 2024 had a noticeable impact on daily electricity consumption in the Houston area and surroundings.

The extremely cold days observed in 2022 and 2024 reached an average daily temperature which was close to or below 0 °C.

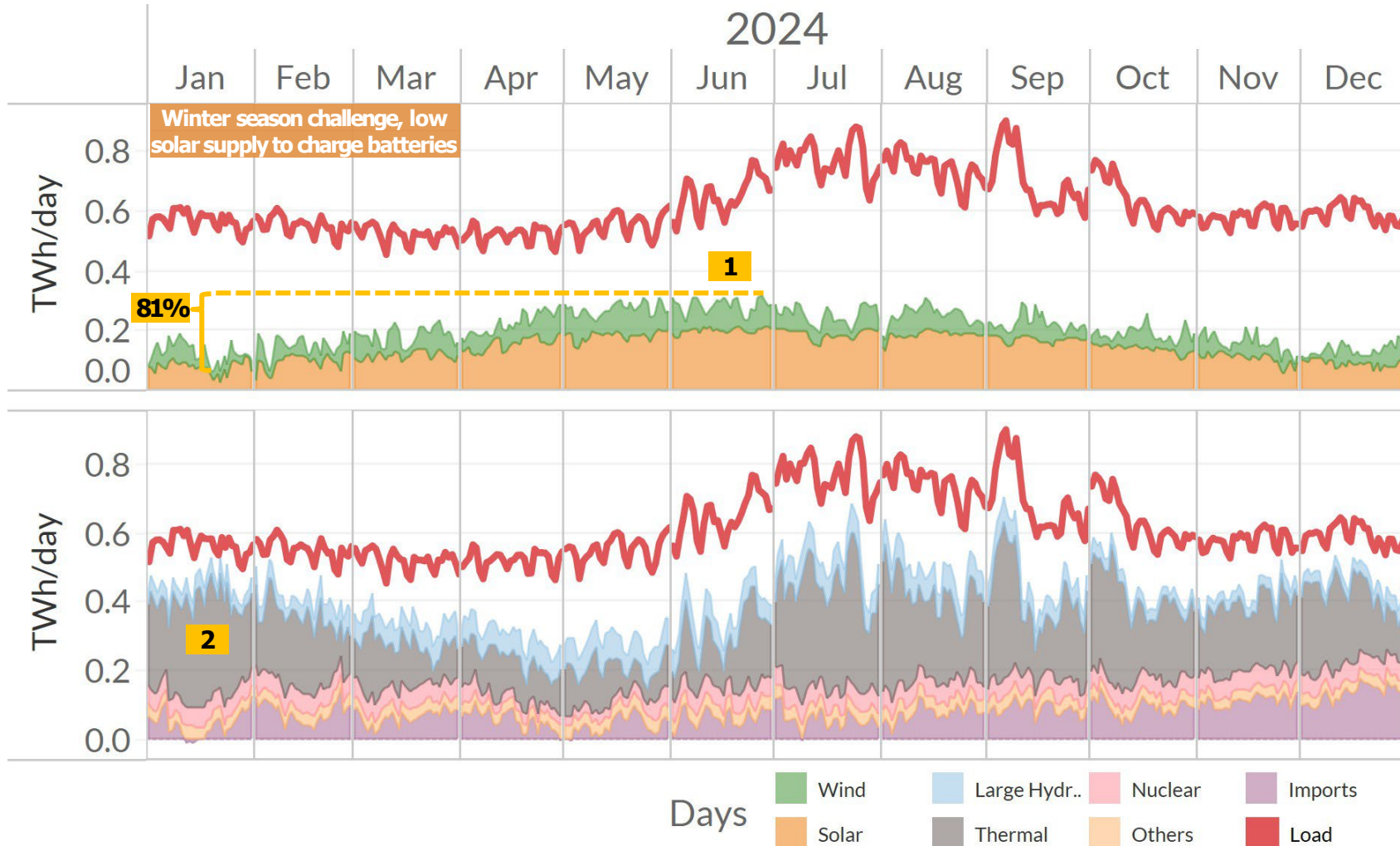
The daily consumption was at least 35% higher for these extreme weather days.

The extreme winter weather occurred in the following days

- 2022 - 4th Feb and 23rd Dec
- 2024 - 15th-17th Jan

*The load shown in this report does not include the load that is being supplied by behind the meter generation.

5 Constrained seasonal energy supply – CAISO in 2024 showed challenges of constrained seasonal supply in the winter



1 Combined daily wind and solar output declines by more than 80% between peak generation days in spring and summer and the lowest levels in winter.

The seasonal decline in generation during winter will persist, even with additional wind or solar capacity in the system.

2 In the winter currently gas generation is being used to address the seasonal availability of wind and solar.

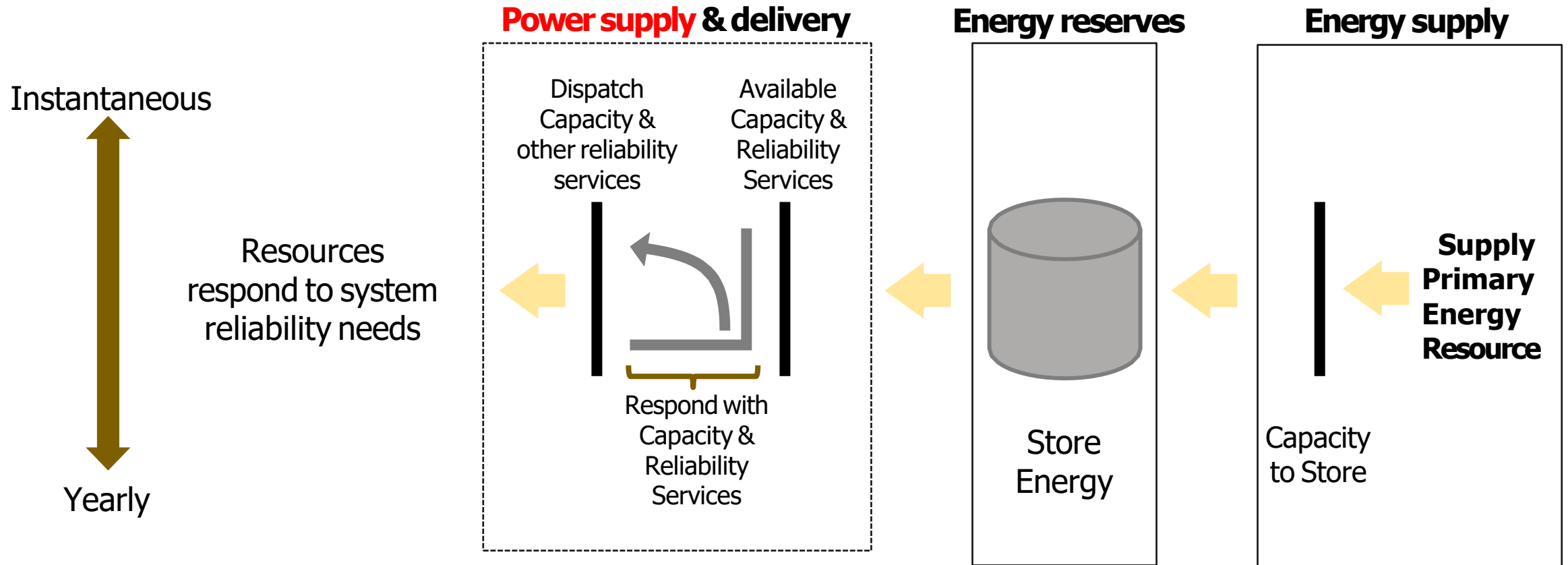
However, when gas units are retired other types of sustainable generation or storage technologies will be needed to cover seasonality and maintain the reliability of the system.

In the winter, wind and solar supply will have less energy available to charge batteries.

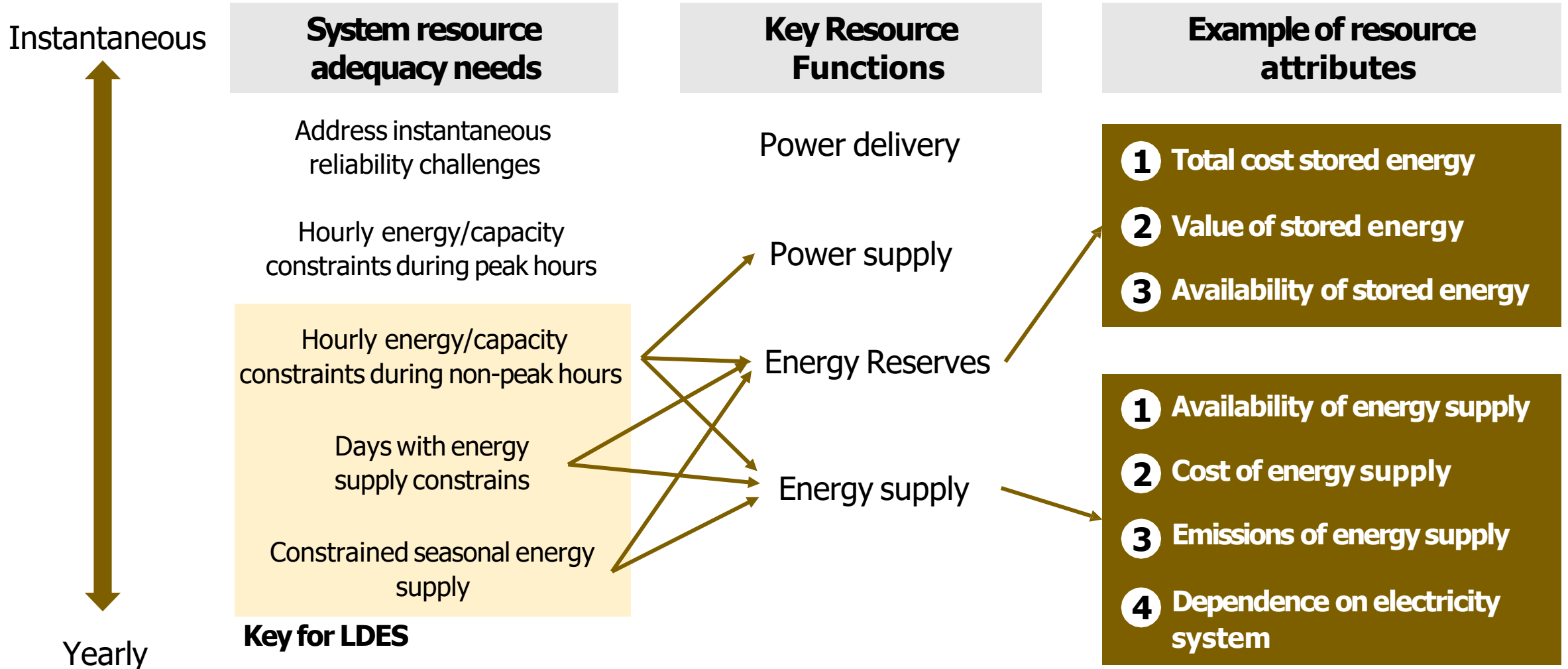
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Challenge 2- Connecting system adequacy needs with resource functions and attributes

Traditionally resource adequacy accreditation has been limited to assessing **power supply** contribution with a limited 4-to-5-hour energy supply guarantee. **Is this valid in the energy transition?**



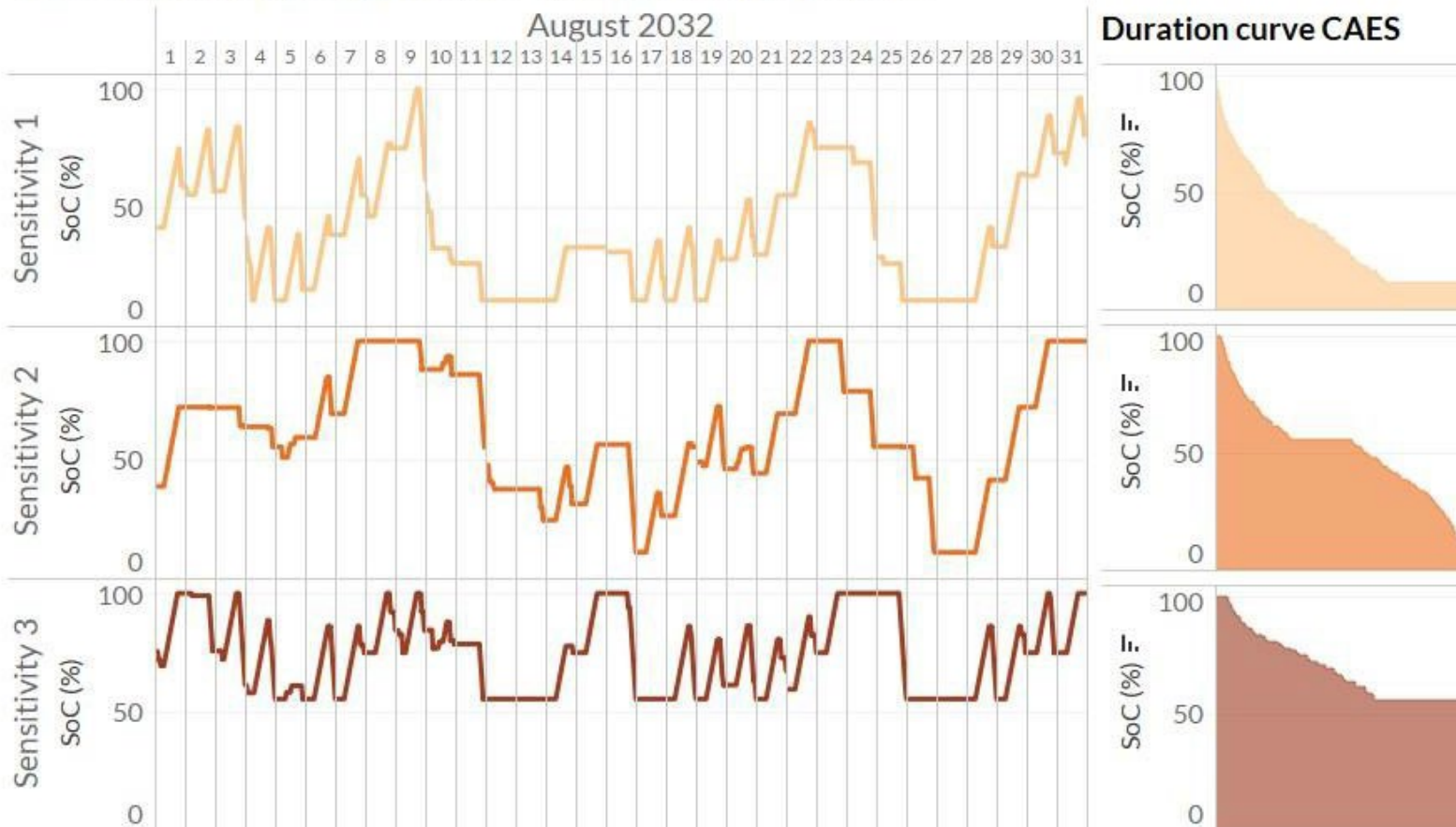
Connecting system adequacy needs with technology agnostic resource functions and attributes can help architect a more effective accreditation and payment framework for resource adequacy



Three operational sensitivities to evaluate the impact of availability and value of 500 MW of 24-h CAES towards resource adequacy in 2032

The sensitivities consider the assumptions for the 25 MMT Core scenario of the Preferred System Plan (PSP) in the IRP 2022-2023 cycle published by the California Public Utilities Commission (CPUC), 500 MWs of 24-hour CAES are installed in this scenario.

State of charge (SoC) for different operational policies



Sensitivity 1

CAES State of Charge (SOC) can operate between 10 and 100%.

Sensitivity 2

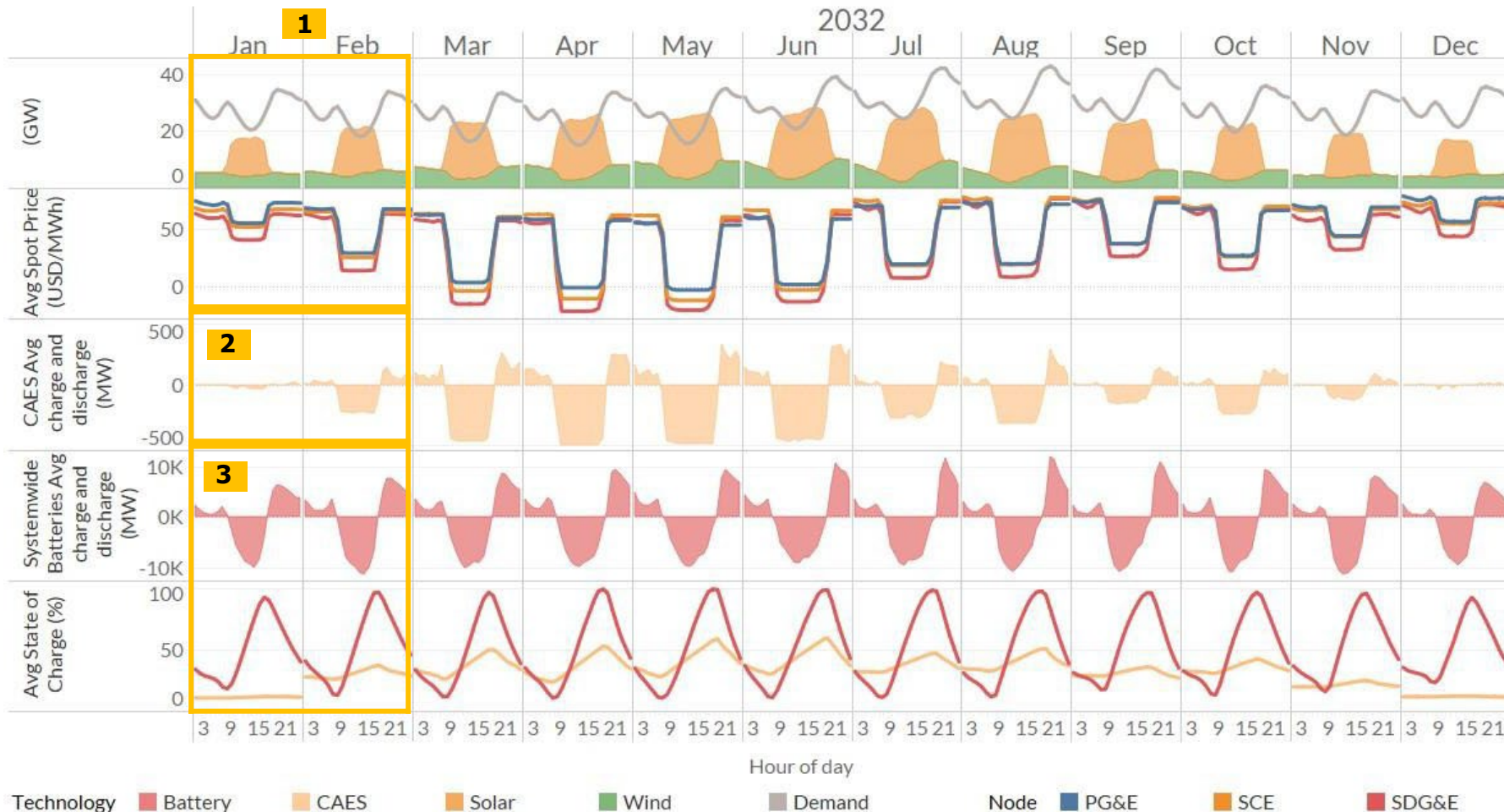
CAES SoC can operate between 10% and 100%, but by the end of the week it should reach 50%.

Sensitivity 3

CAES SoC can operate between 50 and 100%.

Operating 24-hr CAES based solely on spot prices may result in a low state of charge, limiting its ability to support system adequacy

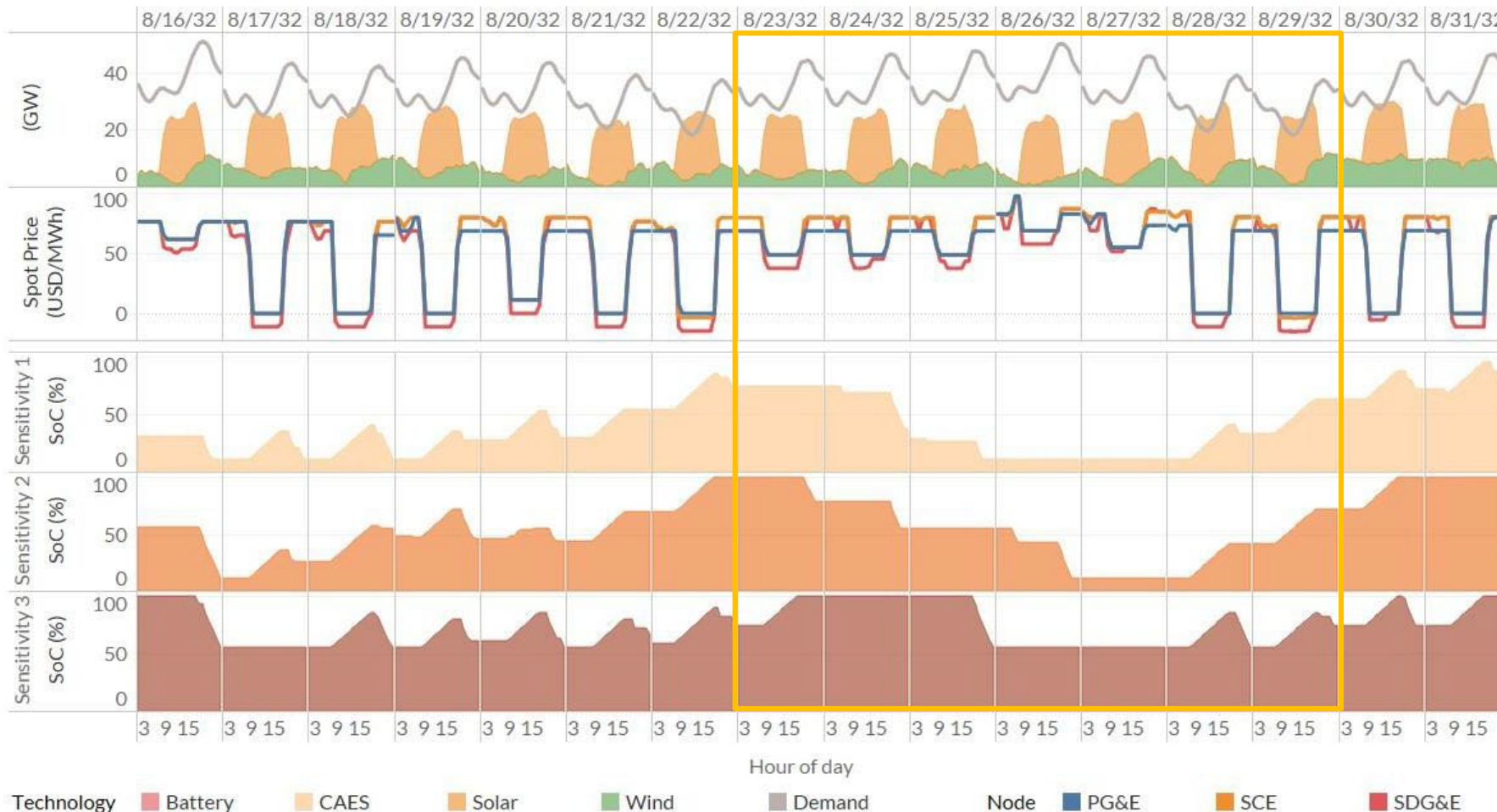
Hourly operations in Sensitivity 1



- 1** In winter, due to lower solar availability during the day spot price differentials are lower than in summer.
- 2** CAES are less efficient. This, combined with **1** provide little incentive to charge the system through the energy market. As a result, economically optimal operation often leads to lower states of charge.
- 3** In comparison, BESS maintain a relatively stable State of Charge throughout the year due to their higher efficiency, enabling them to charge even when spot price differentials are low.

State of charge limitations can arise on high-stress summer days when charging is based solely on spot price optimization

Response for 3 operational policy for CAES between 8/16 and 8/31 2032



1

1 From 8/23 to 8/27, load increases while solar and wind availability decrease, resulting in lower spot price differentials.

In Sensitivity 1, the state of charge is depleted, but there is little incentive to recharge the CAES system, leading to a low state of charge during the most constrained days on 8/26 and 8/27.

The higher state of charge observed in Sensitivities 2 and 3 results from a more prescriptive charging policy.

Establishing charging policy that ensure stored energy availability in LDES will be essential for supporting their role in resource adequacy

5

Conclusions and questions to ESIG community

Conclusions

An expansion of resource adequacy evaluation approach is required to uncover the value of resources such as LDES in the energy transition. This approach requires:

- Broader temporal perspective (from instantaneous adequacy to year-over-year) to determine contribution and accreditation of resources.
- Concept analysis to refine the architecture of resource adequate system by ensuring it meets system needs, goals and critical envisioned operational scenarios, prior to stochastic risk methods.
- Broader range of approaches and tools to uncover potential operational environments.
- A validation process
 - Validation involves ensuring architecture of resource adequate system meets system needs, goals and achieving the desired performance in potential future operational environments.
 - The validation process could also help improve the alignment between resource contribution and accreditation.
 - Validation will help communicate how the stakeholder needs are being met.
- The attributes which determine LDES contribution to system reliability and adequacy should be clearly identified, defined and assessed in a technology-agnostic manner. These attributes should address system needs.

Questions to ESIG members

- Is there a need to establish a guide that focuses on validating a resource adequate system against stakeholder needs, system goals and desired performance against a broader range of potential future operational environments? Is this important to determine the value of new and existing technologies needed in the energy transition?
- Do we need to establish a technology agnostic common language of the functionality and attributes resources that will allow to compare and explore the value of different resources such as LDES current and potential future operational environments?
- How can we use a more robust understanding of system needs, along with a technology-agnostic definition of resource functions and attributes, to design a resource adequacy accreditation and payment framework that ensures system needs are met efficiently and reliably?
 - Would evaluating the energy supply, energy reserve, power supply and power delivery needs of the system and the potential contribution of different resources help us align resource adequacy needs, contribution and accreditation?

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