When and How Much?

Demand Response (DR) Utilization Dynamics in MISO and PJM

Prepared for Google

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Energy+Environmental Economics

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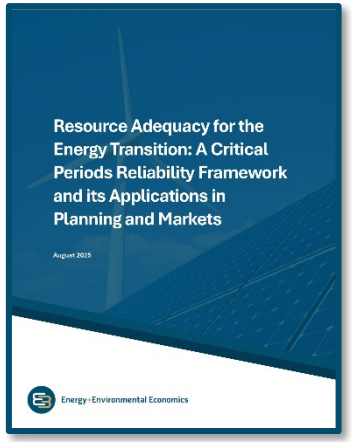
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About E3

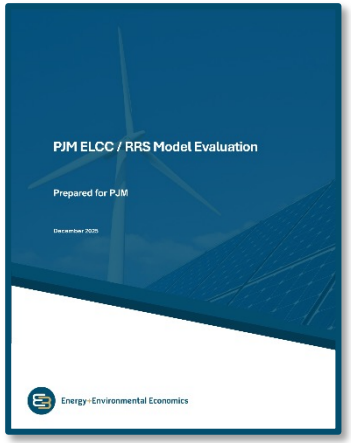
- Founded in 1989, E3 is a leading energy consultancy with offices in San Francisco, Boston, New York, Chicago, Denver, and Calgary
- E3 works extensively with utilities, developers, government agencies, and environmental groups to inform strategy and key decisions
- Our experts lead rigorous technical analyses, develop innovative methods to study new problems, and provide critical thought leadership to the industry
- E3 is an industry leader in studying resource adequacy needs in the transition to a decarbonized grid



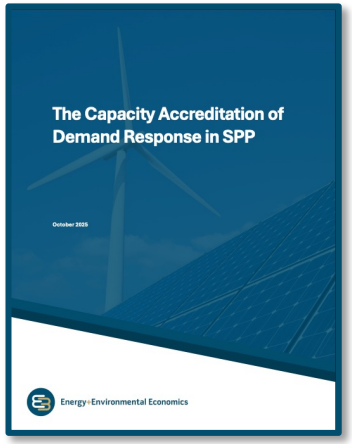
[A Critical Periods Reliability Framework and its Applications in Planning and Markets]
(E3 whitepaper)



[PJM ELCC / RRS Model Evaluation]
(prepared for PJM)



[The Capacity Accreditation of Demand Response in SPP]
(sponsored by Google)



Demand Response Use for Grid Reliability

Introduction

+ **High load growth has increased attention to the role of load flexibility in supporting system reliability**
  - Many systems today use demand response (DR) programs to provide capacity, particularly when the lead time for building new resources can be many years
+ **Industry literature continues to assess the capacity value, measurement & verification approaches, and utilization dynamics of flexible loads**
  - E3's 2025 study with Google evaluated the capacity value of DR in SPP using Effective Load Carrying Capability (ELCC), as well as DR utilization dynamics
    - The 2025 study demonstrated DR has high capacity value in SPP when available for up to 100 hours/year; daily call limits (4 hours/day vs. 10 hours/day) have a more consequential impact on capacity value
    - This study, conducted in 2026, uses the same modeling framework, and its findings are consistent with E3's 2025 study
+ **This study further explores DR utilization dynamics by addressing:**
  1. When is DR needed for reliability?
  2. How often is DR needed?
  3. What key factors drive changes to DR utilization?



RECAP

A loss-of-load-probability model designed to study electric system reliability dynamics

- **E3 used the RECAP modeling tool to conduct all analysis in this report**
- **RECAP is a loss-of-load-probability model developed and maintained by E3 to study the reliability dynamics of electricity systems as they evolve**
  - RECAP simulates the operations of the electricity system under thousands of scenarios to capture different conditions
- **RECAP was used to simulate both MISO & PJM systems across multiple scenarios**
  - The frequency, timing, and magnitude of DR use are examined within and across the scenarios
  - The scenarios demonstrate key drivers of DR utilization

Temperature and Load Artificial Neural Network Simulation

Capturing hourly load conditions under mild and extreme historical weather

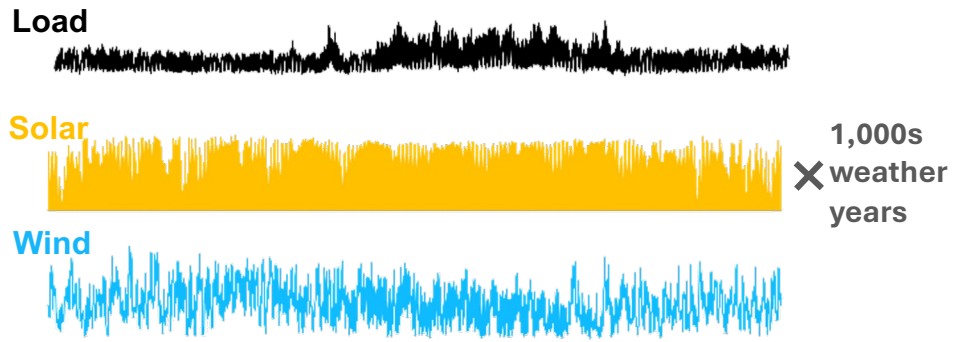


Operational Module

Dispatching resources based on outage characteristics, weather dependency, state of charge availability, and demand-side management

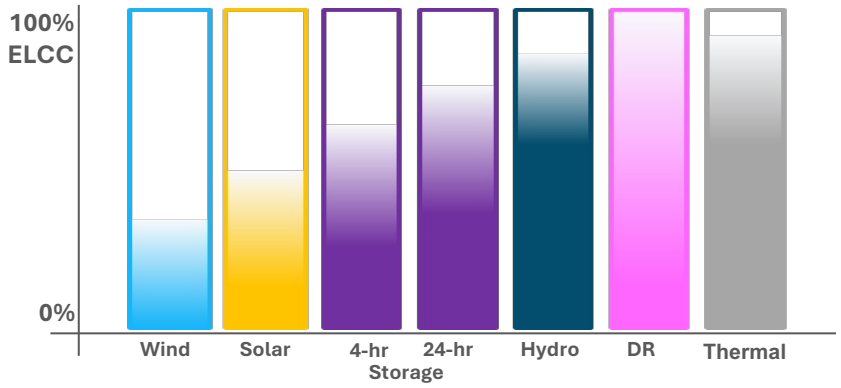


System Reliability: simulates the operations of the electricity system under thousands of scenarios to capture different conditions



Resource Capacity Value: measures a resource's ability to contribute to reliability under a marginal or average ELCC methodology

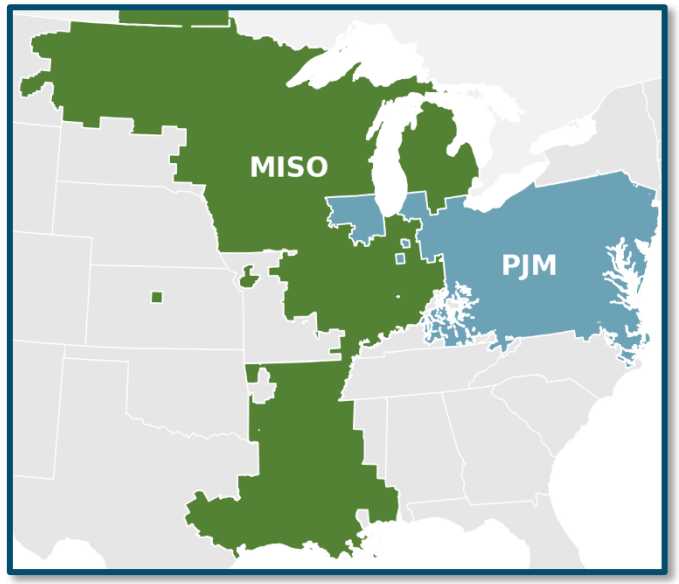
Illustrative ELCC Values Across Technologies



Description of 2030 Study Scenarios

MISO & PJM

+ **This study identified two key drivers of DR use:**
  1. **Capacity Surplus/Shortfall:** The system's capacity position relative to the target reliability standard (1 day in 10 years loss of load expectation)
  2. **DR Penetration:** The size (GW) of the DR fleet
+ **E3 developed six scenarios across both MISO and PJM for 2030 to understand Reliability DR utilization dynamics**
  - High DR scenarios show how usage increases as the DR fleet size increases
  - Shortfall scenarios show the impact of a system capacity/reliability deficit due to accelerated load growth
  - "Reliability DR" represents DR registered to be solely dispatched to support system reliability[1,2]



MISO 2030		
Scenario	**Reliability DR Penetration**	**Capacity Position**
Base	**14 GW**	**At Target Reliability** *1 day in 10 years*
High DR	**17 GW**	**At Target Reliability** *1 day in 10 years*
Shortfall	**14 GW**	**Capacity Shortfall** *5 GW short*

PJM 2030		
Scenario	**Reliability DR Penetration**	**Capacity Position**
Base	**8 GW**	**At Target Reliability** *1 day in 10 years*
High DR	**13 GW**	**At Target Reliability** *1 day in 10 years*
High DR + Shortfall	**17 GW**	**Capacity Shortfall** *6.8 GW short*

1. In MISO, Reliability DR includes providers solely registered as Load Modifying Resources and Emergency Demand Response. In PJM, Reliability DR includes providers solely registered as Emergency/Pre-Emergency Load Response and Price Responsive Demand. DR providers registered for economic participation options are modeled as separate Economic DR (1 GW in MISO, 4 GW in PJM) which are dispatched before Reliability DR, unless dispatch order impacts reliability.

Demand Response Utilization Dynamics in MISO & PJM

Results Summary

How often DR is needed is inherently uncertain; however, regional weather, resource mix, and resource adequacy are fundamental drivers of DR use

Key Findings:

1. DR is used during hours with high loads and low supply
2. DR use differs by season and time of day
3. DR use depends on system characteristics: Usage increases with DR penetration and depends on whether the system has a capacity deficit
4. DR use depends on what resource performance and weather conditions arise, so annual usage cannot be known in advance
5. The DR fleet is needed more than any individual DR load
6. Loads providing DR could shift demand to neighboring regions that are able to absorb higher load

MISO 2030

Scenario	Annual DR Utilization (hours/year)		
	Mild Year *10th Percentile*	Average Year *Mean*	Severe Year *90th Percentile*
Base	1	11	26
High DR	3	19	40
Shortfall	9	33	65

PJM 2030

Scenario	Annual DR Utilization (hours/year)		
	Mild Year *10th Percentile*	Average Year *Mean*	Severe Year *90th Percentile*
Base	0	2	5
High DR	0	3	10
High DR + Shortfall	0	14	39

Key Findings



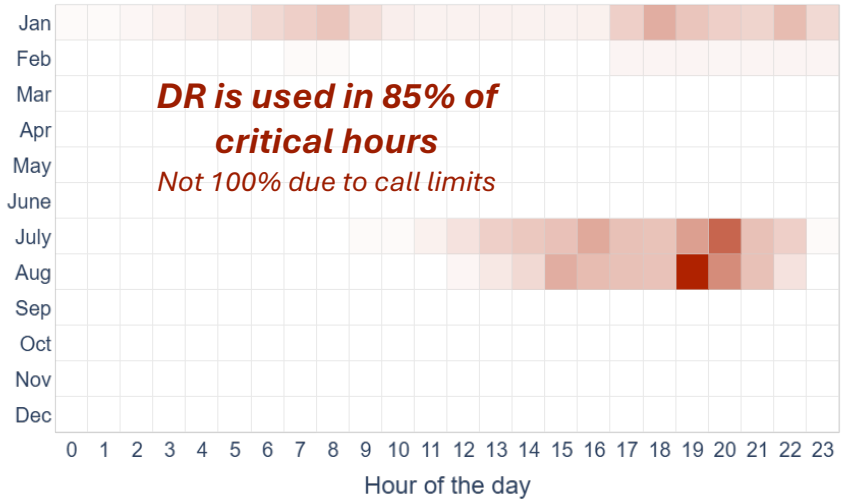
Energy+Environmental Economics

DR is used during hours when loads are high and supply is low

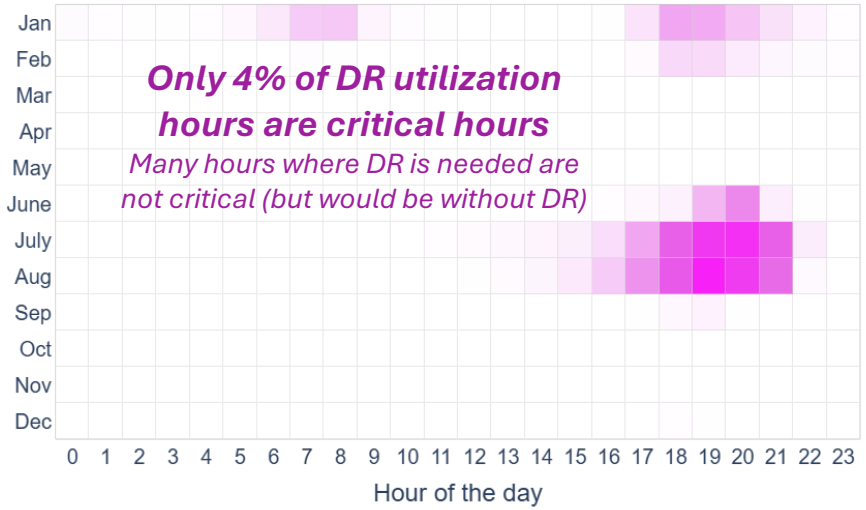
MISO 2030 Base

*An hour is **critical** if adding load **reduces system reliability***

Critical Hours



DR Utilization Hours



*In MISO, DR is mostly needed during **non-critical hours***

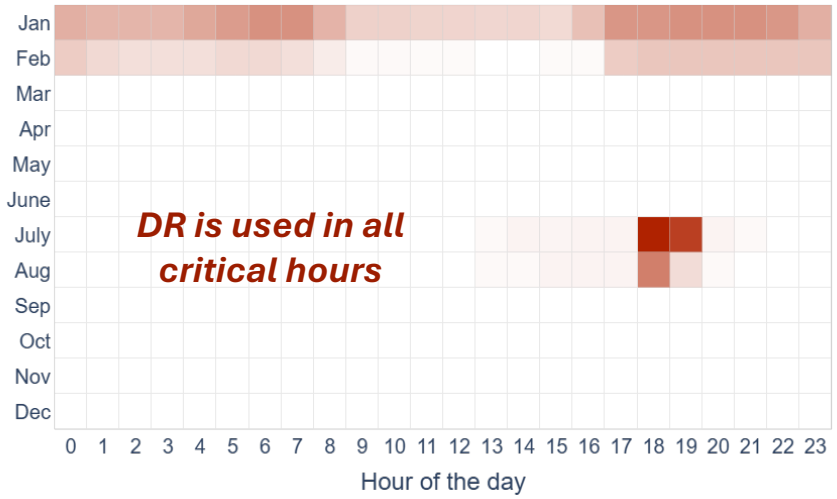
+ **Critical hours show when the system is most likely to experience reliability risk**
  - Critical hours have been shifting from solely peak load hours, due to growing risks of low generation events caused by renewable, storage, or thermal resources
+ **DR is used during all critical hours, unless prevented by a call limit**
  - In MISO, each DR provider is only required to perform for 4 hours per day and 16 calls per year, preventing the DR fleet from being used in 15% of critical hours
+ **DR is also needed for reliability during non-critical hours**
  - Reliability DR is needed when supply resources and economic DR are not enough to serve load
  - 96% of these hours are still not critical due to the significant fraction of the Reliability DR fleet that remains available and unused

In PJM, DR is used during all critical hours and other hours with high net load

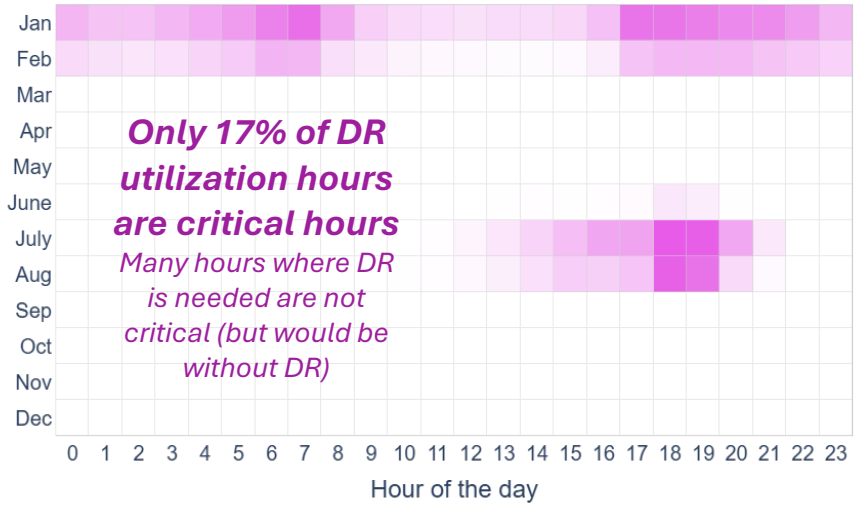
PJM 2030 Base

*An hour is **critical** if adding load **reduces system reliability***

Critical Hours



DR Utilization Hours



*Without **timing limits,** DR in PJM can be used **around the clock***

+ DR utilization in winter is spread across the day, while summer usage is more concentrated

- DR use begins in near-critical hours and continues as conditions become critical

+ Without limits on the number of DR calls, DR is used in 100% of critical hours as well as near-critical hours

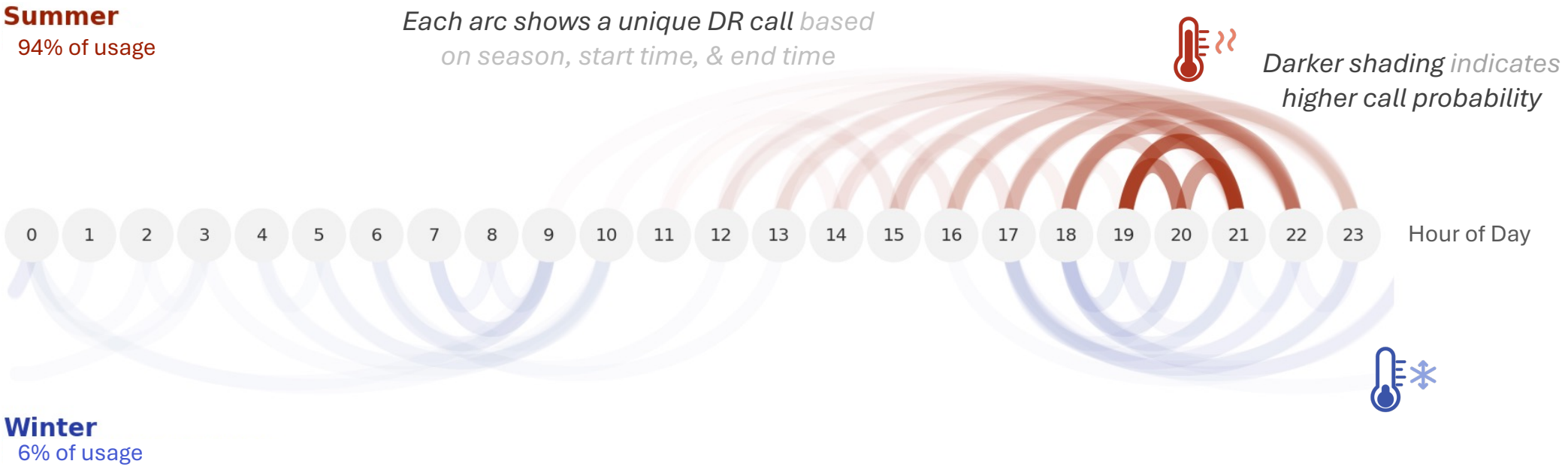
- A resource's capacity value (marginal ELCC) is equivalent to its average availability during critical hours[1]; call limits can reduce resource availability in hours when needed
- DR call limits do not impact capacity value if call limits remain high enough to cover system needs

1. For more information on capacity value measured as marginal Effective Load Carrying Capability (ELCC), see: https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/elccstf/2025/20251209/20251209-item-02---pjm-elcc-rrs-model-evaluation---e3-report.pdf

DR use differs by season and time of day, with many summer evening calls

MISO 2030 Base

Timing and Duration of DR Calls

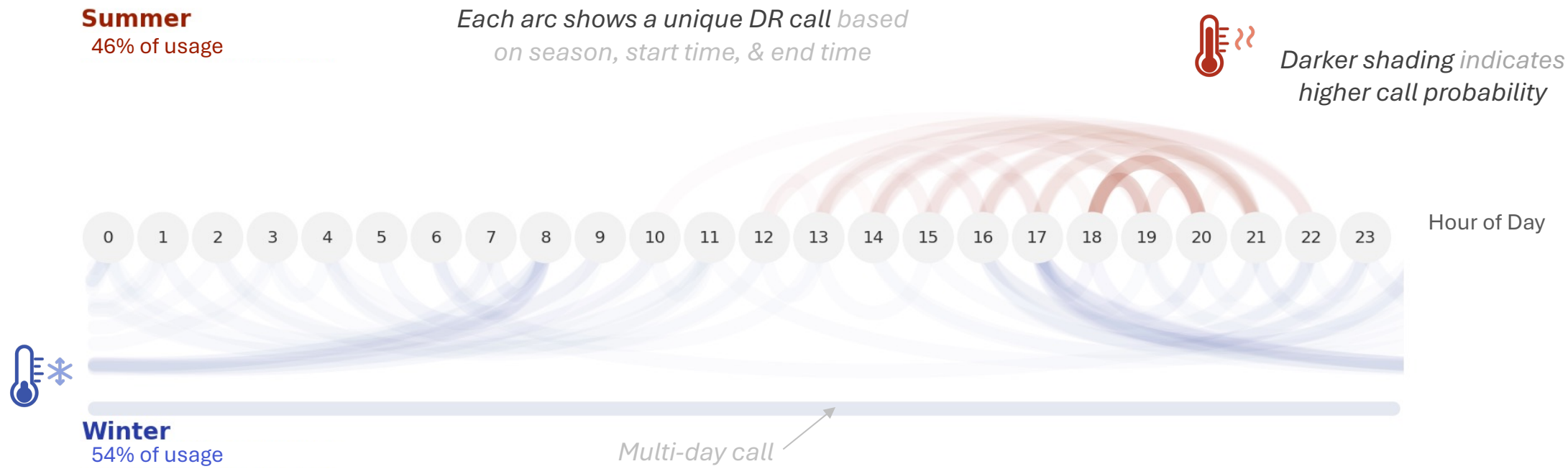


+ **In MISO, DR is primarily used in summer, particularly between 6 and 10pm**
  - DR is used on hot summer days when cooling loads are high
  - DR use is concentrated in the evening periods as solar generation declines and load remains high
+ **DR is used less frequently in winter, but usage stretches from evening to morning periods**
  - Winter DR use is driven by high heating loads during severe temperature drops in winter storms

DR use differs by season and time of day, and winter calls tend to last longer

PJM 2030 Base

Timing and Duration of DR Calls

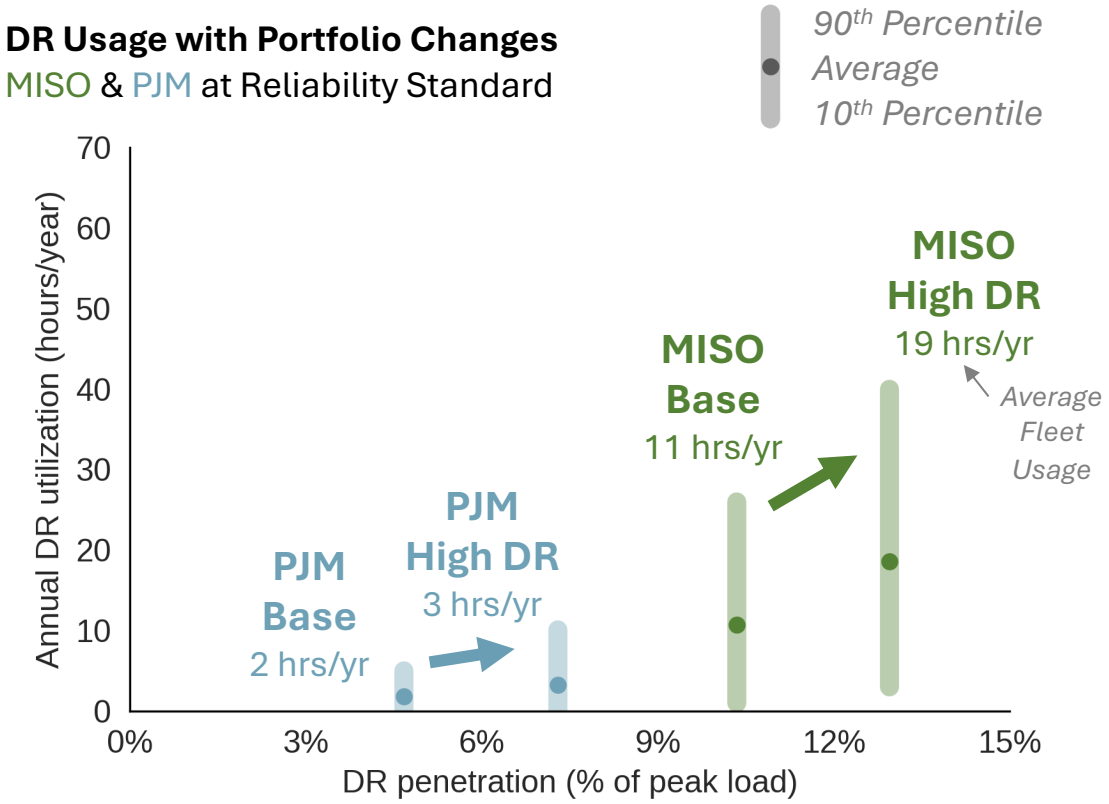


+ **A large share of PJM DR use happens in winter, due to the region's resource mix and weather dynamics**
  - DR use is triggered by winter storms driving long periods of high load and supply outages
  - DR is also used during summer heatwaves, across a narrower set of hours with high load net of supply
+ **Since DR in PJM does not have call limits, DR can be used across multiple days**
  - Multi-day calls include a 1-in-1,000-year event with 64 hours of continuous DR use in winter

DR use depends on system characteristics, especially DR penetration

MISO & PJM 2030

+ **All else equal, systems with more DR require its use more often**
  - At very high penetrations, DR use becomes part of "normal" system operations
+ **At target reliability, DR is used on average 2-19 hours per year, but this can more than double in high-usage years**
  - This utilization is low relative to many supply-side resources
  - DR is used less often in years with mild weather and more in years with severe weather and poor supply-side performance
+ **Weather dynamics and resource mix drive DR usage differences between MISO & PJM**
  - MISO needs DR during relatively frequent hot evenings in most summers
  - PJM has more system risk in winter, which has fewer "close calls" than summer and thus requires less frequent DR calls
  - Future changes to loads and resources can shift the timing and frequency of both critical hours and DR utilization hours

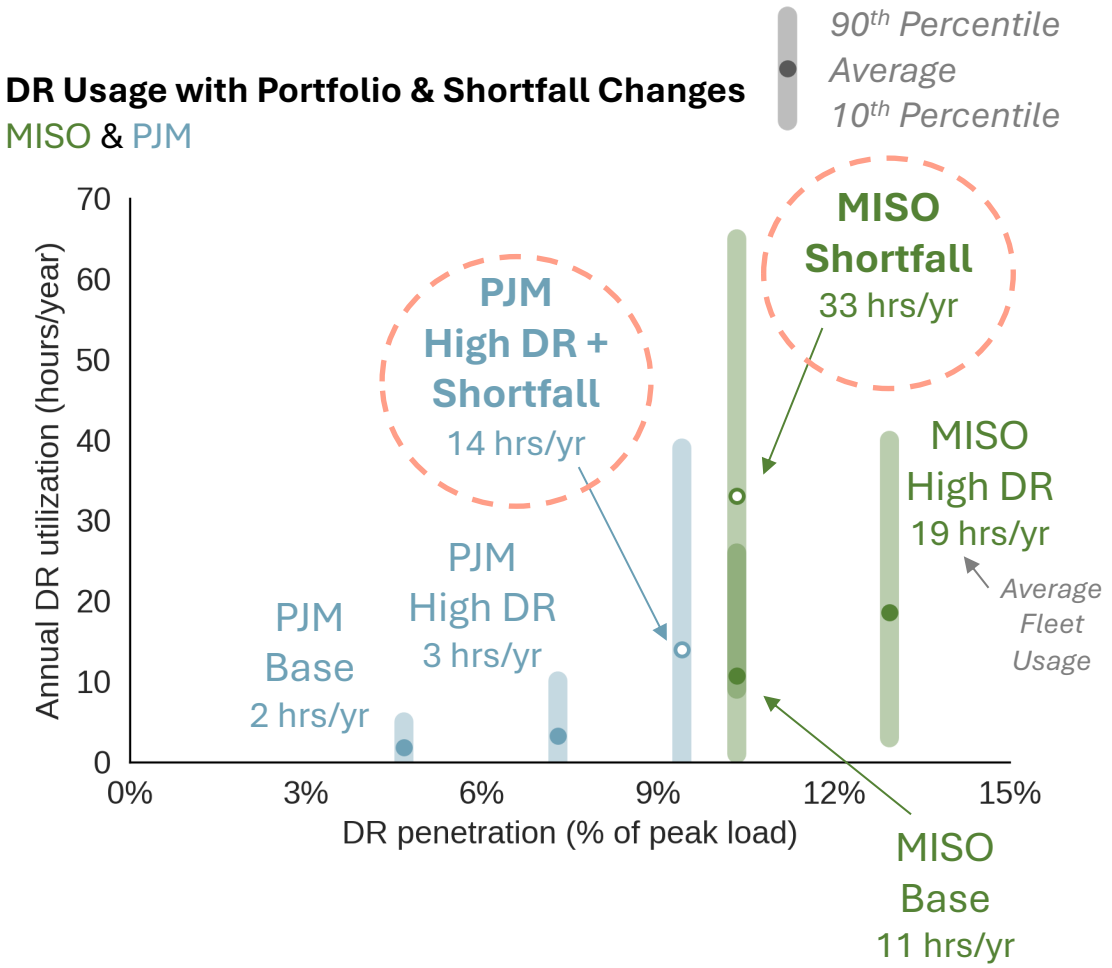


1. Results are only for DR used solely for reliability; additional DR that participates economically in MISO (1 GW) and PJM (4 GW) is modeled separately.

DR use is higher in systems with capacity shortfall

MISO & PJM 2030

+ **The shortfall cases show DR utilization if the system has a capacity deficit and is below target system reliability**
  - The current reliability standard in MISO & PJM is 1 day with loss of load every 10 years (0.1 days/year loss of load expectation)
  - Shortfall scenarios show DR use given a ~4% capacity procurement deficit in each region (5 GW in MISO, 6.8 GW in PJM)[1]
+ **Required DR utilization increases as reliability declines**
  - DR use rises to an average of 33 hours/year in MISO and 14 hours/year in PJM shortfall scenarios
  - Years with severe weather have more than double this DR use
+ **Annual DR use remains low compared to supply-side resources**
  - Even at high DR penetrations with a capacity shortfall, DR use is still lower than typical peaking units that often dispatch 100+ hours/year

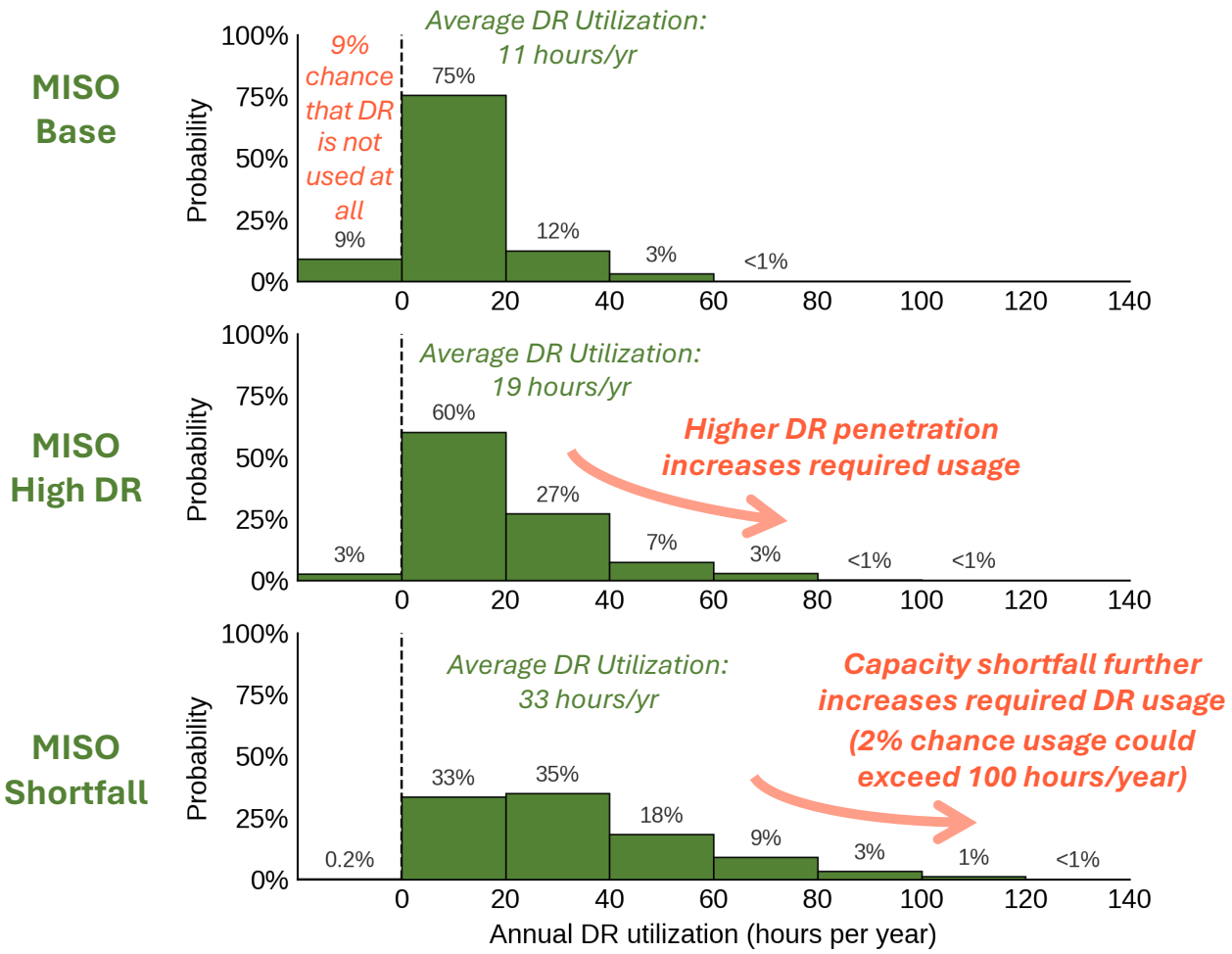


1. The PJM shortfall scenario extrapolates trends from the pre-RBP shortfall in the 2028/2029 PJM Base Residual Auction: https://www.pjm.com/-/media/DotCom/about-pjm/newsroom/2026-releases/20260714-pjm-capacity-auction-procures-138318-mw-of-generation-resources.pdf

DR use depends on what resource performance and weather conditions arise, so annual usage cannot be known in advance

MISO 2030

Annual DR Usage is Uncertain

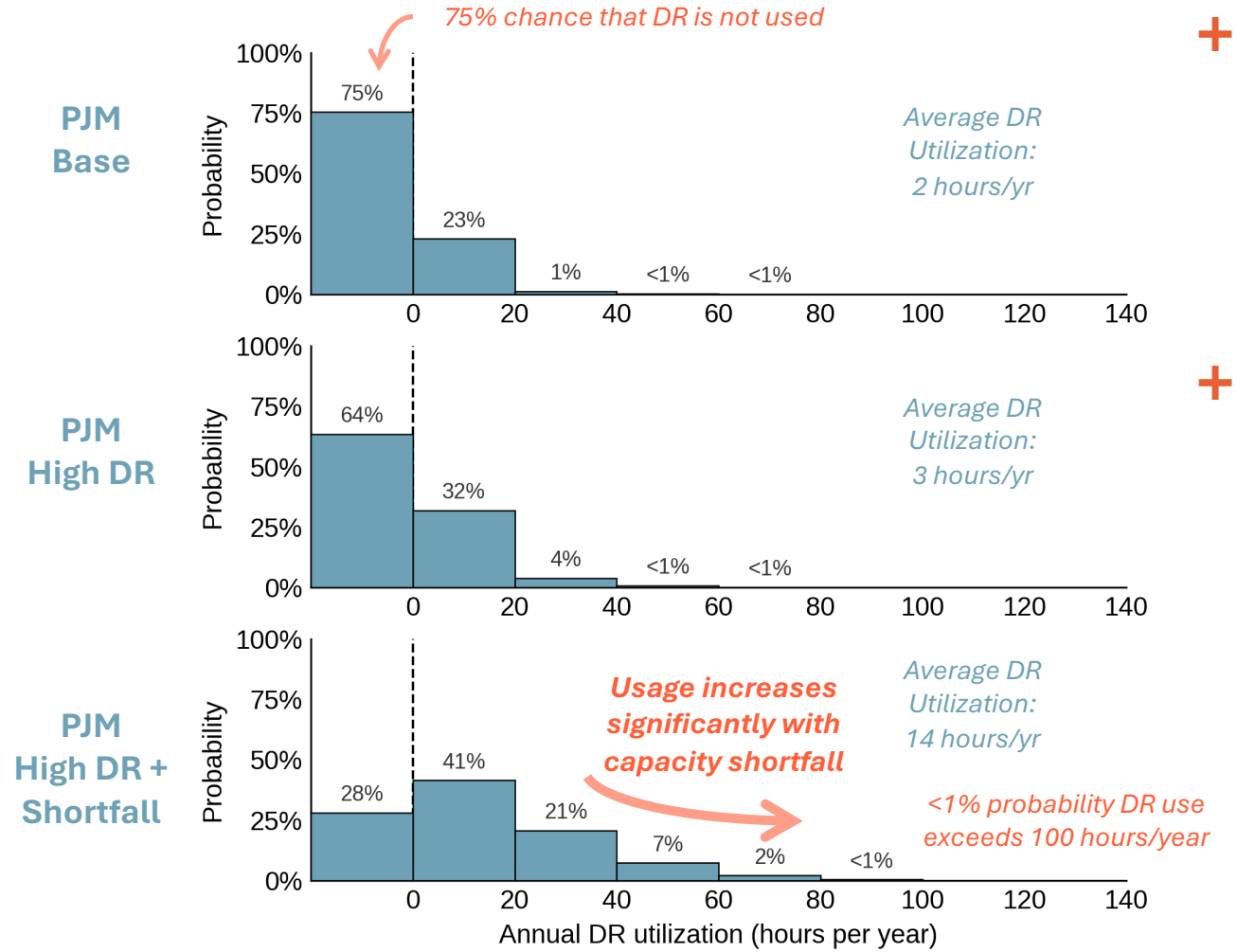


+ **While average DR utilization is 11 hours/year in the Base case, annual outcomes vary**
  - There is a 3% chance DR is used more than 40 hours/year, and a 9% chance it is not used at all
  - High utilization occurs in years with severe weather and poor resource performance
  - Years with mild weather have little to no usage
+ **With High DR penetration, there is only a 3% chance DR is not used, and higher outcomes become more likely**
  - Expected annual use grows to 19 hours, with an 11% chance it exceeds 40 hours
+ **Annual DR use becomes less certain under Shortfall conditions**
  - DR is used in almost every year, but with a much wider range of potential usage volumes
  - 2% chance DR use exceeds 100 hours/year

DR use depends on what resource performance and weather conditions arise; in some years, the DR fleet may not be needed at all

PJM 2030

Annual DR Usage is Uncertain



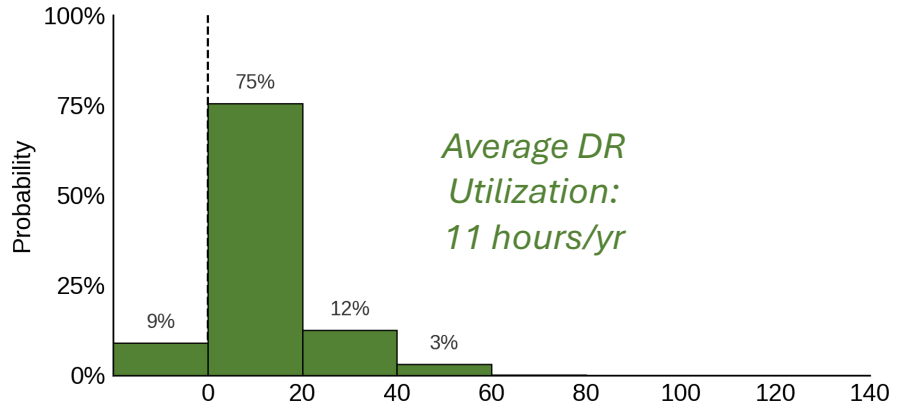
+ **In PJM, there are many years where DR is not needed at all**
  - This is because PJM's winter risk leads to fewer "close calls" than a summer-peaking system; in other words, PJM either has a severe winter event or it doesn't
+ **While DR is used less frequently in PJM than MISO, each DR call can last longer**
  - Severe winter conditions can result in multiple days of continuous DR use
  - The probability that DR is used more than 100 hours/year is low across all scenarios

The DR fleet is needed more than any individual DR load

MISO 2030 Base

Annual Utilization of DR Fleet and Single DR Load

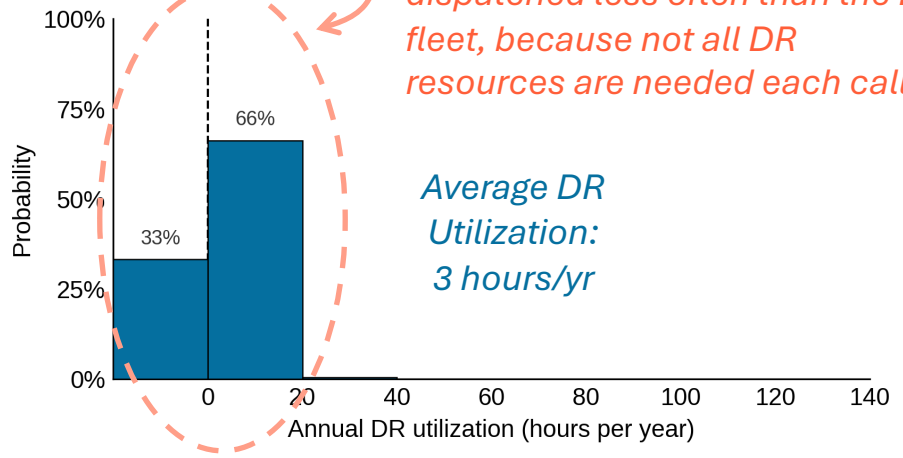
Overall DR Fleet



Average DR Utilization: 11 hours/yr

A single DR load can be dispatched less often than the DR fleet, because not all DR resources are needed each call

Individual DR Load



Average DR Utilization: 3 hours/yr

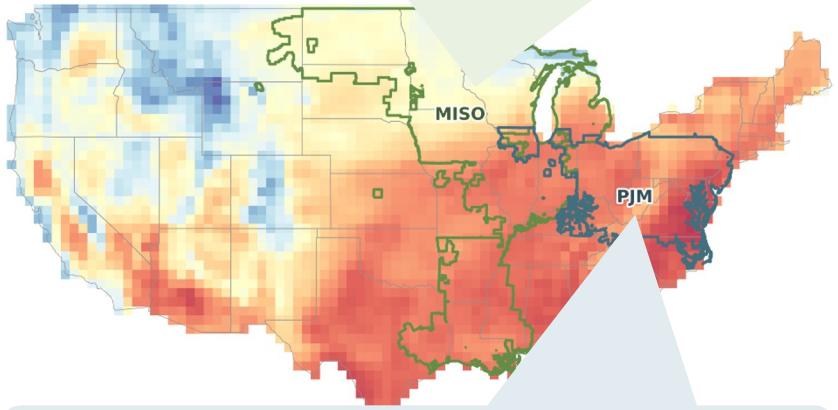
- **The DR fleet comprises many DR loads which are dispatched by the system operator**
- **Some DR utilization events require full dispatch of the entire fleet, while others only require partial dispatch**
- **If MISO calls DR loads by equitably rotating among all DR loads, any individual load can expect to be called an average of 3 hours/year, even though MISO is using DR 11 hours/year**
  - Alternatively, MISO could partially call all DR loads each time it calls DR, which means an individual load would expect to be called 11 hours/year but only partially curtailed in those hours

Loads providing DR could shift demand to neighboring regions that are able to absorb higher load

MISO & PJM 2030

Feasibility of Locational Load Shifting During DR Calls
MISO & PJM

When MISO needs DR, there is an 80-98% chance these loads can shift to PJM[1]



When PJM needs DR, there is a 48-74% chance these loads can shift to MISO[1]

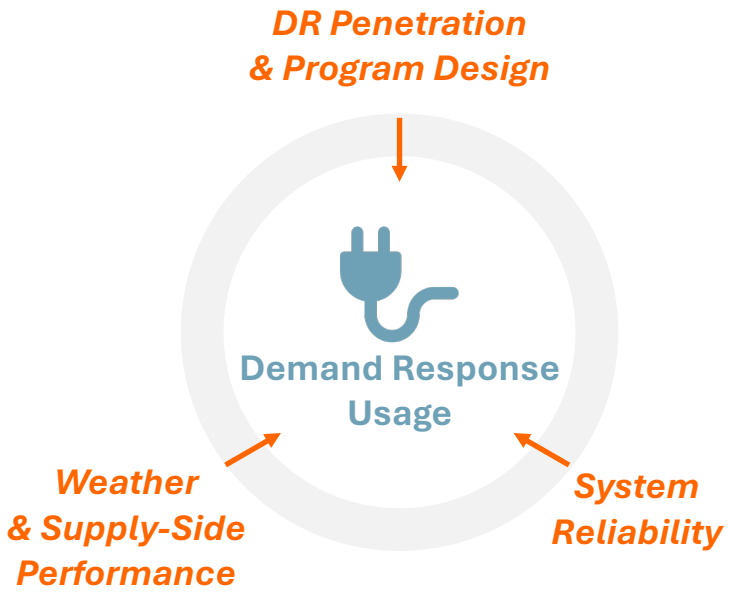
+ **Loads have opportunities to shift demand to neighboring regions when called to provide DR**
+ **For locational demand shifting to happen, the receiving region must be able to accommodate higher load at that time**
  - During continent-scale weather events, all supply resources can be needed across multiple regions at once, preventing locational demand shifting
+ **E3 performed integrated loss-of-load-probability modeling across both regions simultaneously to investigate this question**
+ **Opportunities for locational demand shifting are higher for systems that use DR in normal operations**
  - For example, MISO uses DR more often and in milder weather conditions than PJM; this gives MISO DR providers a higher chance of shifting demand to PJM across study scenarios than the reverse
  - Chances for shifting demand to regions with a capacity shortfall are lower, since those regions are less likely to have available supply
+ **Locational demand shifting also requires types of load with appropriate flexibility and coordination capabilities**

1. Probabilities show the chance that neighboring market can absorb higher load; see appendix for more details
2. Figure shows average 2m air temperature on June 24, 2025 from NASA POWER (power.larc.nasa.gov)

Demand Response Utilization Dynamics

Key Findings

What Determines DR Usage?



1. **DR is used during hours with high loads and low supply**
   - DR is needed for reliability in more than peak-load and critical hours
2. **DR use differs by season and time of day**
   - In MISO & PJM, summer DR calls are shorter and more concentrated between 6 and 10pm; winter DR calls are spread across more hours but occur less frequently
3. **DR use depends on system characteristics: Usage increases with DR penetration and depends on whether the system has a capacity deficit**
   - Systems that rely on more DR to maintain reliability must use it more often
   - Less reliable systems with a capacity deficit require higher utilization of all resources
4. **DR use depends on what resource performance and weather conditions arise, so annual usage cannot be known in advance**
   - Years with mild weather can have no DR usage; DR may be used up to call limits in years with severe weather and poor supply performance, if call limits are in place
5. **The DR fleet is needed more than any individual DR load**
   - Not all providers are needed each time the DR fleet is used
6. **Loads providing DR could shift demand to neighboring regions that are able to absorb higher load**
   - If locational demand shifting can be coordinated and there is available supply in the receiving region

Appendix



Energy+Environmental Economics

About RECAP

+ RECAP simulates time-sequential electric system dispatch over thousands of years

Inputs

Load
- *Hourly load for many weather years*

Dispatchable Generation
- *Capacity*
- *FOR*
- *Maintenance*

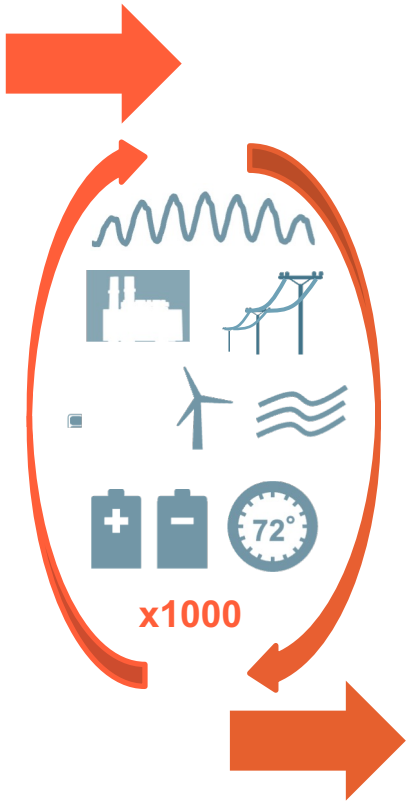
Renewables
- *Capacity*
- *Hourly generation profiles for many weather years*

Hydro
- *Hydro availability for many hydro years*
- *Max/min constraints*

Storage
- *Capacity*
- *Duration*
- *Round-trip efficiency*
- *FOR*

Demand Response
- *Capacity*
- *Max # of calls*
- *Duration of each call*

Flexible Load
- *Capacity*
- *Max hours of shift*



Outputs

LOLH
- *Loss of load hours*
- *Hrs/yr of total expected lost load*

LOLE
- *Loss of load expectation*
- *Days/yr of total expected lost load*

ALOLP
- *Annual loss of load probability*
- *% probability of having a single loss of load in any given year*

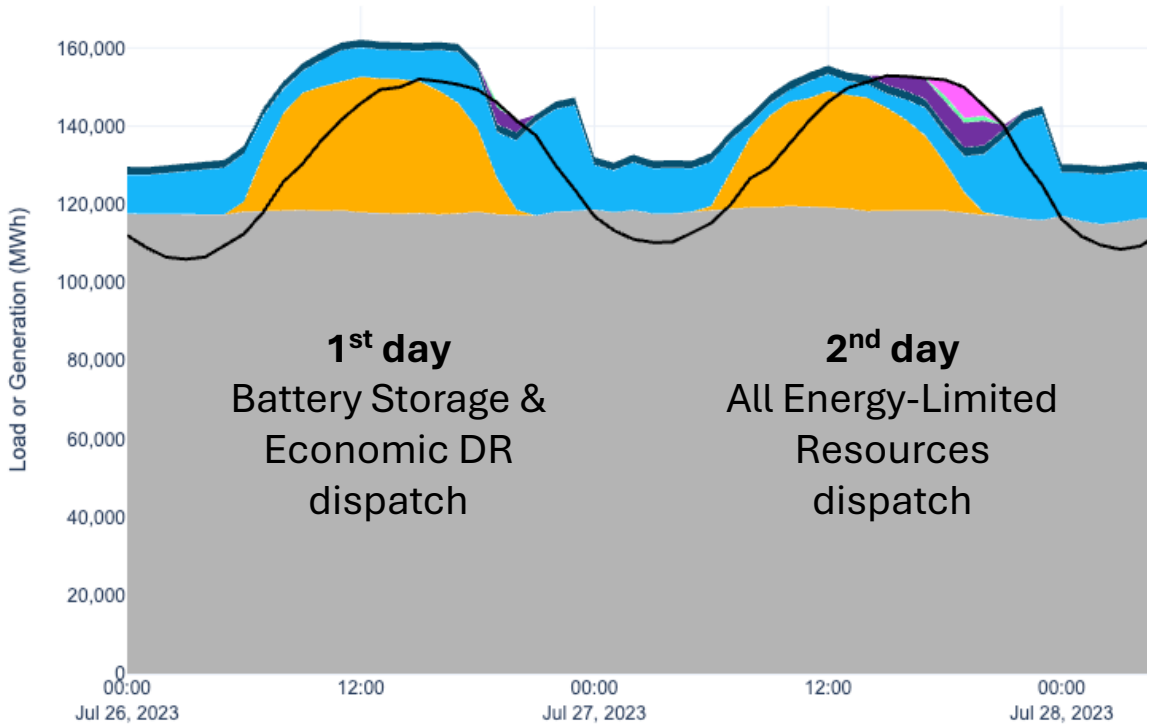
EUE
- *Expected unserved energy*
- *MWh/yr of energy that cannot be served*

ELCC
- *Effective Load Carrying Capability*
- *Equivalent quantity of 'perfect capacity' for a variable or energy-limited resource*

TPRM
- *Target planning reserve margin*
- *PRM required to achieve a specified reliability threshold (i.e., LOLH, LOLE, ALOLP, or EUE)*

RECAP System Dispatch Example

Example of System Dispatch – Summer Heatwave
2030 MISO System

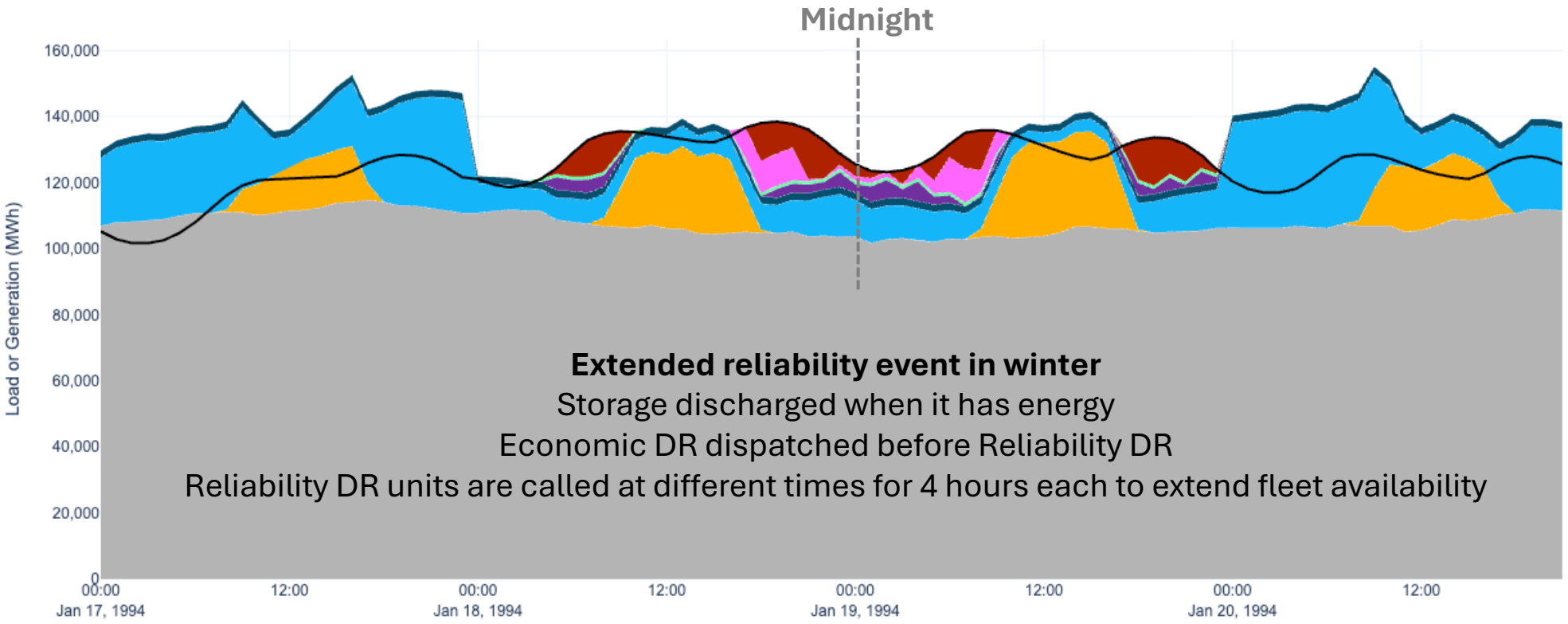


Legend
Unserved Energy
Reliability DR
Economic DR
Battery Storage
Hydro
Wind
Solar
Thermal
Gross Load

+ **RECAP optimally dispatches resources to minimize system unserved energy**
  - Reliability DR is dispatched last, unless this results in higher unserved energy

RECAP System Dispatch Example

Example of System Dispatch – Winter Loss-of-Load Event
2030 MISO System

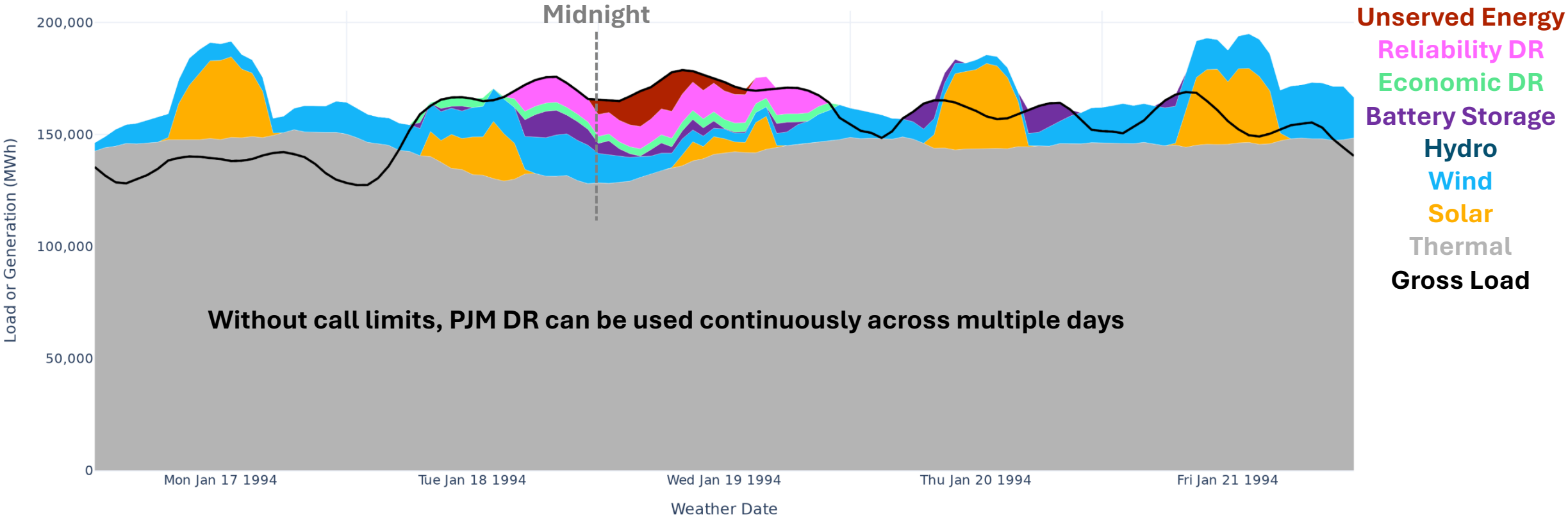


Extended reliability event in winter
Storage discharged when it has energy
Economic DR dispatched before Reliability DR
Reliability DR units are called at different times for 4 hours each to extend fleet availability

Legend
Unserved Energy
Reliability DR
Economic DR
Battery Storage
Hydro
Wind
Solar
Thermal
Gross Load

Examples of Reliability & Economic DR Utilization

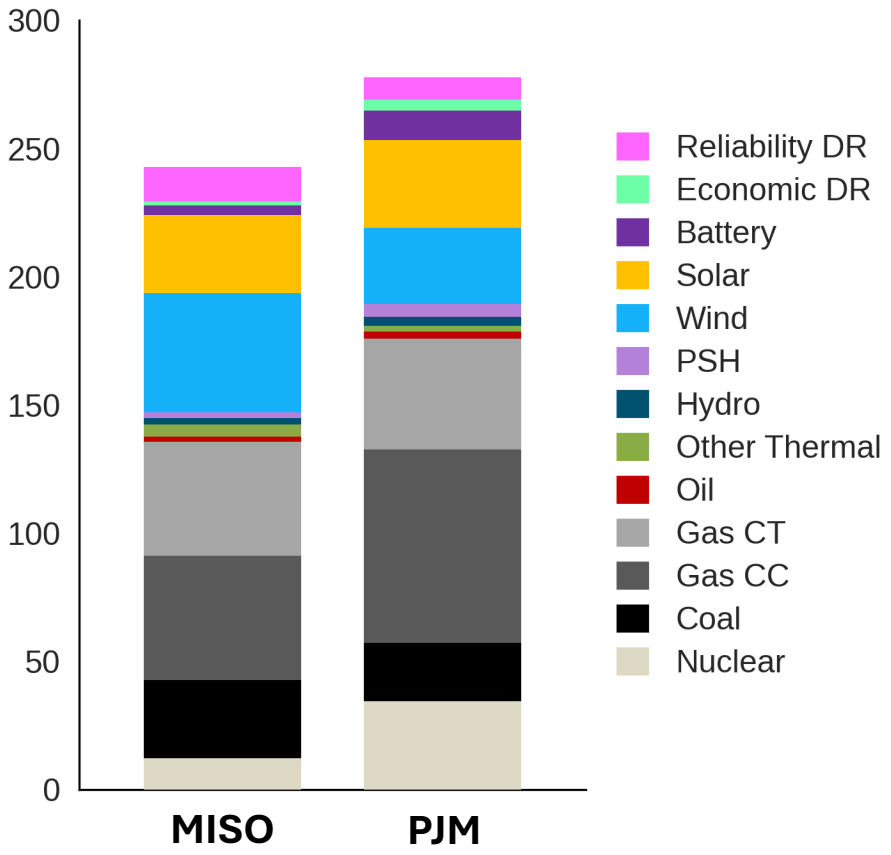
Example of System Dispatch – Winter Loss-of-Load Event
2030 PJM System



Representation of MISO & PJM Systems

- **Each region's portfolio is simulated as a single-zone system using aligned weather data**
- **Reliability DR penetration and system reliability levels are varied across scenarios while penetrations of other portfolio resources are held constant**
  - Systems are tuned to each scenario's specified reliability level by adjusting load
- **Economic DR dispatches before Reliability DR, unless this reduces system reliability**
  - Reported results are for Reliability DR, referred to as "DR"

MISO & PJM 2030 Resource Portfolios
Nameplate Capacity (GW)

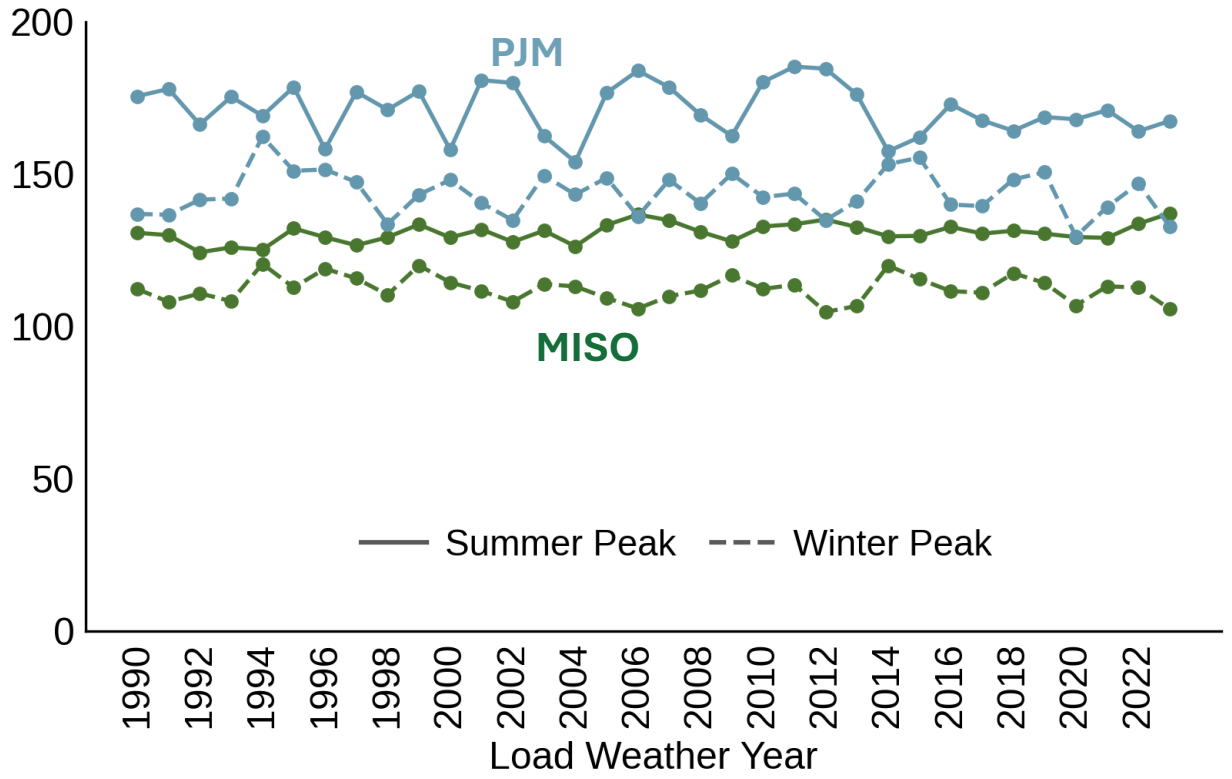


Representation of MISO & PJM Loads

- **A diverse range of potential load conditions is represented using 34 weather years of hourly loads**
  - 1990-2023 load weather years are used for both systems
- **Both MISO & PJM have higher peak loads in summer**
  - Peak load indicates but does not determine timing of critical hours and DR utilization hours, which are also impacted by resource availability

MISO & PJM Seasonal Peak Loads in 2030

Summer & Winter Peak Load by Load Weather Year (GW)



Additional Details on Coincident DR Utilization & Locational Load Shifting

When MISO needs DR, there is an 80-98% chance these loads can shift to PJM

Higher DR use in PJM →

Higher DR use in MISO ↓

	PJM Base	PJM High DR	PJM Shortfall
MISO Base	96%	94%	80%
MISO High DR	97%	95%	83%
MISO Shortfall	98%	96%	86%

When PJM needs DR, there is a 48-74% chance these loads can shift to MISO

Higher DR use in MISO →

Higher DR use in PJM ↓

	MISO Base	MISO High DR	MISO Shortfall
PJM Base	64%	57%	48%
PJM High DR	68%	58%	48%
PJM Shortfall	74%	66%	54%

+ **The timing of DR calls is compared between MISO and PJM to identify overlapping and non-overlapping calls**
  - Timing of DR calls is driven by the severity of weather conditions, which are aligned across the MISO and PJM simulations
+ **Probabilities that DR providers can shift demand to the neighboring region when called are calculated for each MISO-PJM scenario pairing**
  - Locational demand shifting requires the receiving region to absorb higher load when the demand-sending region is using DR; this is not possible if the receiving region is already using DR
  - When MISO needs DR, loads are defined as shiftable to PJM if PJM does not need DR in any of those hours (i.e., no overlap in DR calls), and vice versa; the results show the % of all simulated DR calls that can be shifted
  - Results are for marginal levels of demand shifting; probabilities that large quantities (e.g., several GW) of demand can be shifted at once will be lower
+ **Scenario pairings show how probabilities are impacted by the system conditions of both the demand-sending and -receiving regions**
  - Locational demand shifting is less feasible if the receiving region is using DR often (e.g., due to capacity shortfall or high DR penetration)

1. PJM's "High DR + Shortfall" scenario abbreviated to "PJM Shortfall" in tables.

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