Assessing Nodal Adequacy of Large VRE Power Systems with New Adequacy Metrics Reflecting RA Contributions of G, T, & D

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Traditional Resource Adequacy

Traditional

1. Annual assessment of needs for capacity
2. Stylized power system models
3. Not applicable in the presence of transmission constraints
4. Do not capture the impacts of extreme weather events and common mode events
5. Do not capture the impact of operational flexibility
6. Used as a planning tool in determining capacity requirements and justify needs for investments in generation but not for transmission

Needs

1. Decisions in many timeframes including short-term
2. Physically sound power system models
3. Locational economic signals provided to generation, transmission and demand that incorporate value of adequacy
4. Effects of extreme weather and common mode events
5. High operational details distinguishing flexible resources under non-recourse decisions
6. Planning tools and market design mechanisms facilitating co-optimization of investments in generation, transmission and demand-side technologies

What Are the Needs to Assess the Impact of Extreme Market Events?

Traditional

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2. Stylized power system models
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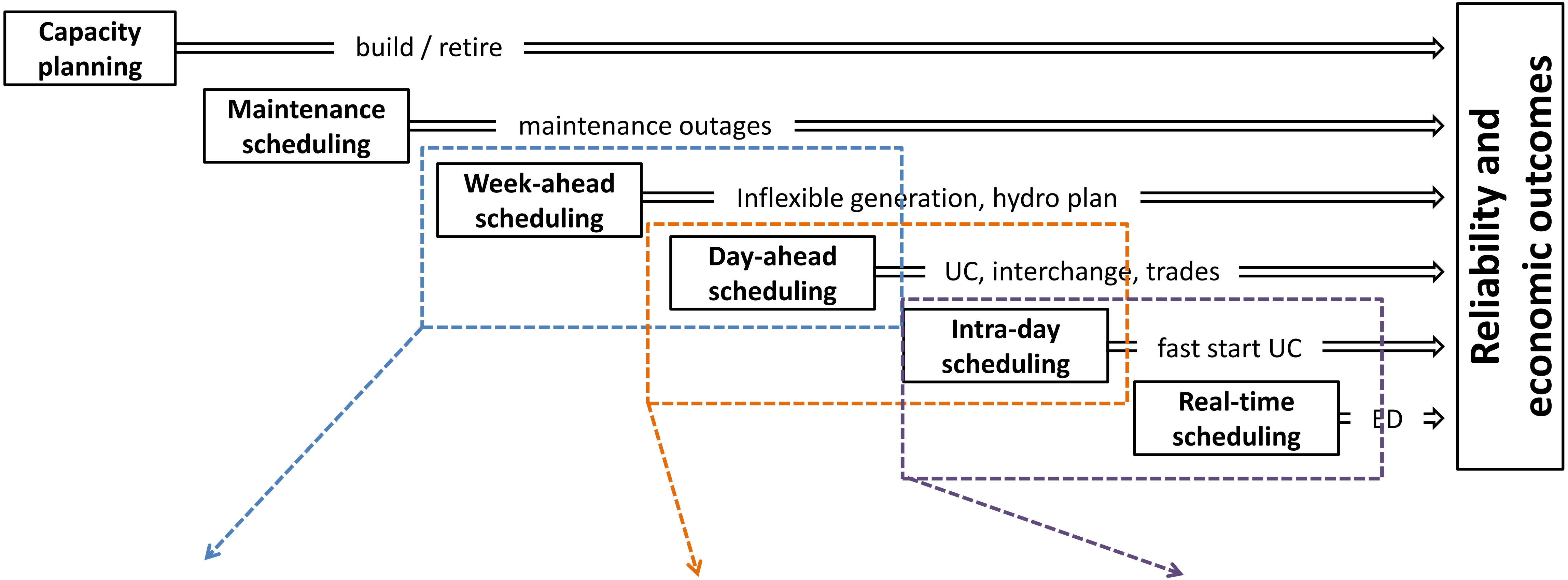
Resource Adequacy Applied to Different Timeframes



Week-ahead & Day-ahead:
Assessment of the adequacy of the fleet

Day ahead & Intra-day:
Impacts of non-recourse decisions (commitment, dispatch of inflexible generation, deployment of demand response, etc.)

Intra-day & Real-time:
Assessment of the adequacy of the reserve procurement policy

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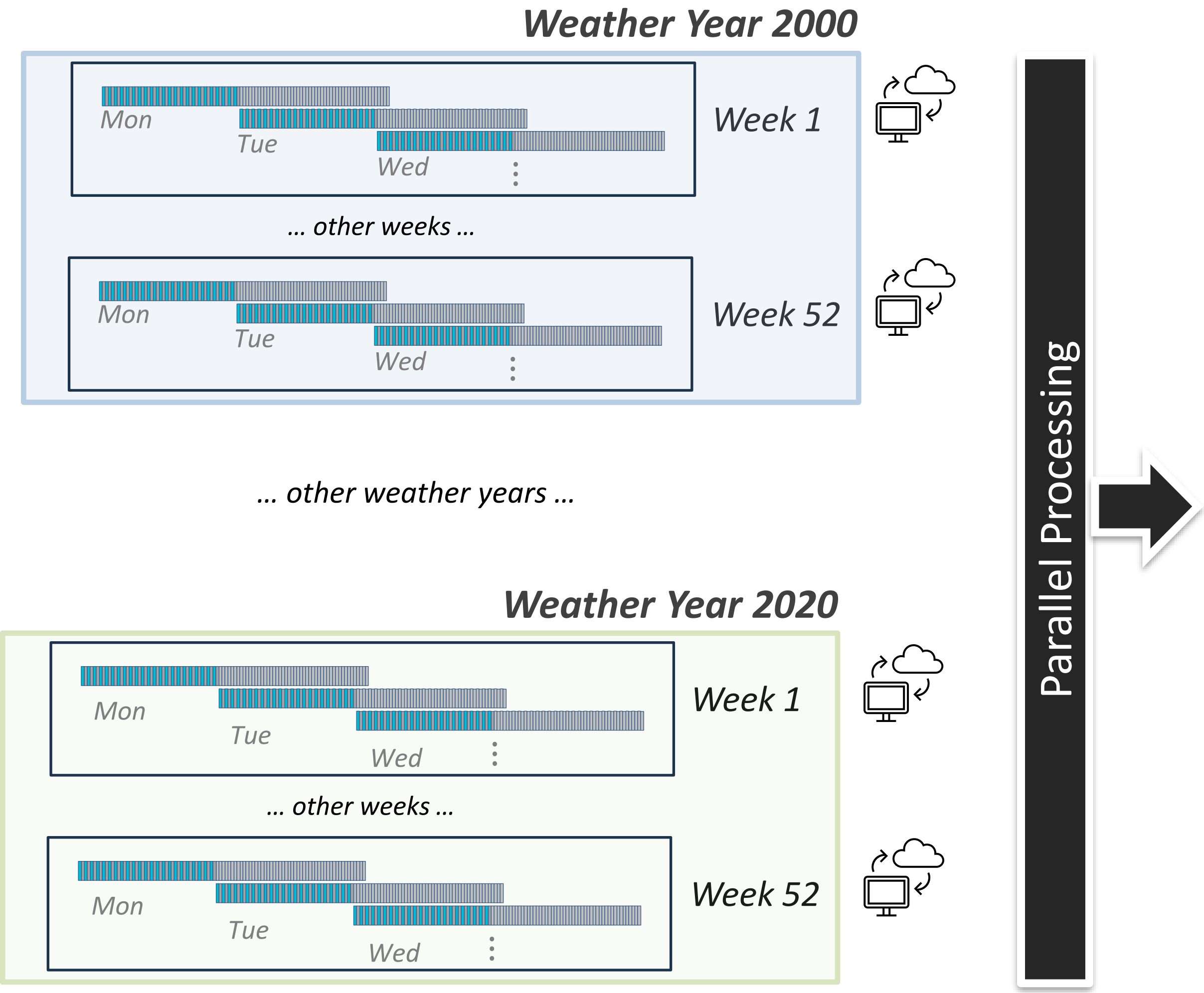
All Decisions Have Reliability Impacts

Assessment of adequacy for **system annual planning**

Is there sufficient capacity available for Day-Ahead commitment?

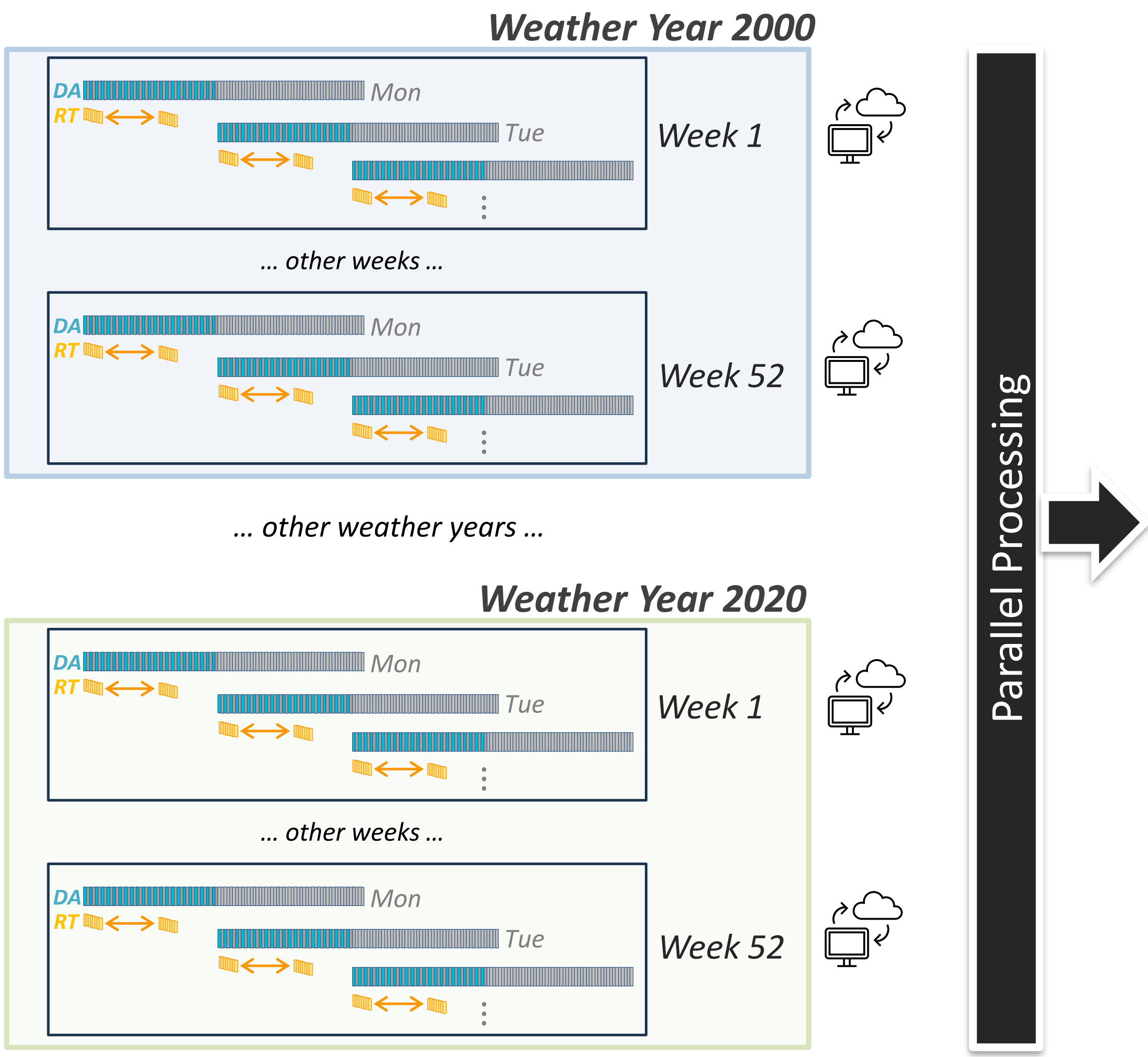


- Risk locations and periods
- Generator performance
- Payment to participants for providing adequacy

All Decisions Have Reliability Impacts

Annual assessment of adequacy for **reserve procurement policy**

Are there insufficient reserves to respond to contingencies or ability to replenish reserves in time?

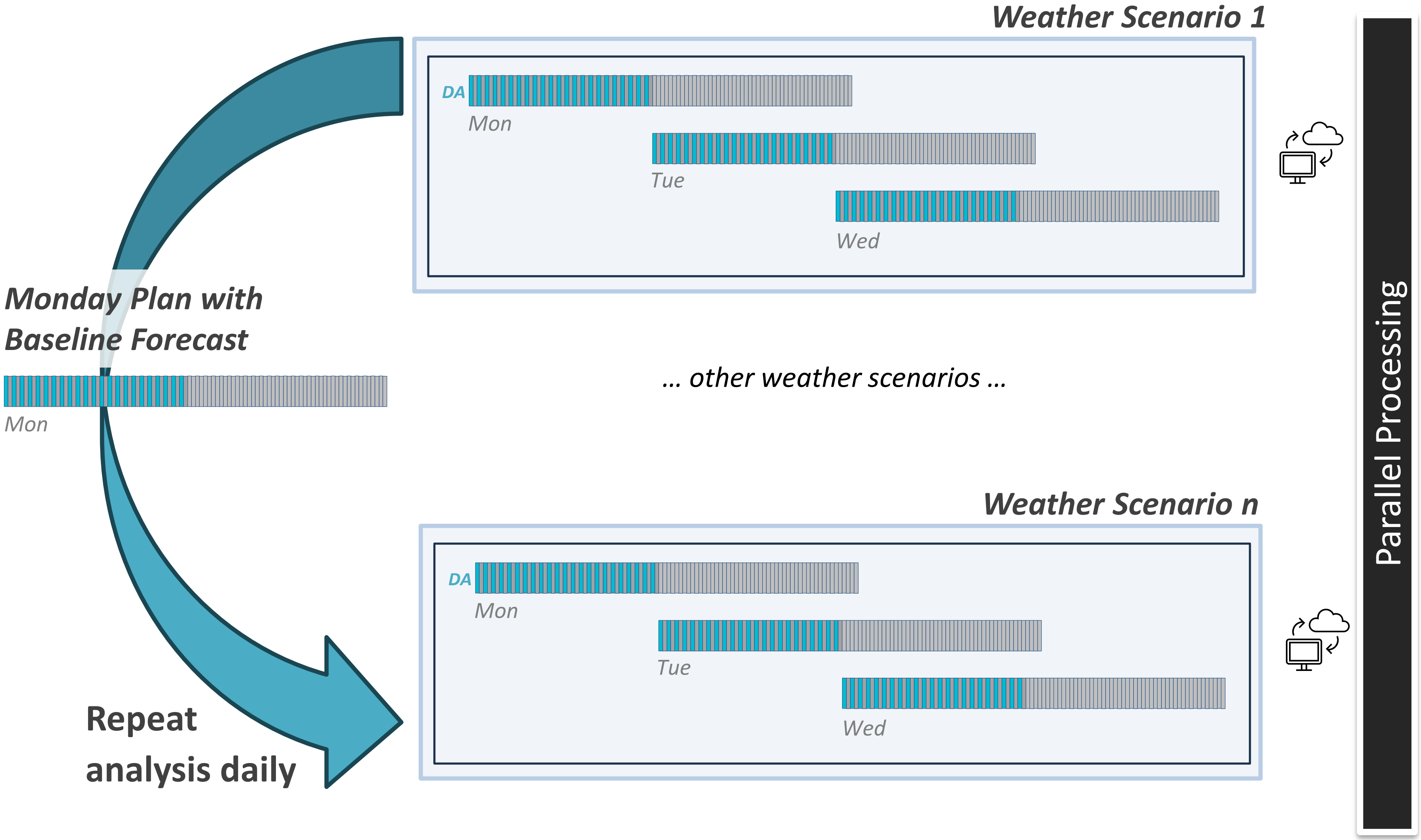


- Risk locations and periods given the reserve policy
- Risk metrics

All Decisions Have Reliability Impacts

Assessment of adequacy for **short term (2-5 day) system planning** *

Are there insufficient reserves to respond to contingencies or ability to replenish reserves in time?



*Project under development funded by ARPA-E

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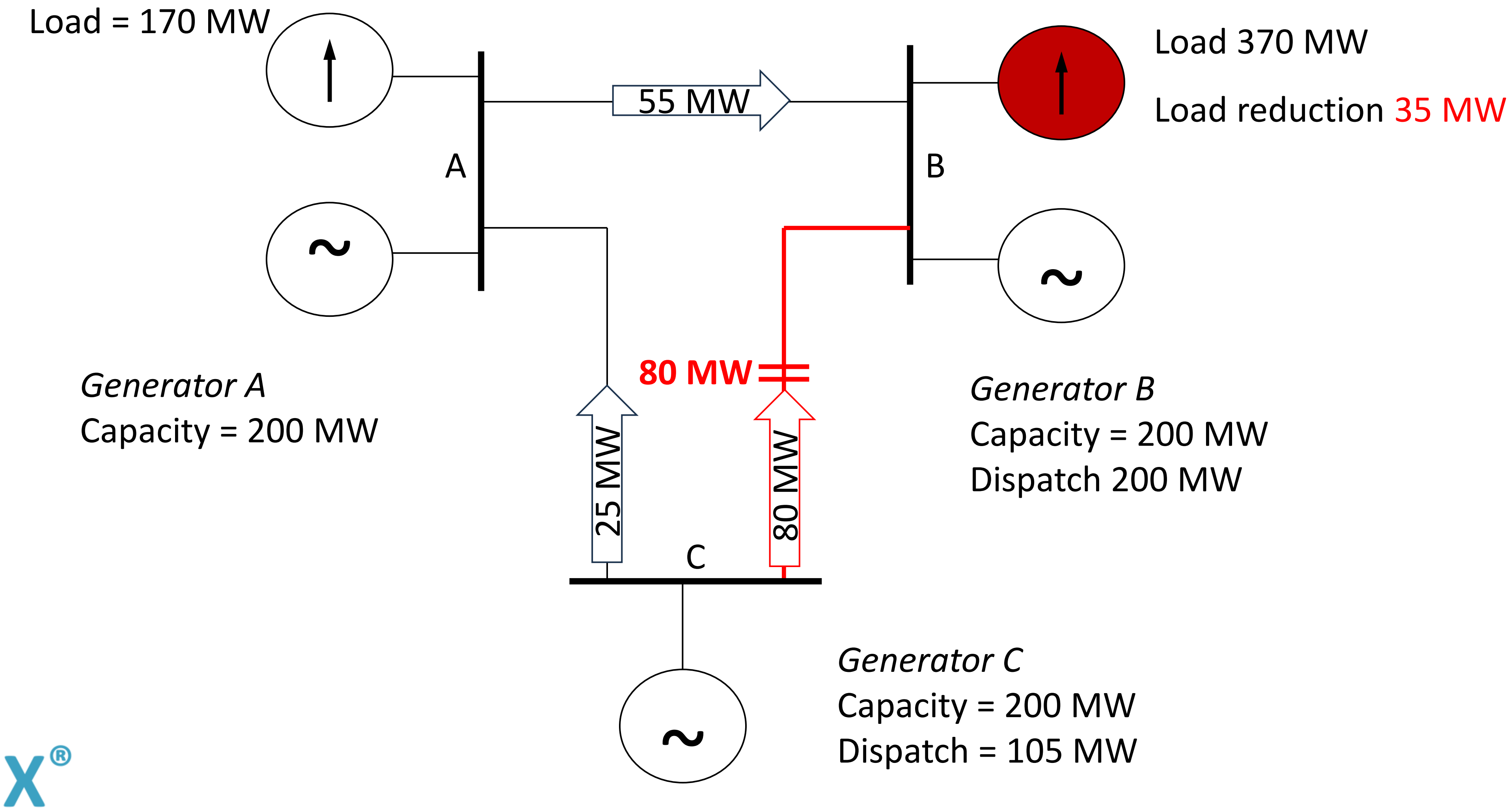
Shortage Is Local

System Load = 540 MW
Generation Capacity = 600 MW

Limited transmission capacity from B to C causes load shed



Load 370 MW

Load reduction 35 MW

Generator A
Capacity = 200 MW

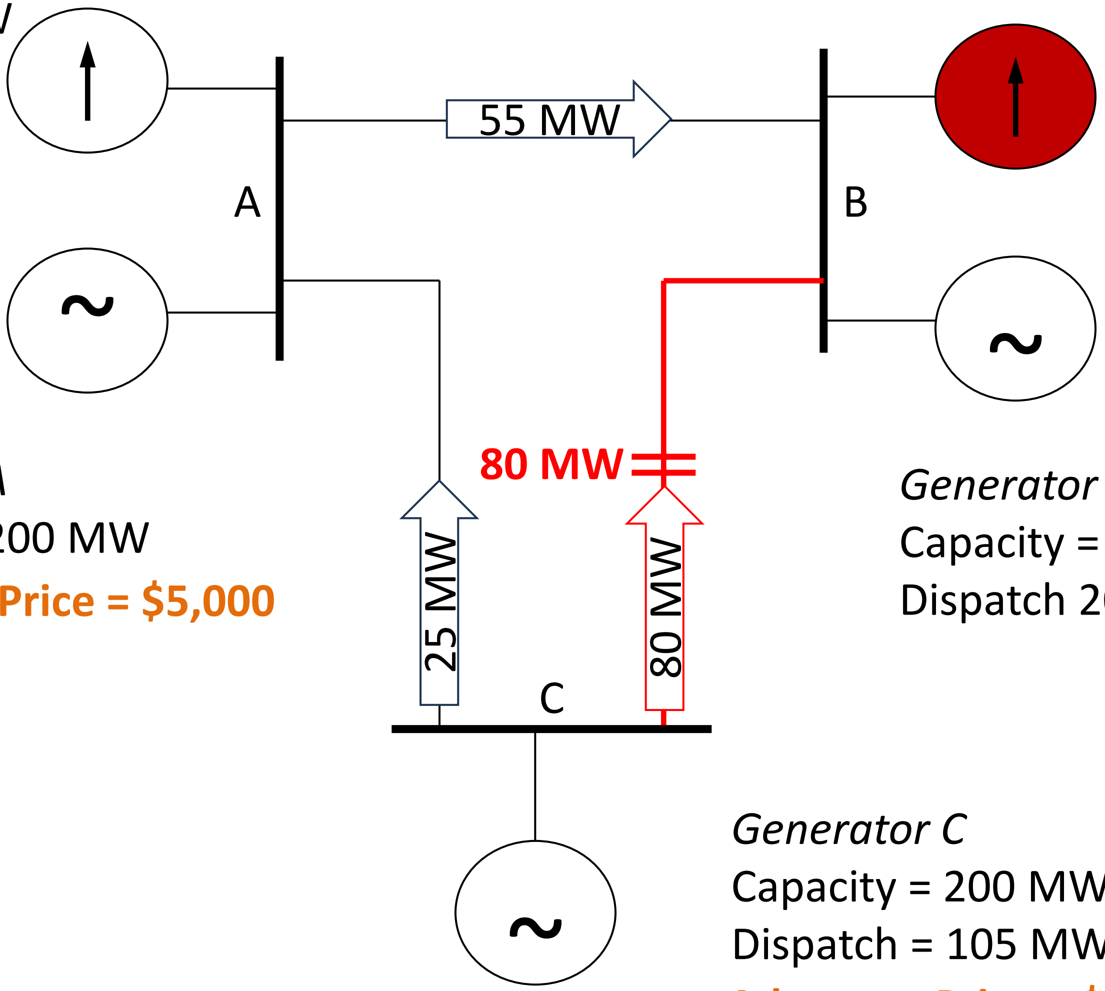
Generator B
Capacity = 200 MW
Dispatch 200 MW

Generator C
Capacity = 200 MW
Dispatch = 105 MW

Shortage Is Local

System Load = 540 MW
Generation Capacity = 600 MW

Load shed sets the price to
VOLL=$10,000/MWh



Load = 170 MW

Load 370 MW

Load reduction 35 MW

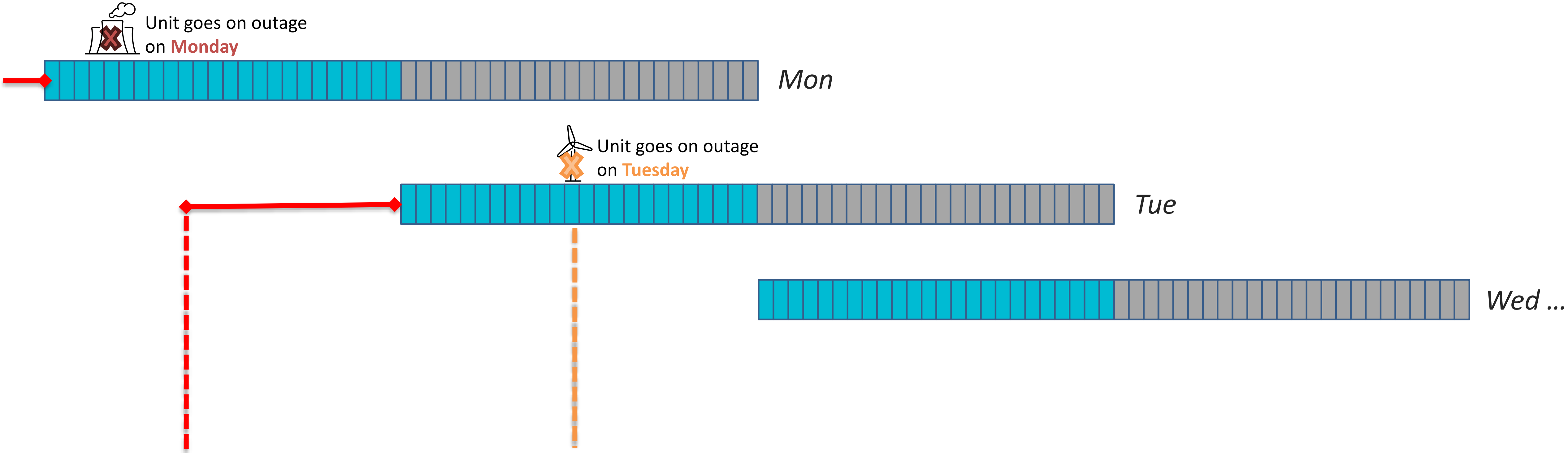
Adequacy Price = $10,000

Generator A
Capacity = 200 MW
Adequacy Price = $5,000

Generator B
Capacity = 200 MW
Dispatch 200 MW

Generator C
Capacity = 200 MW
Dispatch = 105 MW
Adequacy Price = $0

Operational Impact of Outages



Unit goes on outage on **Monday**

Mon

Unit goes on outage on **Tuesday**

Tue

Wed …

Make commitment decisions for Tuesday, given the current stage of the grid (e.g., Monday outages)

Not all outages are known!

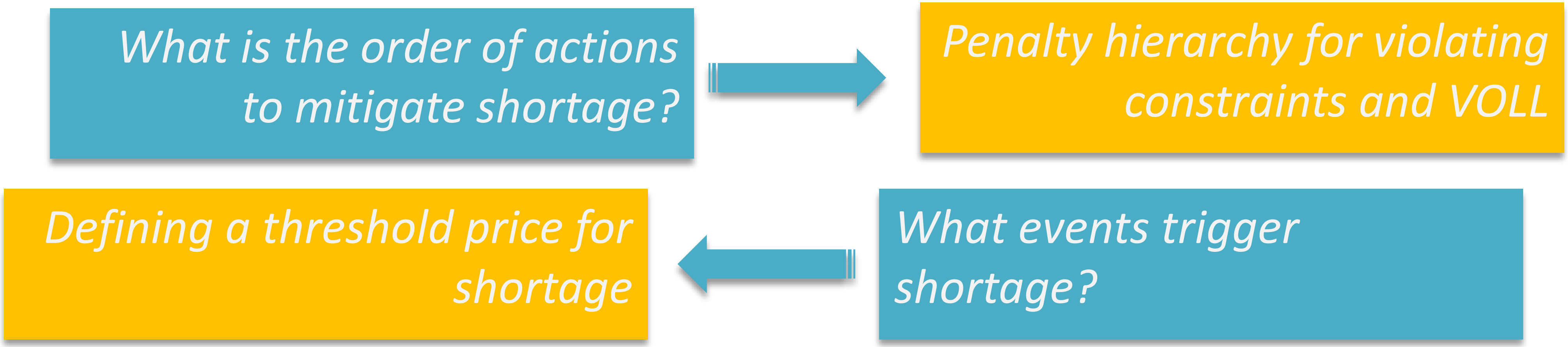
Respond to future outages subject to Monday’s plan

What flexibility do we have in the system?

What is the reliability impact, subject to a base plan?

What Is Shortage, Anyways?

- Should **shortage** be limited to Load Shed?
  - What about reserve shortfalls, dispatch of demand response injectors, emergency purchases?
- Provide flexibility in defining shortage (near-misses) by detecting shortage economically



What is the order of actions to mitigate shortage?

Penalty hierarchy for violating constraints and VOLL

What events trigger shortage?

Defining a threshold price for shortage

An Annual Resource Adequacy Study of ERCOT

Annual study for 2024, each week processed in parallel with 100 outage samples per week

Nodal analysis with all major interfaces, 345 kV and 138 kV constraints

Single weather year study (2022): find weeks and locations with capacity needs

Reliability impact of day ahead decisions

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These results are based on public data and are not benchmarked against ERCOT's Resource Adequacy studies

An Annual Resource Adequacy Study of ERCOT

- Annual study for 2024, each week processed in parallel with 100 outage samples per week
- Nodal analysis with all major interfaces, 345 kV and 138 kV constraints
- Single weather year study (2022): find weeks and locations with capacity needs
- Reliability impact of day ahead decisions

Turn-around time for this analysis: 3 hours
Total Virtual Machine time: 88.5 hours

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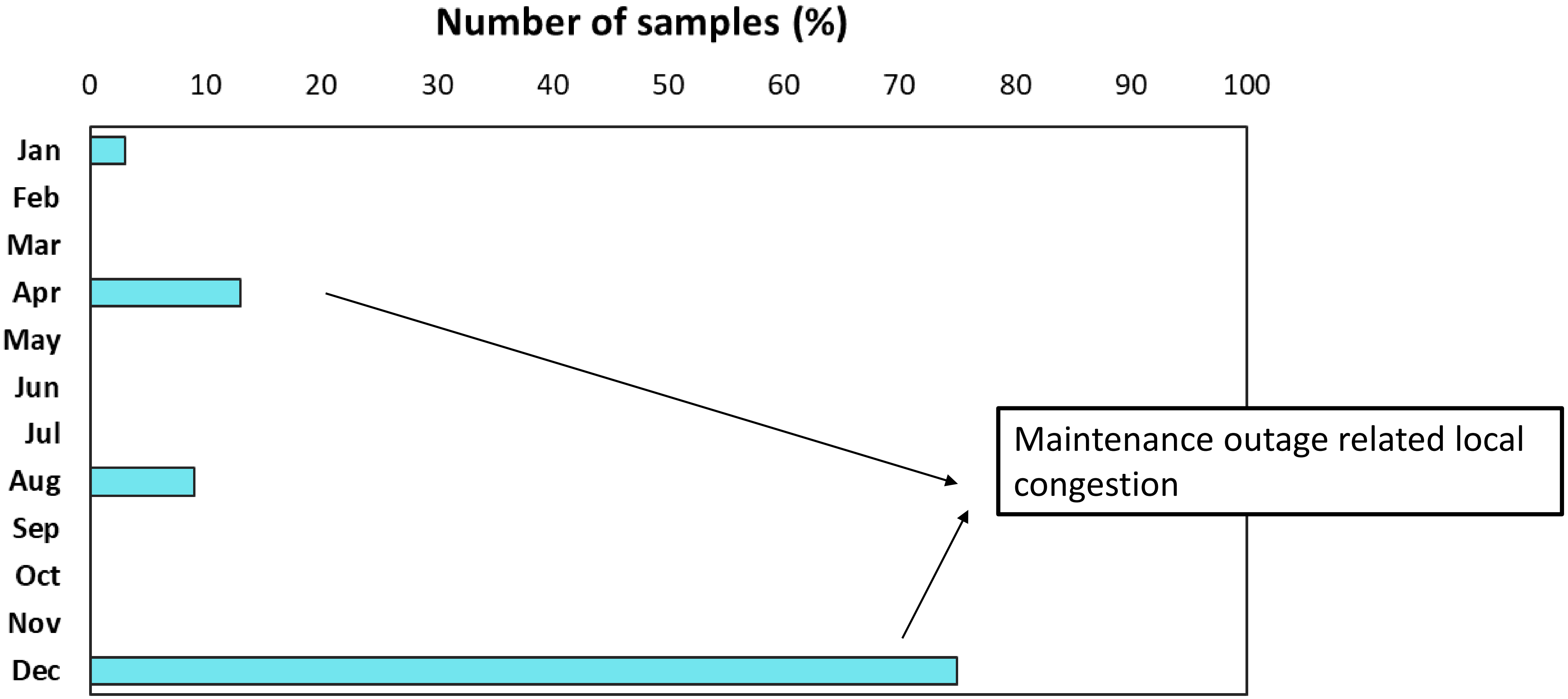
Summary of Findings

- Shortage is location specific
  - Local shortages can occur regardless of capacity available elsewhere
- Operational policies and flexibility matter
- Changing grid conditions mean that traditional maintenance scheduling can lead to shortages without greater coordination and flexibility
- Severity and duration can be different

Which Months Should We Focus Our Computational Efforts On?

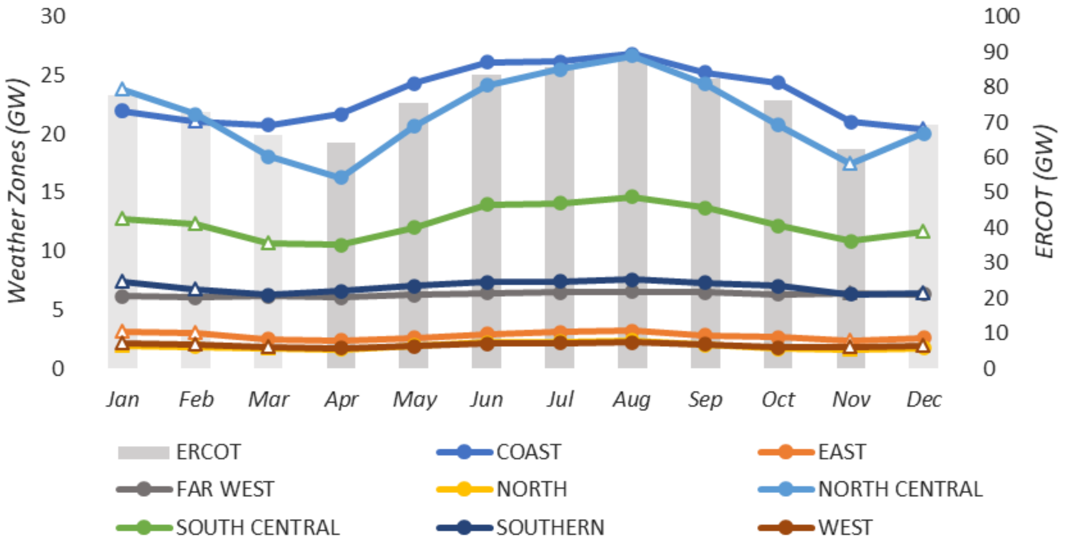


Maintenance outage related local congestion

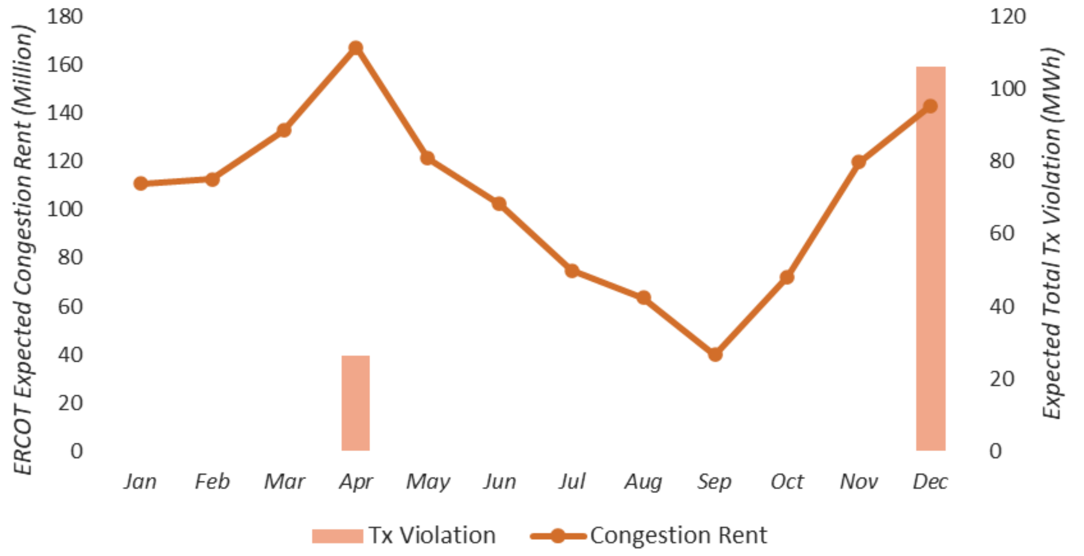
Based on both area and local shortage

Is December the worst month for load shed?

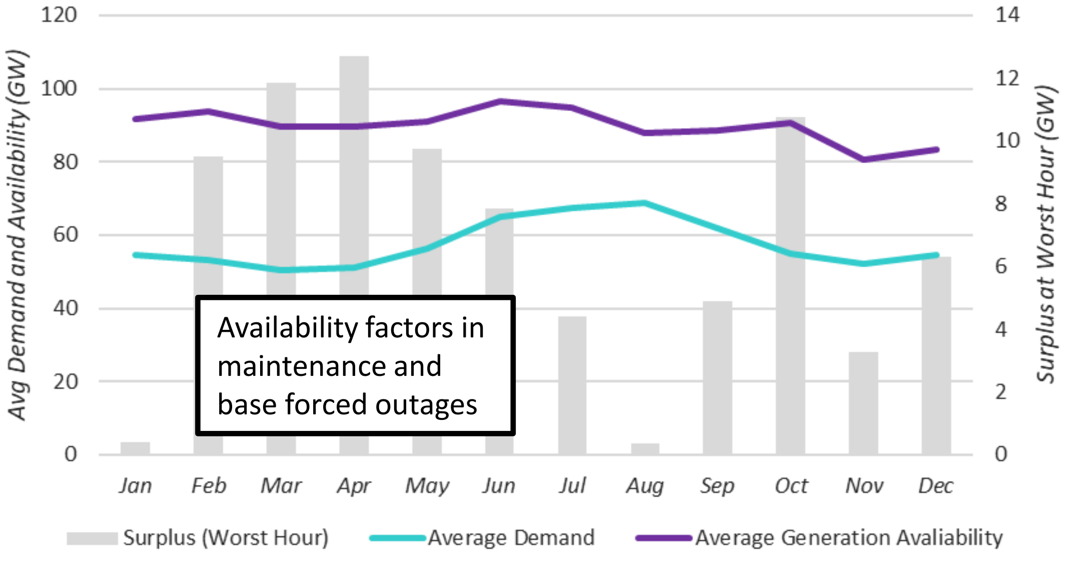
Monthly Peak Load



Congestion Rent and Tx Violations

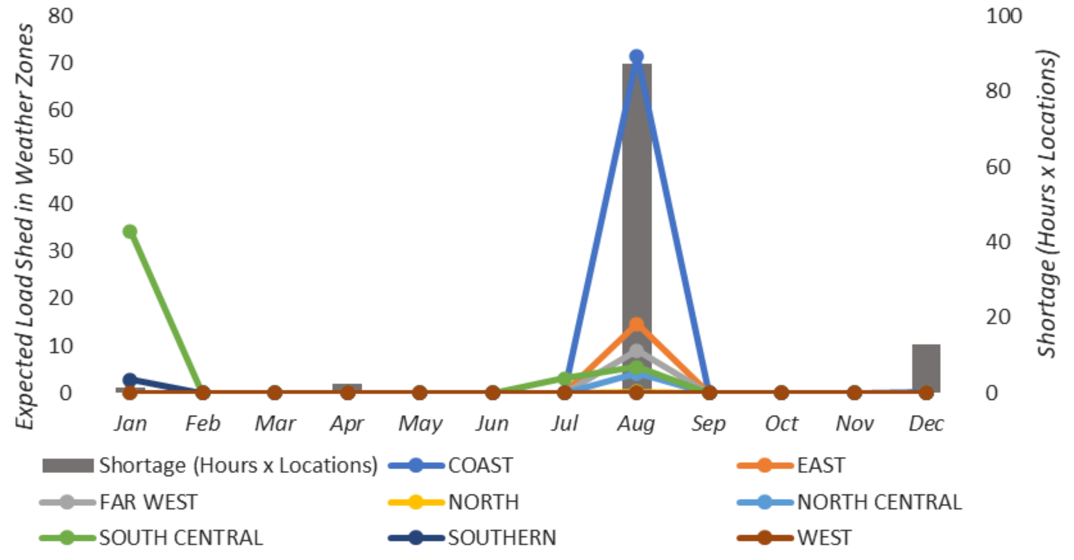


Average Load and Generation Availability



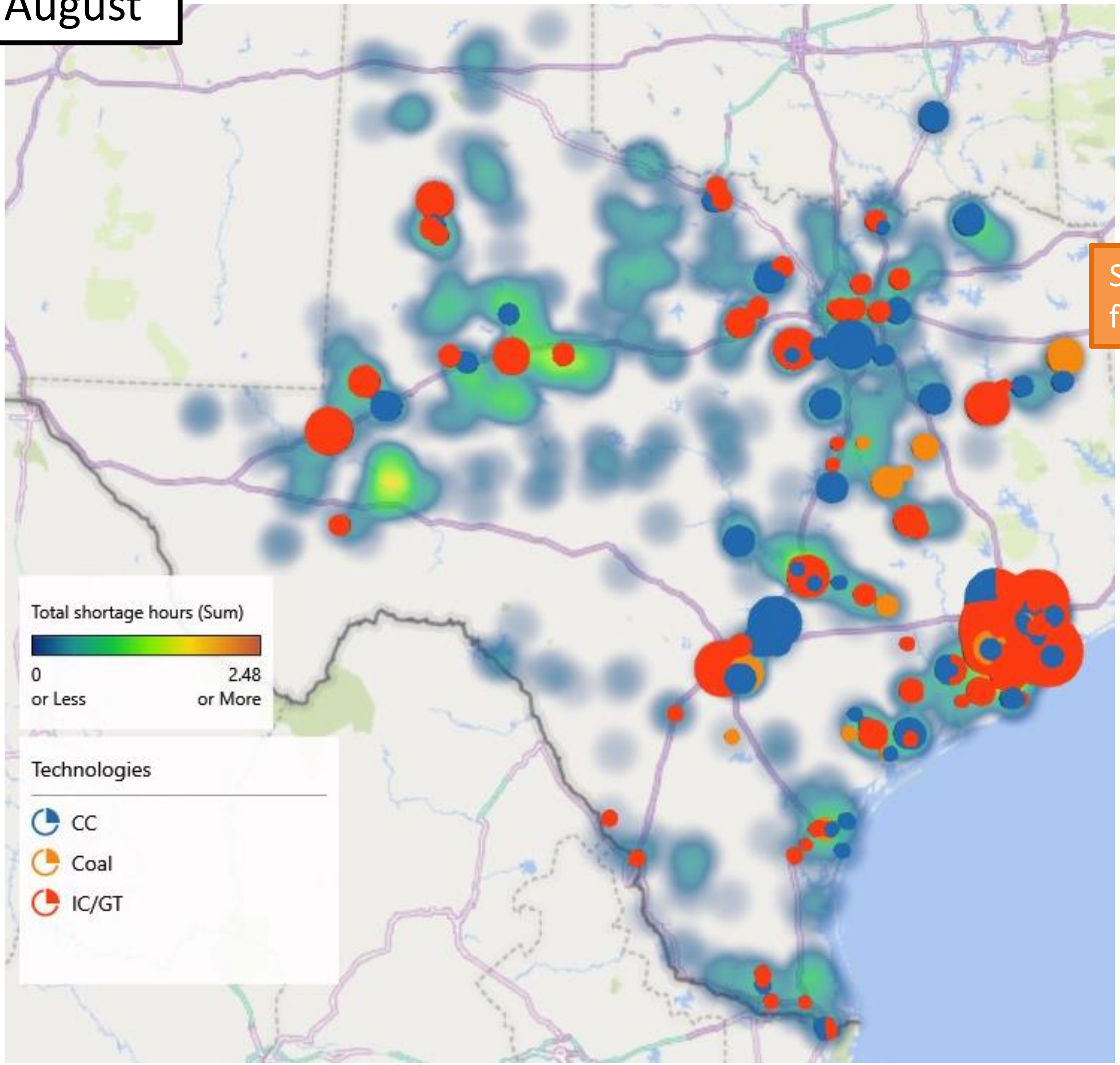
Availability factors in maintenance and base forced outages

Load Shed in Weather Zones and Total Shortage



Generator Performance for a Summer Month
Normalized ELCC-d

August



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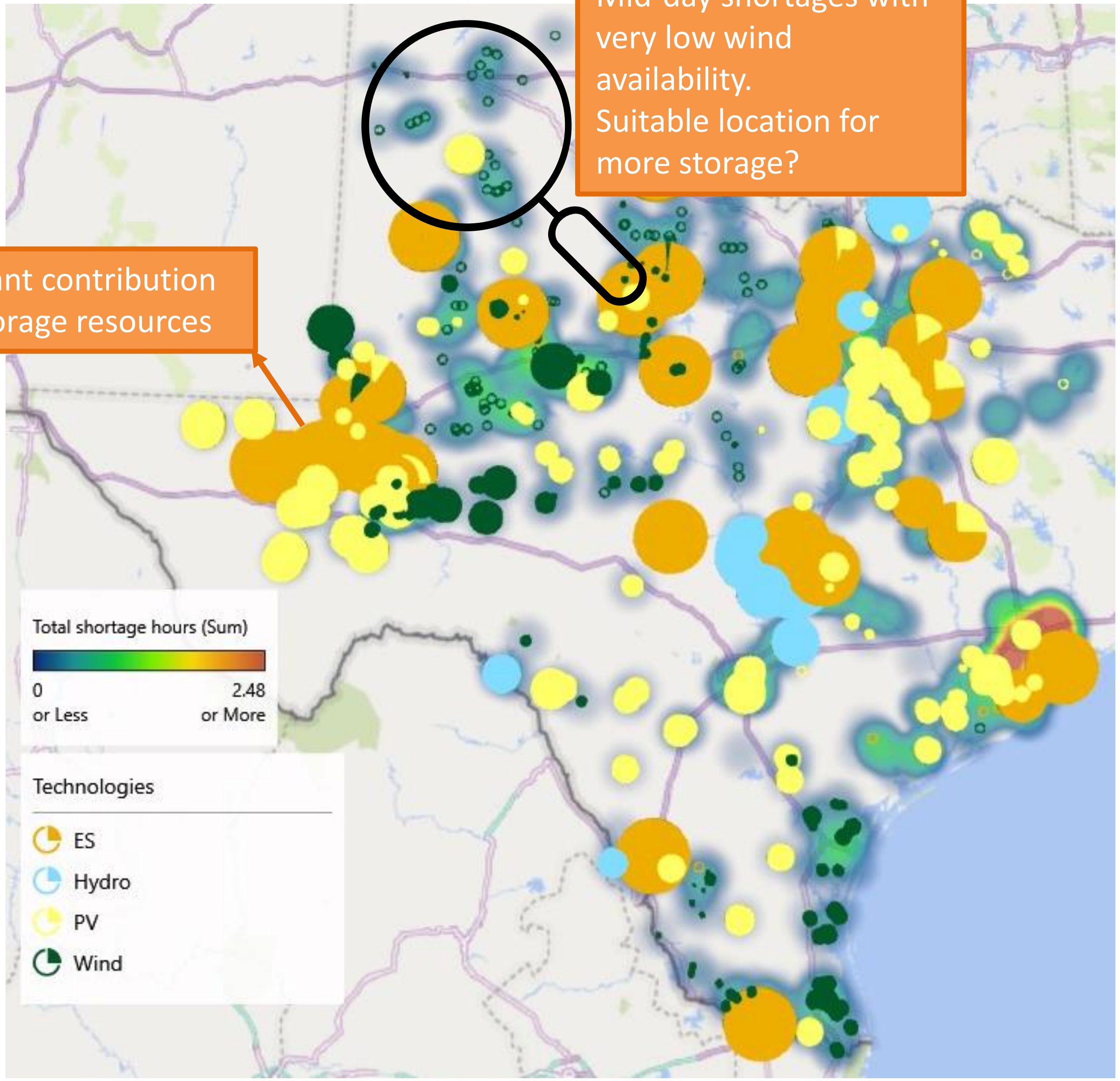

Significant contribution from storage resources

Mid-day shortages with very low wind availability.
Suitable location for more storage?

How Dispersed Is Shortage?

Shortage hours x locations

Hour

		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Jan								1.29																
	Feb																								
	Mar																								
	Apr	0.12	0.12	0.12	0.12	0.12	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.12	0.12	0.12	0.12	0.18	0.18
Month	**May**																								
	Jun																								
	Jul																			0.54					
	Aug															6.69	79.4		0.22	0.56	0.56				
	Sep																								
	Oct																								
	Nov																								
	Dec	0.24	0.24	0.3	0.36	0.42	0.42	0.42	0.42	0.48	0.48	0.48	0.54	0.54	0.59	0.59	0.6	0.66	0.72	0.72	0.72	0.72	0.72	0.78	0.78

Total expected load shed (MWh)

Hour

		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Jan								37.2																
	Feb																								
	Mar																								
	Apr																								
Month	**May**																								
	Jun																								
	Jul																			3					
	Aug															13.7	85.9			1.54	3.99				
	Sep																								
	Oct																								
	Nov																								
	Dec															0.01									

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How Dispersed Is Shortage?

Shortage hours x locations

		Hour																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Jan								1.29																
	Feb																								
	Mar																								
	Apr	0.12	0.12	0.12	0.12	0.12	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.12	0.12	0.12	0.12	0.18	0.18
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Total expected load shed (MWh)

		Hour																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
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	Nov																								
	Dec																								

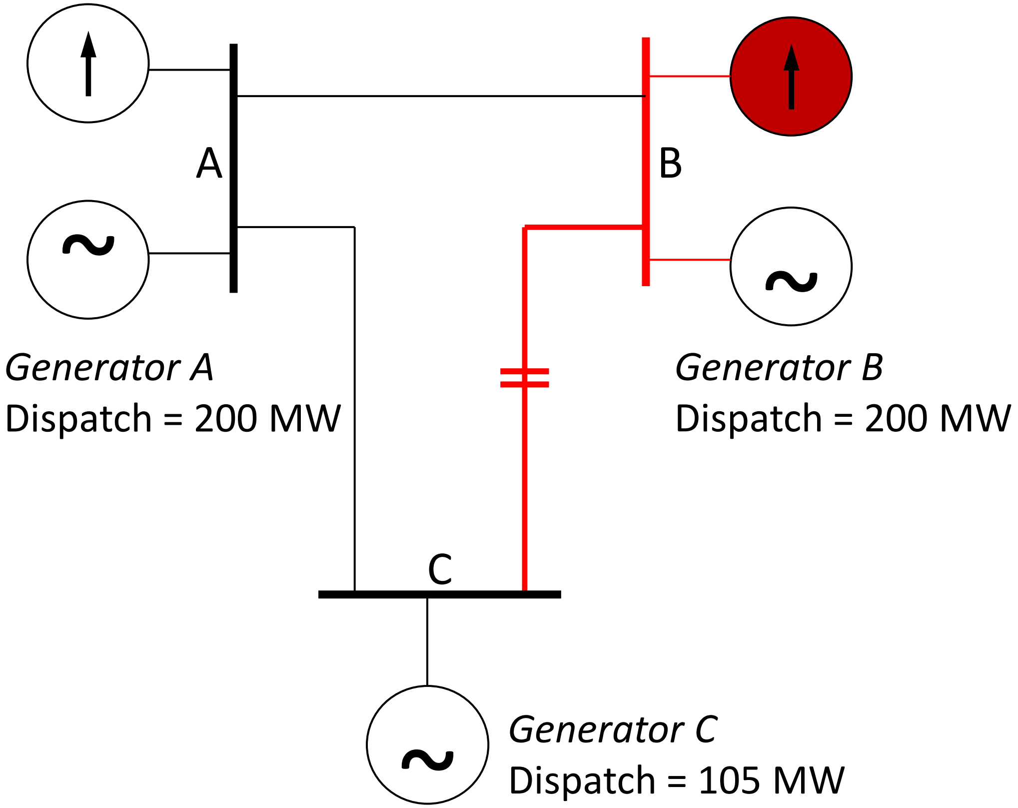
Consistent shortage in December with very little load shed. What is happening?

Local congestion due to combined impact of maintenance and forced outages, cannot be resolved through area level load shed

How Local vs Widespread Is Shortage?

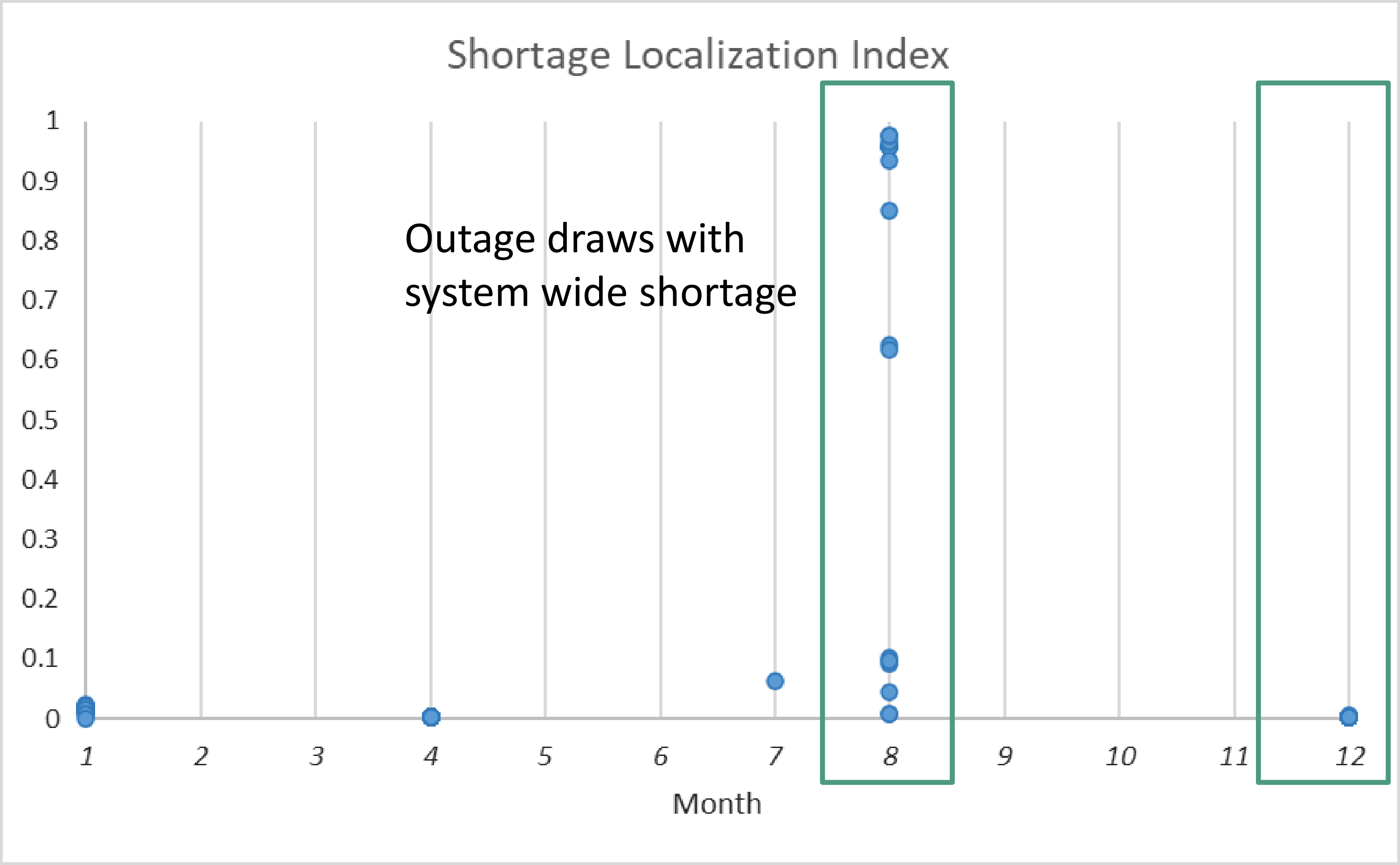
- How widespread or local is shortage?
- If equal to 1, shortage is system wide

$$\mathit{Shortage\ Localization\ Index} = \frac{\mathit{Total\ dispatch\ in\ shortage\ locations}}{\mathit{System\ dispatch}}$$



Total system dispatch during shortage = 505 MW
Total dispatch in locations with shortage = 200 MW (Bus B)
Shortage Localization Index = 0.40

How Local vs Widespread Is Shortage?



Outage draws with system wide shortage

December has local shortages

How Much Generation is Exposed to Shortage?

Generation Exposed to Shortage (MWh)

	Hour																							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Jan								2,751																
Feb																								
Mar																								
Apr	729	711	658	600	582	592	284	299	423	433	449	422	390	403	381	380	403	459	827	814	802	843	757	734
May																								
Jun																								
Jul																			6,327					
Aug															52,510	83,778		4,395	7,840	7,827				
Sep																								
Oct																								
Nov																								
Dec	1,074	1,047	1,048	1,444	1,818	1,807	1,791	1,857	1,842	1,789	1,839	1,856	1,840	1,828	1,774	2,054	2,376	2,432	2,527	2,585	2,590	2,560	2,475	2,458

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Shortage Definition
Detect Events Other Than Load Shed

Shortage hours x locations (August)

		Hour																							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Shortage Price Threshold	**4,850**															6.7	79.4		0.2	0.6	0.6				
	3,200															16.1	129.6	0.3	7.0	6.8	6.8	0.1			

More shortage

Total expected load shed (MW) (August)

		Hour																							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Shortage Price Threshold	**4,850**															13.7	85.9			1.5	4.0				
	3,200															13.7	85.9			1.5	4.0				

Same load shed

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Shortage Definition
Detect Events Other Than Load Shed

Shortage hours x locations

Hour

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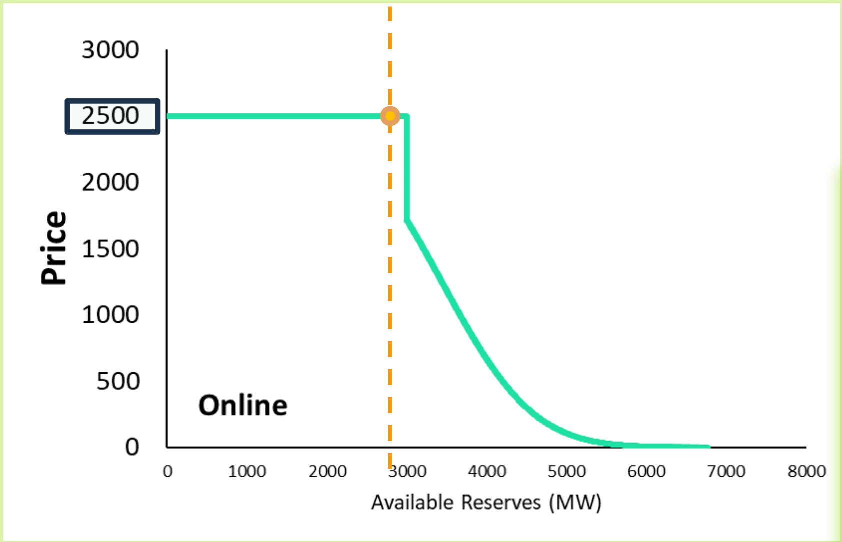
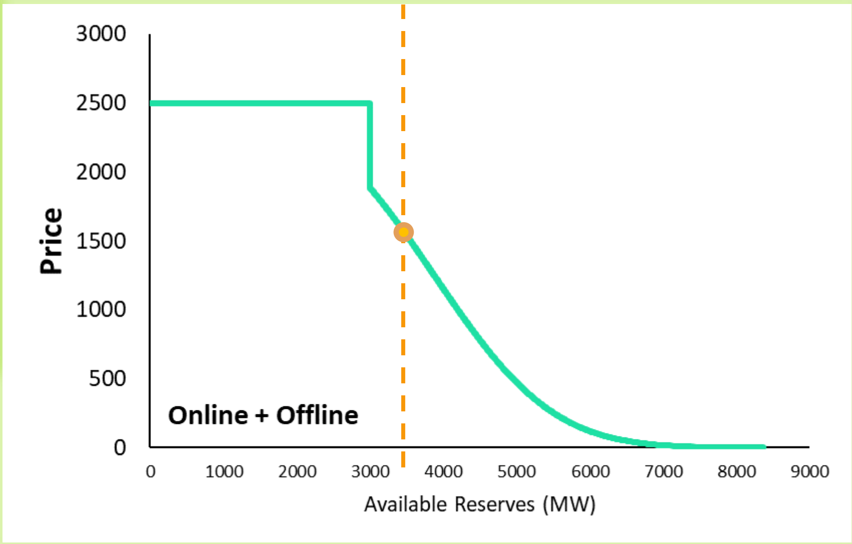
	3,200															16.1	129.6	0.3	7.0	6.8	6.8	0.1			

Shortage event due to reserve shortfalls and/or congestion price:





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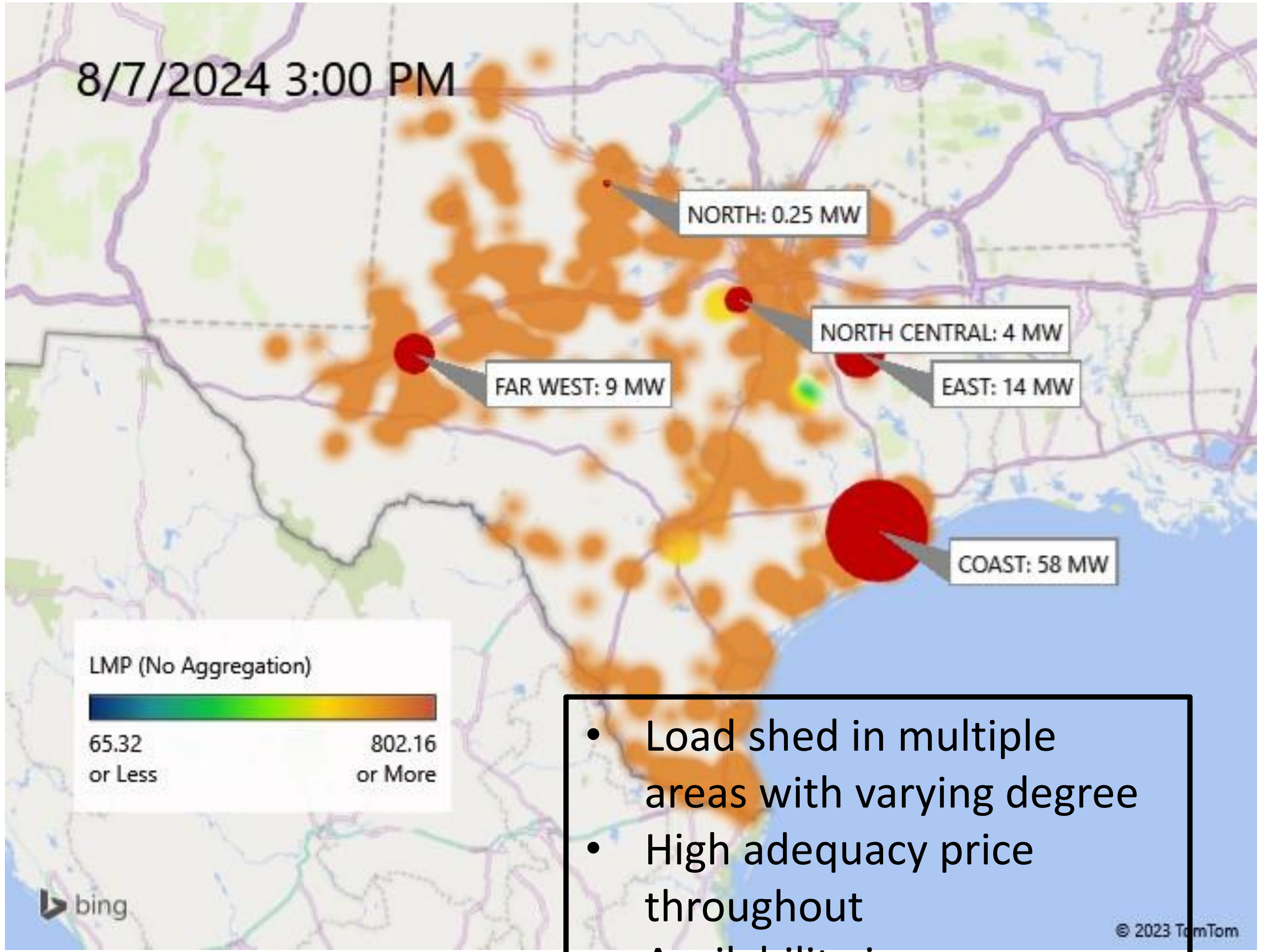
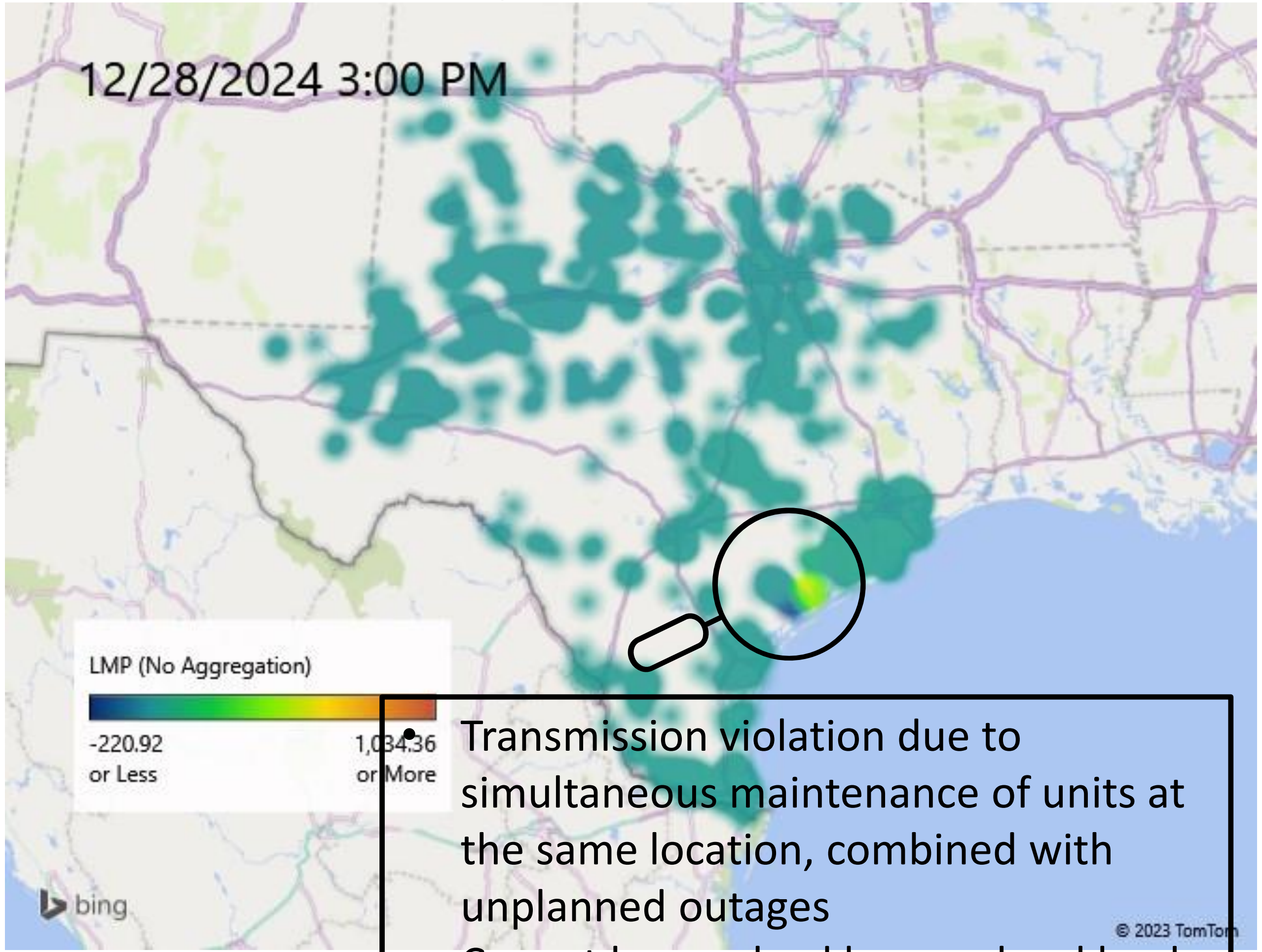
Two Different Days (Reasons) With Shortage Price Heatmap

Low availability + High load



- Load shed in multiple areas with varying degree
- High adequacy price throughout
- Availability issue

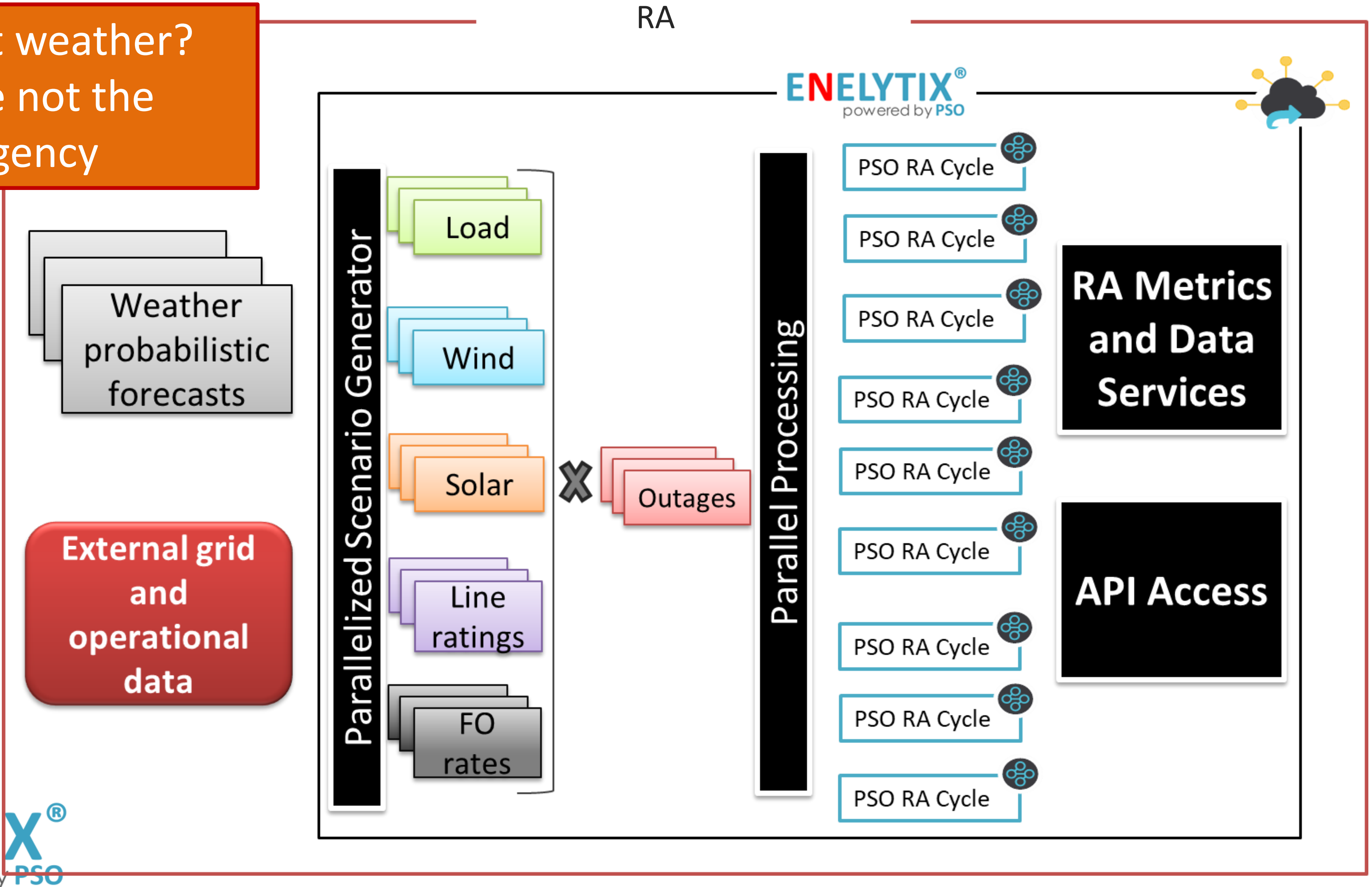
Local congestion driven shortage



- Transmission violation due to simultaneous maintenance of units at the same location, combined with unplanned outages
- Cannot be resolved by area level load shed
- Staggering maintenance at this location resolves shortage!

Solution Methodology: Probabilistic World of Resource Adequacy

What about weather? Outages are not the only contingency


RA

Weather probabilistic forecasts

External grid and operational data

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Parallelized Scenario Generator

Load

Wind

Solar

Line ratings

FO rates

X

Outages

Parallel Processing

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

PSO RA Cycle

RA Metrics and Data Services

API Access

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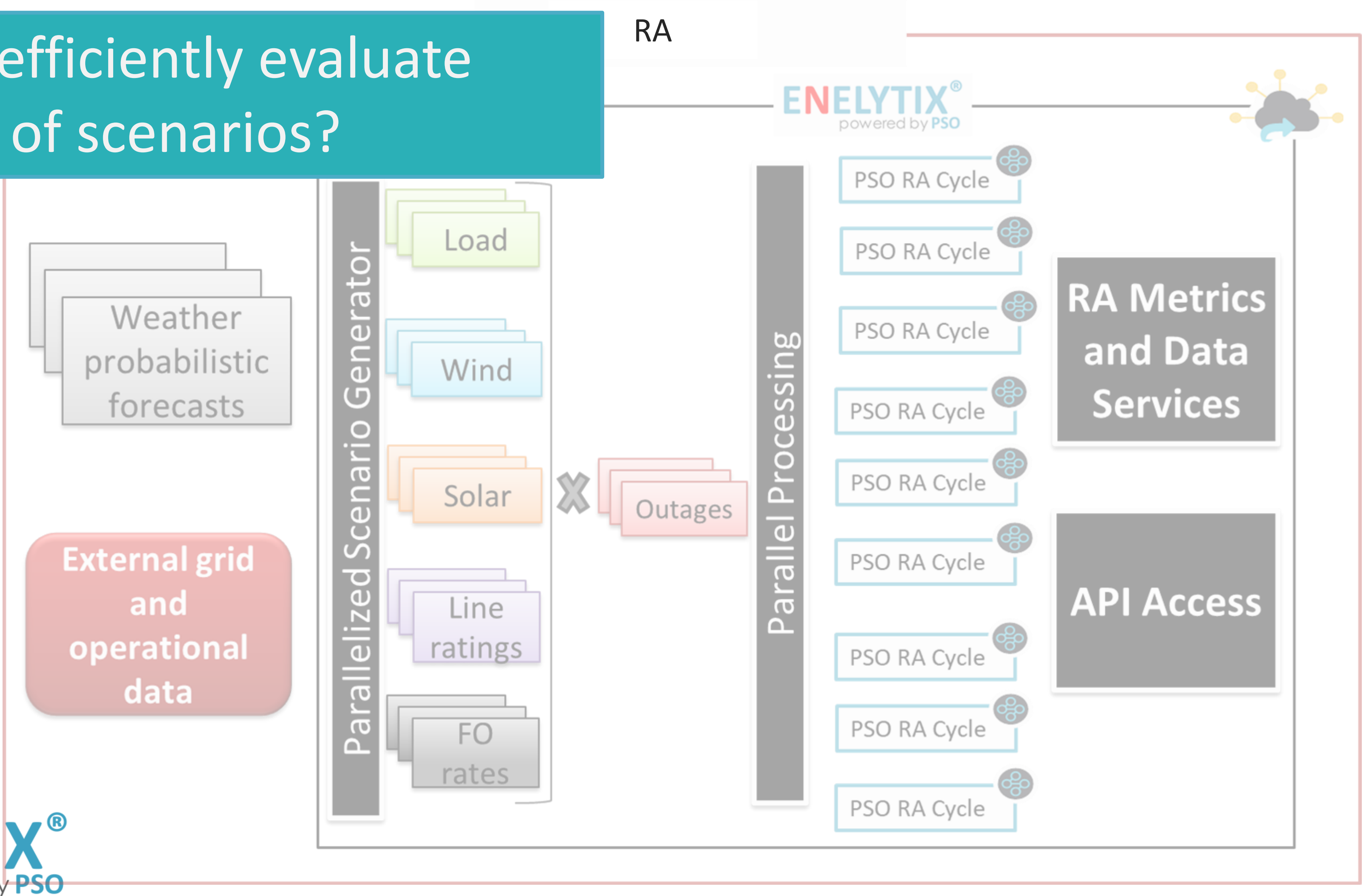
Solution Methodology: Probabilistic World of Resource Adequacy

How to efficiently evaluate 10,000s of scenarios?



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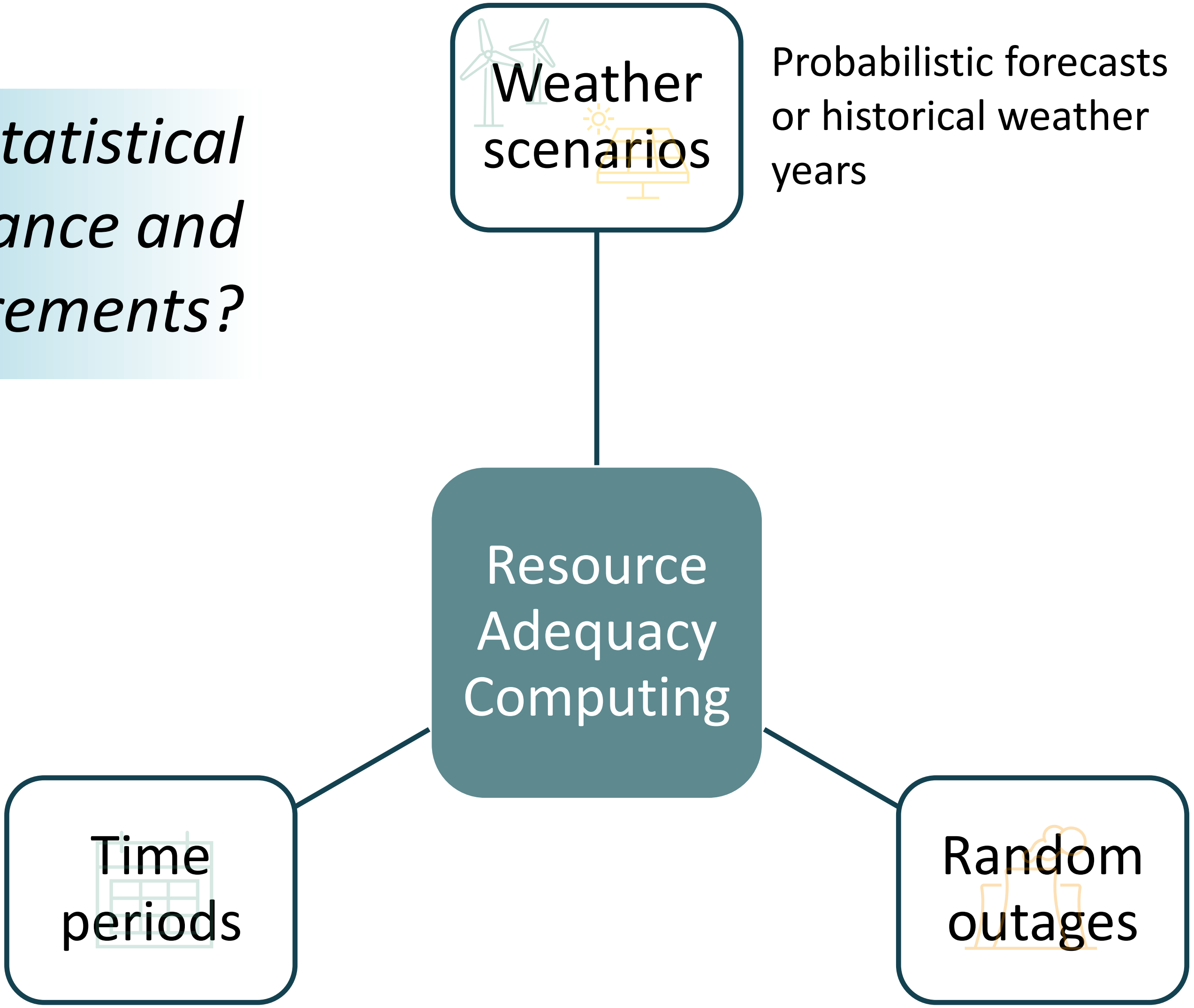
Computational Efficiency

How to balance statistical significance and computational requirements?



Weather scenarios

Probabilistic forecasts or historical weather years

Resource Adequacy Computing

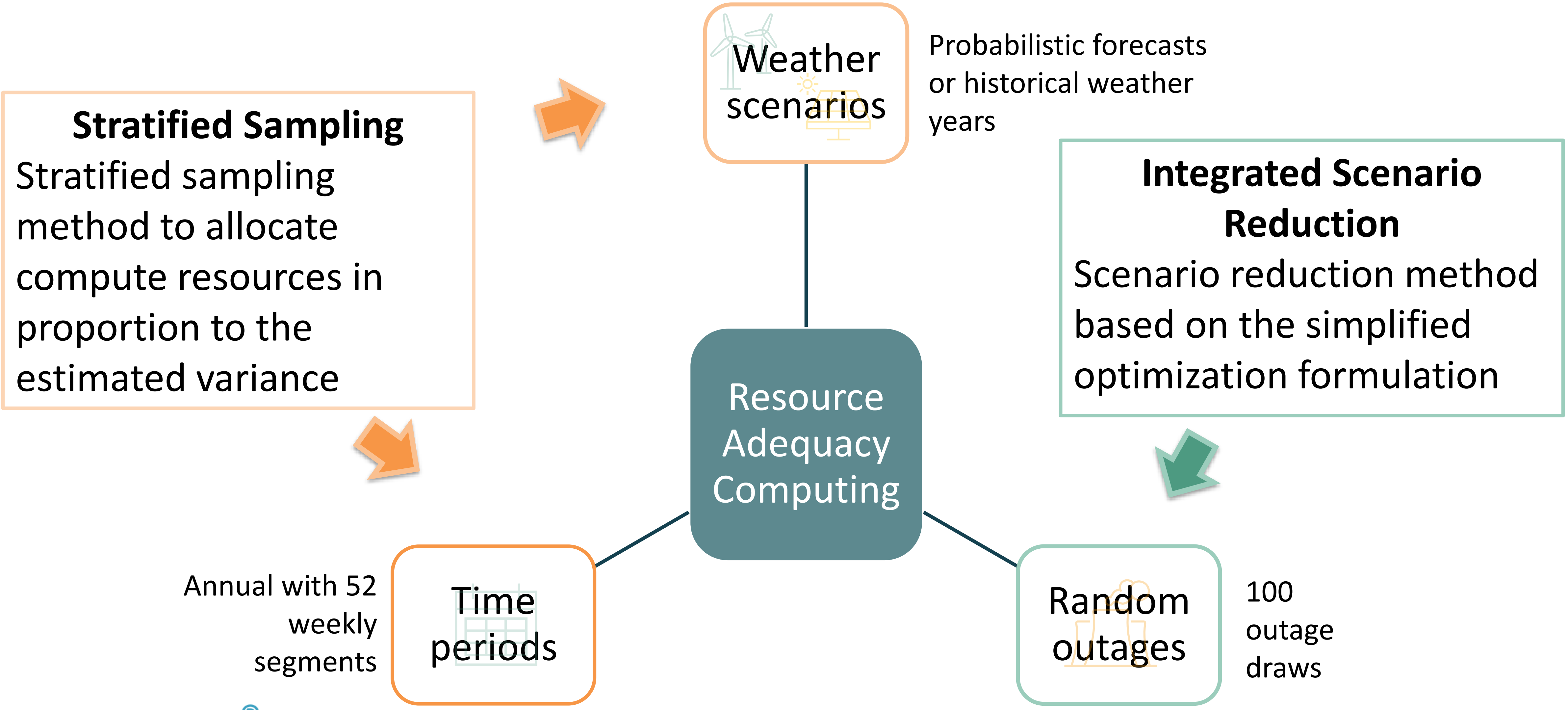
Time periods

Annual with 52 weekly segments

Random outages

100 outage draws

Computational Efficiency



Stratified Sampling
Stratified sampling method to allocate compute resources in proportion to the estimated variance

Weather scenarios

Probabilistic forecasts or historical weather years

Integrated Scenario Reduction
Scenario reduction method based on the simplified optimization formulation

Resource Adequacy Computing

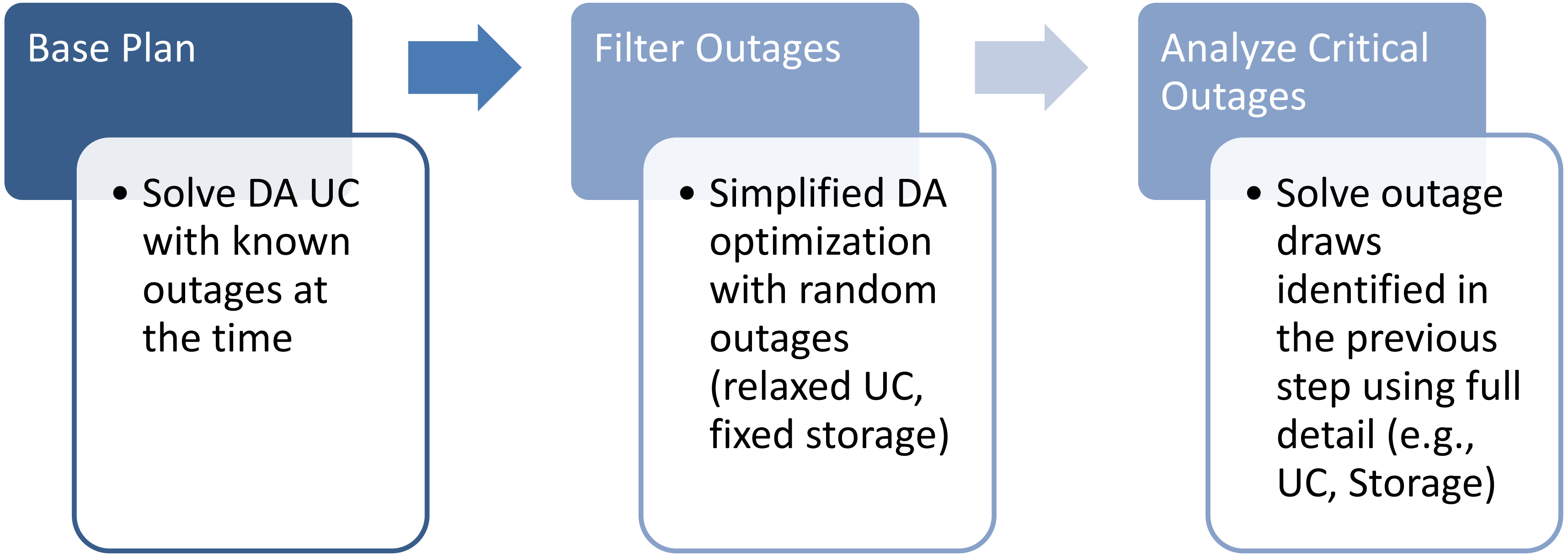
Annual with 52 weekly segments

Time periods

Random outages

100 outage draws

Integrated Scenario Reduction: Random Outage Draws



Base Plan

- Solve DA UC with known outages at the time

Filter Outages

- Simplified DA optimization with random outages (relaxed UC, fixed storage)

Analyze Critical Outages

- Solve outage draws identified in the previous step using full detail (e.g., UC, Storage)

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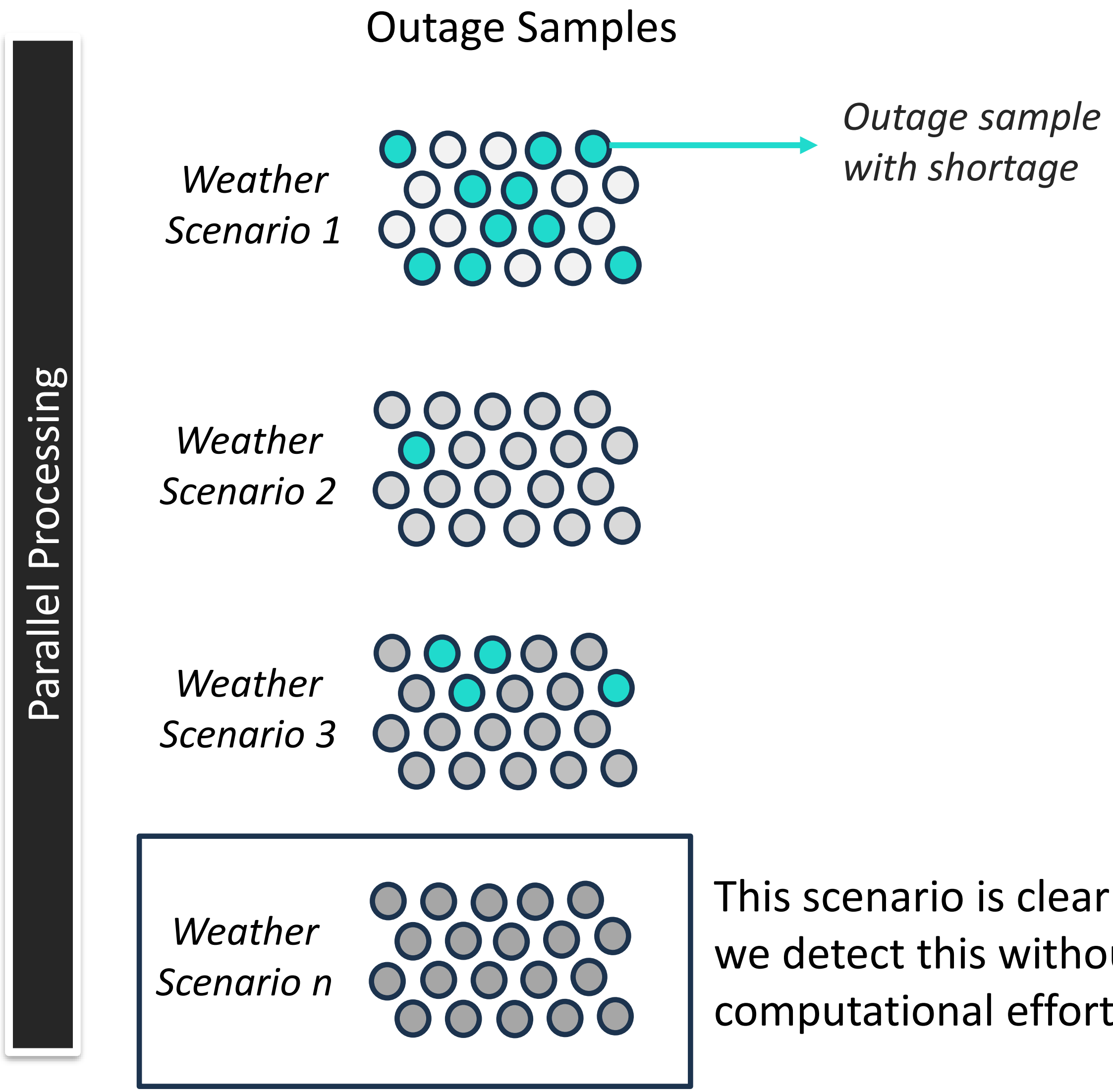
Stratified Sampling For Weather and Time Dimension



Parallel Processing

Outage Samples

Outage sample with shortage

Weather Scenario 1

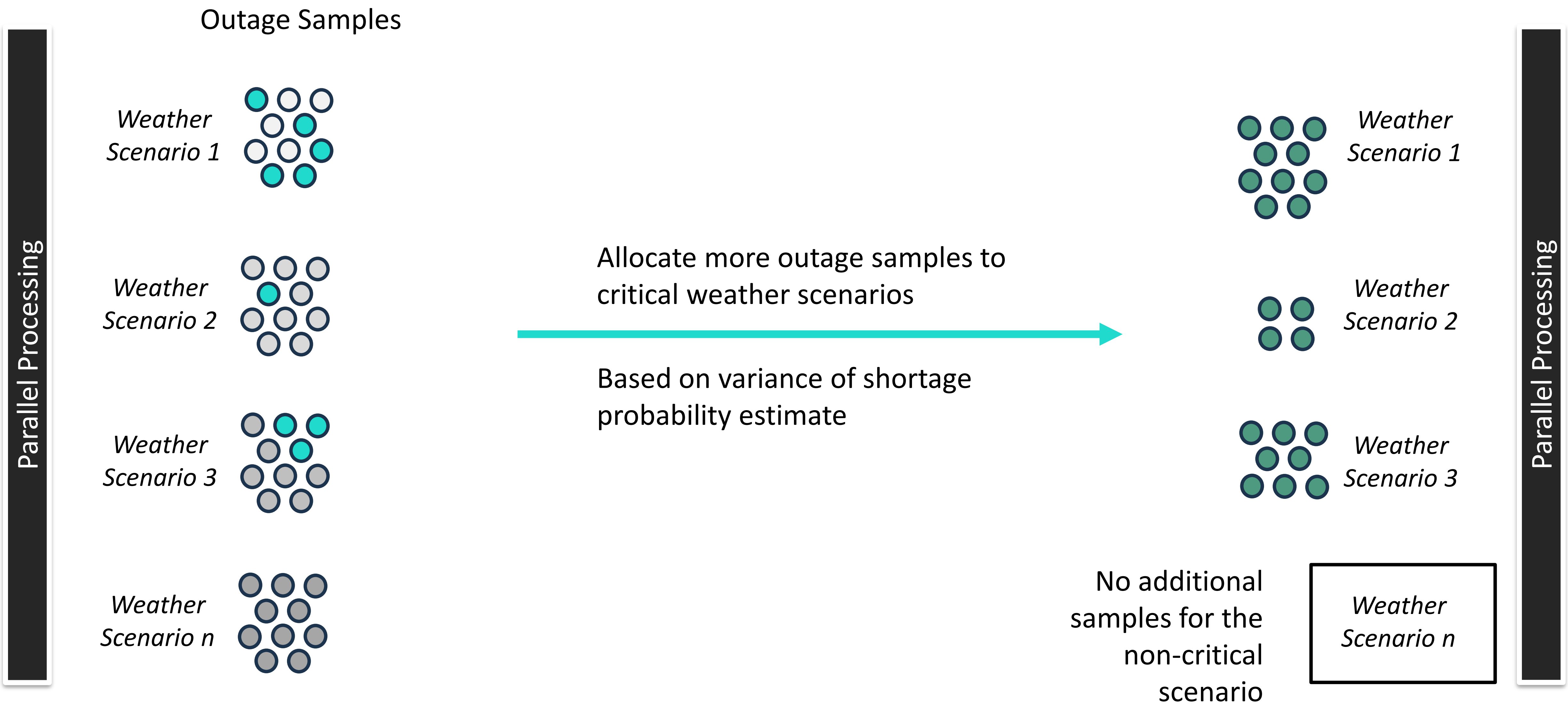
Weather Scenario 2

Weather Scenario 3

Weather Scenario n

This scenario is clearly not critical. Can we detect this without spending heavy computational effort on this scenario?

Stratified Sampling For Weather and Time Dimension



Parallel Processing

Outage Samples

Weather Scenario 1

Weather Scenario 2

Weather Scenario 3

Weather Scenario n

Allocate more outage samples to critical weather scenarios

Based on variance of shortage probability estimate

Weather Scenario 1

Weather Scenario 2

Weather Scenario 3

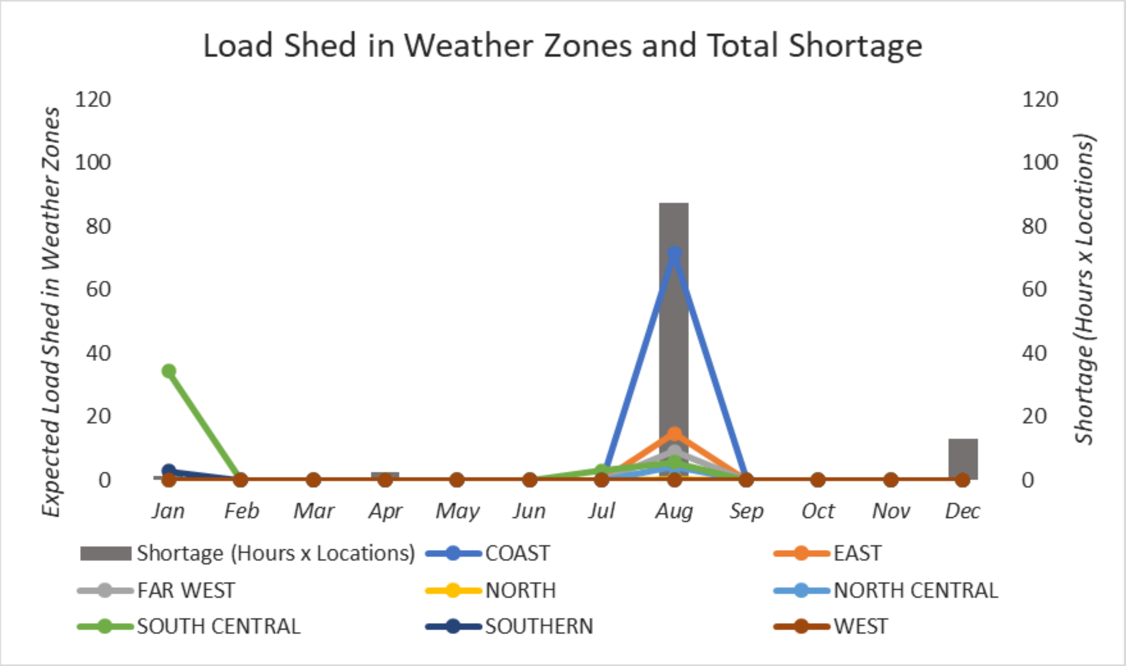
No additional samples for the non-critical scenario

Weather Scenario n

Parallel Processing

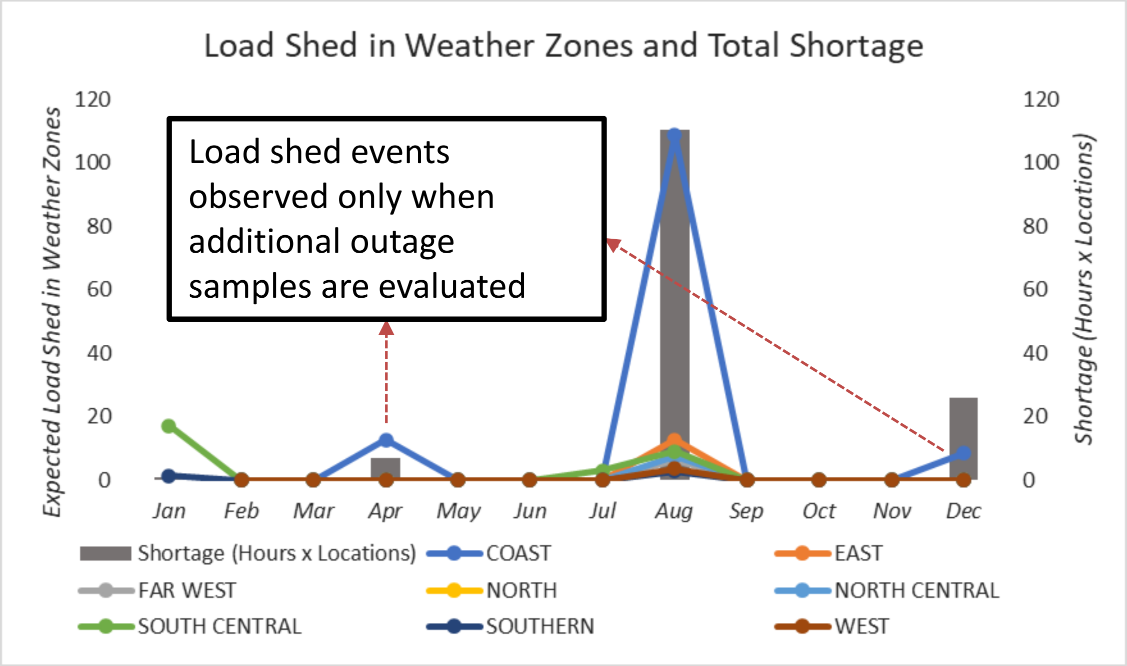
Stratified Sampling for ERCOT

100 outage draws x 52 weeks = 5200 samples



Turn-around time: 3 hours

100 outage draws x 52 weeks = 5200 samples
Additional samples: 2700 draws /week



Load shed events observed only when additional outage samples are evaluated

Turn-around time: 3 + 8 hours = 11 hours

In Summary

- Resource Adequacy can assess impacts on a physically detailed and operationally accurate model of energy systems:
  - Powerflow constraints and contingency analysis,
  - Unit commitment,
  - Storage, ramping, emissions, and a wide range of other physical and system constraints
- Assessment is both for planning and operational studies
- Operational details impact study outcomes (not all outages are known in advance, and not all decisions are flexible)
- We illustrated inclusion of transmission model with unit commitment and storage optimization
  - Other modeling options:
    - Impacts from any non-recourse decisions on later reliability
    - Sharing with neighbors in multi-footprint models
    - Impacts from other energy systems (gas supply limitations)
    - Load participation and impacts of changing policies (e.g., retail rate design)