

Understanding the linkage between transmission deliverability and resource adequacy

Technical presentation
Update 1

July 2026

GridLAB

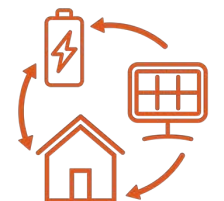


TELOS
ENERGY



Agenda

- 01** Introduction & Motivation
- 02** Historical Curtailment and Congestion
- 03** Resource Adequacy and ELCC Modeling
- 04** Key Findings and Recommendations



Introduction & Motivation

GridLAB



TELOS
ENERGY



Transmission Deliverability and Resource Adequacy

Context

Typically generating resources must have firm interconnection status, or be deliverable, to be eligible for participation in capacity markets or resource adequacy programs; these resources are also often excluded from resource adequacy analysis that determines overall resource needs and accreditation values. However, little analysis exists on whether deliverability analysis conducted under the interconnection process is a reasonable foundation for how generating resources contribute to resource adequacy during times of elevated reliability risk.

Motivation

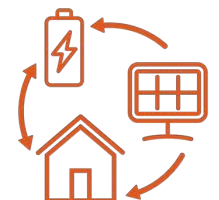
The core motivation of this study is to better understand, test, and quantify the effect of deliverability assumptions on system capacity needs and individual resource accreditation.

*While there has been significant attention recently to differences between NRIS (Network Resources) and ERIS (Energy Resources) with respect to **interconnection and transmission cost allocation**, there has been limited or no research to the implications on resource adequacy.*

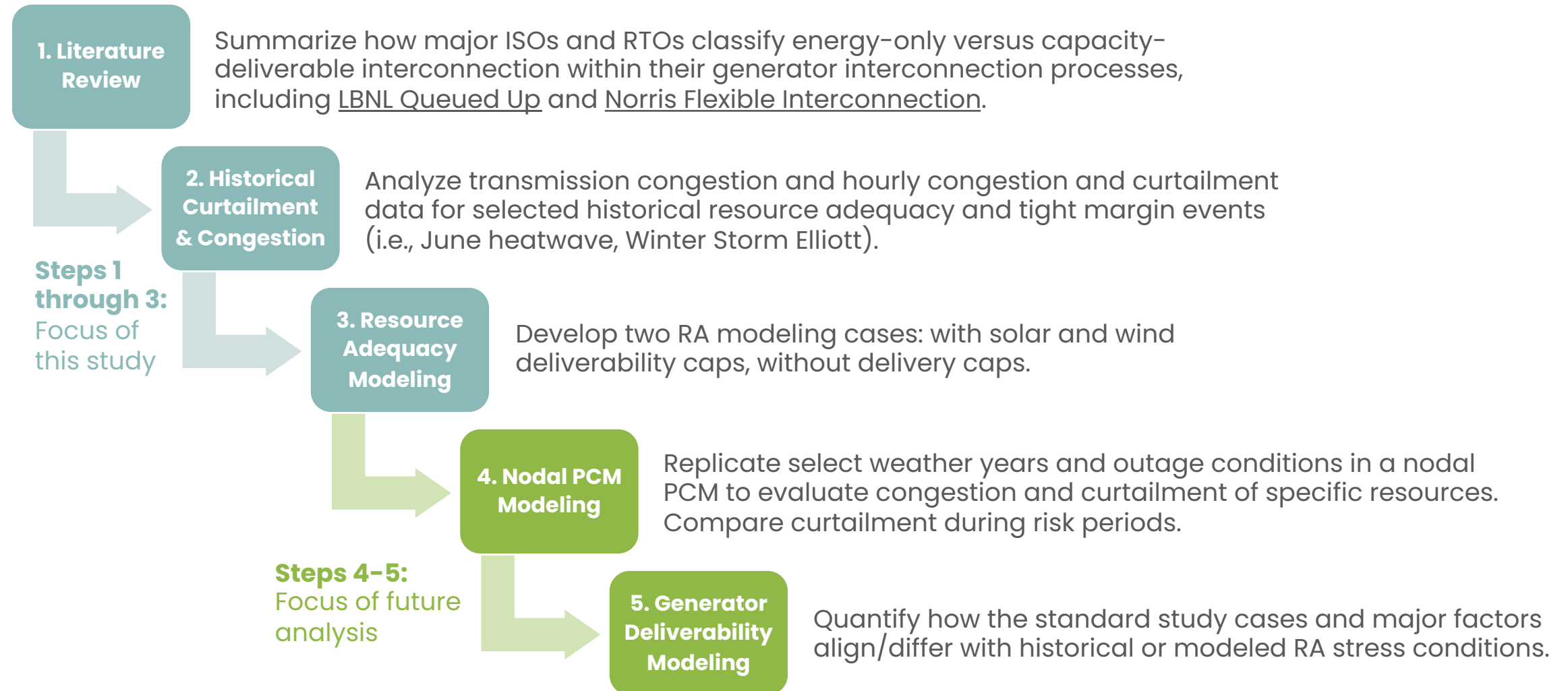
Study Objectives

1. Evaluate the relationship between **generator deliverability**, including energy-only interconnection status (ERIS) versus firm interconnection status (NRIS), and their **implications for resource adequacy outcomes**.
2. Identify how current ISO market rules treat deliverability and quantify the extent to which energy-only resources support resource adequacy.
3. Quantify the impact of gen deliverability constraints on resource adequacy, specifically for accreditation (ELCC) and total capacity needs for a select market (i.e., PJM)

RETHINKING RELIABILITY



Study Process and Tasks



A Comparison of NRIS and ERIS in Capacity Markets and Resource Adequacy Programs

Energy Resource Interconnection Service (ERIS) allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an "as available" basis.

Network Resource Interconnection Service (NRIS) allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System and be deliverable during congested grid conditions, such that the generator can be designated as a capacity resource and contribute to resource adequacy requirements.

ERIS service: enables participation only in energy markets

"As available" transmission service; typically ineligible for RA capacity value, but potentially faster interconnection and cheaper transmission upgrades.

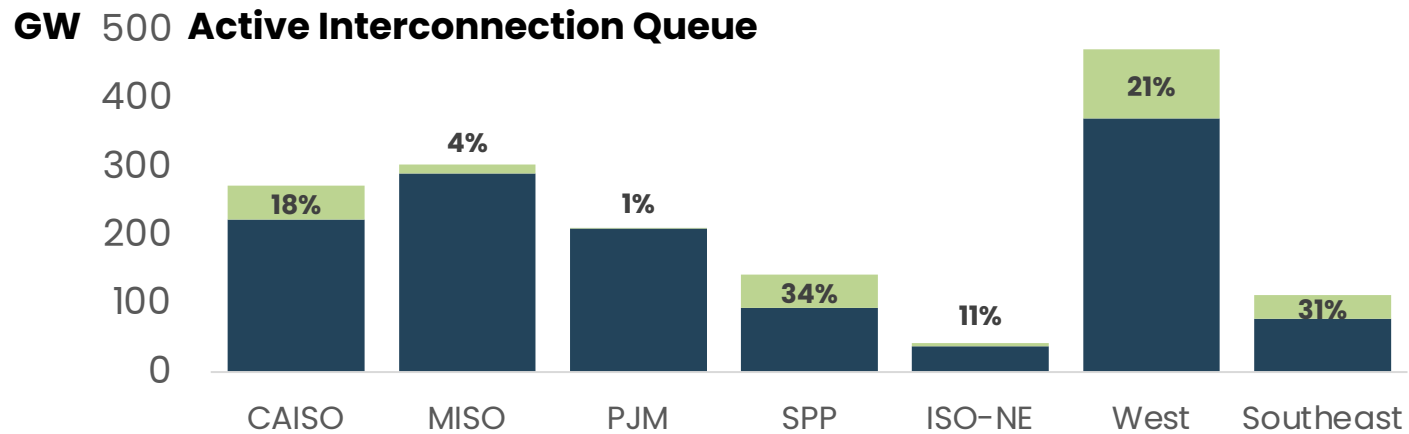
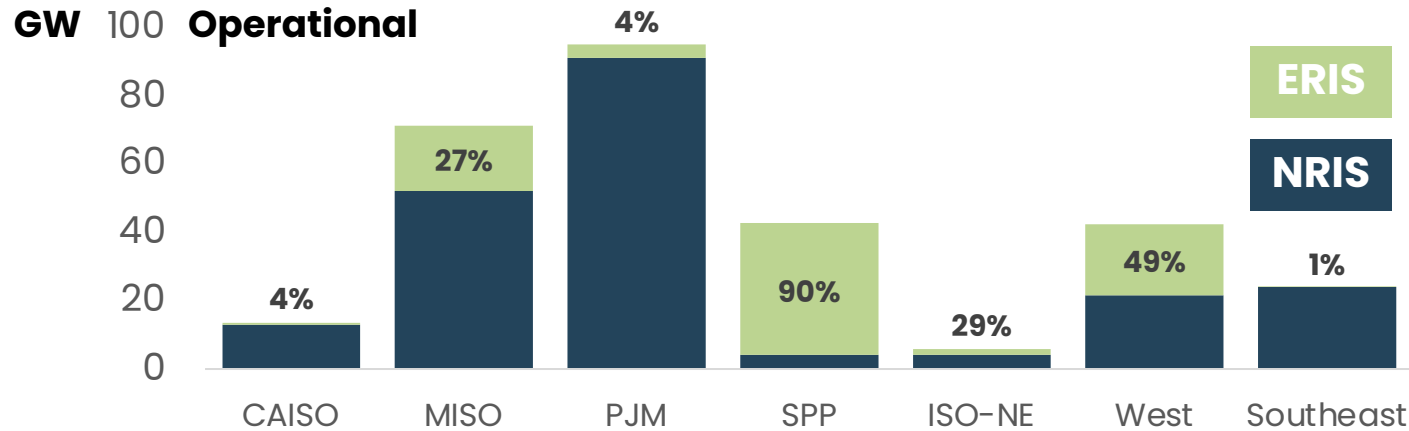
Often completely ignored in resource adequacy modeling, determining capacity needs, and accrediting other resources

NRIS service: required for capacity market entrance or eligibility for capacity accreditation

Studied for full transmission deliverability, a prerequisite for RA and capacity, but requires more extensive interconnection study and more expensive transmission upgrades.

In addition, even NRIS resources are further artificially limited by deliverability caps in some markets

NRIS vs. ERIS Interconnection Requests by ISO



NRIS is the primary interconnection service for operational resources across the US (excluding ERCOT).

Interconnection requests are trending towards more NRIS in most, but not all, regions.

MISO, SPP and the Western US lead in ERIS interconnections in the operating fleet.

New interconnection requests in the Southeast and CAISO are beginning to favor ERIS.

PJM ERIS remains low for both operating and active requests.

Data Source: [LBNL Queued Up, 2025](#)

*NRIS includes projects choosing the NRIS/ERIS study option at time of request

Example: Deliverability Caps in PJM's ELCC model

Table 16. Assessed Deliverability caps for wind and solar ELCC Classes

ELCC Class	Zone	Summer Deliverability	Winter Deliverability MW (as percent of ENC)	Light Load Deliverability MW (as percent of ENC)
Onshore Wind	MAAC	Max(CIR, Transitional Deliv)	71%	64%
Onshore Wind	PJMWEST	Max(CIR, Transitional Deliv)	84%	80%
Onshore Wind	DOM	Max(CIR, Transitional Deliv)	77%	70%
Offshore Wind	MAAC	Max(CIR, Transitional Deliv)	95%	88%
Offshore Wind	DOM	Max(CIR, Transitional Deliv)	97%	92%
Solar Fixed	MAAC	Max(CIR, Transitional Deliv)	5%	51%
Solar Fixed	PJMWEST	Max(CIR, Transitional Deliv)	5%	56%
Solar Fixed	DOM	Max(CIR, Transitional Deliv)	5%	54%
Solar Tracking	MAAC	Max(CIR, Transitional Deliv)	5%	53%
Solar Tracking	PJMWEST	Max(CIR, Transitional Deliv)	5%	51%
Solar Tracking	DOM	Max(CIR, Transitional Deliv)	5%	58%

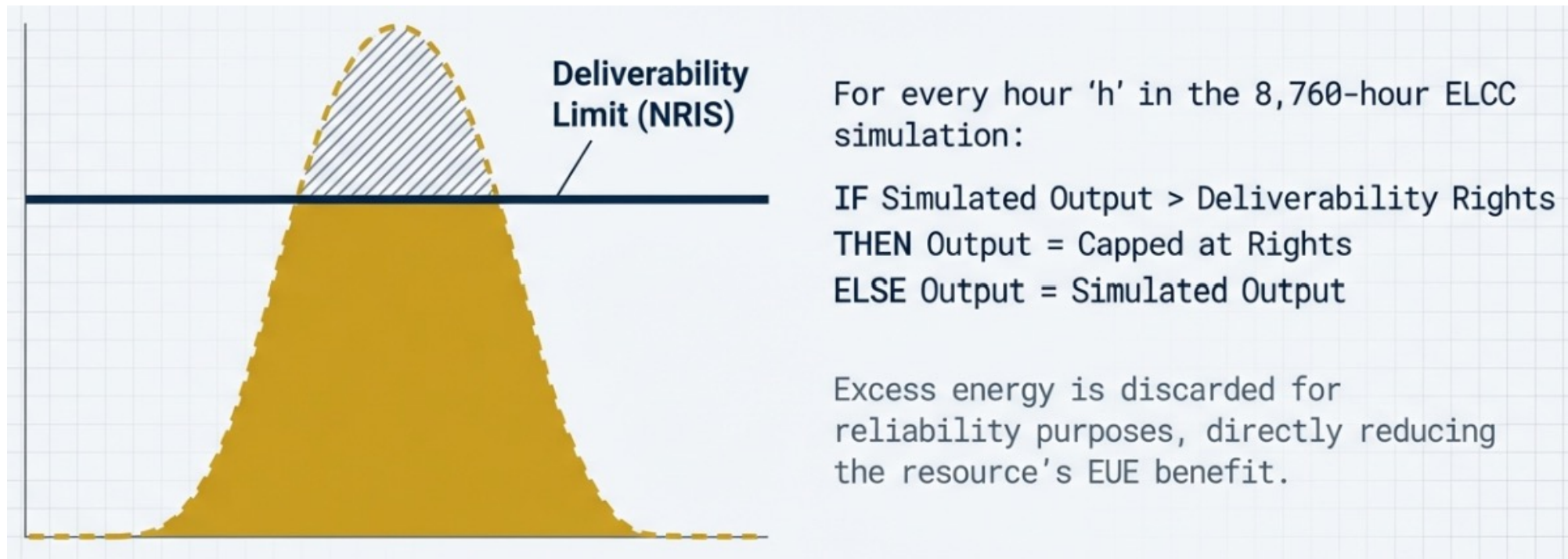
Furthermore, since the ENC values for Variable Resources can exceed the assessed deliverability of such resources, the values in the above hourly availability time series are capped by: (i) the greater of the unit's CIR megawatt value, or the transitional system capability awarded for the applicable Delivery Year during hours in the months of June through October and the following May of the Delivery Year and ii) the unit's assessed deliverability as defined in PJM Manual 14B: PJM Region Transmission Planning Process for the applicable Delivery Year during hours in the months of November through April of the Delivery Year. Specifically, for winter hours beginning 0, 1, 2, 3, 4, 5, 6, 7, 8, 18, 19, 20, 21, 22, 23, the cap is the winter deliverability megawatts, while for winter hours beginning 9, 10, 11, 12, 13, 14, 15, 16, 17, the cap is the light load deliverability megawatts. Also, the hourly availability time series of a Variable Resource is adjusted to reflect a unit's actual historical curtailments. As shown in Table 16, in the 2025 RRS, the assessed deliverability for Variable Resources are as follows (note that for resources other than Variable Resources the assessed deliverability throughout the entire year is the maximum of CIRs and transitional CIRs and therefore, the hourly output during any hour of the year for those resources is capped at this value):



Furthermore, **since the ENC values for Variable Resources can exceed the assessed deliverability of such resources, the values in the above hourly availability time series are capped** by: (i) the greater of the unit's CIR megawatt value, or the transitional system capability awarded for the applicable Delivery Year during hours in the months of June through October and the following May of the Delivery Year

Source: PJM, 2025 Effective Load Carrying Capability and Reserve Requirement Study (ELCC/RRS)

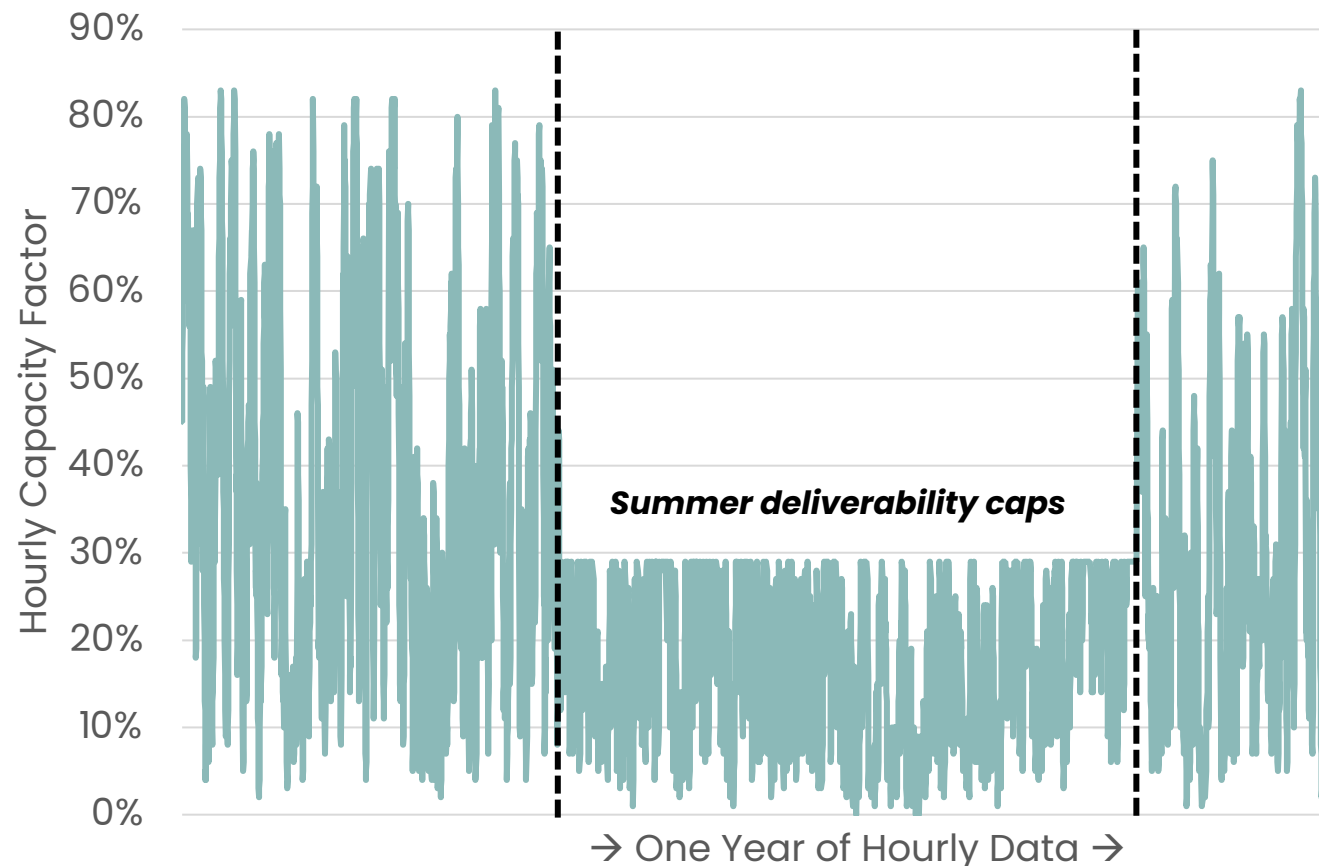
Example: PJM Methodology on Chronological Deliverability Caps



Both PJM's LOLE and ELCC models limit resource output to deliverability limits.

Example: PJM Methodology on Wind Deliverability Caps

Aggregate PJM-wide Hourly Wind Profile



Deliverability caps are added to the resource adequacy *input hourly profiles*, instead of a limit on the output capacity

Applied across *all hours of the year*, despite surplus transmission available in most hours

Assumes all wind or solar resources are curtailed simultaneously across the entire footprint

Misrepresents actual system risk and energy limitations with the intent of capturing transmission limitations in RA models

Historical Curtailment & Congestion

GridLAB



TELOS
ENERGY



Analysis: Historical Pricing Data as a Proxy for Deliverability

Step 1

Identify recent “RA Events” based on historical pricing and load data

1. Scarcity pricing hour where PJM RTO price $> \$500/\text{MWh}$, or
2. Net Load in the top 0.5% of hours

Step 2

Download Nodal Hourly LMP during RA Event hours

Query all generator LMP data for select hours, group by zone

Step 3

Identify nodal outliers relative to zonal average

Visualize nodal LMP relative to zonal average to identify resources that are curtailed during RA Events (curtailment indicated by significantly lower nodal LMP relative to zonal average)

Key finding | During RA events, there are limited deliverability constraints at the nodal level and little/no relationship by resource type

RA Event Selection in PJM, 2020-2025

Scarcity pricing event days

RA Event Day	Count of Hours	Max Price	Avg Price	Hour of Max Price	Top Net Load
3/22/2021	1	543	46	19	NO
1/13/2022	1	630	72	6	NO
1/16/2022	1	544	191	7	NO
1/31/2022	1	540	122	6	NO
6/13/2022	3	2644	361	16	NO
8/8/2022	3	617	223	13	YES
8/9/2022	3	817	216	17	YES
12/23/2022	10	3706	768	17	NO
12/24/2022	14	3666	1141	4	NO
12/26/2022	1	553	173	0	NO
1/10/2023	1	652	76	7	NO
4/8/2025	1	898	75	7	NO
5/2/2025	1	548	75	17	NO
6/22/2025	1	824	85	19	NO
6/23/2025	3	1336	224	19	YES
6/24/2025	3	1841	284	18	YES
6/25/2025	1	505	112	17	YES
7/28/2025	1	534	100	19	YES
10/3/2025	1	692	64	17	NO
Total	51				

Hourly Percentile Price, \$

Percentile	2020	2021	2022	2023	2024	2025
0.995	83.82	170.48	360.91	112.87	170.67	258.81
0.990	68.09	132.49	223.84	92.16	134.23	195.46
0.980	56.48	108.46	184.03	75.86	104.56	148.18

Hourly Percentile Net Load, MW (Load minus wind & solar)

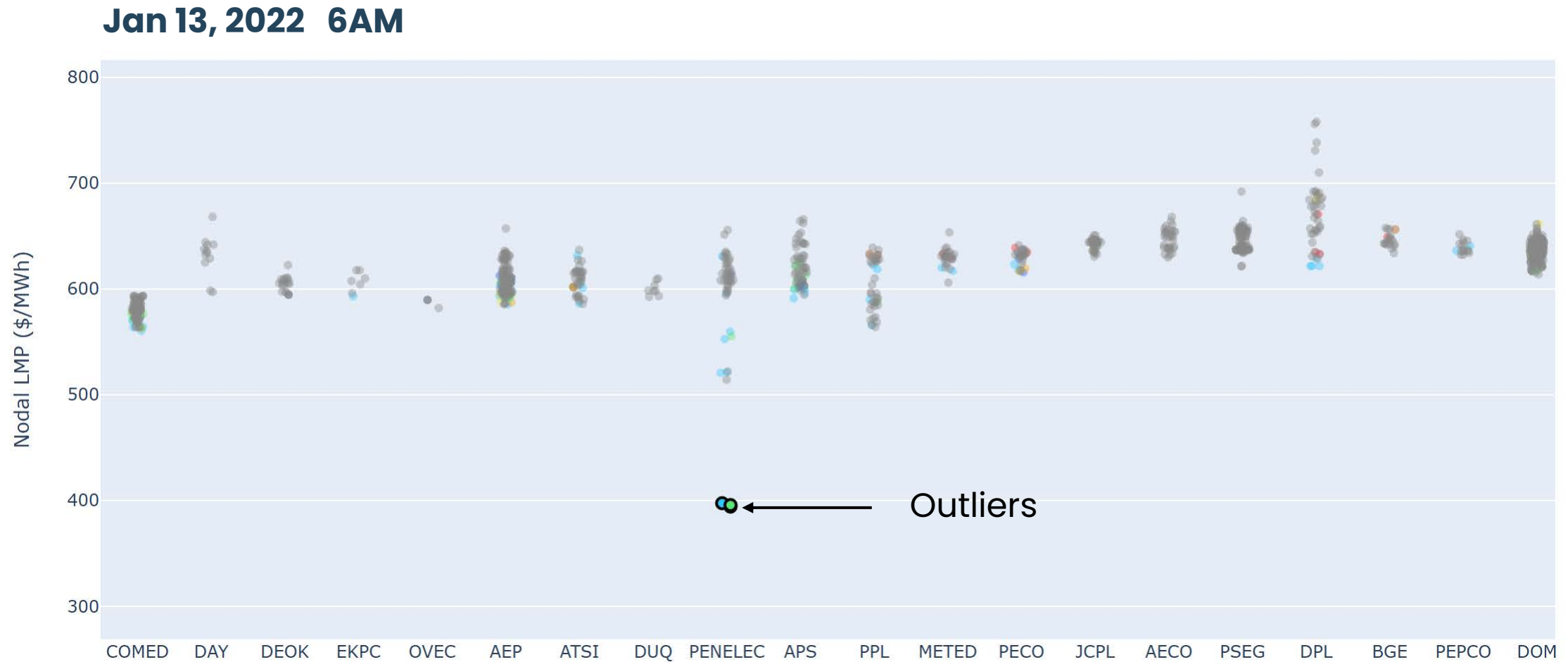
Percentile	2020	2021	2022	2023	2024	2025
0.995	137,484	139,117	135,711	132,122	139,300	139,576
0.990	134,211	134,872	130,956	127,145	134,491	135,394
0.980	128,851	128,830	126,136	122,137	128,895	131,047

Event 1: Single outlier, coal plant in DEOK



Notes: Each dot represents a nodal LMP (y-axis) of a specific generator node, clustered by transmission zone ordered west to east (x-axis). Dot coloring represents generator fuel type, for select generators

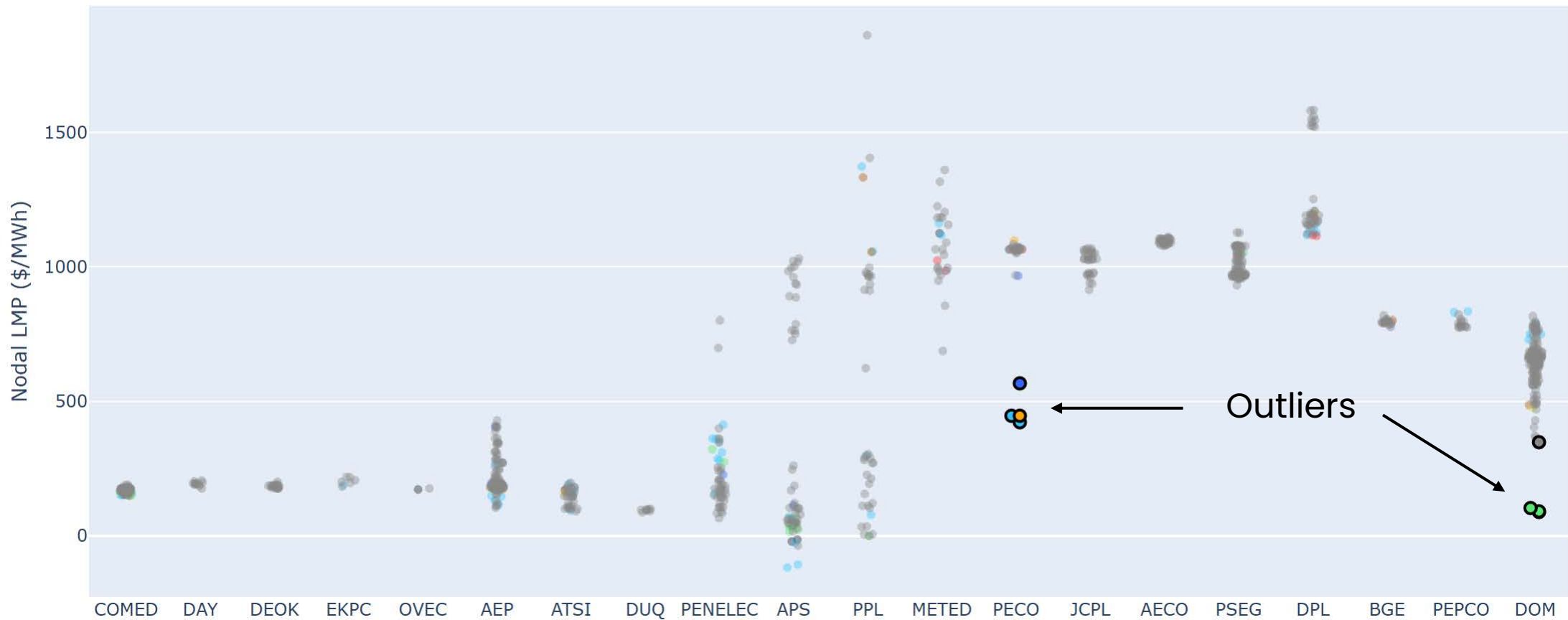
Event 2: Two outliers, wind and gas in PENELEC



Notes: Each dot represents a nodal LMP (y-axis) of a specific generator node, clustered by transmission zone ordered west to east (x-axis). Dot coloring represents generator fuel type, for select generators

Event 3: PJM West → East congestion

Jan 16, 2022 7AM



Notes: Each dot represents a nodal LMP (y-axis) of a specific generator node, clustered by transmission zone ordered west to east (x-axis). Dot coloring represents generator fuel type, for select generators

Summary of Historical Congestion and Curtailment Analysis

Overall, we see limited evidence of curtailment during RA events based on LMPs as a proxy.

- Of all the events analyzed, there are only a limited number of outlier pricing nodes and hours that experience very low nodal LMPs.
- In some events there is system-level transmission congestion across the PJM footprint, creating price separation by zone, but this is not a result of transmission deliverability constraints.
- In cases where there is nodal price separation, it is not consistent across events, nor is it specific to resource types.
- These results indicate that transmission constraints and deliverability are not a limiting factor for either NRIS or ERIS resources in PJM.

Resource Adequacy and ELCC Modeling

GridLAB



TELOS
ENERGY



Understanding the impact of deliverability caps on accreditation: PJM Example

We replicated the PJM ELCC model to test out various assumptions related to generator deliverability and their effects on resource adequacy. ***Our approach mimics PJM's approach of excluding ERIS resources and applies additional deliverability caps for NRIS resources.***

Using EIA data, which does not distinguish between NRIS and ERIS resources, we developed new wind and solar profiles and calculated hourly outputs with and without deliverability caps.

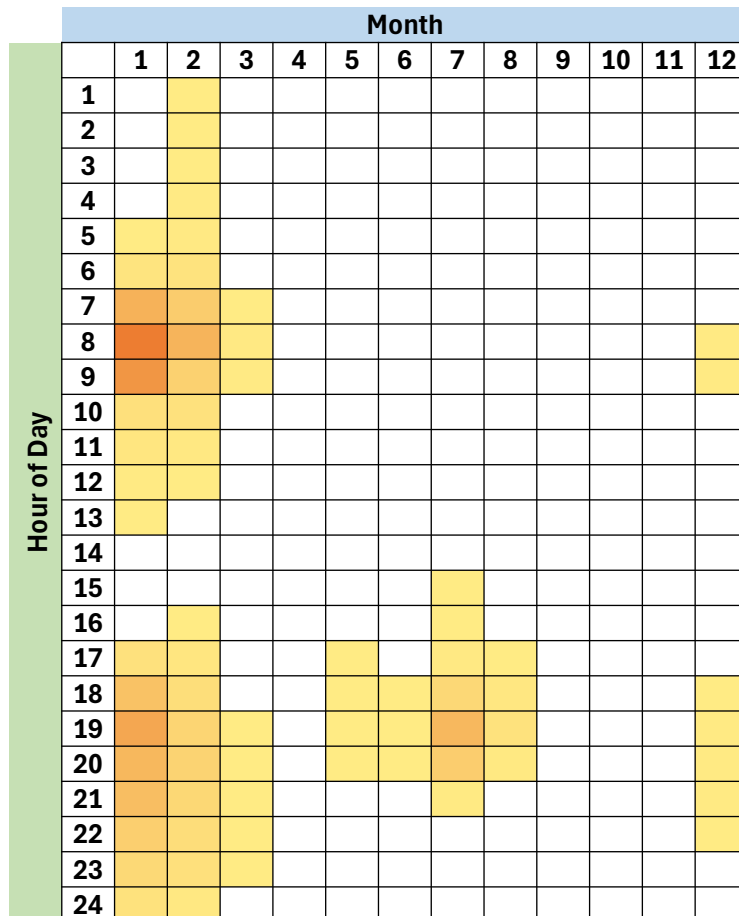
We scaled all wind and solar profiles to reflect NRIS only capacity (~ 96%).

Key Questions

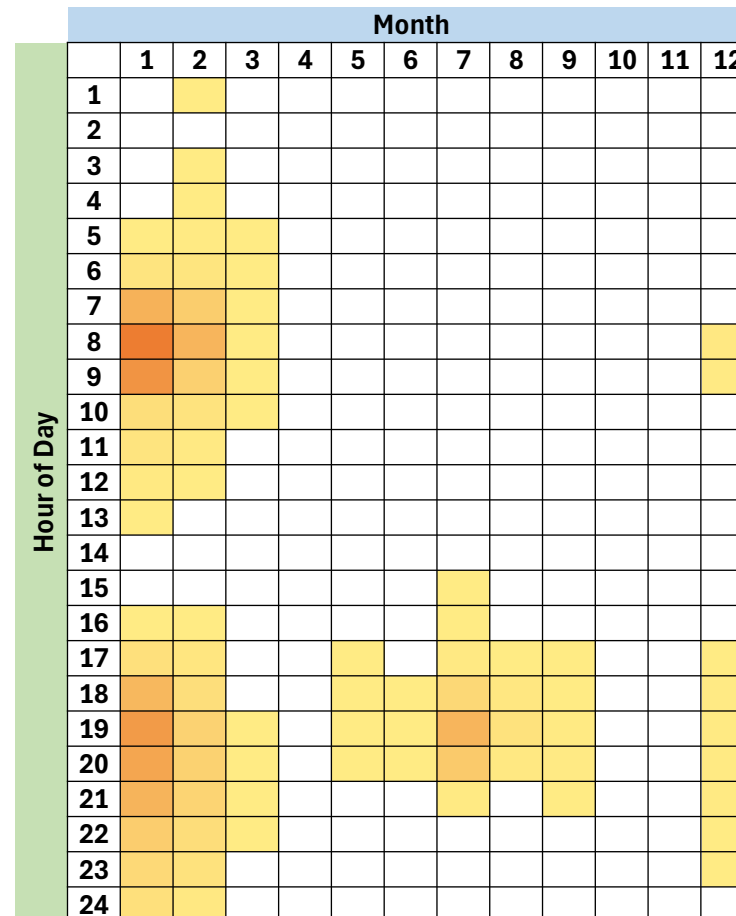
1. Do deliverability caps change resource adequacy risk periods, today or in the future?
2. What is the direct effect on wind and solar accreditation values?
3. What is the indirect effect on other resource accreditation?

Replicated methodology shows robust alignment in risk hours

PJM LOLH Heatmap



Replicated LOLH Heatmap



RA Metric	PJM	This Study
LOLE (days/yr)	0.1	0.1
LOLH (hours/yr)	0.35	0.37
EUE (MWh/yr)	1799	1761

What are weather rotations, and how do they impact loss-of-load results?

PJM's loss-of-load probability (LOLP) model assesses unserved energy across 13 weather rotations (WRs).

WRs are intended to capture that extreme weather events that occur on one day (e.g., a weekday) could occur on a different day (e.g., a weekend).

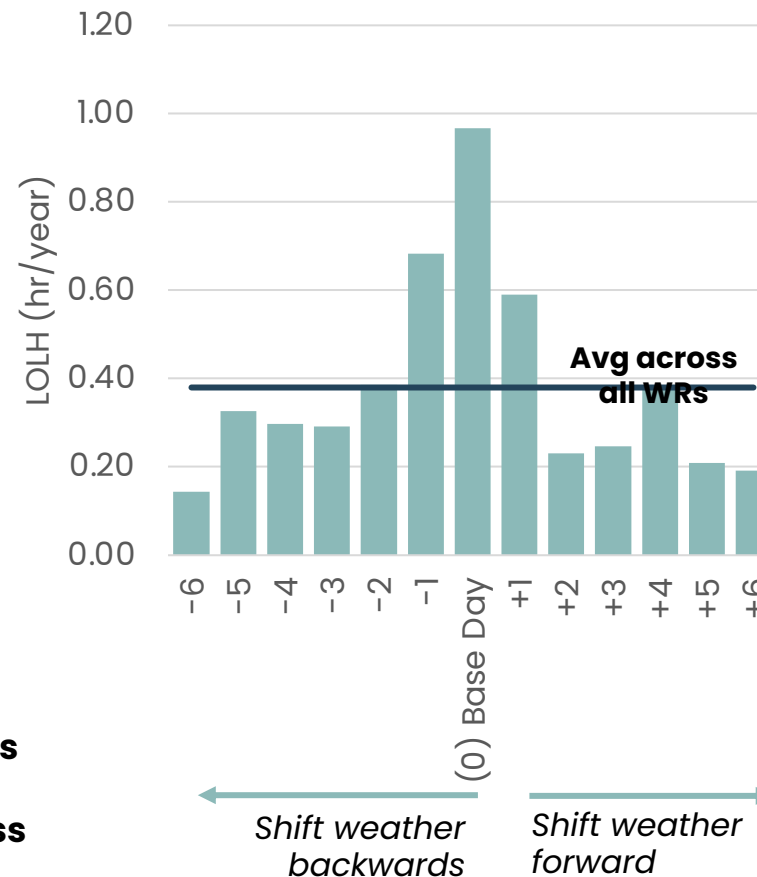
WRs only affect the hourly load shape; they do not impact resource performance (e.g., ambient derates, forced / maintenance outages, and variable resource availability).

As a result, LOLP results in load scenarios with weather-rotated load are misaligned with historical system performance and understate correlated outage risk.

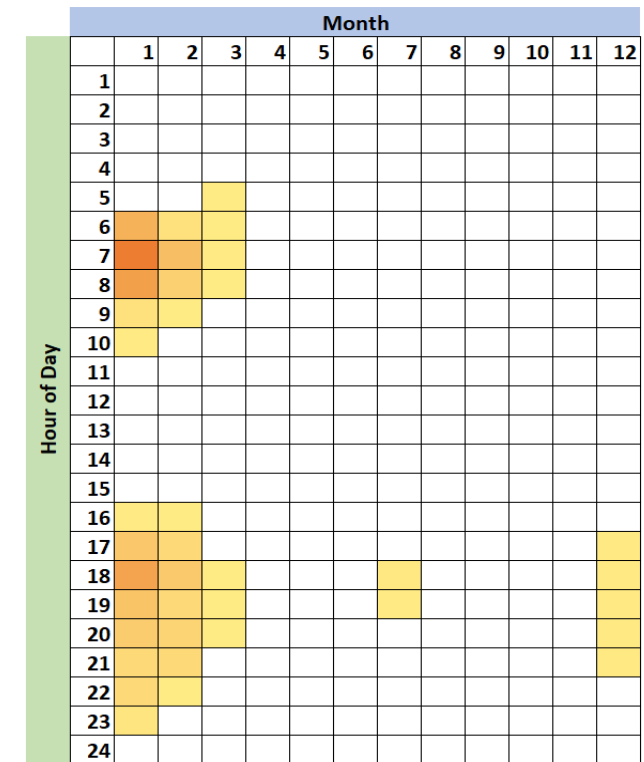
For that reason, this study only utilized the base day weather rotation (unshifted) to preserve correlated weather impact across load and resources.

The net effect of removing the weather rotations is more concentrated winter risk, higher LOLE, and more resources required in the calibration process to achieve the 0.1 days/year LOLE criterion.

LOLH (hrs/yr) by Weather Rotation

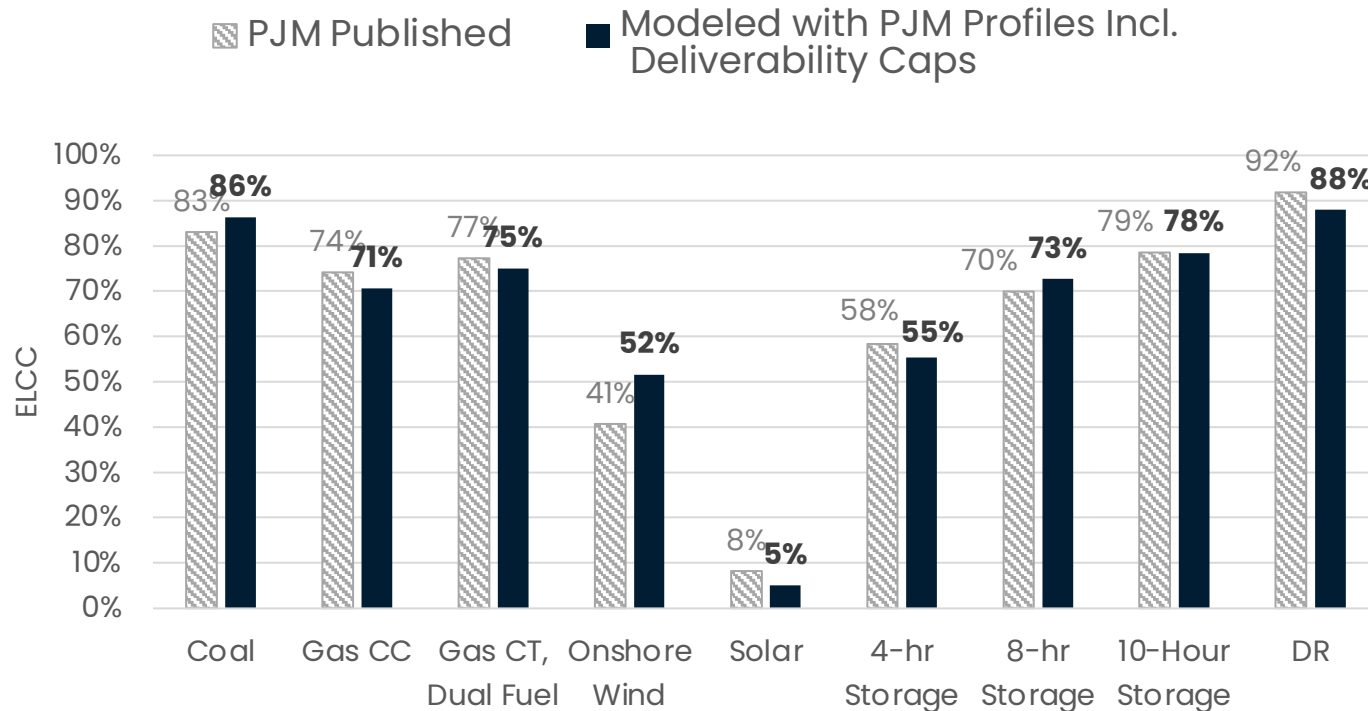


Replicated Base Day LOLH Heatmap*



* Calibrated to 0.1 days/year LOLE criterion without weather rotations applied to load

Replicated methodology shows comparable ELCC across resource types



Our analysis shows strong alignment overall in ELCC by resource class. Discrepancies for onshore wind and solar are driven, in part, by absence of weather year rotations. This gave us confidence to proceed with the next phase of the analysis.

Similarities to PJM Modeling

- Leverages the same capacities by resource type used for the 2027/2028 Base Residual Auction
- Uses PJM published hourly profiles for load, wind, solar, and thermal outages
- Replicates assumptions around energy limited resource sequencing

Potential Discrepancies

- Not all data was made public by PJM for resources with limited capacity
- Fewer number of generator outage samples to improve computational speed
- Did not include 'weather year rotation' used by PJM because it breaks weather correlation

Isolating the effects of deliverability assumptions

PJM provided hourly wind and solar resource profiles

- Based on weather years 2012 – 2024
- Uses historical generation data where available, with curtailment added back
- Aggregated at the PJM-wide level and *includes deliverability caps*

Because PJM data includes deliverability caps and actual availability profiles were not provided, we had to develop our own resource profiles

1. Use simulated weather data by plant location from NLR
2. Convert to power production profiles using plant characteristics (hub height, tracking, inverter loading ratios, etc.)
3. Aggregate to regional profiles and with and without deliverability caps

Recreating wind and solar profiles

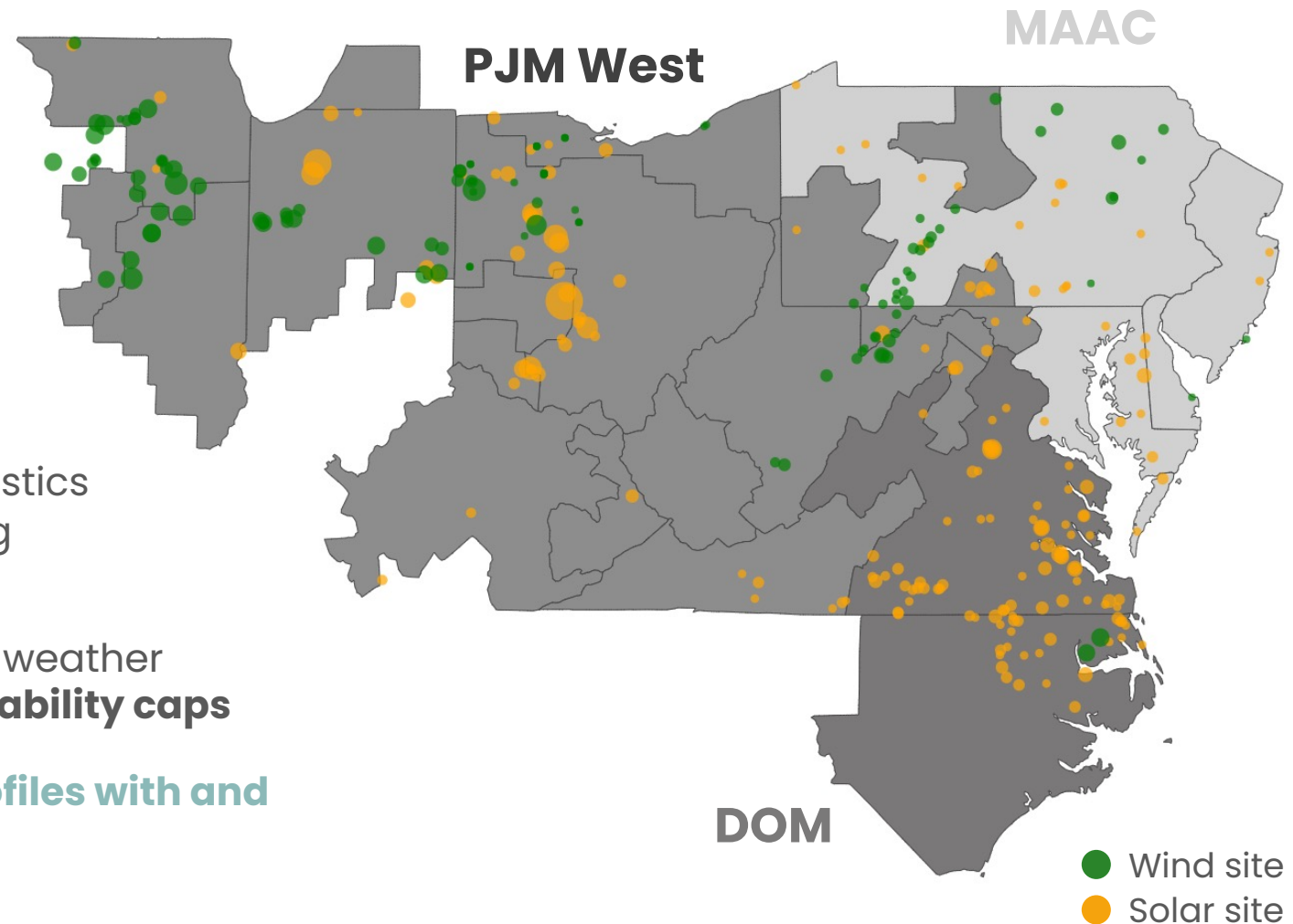
Used NLR NSRDB and WIND Toolkit to download location-specific wind speeds and solar irradiance at each existing and proposed wind and solar project located in the PJM footprint in 2024 EIA 860 data

- All Wind Projects
- All Solar Projects > 20 MW

Utilized unique project-specific characteristics like hub height, tracking, & inverter loading ratios.

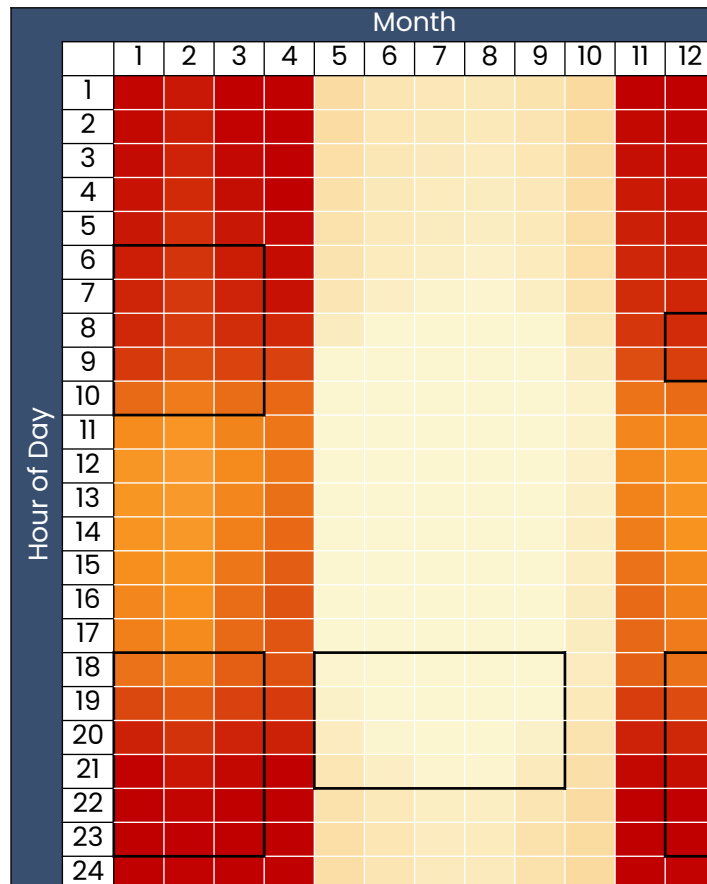
Developed PJM-wide resource profiles for weather years 2012–2024 **with and without deliverability caps**

Allows for development of consistent profiles with and without the deliverability caps

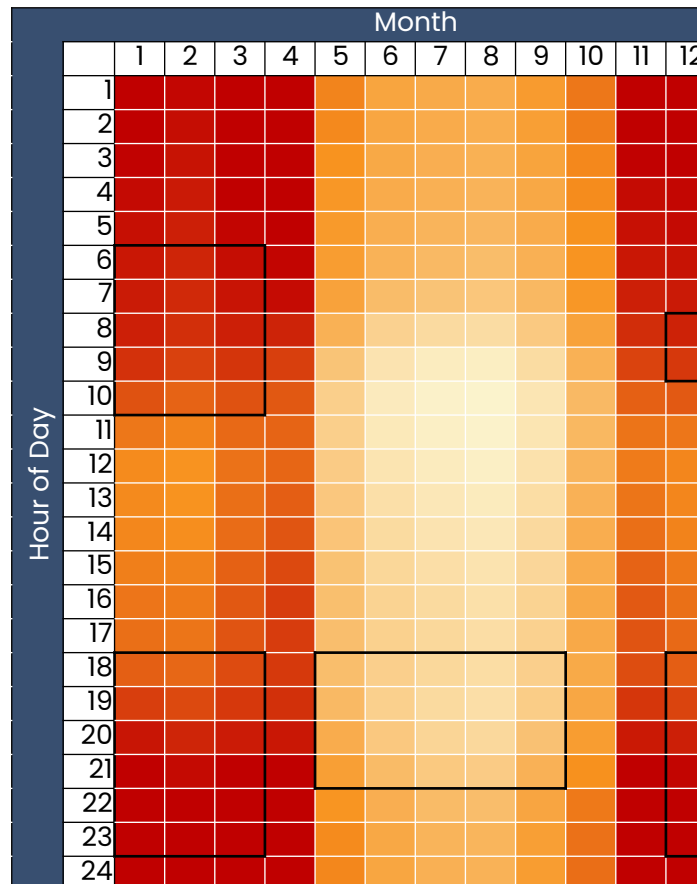


Wind profiles with and without deliverability caps

With Deliverability Caps



Without Deliverability Caps



Legend

90th percentile (~50% CF)

50th percentile (~34% CF)

10th percentile (~15% CF)

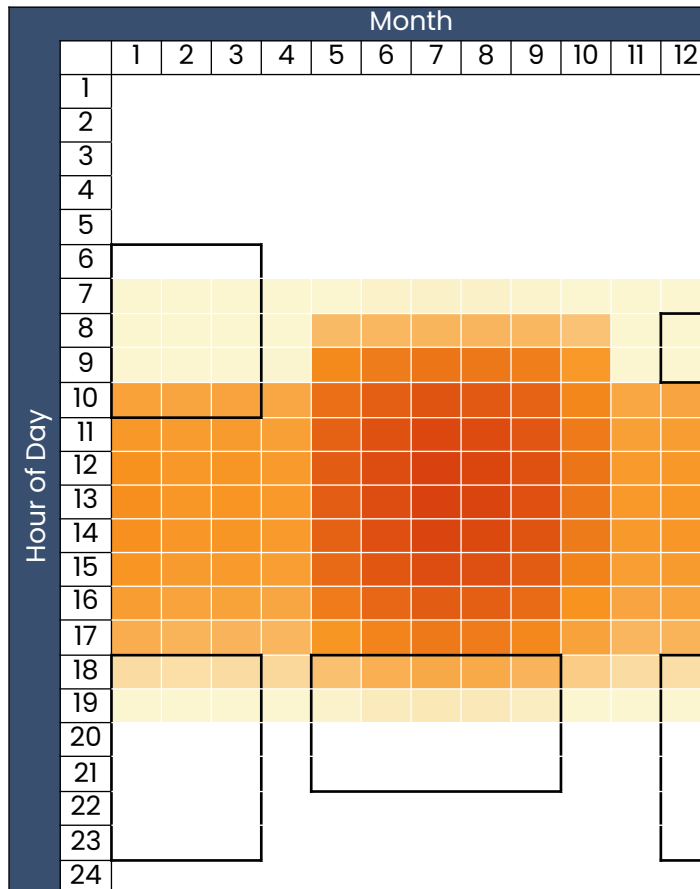
RA Risk Period

*percentiles based on average month-hour output relative to all 8760 hours in the year

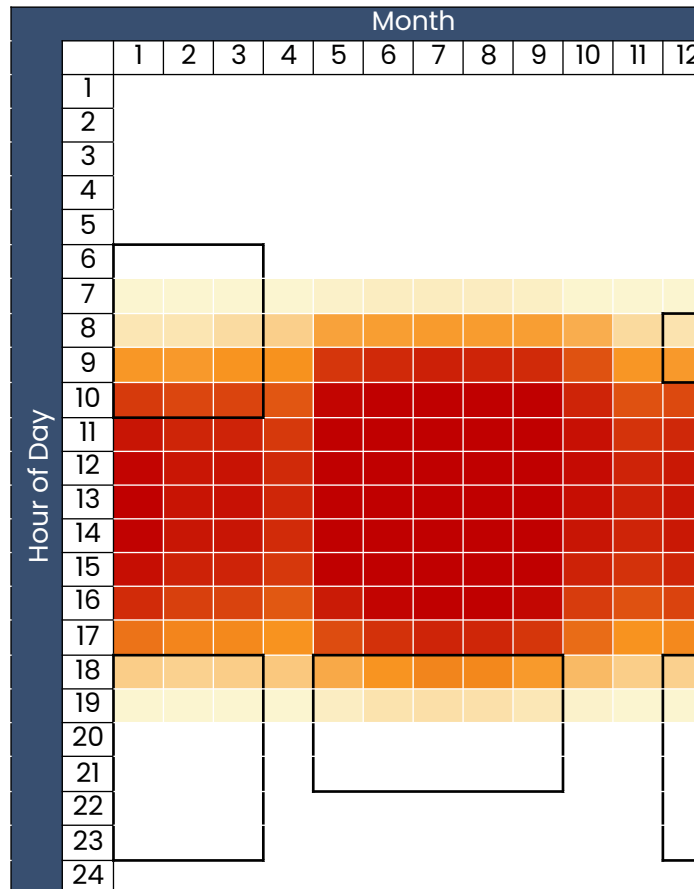
- Without deliverability caps, annual capacity factors increase from 29% to 35%
- During RA risk periods, this capacity factor increases from 34% to 37%
- Increase is most notable during summer afternoon risk periods

Solar profiles with and without deliverability caps

With Deliverability Caps



Without Deliverability Caps



Legend

90th percentile

50th percentile

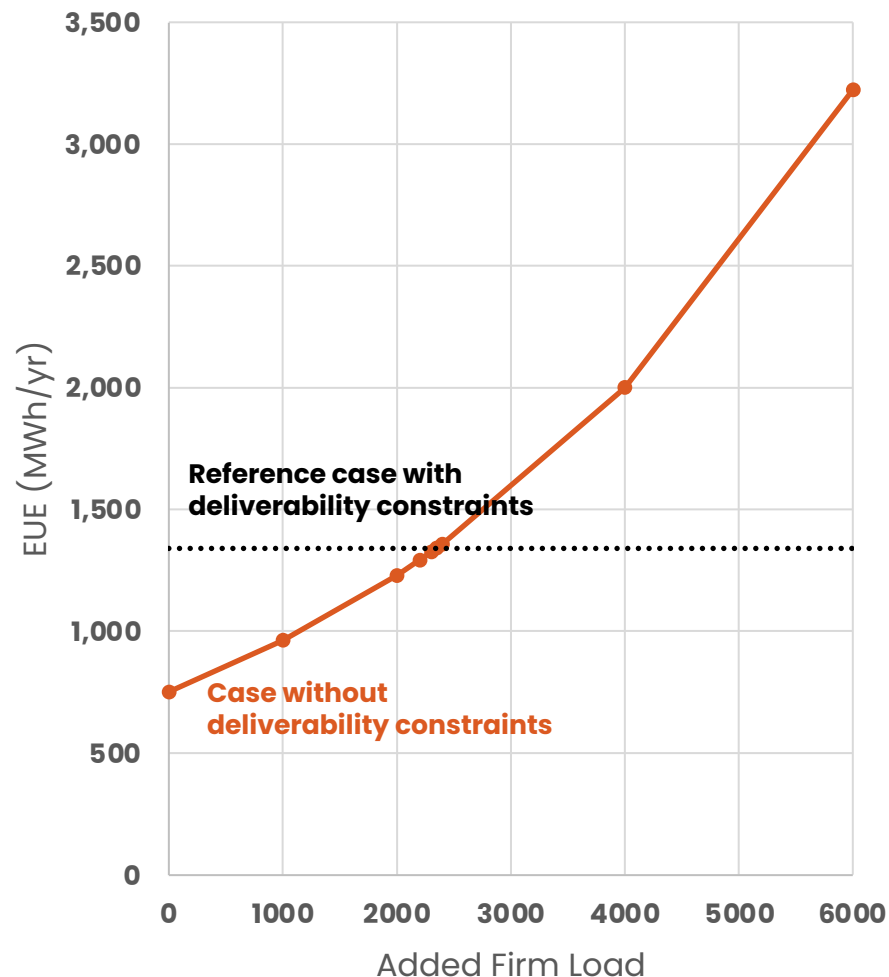
10th percentile

RA Risk Period

*percentiles based on average month-hour output relative to all 8760 hours in the year

- Without deliverability caps, annual capacity factors increase from 16% to 23%
- During RA risk periods, this capacity factor increases from 6% to 11%
- Increase is most notable during summer afternoon risk periods

Deliverability caps reduce 'firm capacity' by 2,350 MW



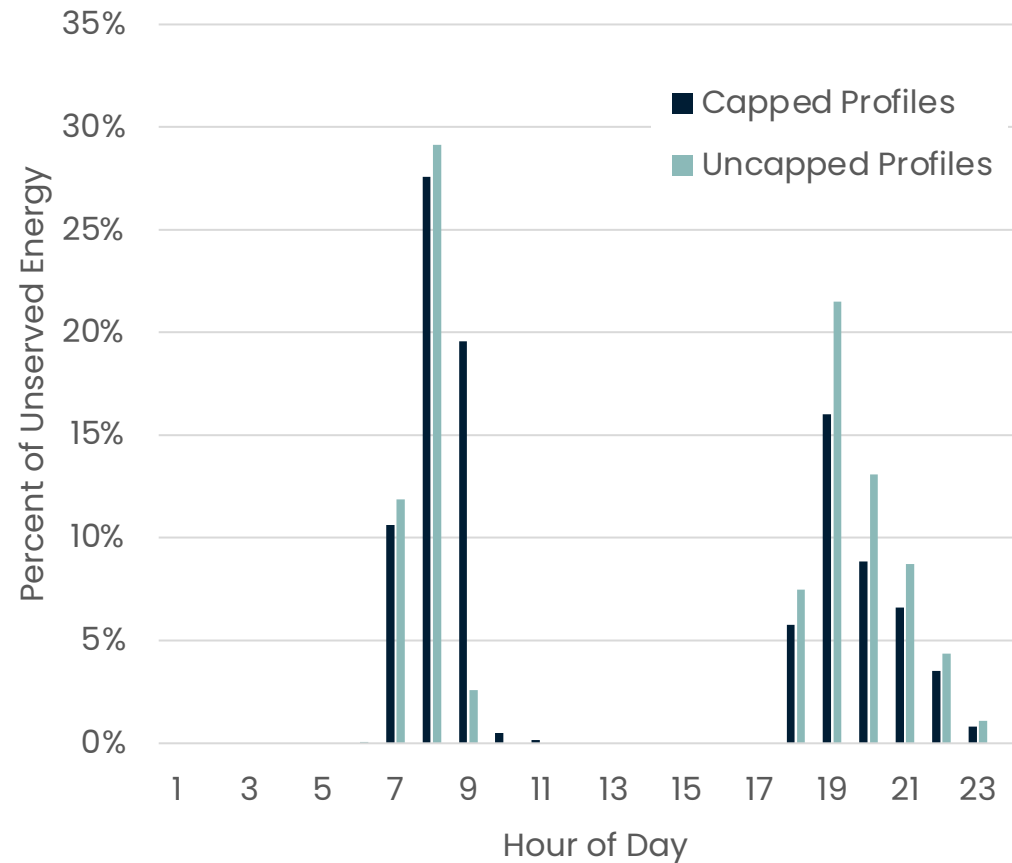
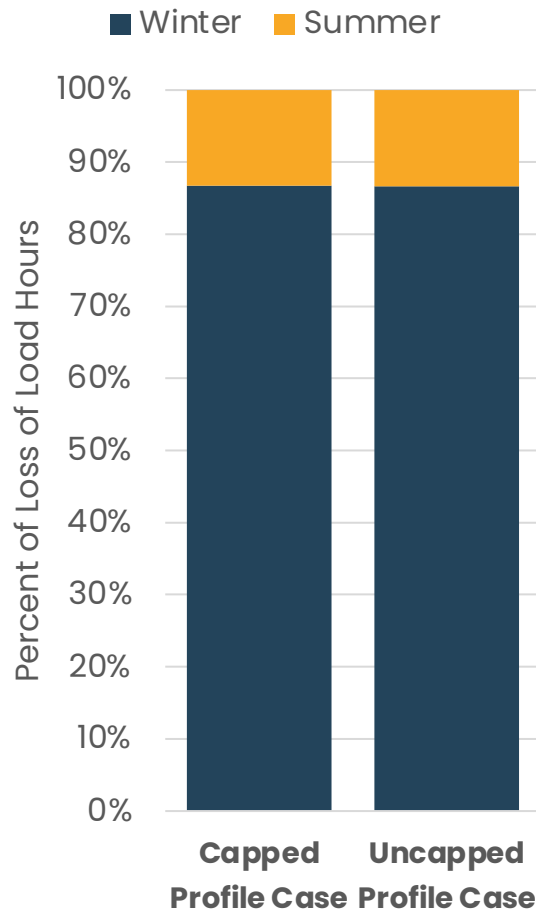
Model Run	Added Load (MW)	LOLE (days/year)	EUE (MWh/year)
Capped Profiles (calibrated to 0.1)		0.10	1,341
Uncapped Profiles (no change to load)		0.06	751
Uncapped +1000	1,000		963
Uncapped +2000	2,000		1,229
Uncapped +2200	2,200		1,292
Uncapped +2300	2,300		1,325
Uncapped +2350	2,350	0.11	1,342
Uncapped +2400	2,400		1,358
Uncapped +4000	4,000		2,000
Uncapped +6000	6,000		3,222

These two cases used for ELCC comparisons

- PJM model calibrated to 0.1 days/year LOLE with the wind and solar deliverability caps in place.
- When wind and solar profiles are adjusted to remove deliverability caps, LOLE is reduced to 0.06 days/year LOLE, and EUE is reduced by 44%.
- This equates to 2,350 MW of additional load being supported or a 2,350 reduction of firm capacity needs.

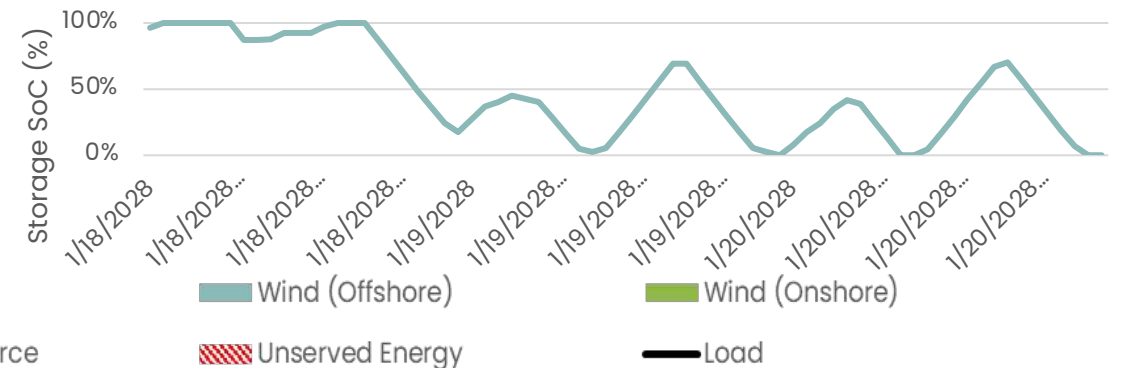
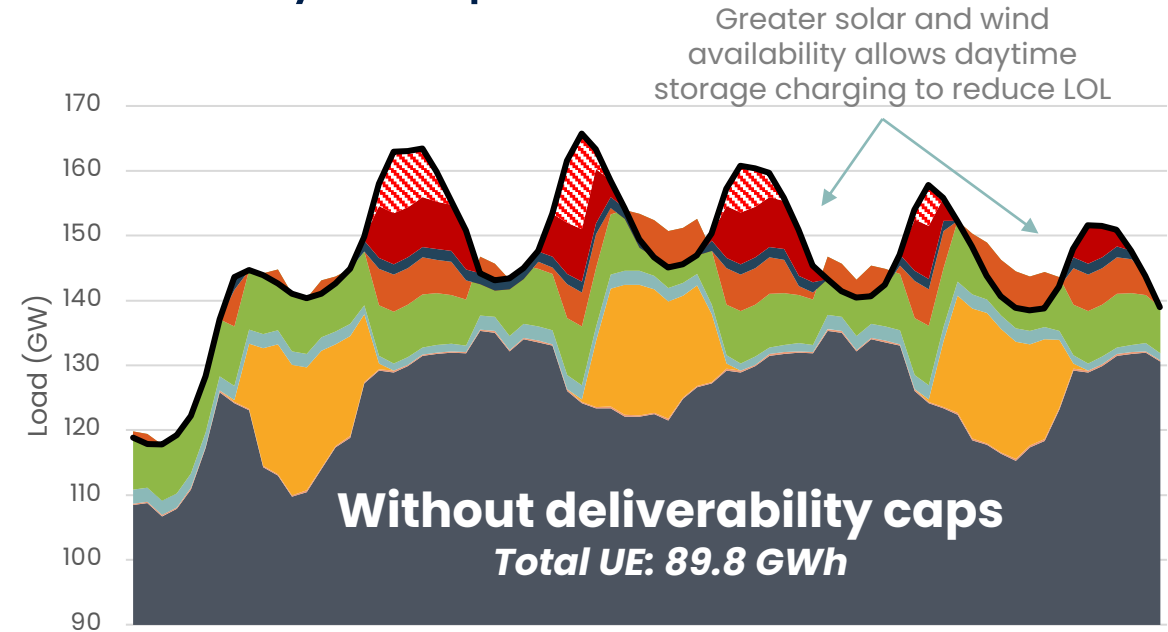
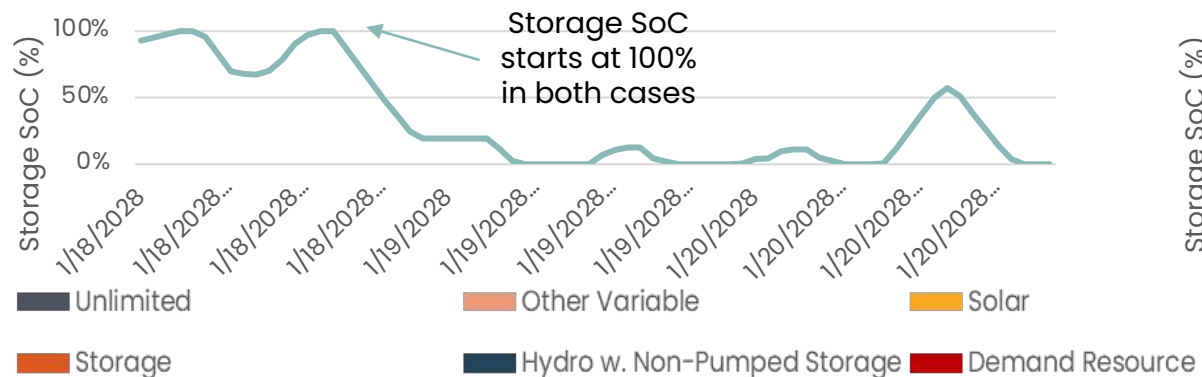
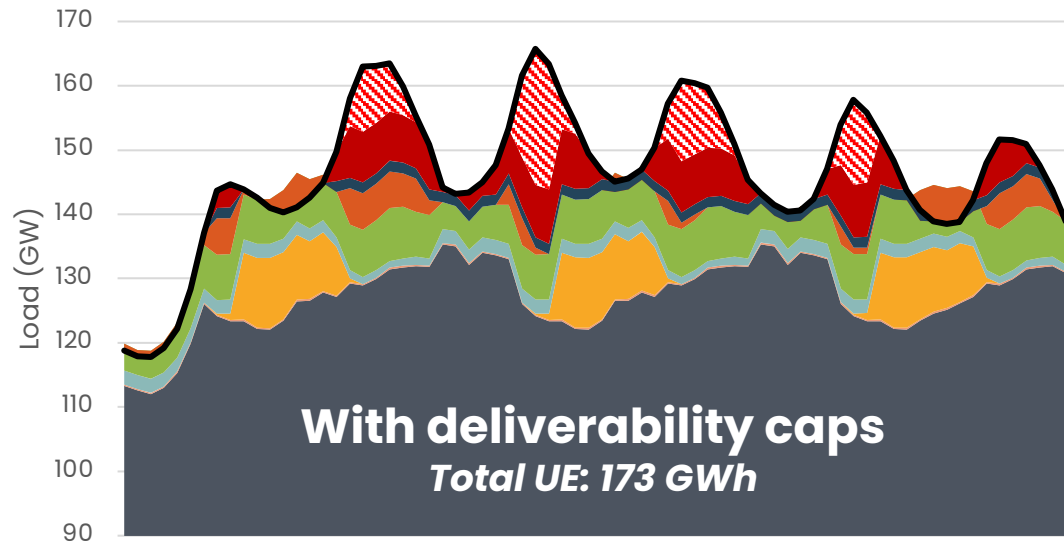
In other words, embedding deliverability caps in the hourly profiles increases the firm capacity requirement in PJM by 2,350 MW

Cases without deliverability caps see similar risk periods

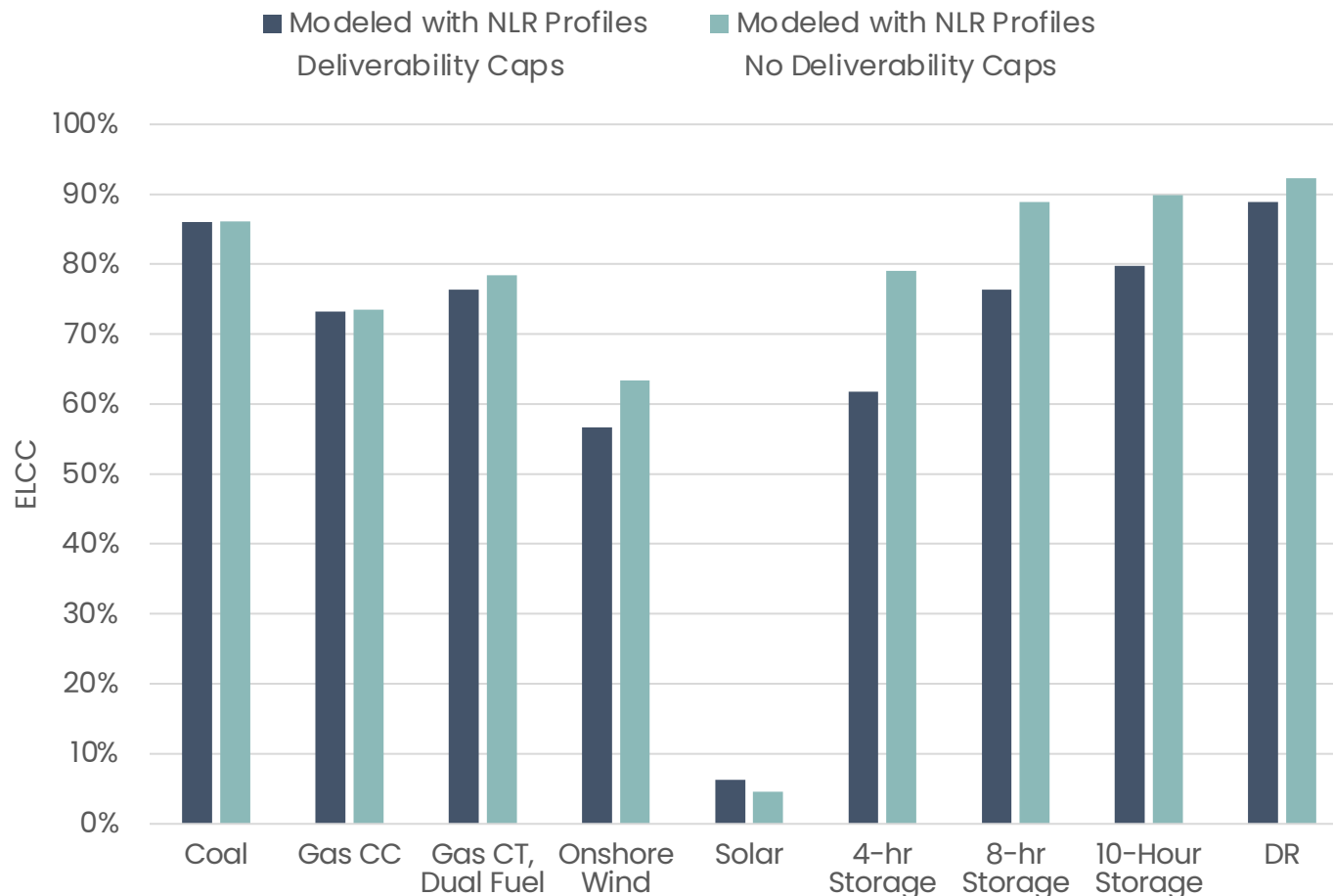


- Results show risk after recalibrating to 0.1 days/year LOLE.
- No change to seasonal risk profile between cases with and without deliverability caps.
- When removing deliverability caps, (winter) morning risk period is shortened with relatively more unserved energy in evenings.

Example dispatch with (left frame) and without (right frame) deliverability caps



Deliverability caps affect accreditation of other resources, not just wind and solar



- Deliverability caps have limited or no effect on thermal resource accreditation, as expected.
- Without deliverability caps in place, wind and solar see only modest changes to ELCC. Increase in wind due to additional availability during RA risk periods.
- Energy storage has a large increase in ELCC due to the increased energy that is available during off-peak periods.
- This shows that resource adequacy is affected by both capacity limitations (deliverability) and energy limitations during risk periods.

Key Findings and Lessons Learned

GridLAB



TELOS
ENERGY



Contrasting approaches to deliverability in RA assessments

Both are wrong, but getting closer to operational reality is possible.



ISO Approach

- Excludes energy-only resources.
- Assumes **deliverability caps on solar and wind** 8,760 hours of the year.
- Distinct summer and winter deliverability caps.
- Reflects actual historical solar and wind curtailments.

Capping deliverability across all hours

underestimates available energy preceding and during RA shortfall events.

Other Options (Closer to Operational Reality)

- 1 Incorporate **historical resource curtailments** instead of deliverability caps.
- 2 Include **energy-only resources in the RA model** or **assign ERS-resource-driven network “headroom” to firm resources** as higher deliverability caps, identified by removing or curtailing ERS resources in deliverability studies to reflect their actual operational treatment during RA events.
- 3 Assess RA risk periods in nodal 8,760 production cost modeling to identify congestion-driven “curtailment” to **incorporate event-specific, deliverability-curtailment performance into the RA model** instead of static seasonal deliverability caps.*
- 4 Embed **nodal transmission constraints** directly into the probabilistic RA assessments used for accreditation.

* Unlike traditional SCED modeling, non-firm wind and solar can be forced to bid after firm transmission resources to ensure curtailment reflects firm transmission rights.

This Study's Approach

- Excludes energy-only resources.
- Assumes **full deliverability of solar and wind** 8,760 hours of the year.
- Models wind and solar at effective nameplate capacity and expected generation based on weather.
- Assumes no curtailment.

Assuming full deliverability across all hours overestimates available energy preceding and during RA shortfall events.

Key Findings and Lessons Learned

Key Findings on PJM ELCC Analysis

- Deliverability caps currently increase firm capacity requirements in PJM by 2,350 MW
- Without deliverability caps in place, wind and solar see only slight changes to ELCC and thermal resources see no changes
- However, energy storage has a larger increase in ELCC due to the increased energy that is available during off-peak periods

Lessons Learned

- Deliverability in resource adequacy assessments changes the amount of surplus energy available, both during risk periods and before risk periods
- In periods prior to RA risk periods, surplus energy could be used by storage resources and shifted to periods of tighter supply, but resources are limited in output based on perceived transmission constraints
- It is not just the peak load conditions, traditionally evaluated in transmission deliverability, that matter for RA
- As wind, solar, and storage resource capacity grows, this effect will increase in magnitude and should be reevaluated proactively

Recommendations for Incorporating Deliverability in RA Assessments

Include all physically interconnected resources in RA models

- Model the full set of resources operating on the grid, including energy-only (ERIS) resources, not just those with capacity-deliverable (NRIS) status
- Excluding operating resources produces an incomplete picture of system reliability and inflates capacity requirements

Use actual resource availability, not blanket deliverability caps

- Reflect full operating capability of each resource in hourly profiles
- Incorporate historical curtailment where it has occurred, rather than applying static seasonal caps across all 8,760 hours

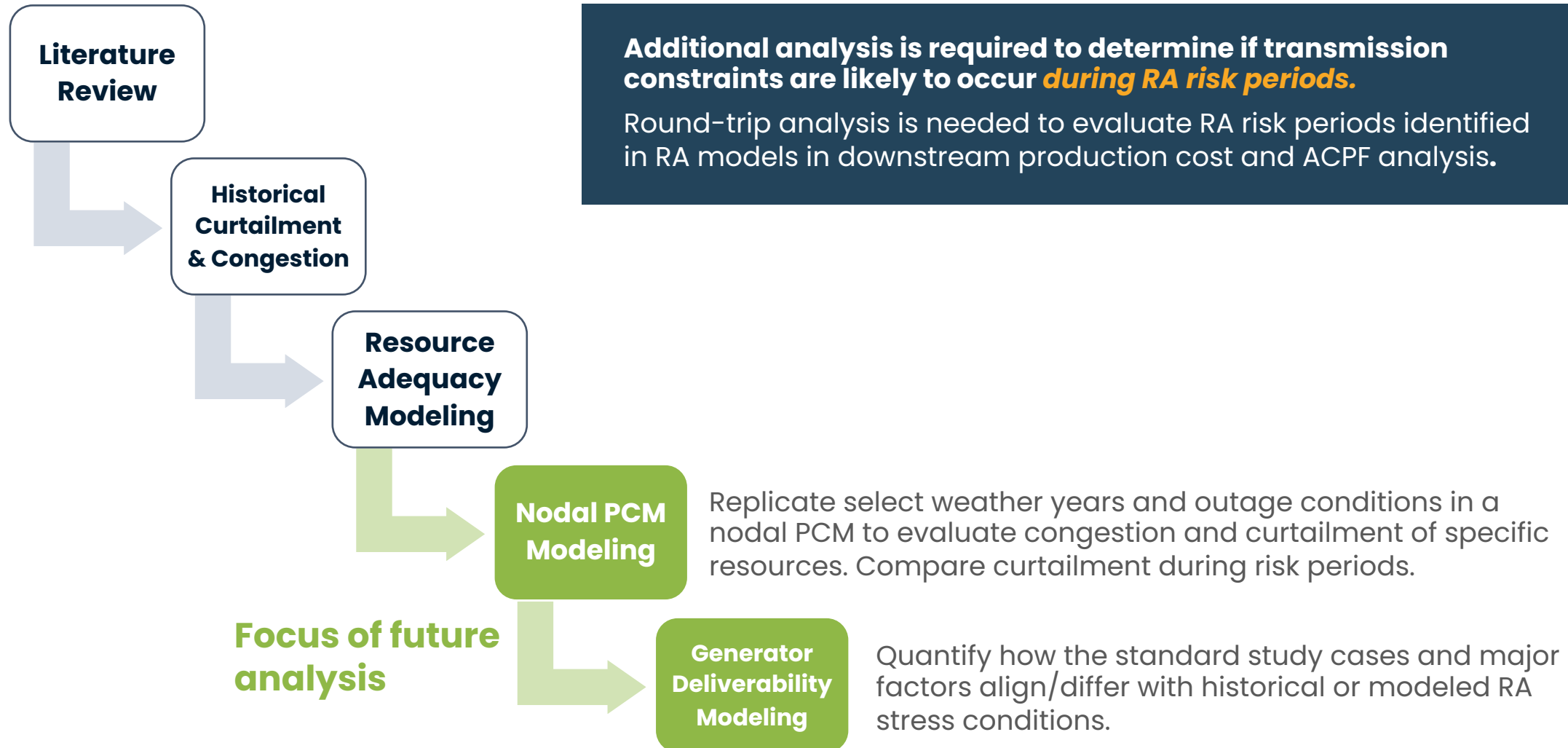
Simulate forward-looking curtailment with appropriate tools

- Where projected curtailment estimates are needed, use hourly security-constrained production cost models that capture locational and temporal specificity
- Avoid assuming simultaneous curtailment of all resources within a class or zone

Apply deliverability adjustments to ELCC results, not input profiles

- Capping input profiles distorts when risk periods occur, how much energy is available for storage charging, and how other resources are accredited
- Adjusting the final ELCC value preserves the integrity of the reliability simulation while still accounting for transmission limitations in capacity valuation

Next Steps



This presentation is based on a report,
“Understanding the linkage between transmission
deliverability and resource adequacy”

Project materials are available at:
gridlab.org/Deliverability_and_resourceadequacy
and gridlab.org/publications

GridLAB



TELOS ENERGY

