Power System Adequacy and Resilience in a Changing Climate

CLIMATE READi
RESILIENCE AND ADAPTATION INITIATIVE

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Resource Adequacy

“The **ability of the electricity system to supply the aggregate electrical demand** and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements” (NERC, 2013)

North American Electric Reliability Corporation. Reliability Terminology, August 2013

Resilience

“The **ability to withstand and reduce the magnitude and/or duration of disruptive events**, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event” (FERC 2018)

Federal Energy Regulatory Commission. Grid Resilience in Regional Transmission Organizations and Independent System Operators, January 2018

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Resource Adequacy

Resilience

Challenges to an Adequate System:

- Load growth and electrification
- Increasing weather-dependent generation
- Common-cause impacts

Challenges to a Resilient System:

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- Load growth and electrification
- Increasing weather-dependent generation
- Common-cause impacts
- Increasing frequency and severity of high-stress events

We care that an outage happens

Resilience

Challenges to a Resilient System:

- Load growth and electrification
- Increasing weather-dependent generation
- Common-cause impacts
- Increasing frequency and severity of high-stress events
- Increasing dependence on electricity

We care what happens as a result of an outage

Resource Adequacy

Resilience

Assessing Adequacy:

- Well-defined metrics
- Concerned with loss of load
  - Frequency
  - Duration
  - Magnitude

- In general, all outages are equally important

Assessing Resilience:

- No standard metrics
- Concerned with loss of load
- Concerned with pre-event preparedness
- Concerned with during-event response
- Concerned with post-event restoration

- Some aspects of outages may be more important than others
  - Widespread, long-duration disruptions
  - Disruptions to critical loads
  - Disruptions to vulnerable customers

Resource Adequacy

Assessing Adequacy:

- Well-defined metrics
- Concerned with loss of load
  - Frequency
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  - Magnitude
- In general, all outages are equally important

Hard to define metrics that capture all aspects of resilience in a meaningful way

Resilience

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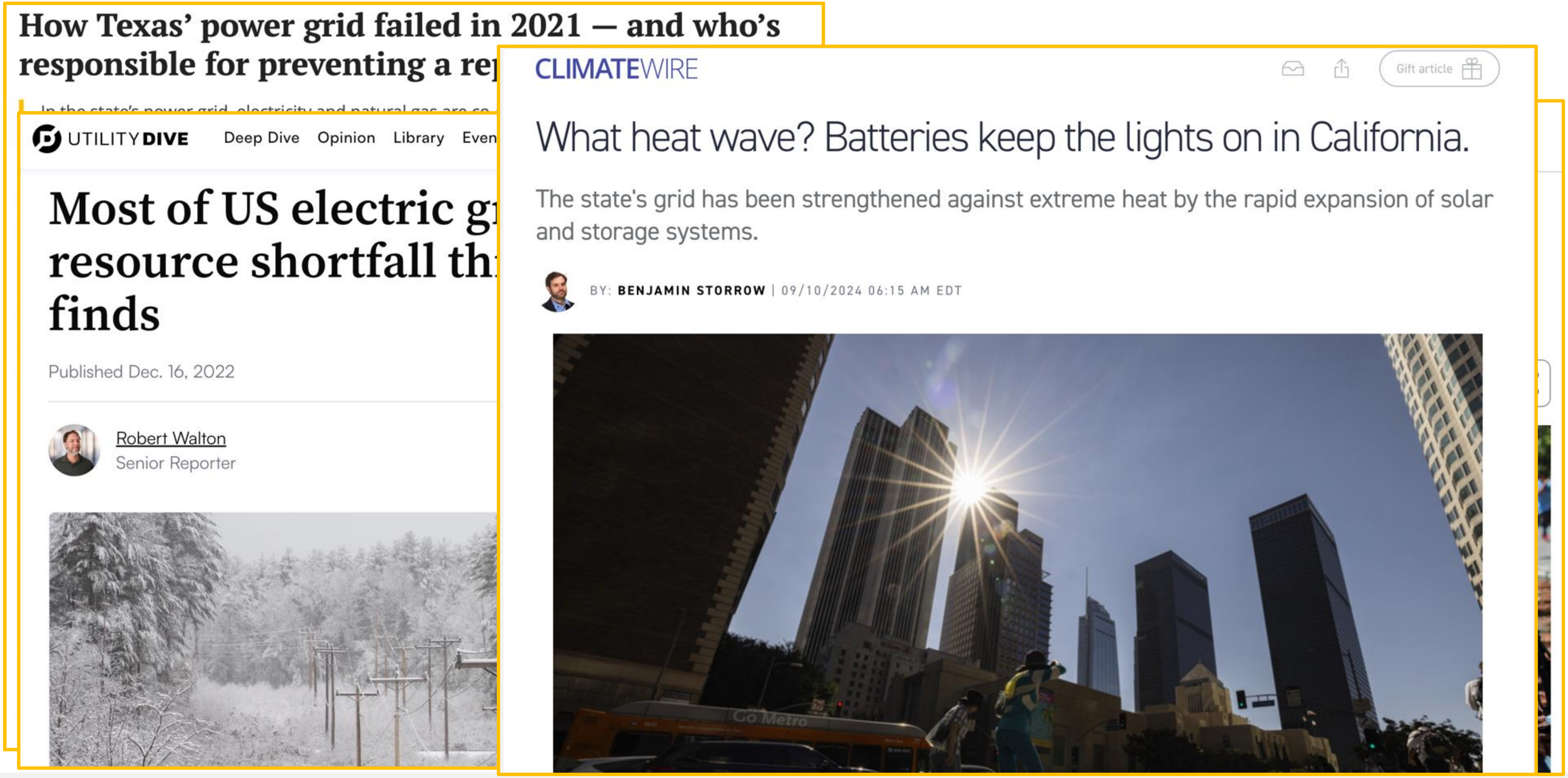
Is the grid adequate? Is it resilient? How do we judge?



How Texas' power grid failed in 2021 — and who's responsible for preventing a rep

In the state's power grid, electricity and natural gas are co

Most of US electric gr resource shortfall th finds

Published Dec. 16, 2022

Robert Walton
Senior Reporter

What heat wave? Batteries keep the lights on in California.

The state's grid has been strengthened against extreme heat by the rapid expansion of solar and storage systems.

BY: **BENJAMIN STORROW** | 09/10/2024 06:15 AM EDT

Long-term planning for adequacy and resilience requires augmenting traditional planning regimes

"Traditional" Planning Uncertainties

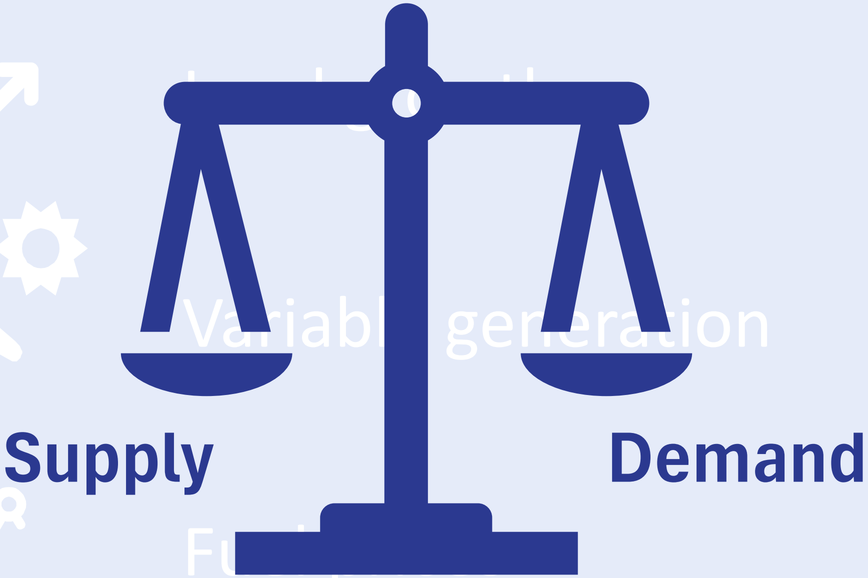
- Load growth
- Variable generation
- Fuel prices
- Policies and regulations

New Uncertainties to Consider

- Electrification
- Climate Change
- Severe weather events
- Climate impacts on assets

Uncertainties drive the scoping and set-up of assessment efforts, for both adequacy and resilience

“Traditional” Planning Uncertainties



Variabl generation

Fu

Policies and regulations

New Uncertainties to Consider

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Workstream 1	Workstream 2	Workstream 3
Physical Climate Data & Guidance	**Energy System & Asset Vulnerability Assessment**	**System Adaptation & Investment Prioritization**
• Identify climate hazards and data required for different applications • Evaluate data availability, suitability, and methods for downscaling & localizing climate information • Address data gaps	• Evaluate vulnerability at the component, system, and market levels from planning to operations • Identify mitigation options from system to customer level • Enhance criteria for planning and operations to account for event probability and uncertainty	• Assess power system and societal impacts: resilience metrics and value measures • Create guidance for optimal investment priorities • Develop cost-benefit analysis, risk mitigation, and adaptation strategies

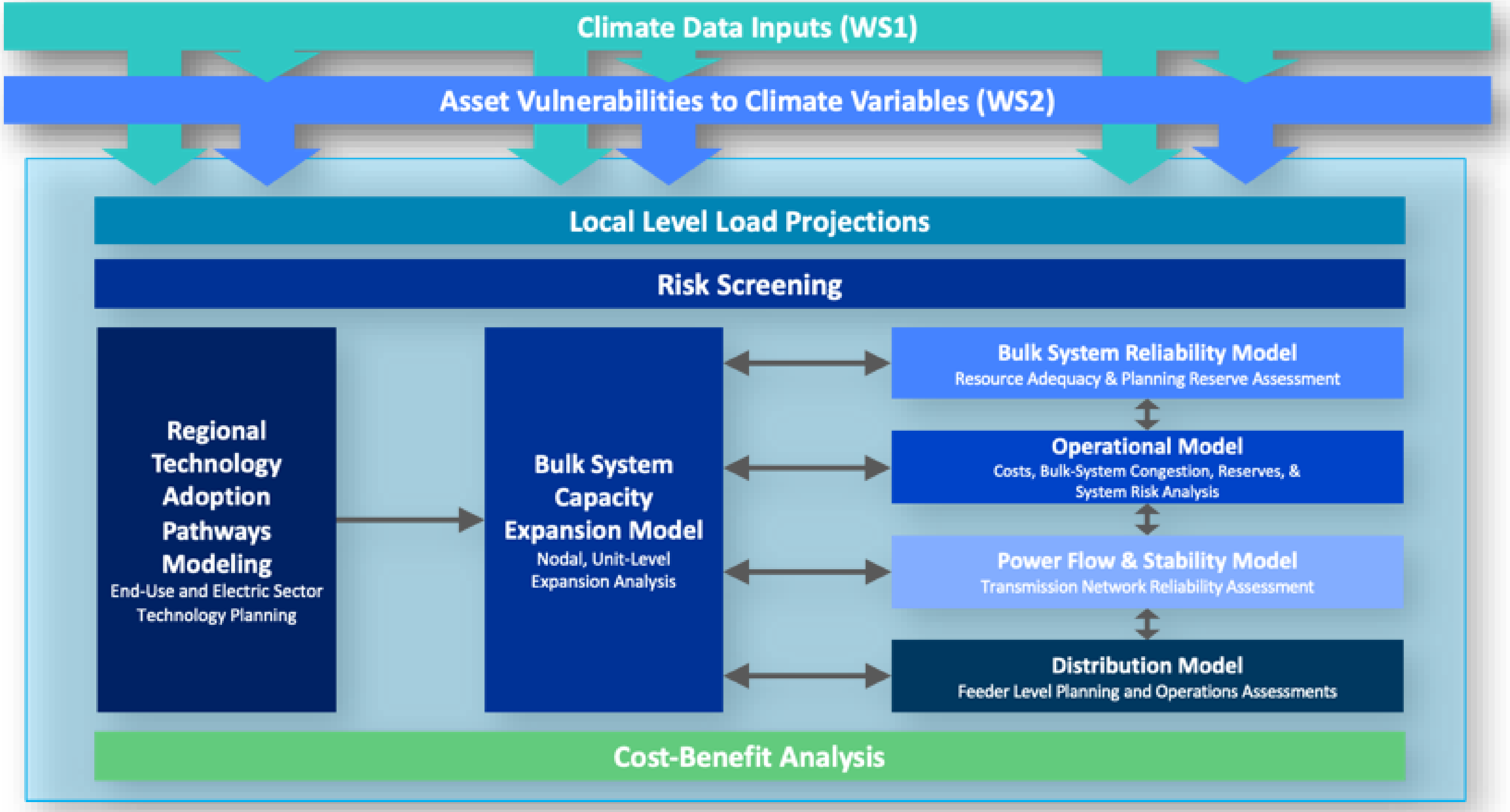
EPRI Climate Resilience and Adaptation Initiative (READi)

- **COMPREHENSIVE:** Develop a *Common Framework* addressing the entirety of the power system, planning through operations
- **CONSISTENT:** Provide an informed approach to climate risk assessment and strategic resilience planning that can be replicated
- **COLLABORATIVE:** Drive stakeholder alignment on adaptation strategies for efficient and effective investment

Deliverables: Common Framework "Guidebooks"

- Climate data assessment and application guidance
- Vulnerability assessment
- Risk mitigation investment
- Recovery planning
- Hardening technologies
- Adaptation strategies
- Research priorities

Climate READi uses an integrated system modeling approach



Climate Data Inputs (WS1)

Asset Vulnerabilities to Climate Variables (WS2)

Local Level Load Projections

Risk Screening

Regional Technology Adoption Pathways Modeling
End-Use and Electric Sector Technology Planning

Bulk System Capacity Expansion Model
Nodal, Unit-Level Expansion Analysis

Bulk System Reliability Model
Resource Adequacy & Planning Reserve Assessment

Operational Model
Costs, Bulk-System Congestion, Reserves, & System Risk Analysis

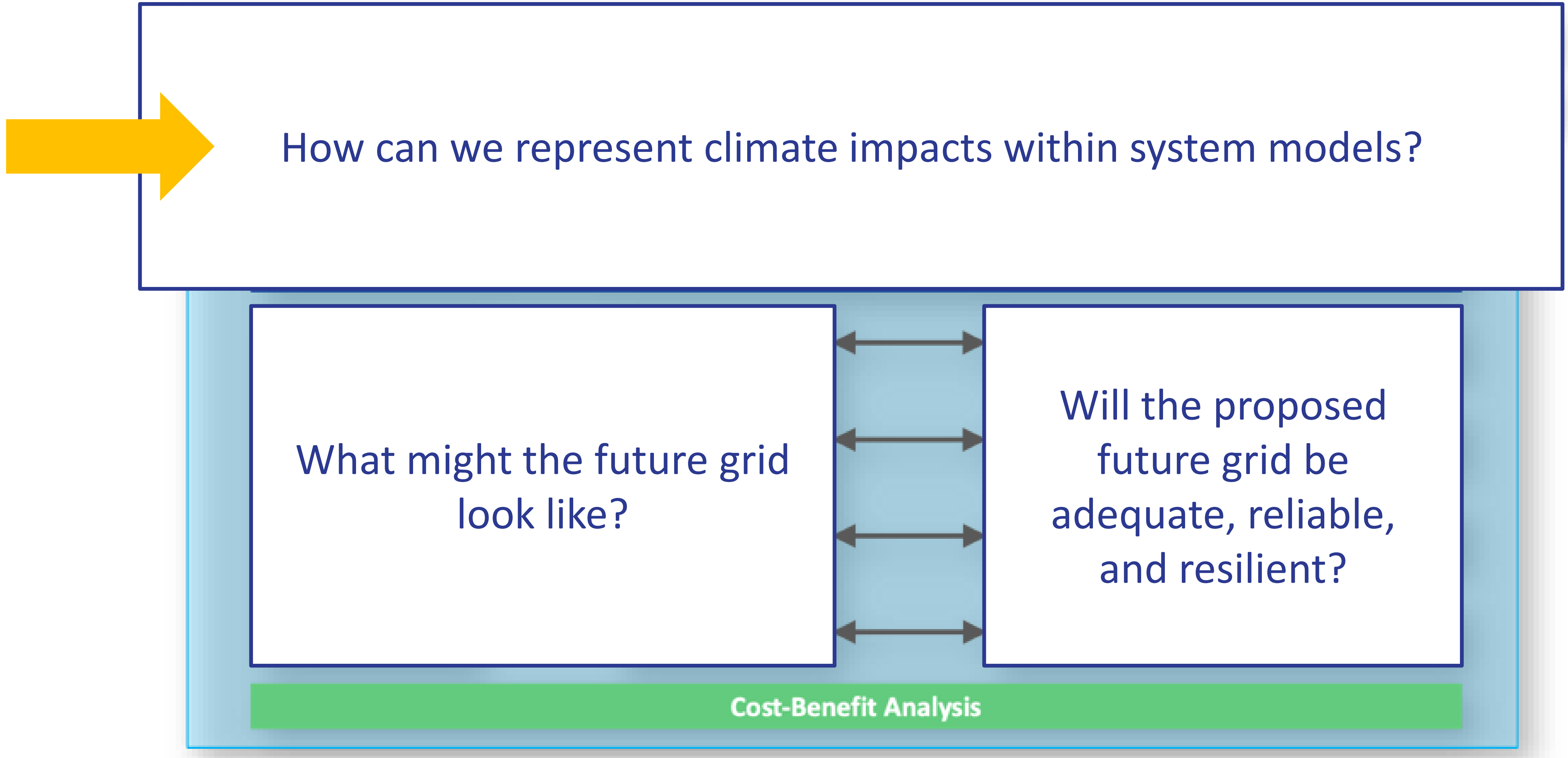
Power Flow & Stability Model
Transmission Network Reliability Assessment

Distribution Model
Feeder Level Planning and Operations Assessments

Cost-Benefit Analysis

Still, there are many decisions required in the selection of climate data and extreme events to plan for

Climate READi uses an integrated system modeling approach



How can we represent climate impacts within system models?

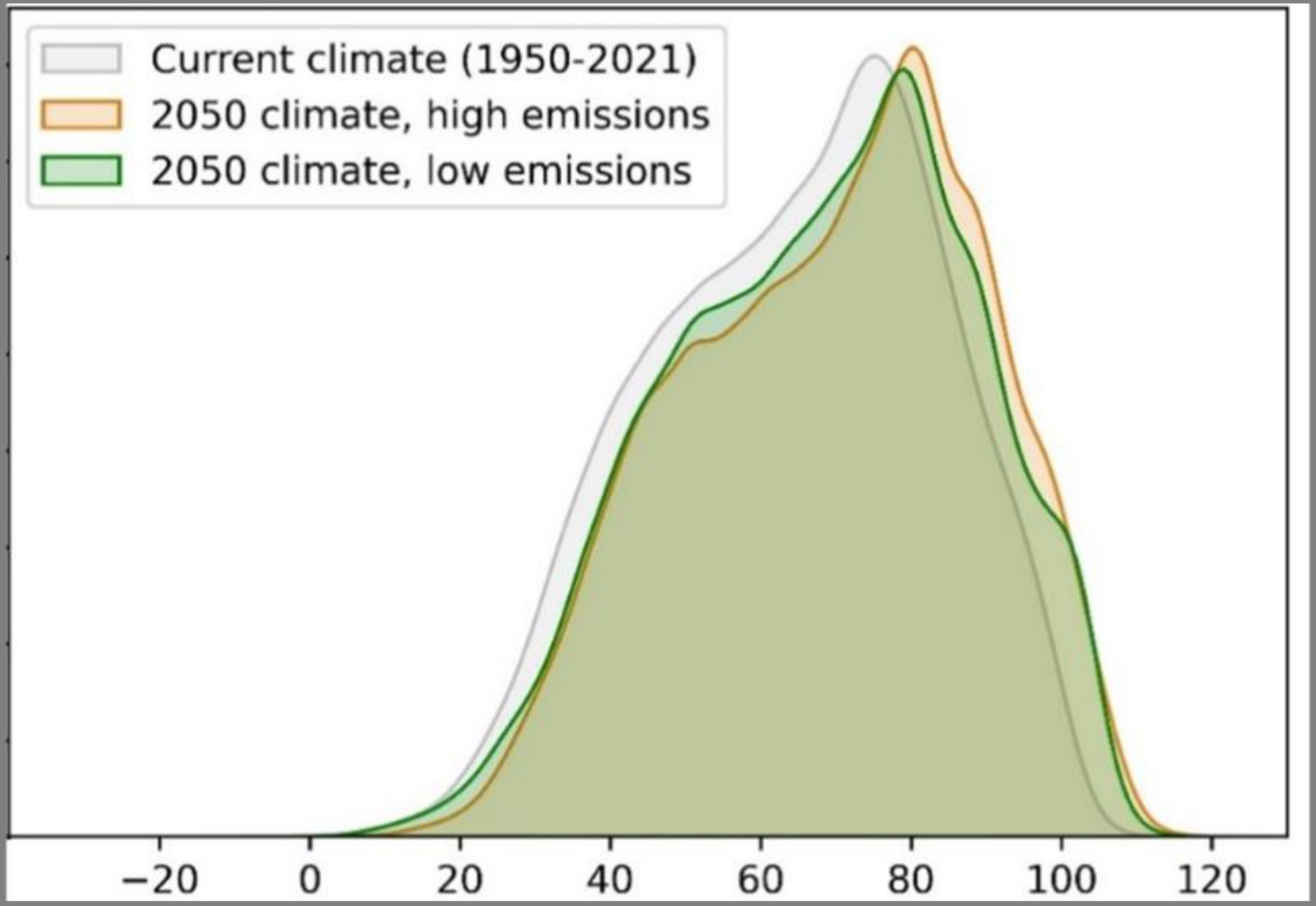
What might the future grid look like?

Will the proposed future grid be adequate, reliable, and resilient?

Still, there are many decisions required in the selection of climate data and extreme events to plan for

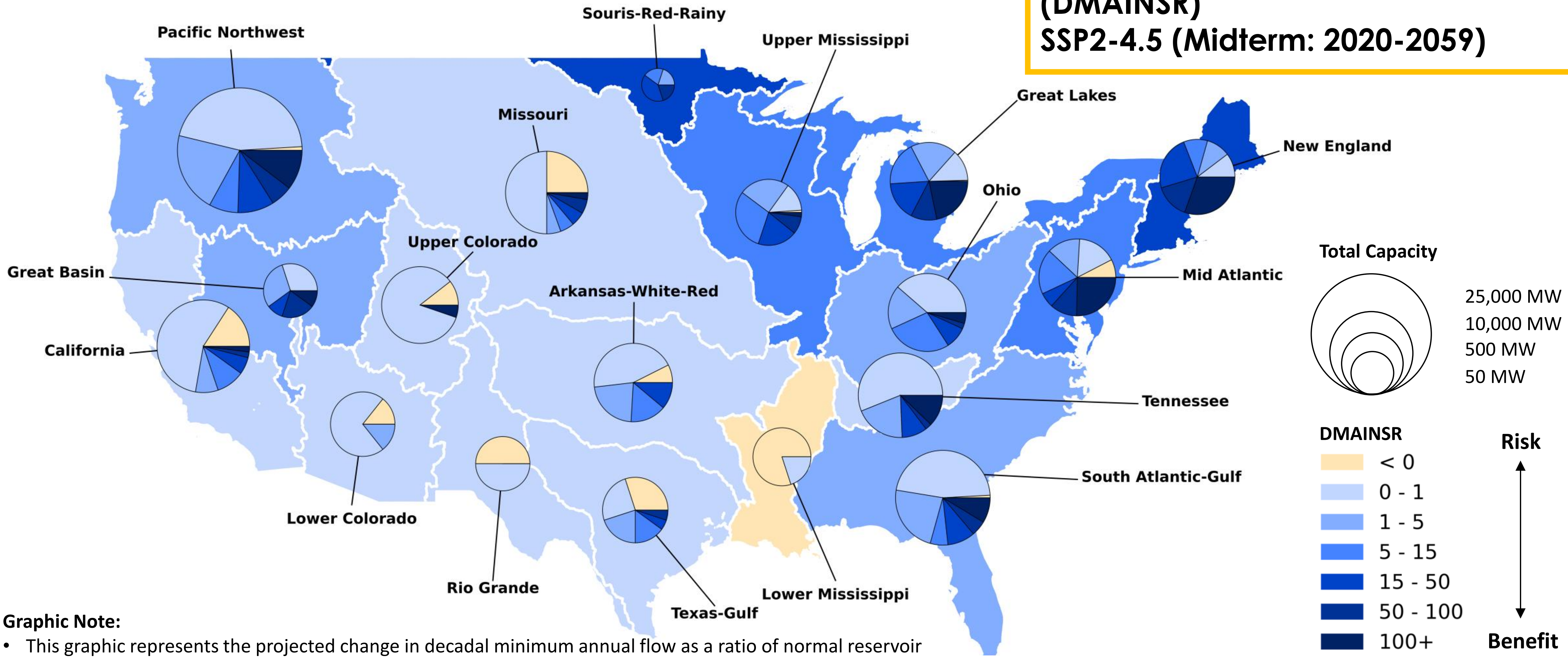
Bounding the data problem: How do we expect climate and weather to change?

- Data choice and preparation should be determined by the application or modeling need, including planning time horizon
- Adequacy and resilience concerns both lie in the tails of a distribution – important to understand what these changes mean
- Relevant data can span both historical and future periods



Bounding the data problem: What might future extreme events look like?

Hydro Generation Risk Indicator: Change in Decadal Minimum Annual Inflow to Normal Storage Ratio (DMAINSR)
SSP2-4.5 (Midterm: 2020-2059)



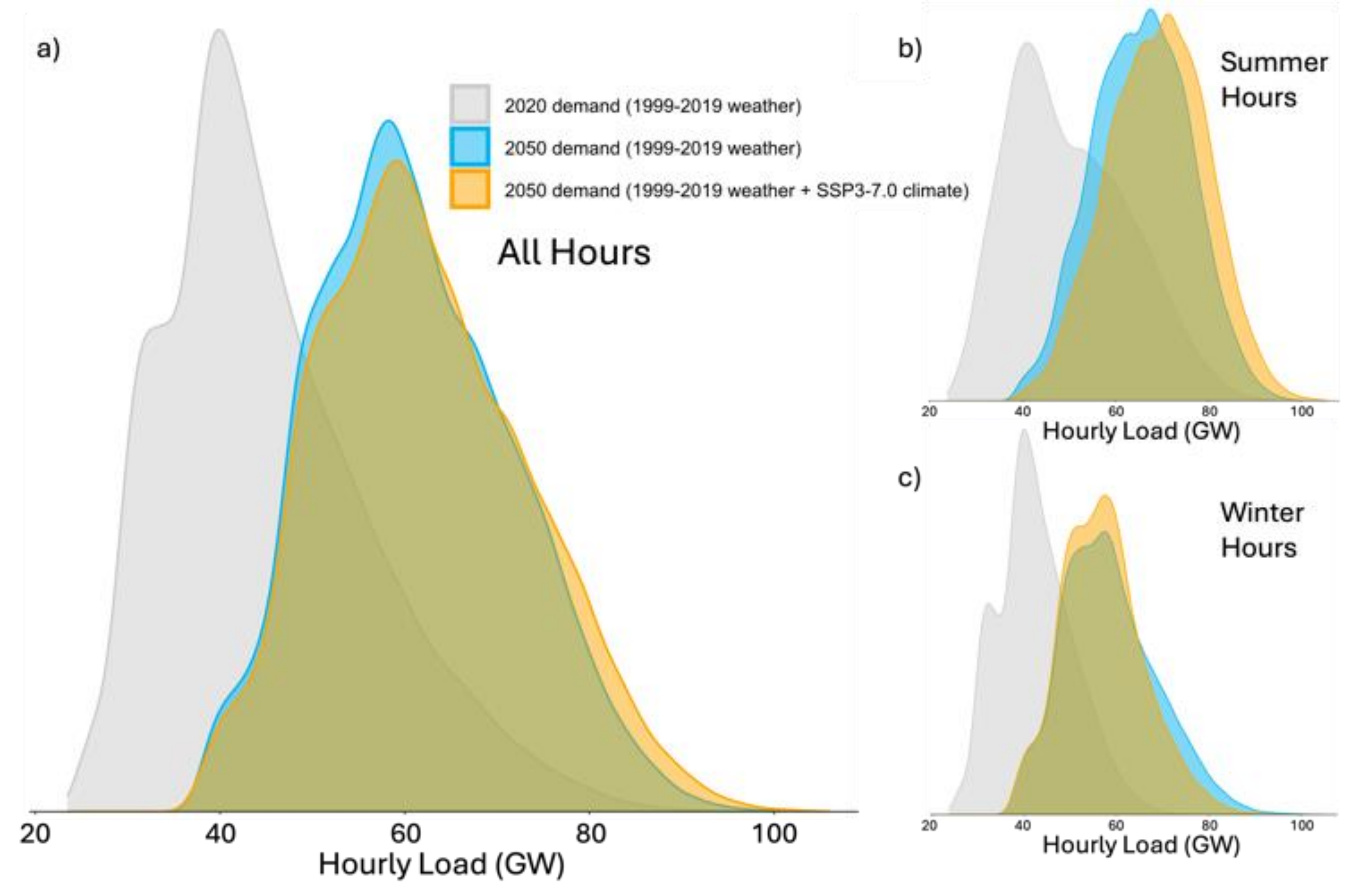
Hydrological region colors: Median generation risk
Pie chart: Distribution of risk across the number of hydropower plants

Graphic Note:

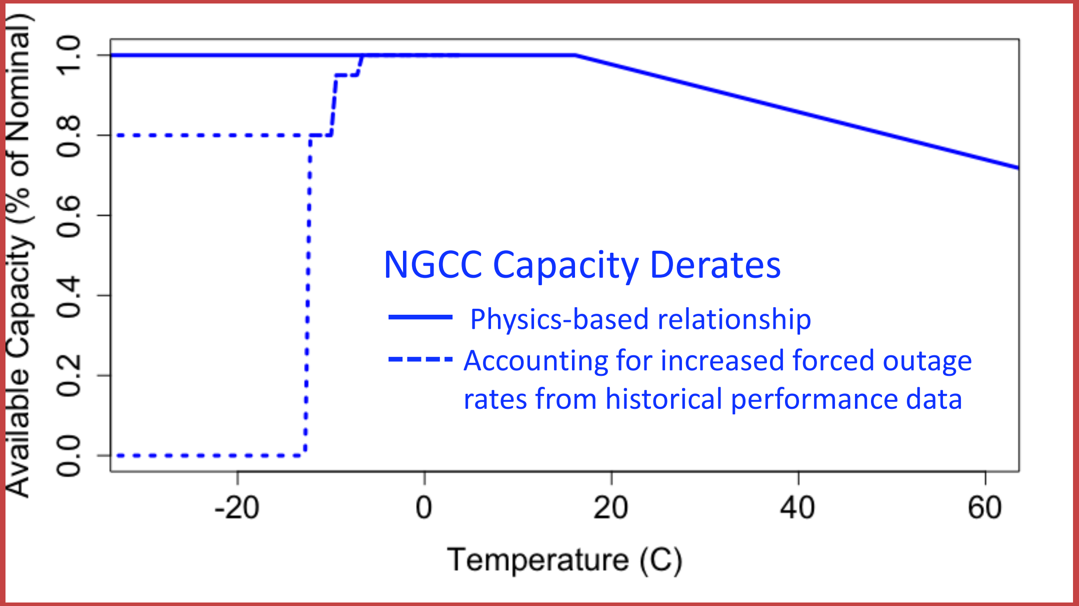
- This graphic represents the projected change in decadal minimum annual flow as a ratio of normal reservoir storage levels. This indicates the projected extent of impacts on generation and the extent that maintaining generation levels will have on reservoir volumes. It is important to note that additional factors such as outflow requirements and timing of the annual inflow play a key role in determining generation impacts at individual sites. This should be further explored in future work.

Beyond the climate data: How will future conditions impact electricity demand?

- Load models have typically accounted for historical or weather-normal conditions
- Need to capture sensitivity of projected end-use technologies to extreme events or extreme meteorological years
- End-use projection models can be useful for understanding sensitives in demand - largest change *not* driven by climate!



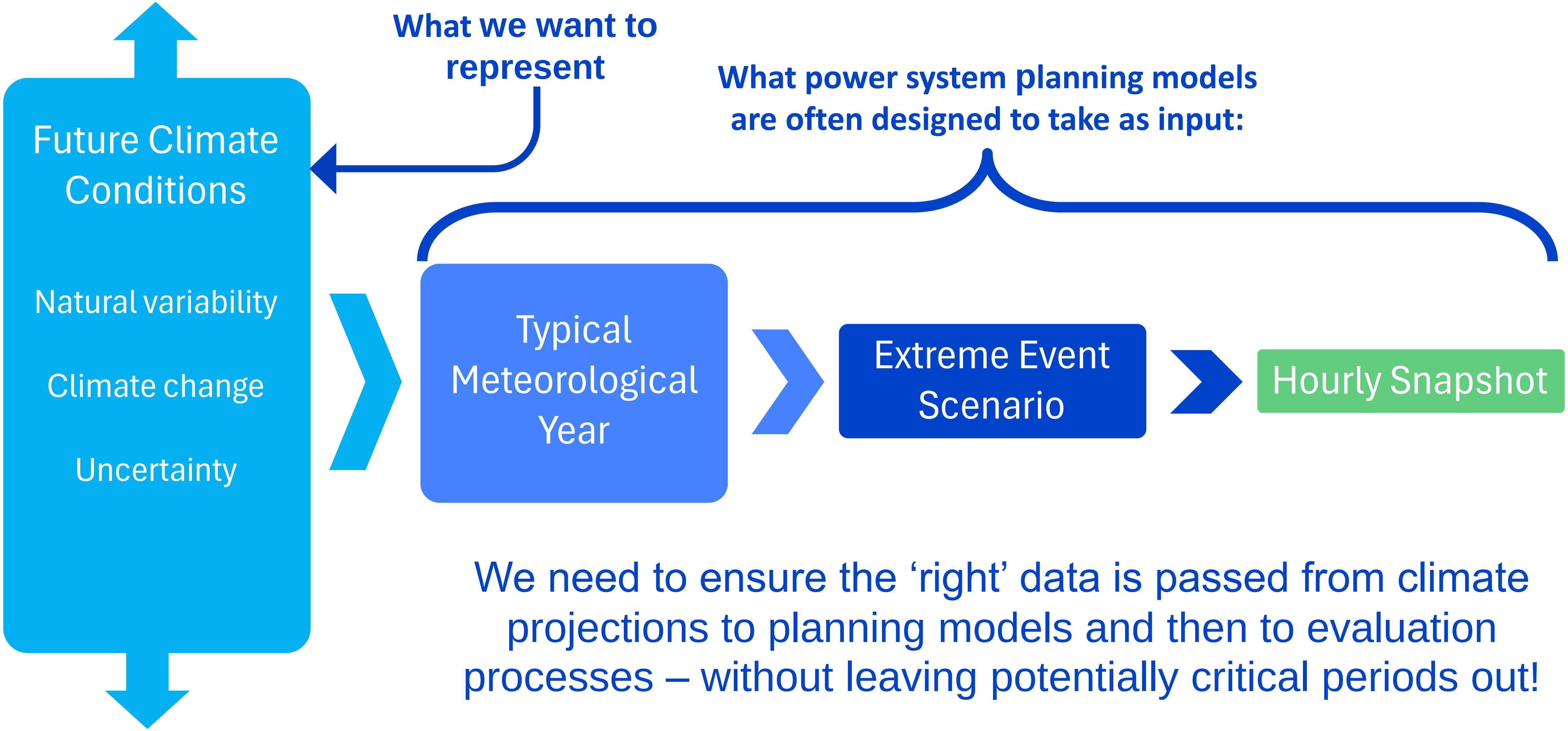
Beyond the climate data: How will future conditions impact asset performance?



HAZARD	VULNERABILITY	ASSET AT RISK	HAZARD IMPACT	MAGNITUDE
High temperature	Heat-induced derate or cooling system constraint	Thermal generators	Reduced capacity	0–30%
Low temperature	Cold-induced fuel disruption	Natural gas plants without backup fuel	Generation unavailable	100%
Low temperature, humidity, and precipitation	Ice accretion	Wind turbines	Reduced capacity	40–80%
Snow	Snow buildup	Solar panels	Generation unavailable	100%

- High-stress events: aggregation of individual asset impacts
- Vulnerabilities vary with asset class, configuration, design standards, adaptations in place, age, maintenance history, etc.
- Accurately capturing vulnerabilities is broader than failures – it gives a realistic assessment of performance across a range of operating conditions

Once we choose the bounds of climate risk, we still need to choose data as input for models



What we want to represent

What power system planning models are often designed to take as input:

Future Climate Conditions

Natural variability

Climate change

Uncertainty

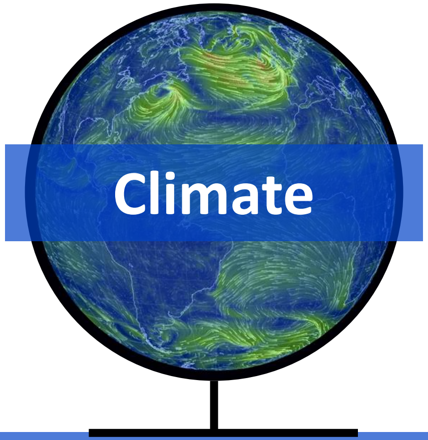
Typical Meteorological Year

Extreme Event Scenario

Hourly Snapshot

We need to ensure the ‘right’ data is passed from climate projections to planning models and then to evaluation processes – without leaving potentially critical periods out!

One approach: Risk Screening (RiSc) to identify relevant data across models

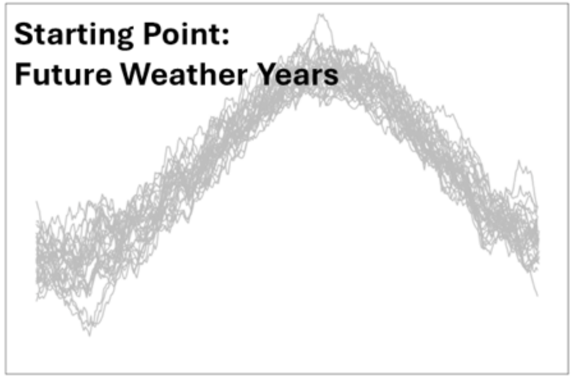


1. Take a large amount of climate data and pass it through fast, approximate models that correlate to stressed grid conditions: high loads and high likelihood of generator unavailability
2. Identify key time periods for more detailed downstream modeling to capture a diverse set of extreme events

Challenges in applying climate data in power system planning assessments:

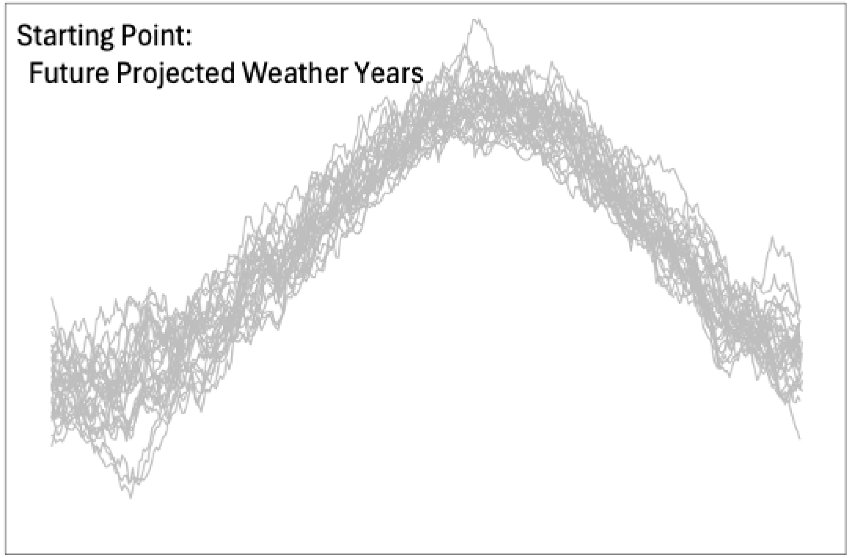
- Climate models provide coarse spatial and temporal resolutions
- Power system operations are sensitive to weather co-variability (e.g., wind and solar)
- Extremes are rare by definition (and we may lack sufficient observations)

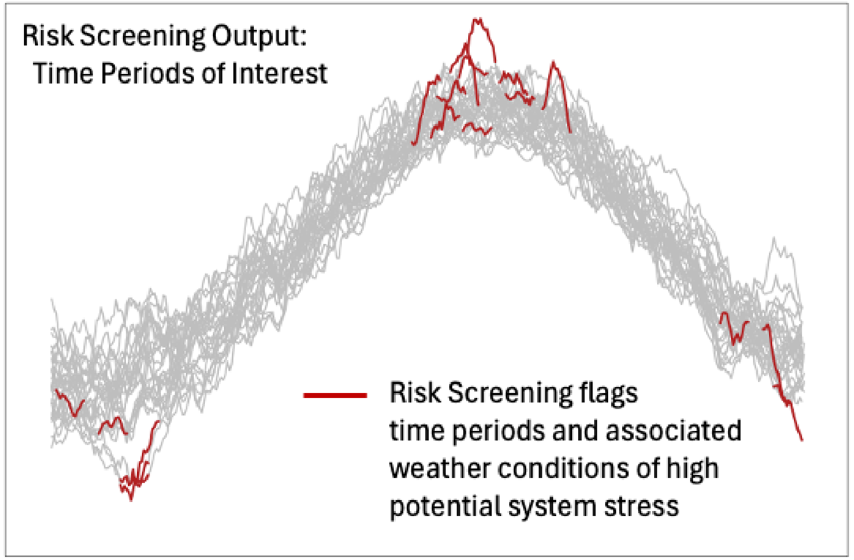
72 Historical years
x 5 global climate models
x 2 emissions scenarios
x 26 asset locations
x 8760 hours per year



Simplified representation of synchronous meteorology (temperature, wind, solar, etc.)

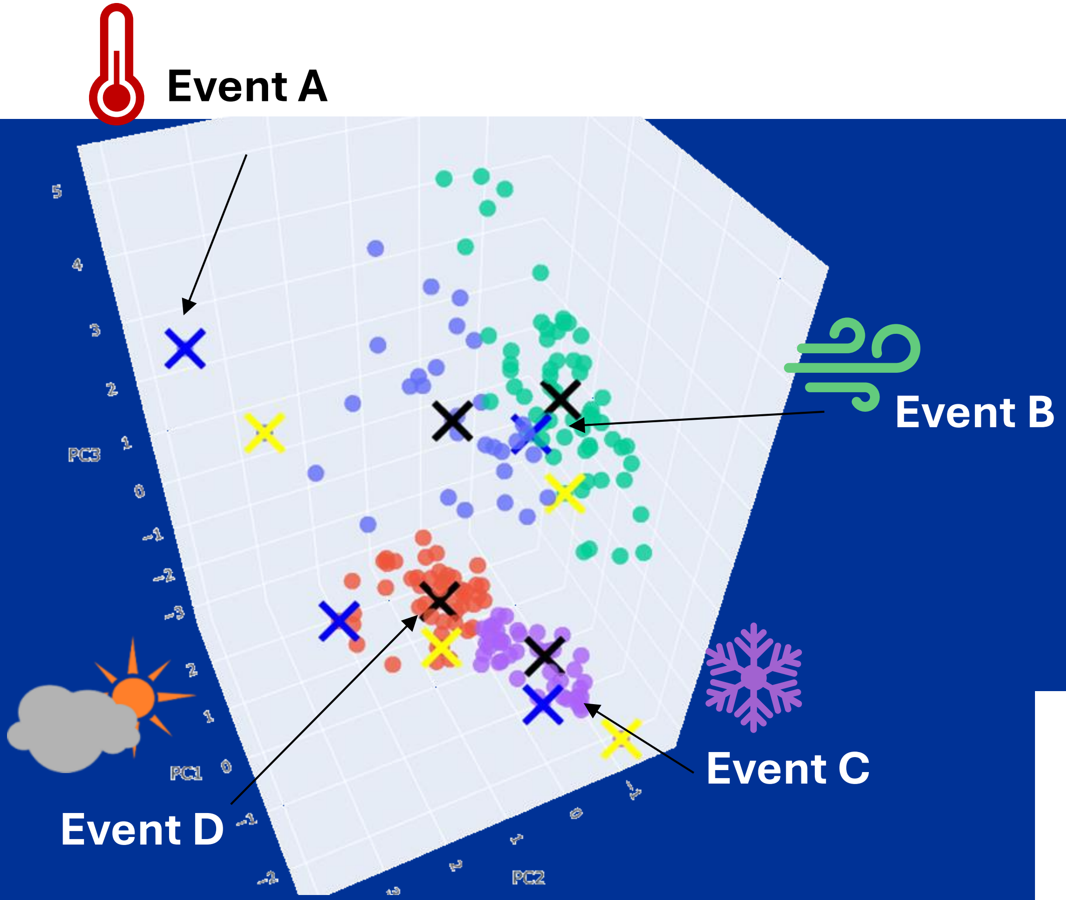
RiSc identifies high-stress time periods of concern


Starting Point:
Future Projected Weather Years


Risk Screening Output:
Time Periods of Interest

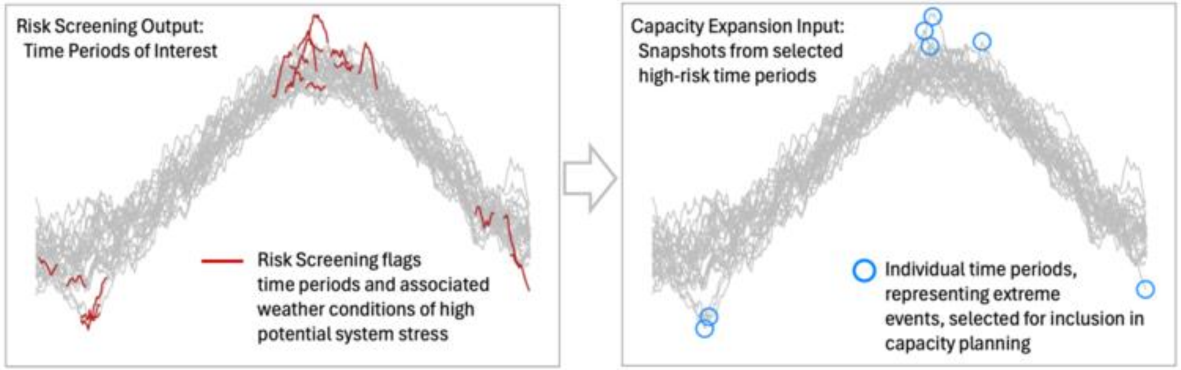
Risk Screening flags time periods and associated weather conditions of high potential system stress

RiSc tool clusters and flags diverse events

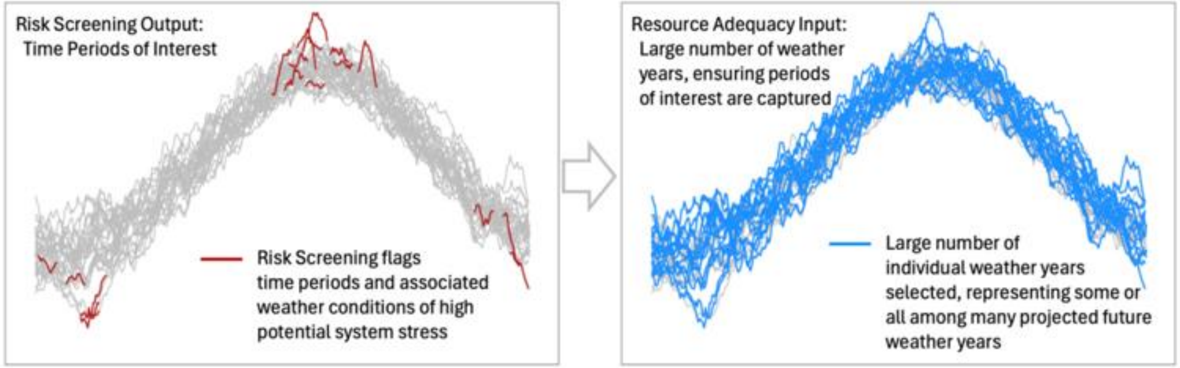


Climate Data Across Modeling Functions: RiSc can support data selection for many uses

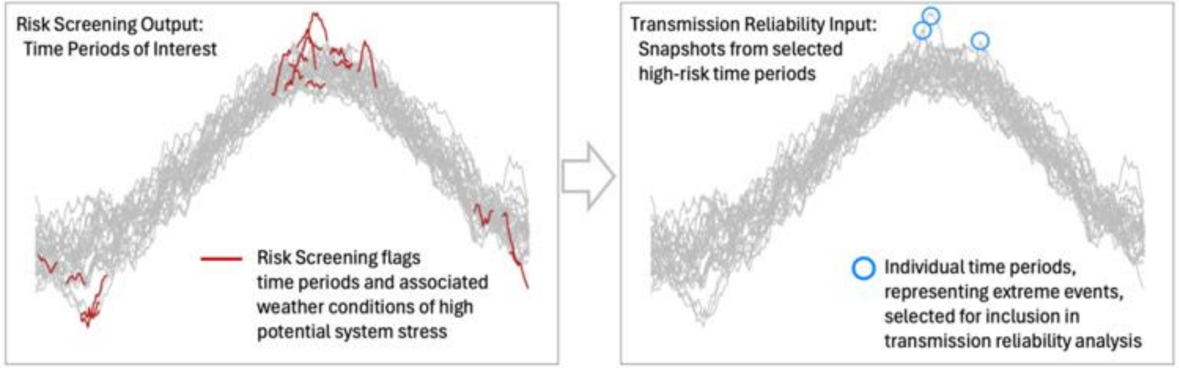
E.g., capacity expansion may use specific events



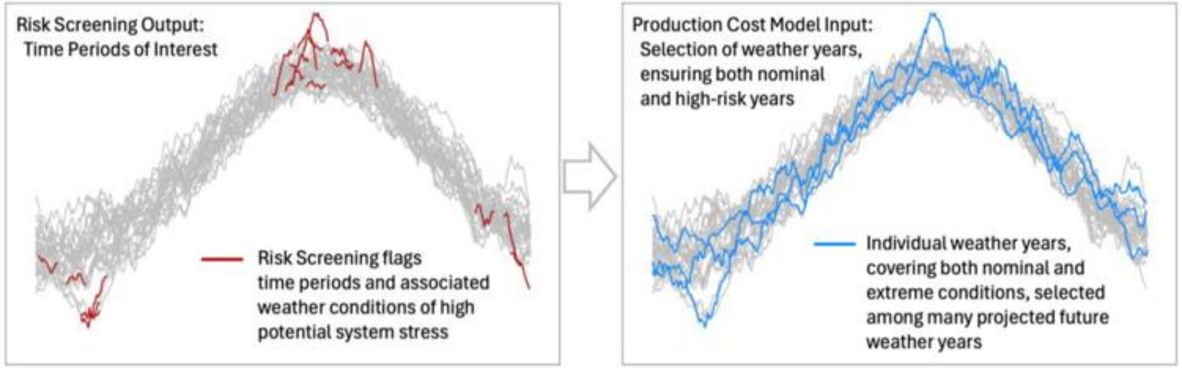
E.g., resource adequacy evaluates many weather years



E.g., transmission reliability requires snapshots

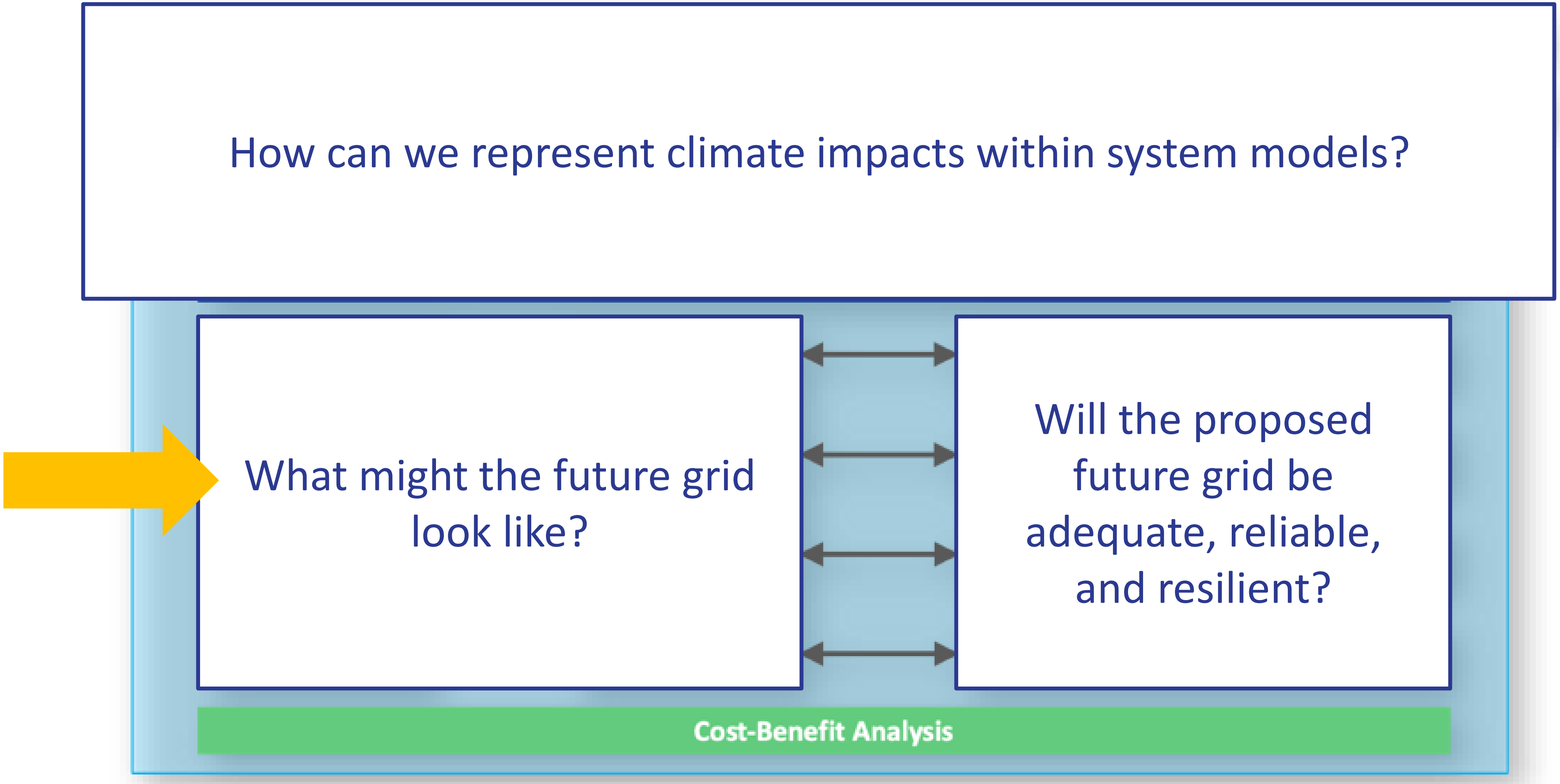


E.g., production cost evaluate specific years or events



Climate data and impacts are consistently captured across bulk system modeling functions

Climate READi uses an integrated system modeling approach



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Cost-Benefit Analysis

Still, there are many decisions required in the selection of climate data and extreme events to plan for

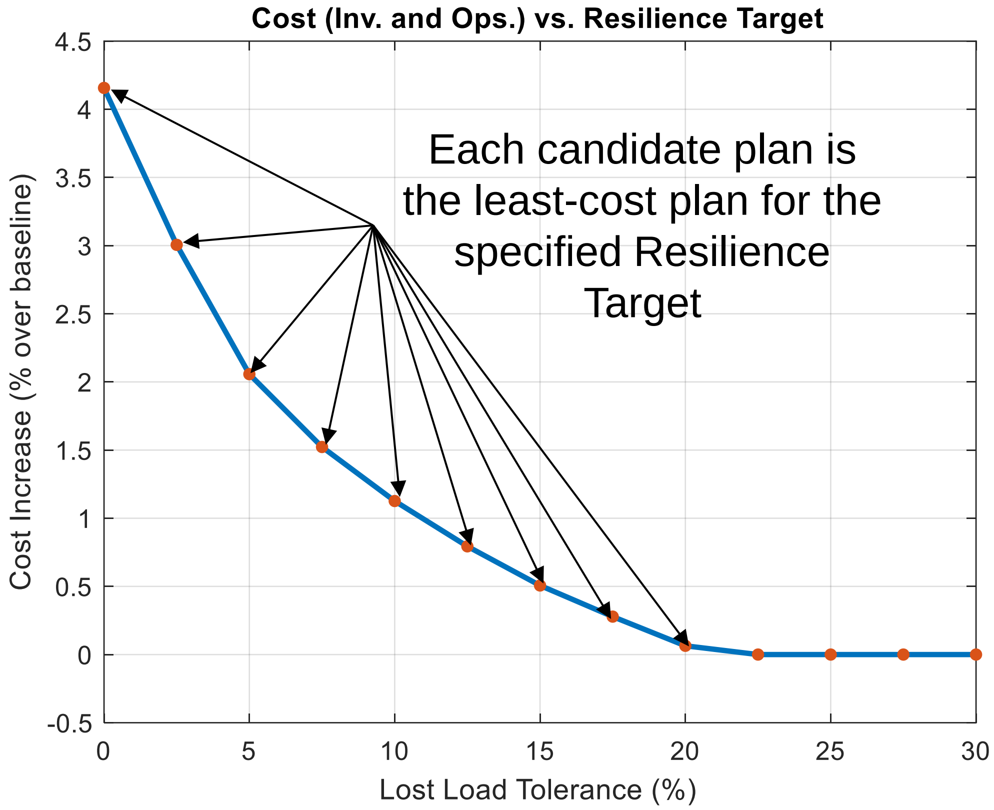
Resilient Capacity Expansion Planning: Directly accounting for high-stress events through planning

- **Baseline Planning Model:** Find the least-cost generation and transmission expansion plan

- **Resilient Planning Model:** Find the least-cost generation, transmission, and **hardening** expansion plan **that meets specified resilience targets during high-stress events**

- Resilience Metric for this example: **Lost Load Tolerance (LLT)**
  - LLT 10% means: No event in the capacity planning model can drop more than 10% of system demand
  - This is a **Planning Target** for the capacity planning model, not an evaluation result

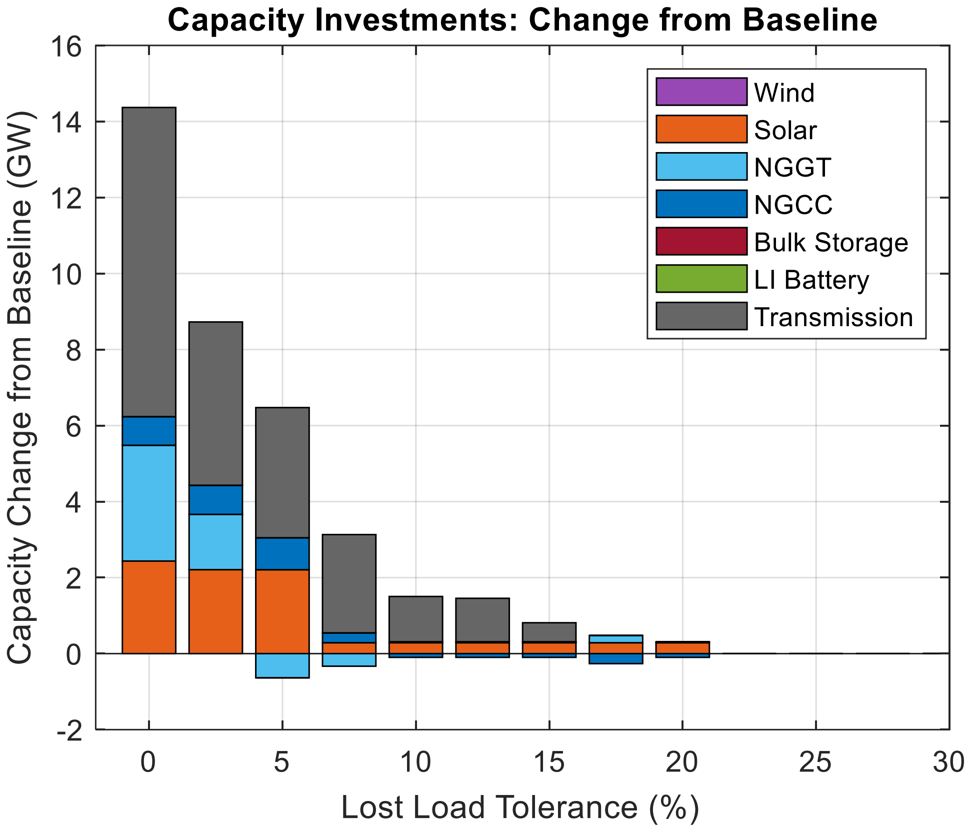
Tighter resilience targets increase total costs for synthetic Texas case study system



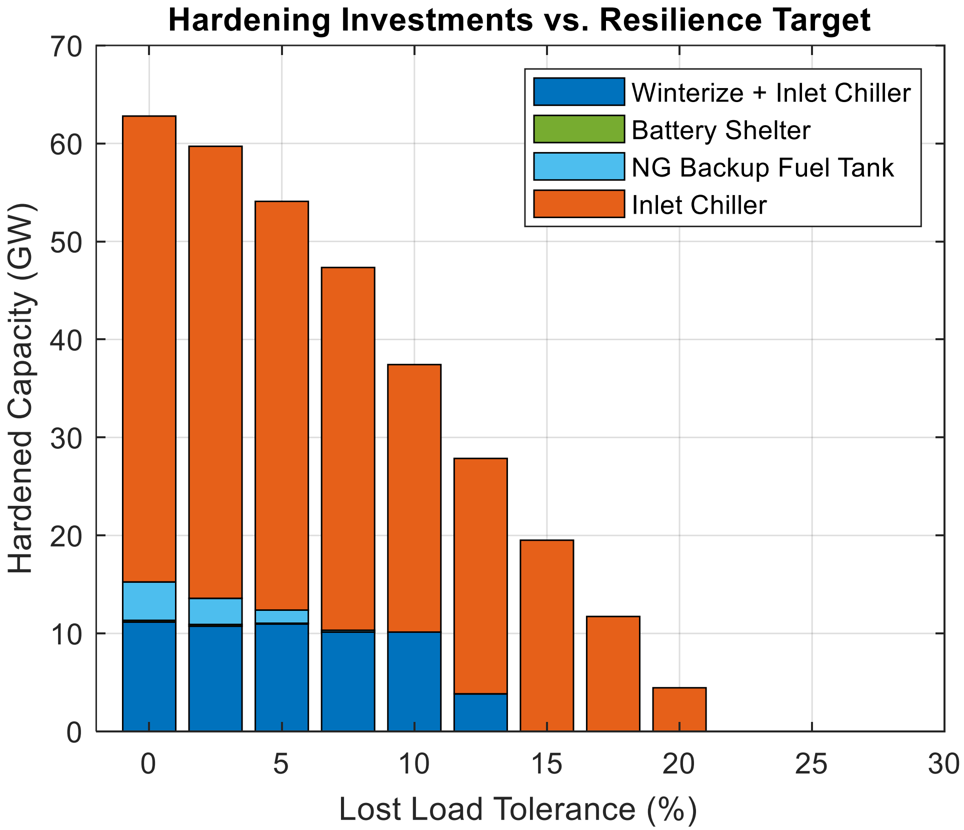
Each candidate plan is the least-cost plan for the specified Resilience Target

Resilient Plans ←→ **Baseline Plan**

The target system buildout changes as it aims to meet a higher resilience target

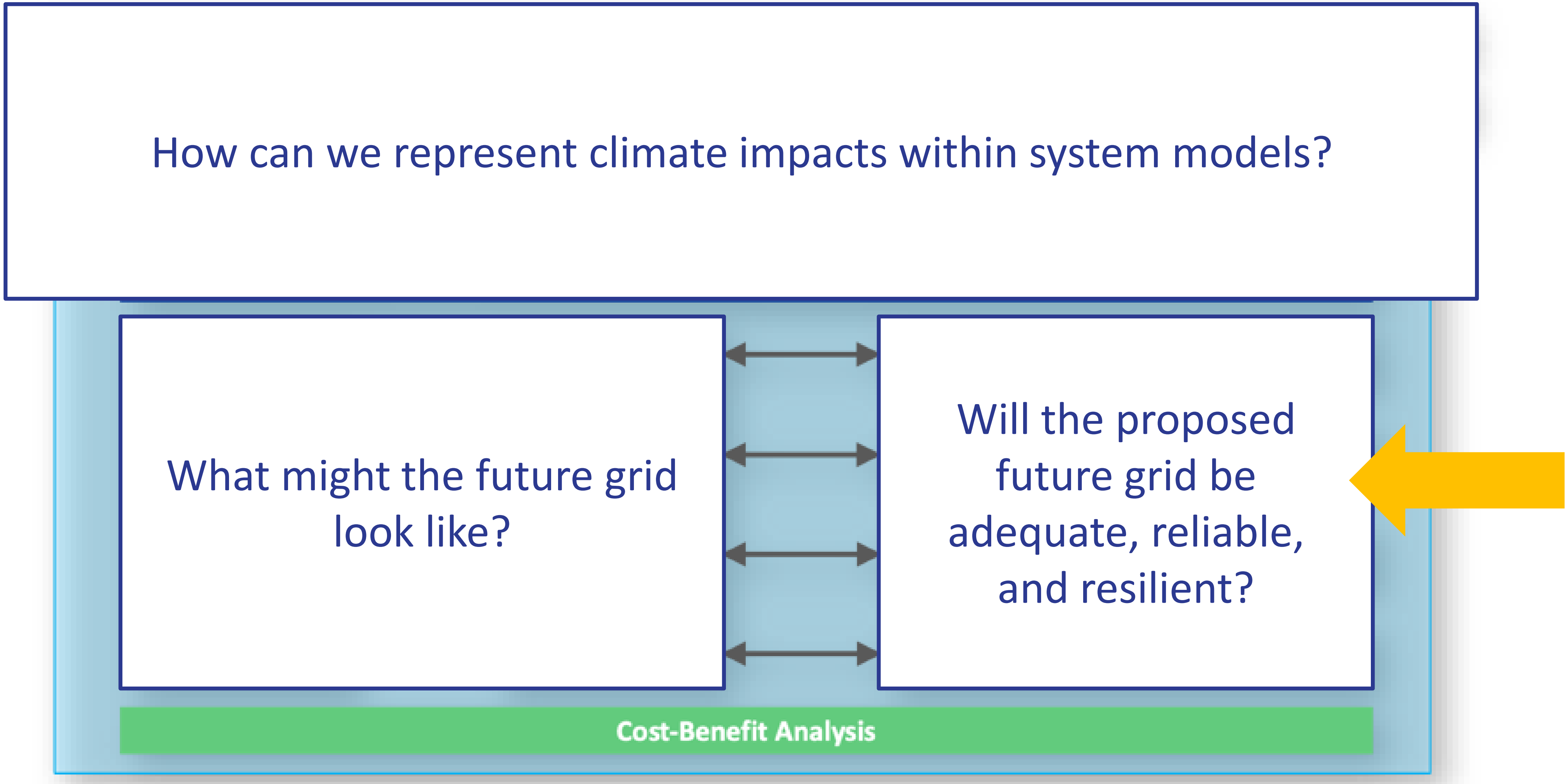


- More transmission capacity is built when resilience targets are tightened
- Solar is often available during extreme heat events so more solar generation is built at all LLT targets
- The added transmission and solar investments help reduce operating costs in non-extreme conditions



- Most resilience costs are driven by hardening investments
- Some capacity receives winter protection
- Most combustion turbines are outfitted with heat protection in the form of advanced inlet air chillers

Climate READi uses an integrated system modeling approach



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Example application: Climate-informed resource adequacy assessment

71 years Weather × **20 Outage Draws Each** = **1420 Samples** × **8760 Hours per Year** = **+12 Million Observations**

- 71 climate projected weather years were selected based on the outcome of the Climate RiSc tool
- Time-sequential optimization-based Monte Carlo simulations including technical detail, such as ramps and minimum operating points
- Network aggregated to eight weather zones across synthetic Texas system
- **Climate data** is incorporated through **weather-dependent load profiles, variable Renewable Energy Sources production, outage probabilities** and **high-temperature derates** of generators
  - Flooding risks, fires, and hurricanes are **not included**
  - Temperature-dependent fuel supply risks only indirectly accounted for via generator outage probabilities

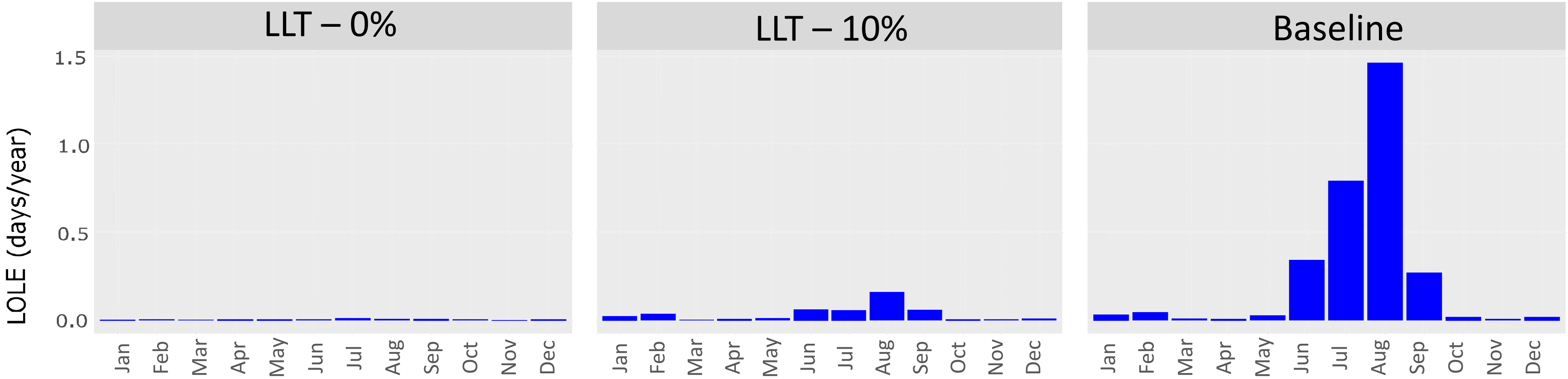
Can standard resource adequacy metrics also provide insights for resilience?

Scenario	Loss-Of-Load-Expectation [days/year]	Expected-Unserved-Energy [MW/year]	Loss-Of-Load-Hours [hours/year]
LLT - 0%	0.08	7.77	0.09
LLT - 10%	0.46	1,837.62	1.16
Baseline	3.06	18,994.21	8.67

Only LLT – 0% falls within standard reliability criterion LOLE ≤ 0.1

38 times more days w. load shedding expected

19GW (Baseline) **vs. 7.8MW** (LLT 0%) expected unserved energy



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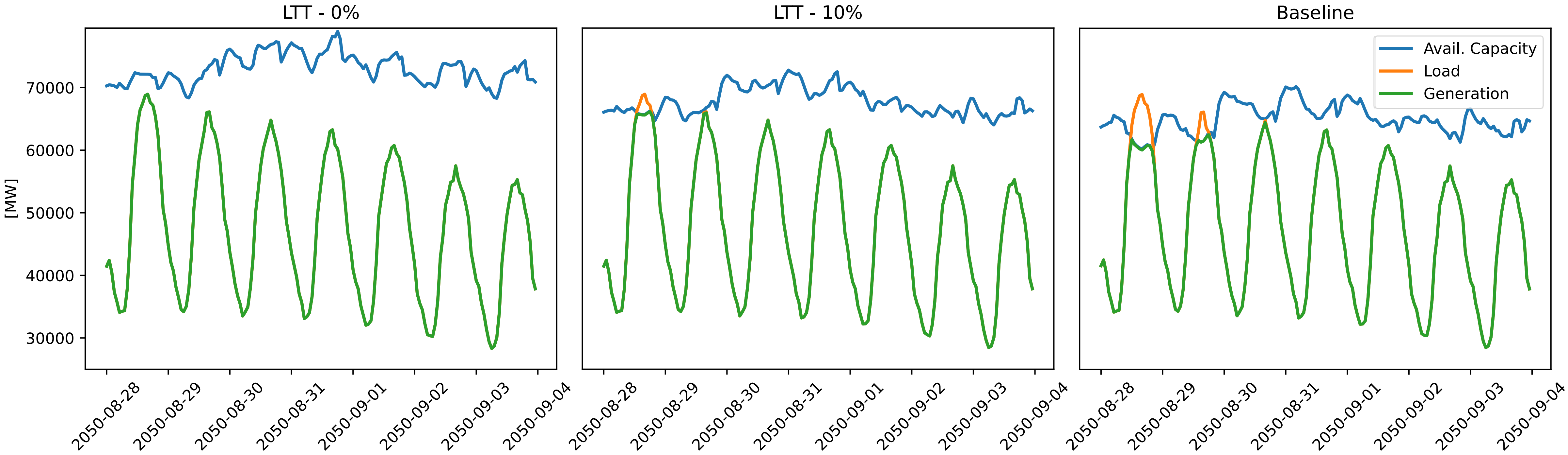
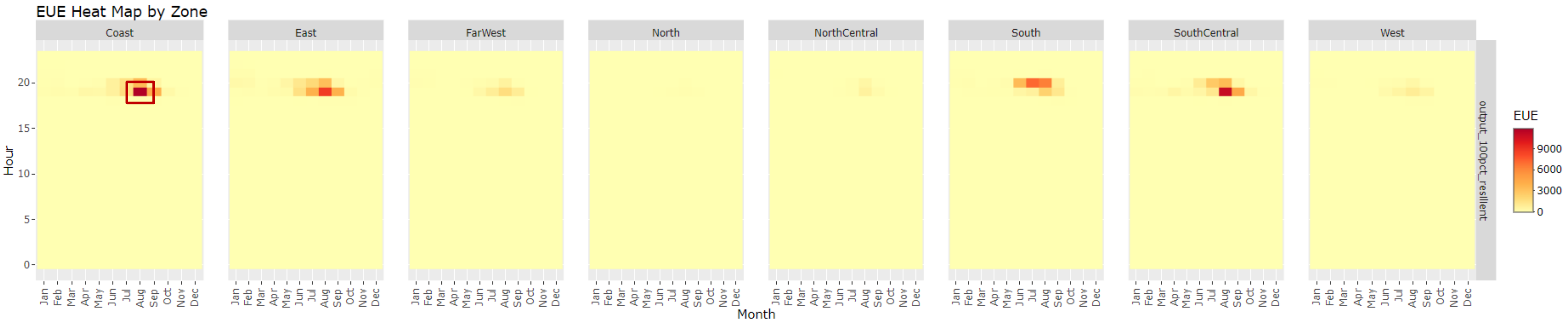


However, model outputs are subject to assumptions regarding the model inputs…

There is significant uncertainty in future load projections – how might different assumptions affect results?

- Looking at load projections with:
  - Higher electrification rates
  - More conservative assumptions around efficiency of end-use technologies
- Resulting in:
  - Much higher-demand projections
  - Requires additional capacity buildout

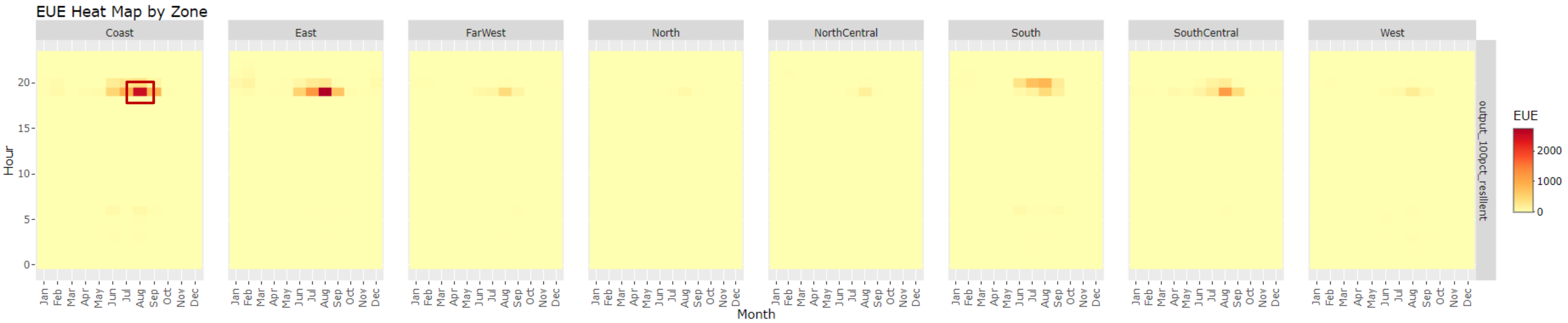
Sensitivity load projections: Updated adequacy results



	LOLE [days/year]	EUE [MWh]	LOLH [hours/year]	NEUE [ppm]
LLT - 0% - v1	23.82	115,801	33.6	254.1

- Update generation portfolio and load profiles are exposed to updated risks
- Afternoon hours in summer months seem to be challenging for the system
  - → Characteristic afternoon event passed back from RA to Capacity Expansion
  - → New system planned to better handle this type of event

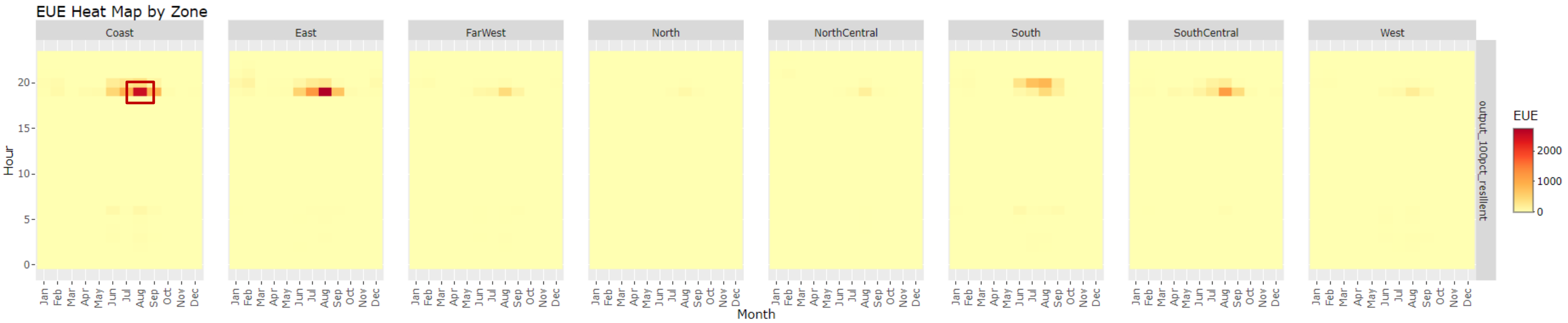
Sensitivity load projections: Updated adequacy results



	LOLE [days/year]	EUE [MWh]	LOLH [hours/year]	NEUE [ppm]
LLT - 0% - v1	23.82	115,801	33.6	254.1
LLT - 0% - v2	6.19	20,829	8.3	45.5

- Iteration with capacity expansion based on RA outputs improves results
  - LOLE reduced by factor of 4; EUE by factor of 5.5
- However, iteration does not entirely remove reliability issues!
  - Integrated process works, but this may be more art than science to get it right – how much fine-tuning is practical in practice?
  - Continue iterating OR pass more severe events OR change the structure of the capacity expansion problem OR…

Are we building an adequate and resilient system?



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Takeaways for climate resilience (and adequacy!)

- Ensuring resilience in a changing climate requires changes to traditional practices, but we (largely) know what this takes
  - Incorporation of forward-looking climate risk with sufficient weather variability
  - Models that account for climate-induced impacts for assets across the system
  - Knowledge of adaptation strategies to include in planning
  - Consistent assumptions and scope across models and data

- Planning for resilience can improve adequacy, but assessing resilience likely requires more than what adequacy alone can tell you
  - Doing this well is a combination of art and science!

Takeaways for climate resilience (and adequacy!)

1

Ensuring resilience in a changing climate requires changes to traditional practices, but we (largely) know what this takes

- Incorporation of forward-looking climate risk with sufficient weather variability
- Models that account for climate-induced impacts for assets across the system
- Knowledge of adaptation strategies to include in planning
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2

Planning for resilience can improve adequacy, but assessing resilience likely requires more than what adequacy alone can tell you

- Additional aspects of system state and behavior may be needed to characterize resilience
- Integration across models can provide confidence in robust solutions
- Doing this well is a combination of art and science!

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