Navigating Future Hazards

From Vulnerability to Resilience

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Technical Meeting on Member States' Experiences in Supporting Operator Actions Before, During and After Severe External Event Scenarios: Measures to Enhance Resilience

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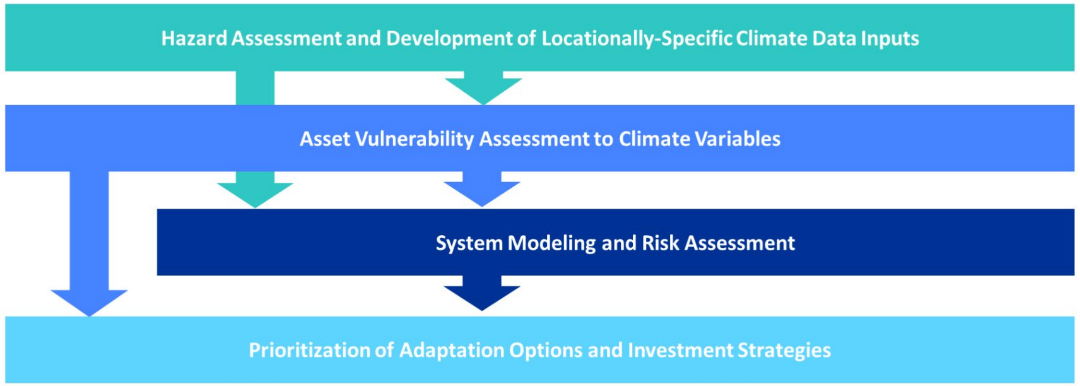
The External Hazard Environment is Changing – and So Must We

- Nuclear plants are encountering environmental conditions that challenge their operating and design basis
- Future extreme events may no longer be bounded by the historical record — the past is no longer a sufficient guide
- Forward-looking assessments allow strategic — not reactive — decisions about resilience investments
- This session: how the industry moves from hazard understanding to plant decision making and action

Climate Change Is Reshaping the Risk Environment for Nuclear Plants

- Extreme weather events are already affecting plant output, cooling margins, and site access — and the trend is intensifying
- The core question is not whether climate change affects nuclear plants — it does — but how to make defensible decisions under deep uncertainty
- EPRI’s program spans hazard characterization, vulnerability assessment, and structured decision frameworks for operators and regulators



Hazard Assessment and Development of Locationally-Specific Climate Data Inputs

Asset Vulnerability Assessment to Climate Variables

System Modeling and Risk Assessment

Prioritization of Adaptation Options and Investment Strategies

Source: EPRI Climate READi

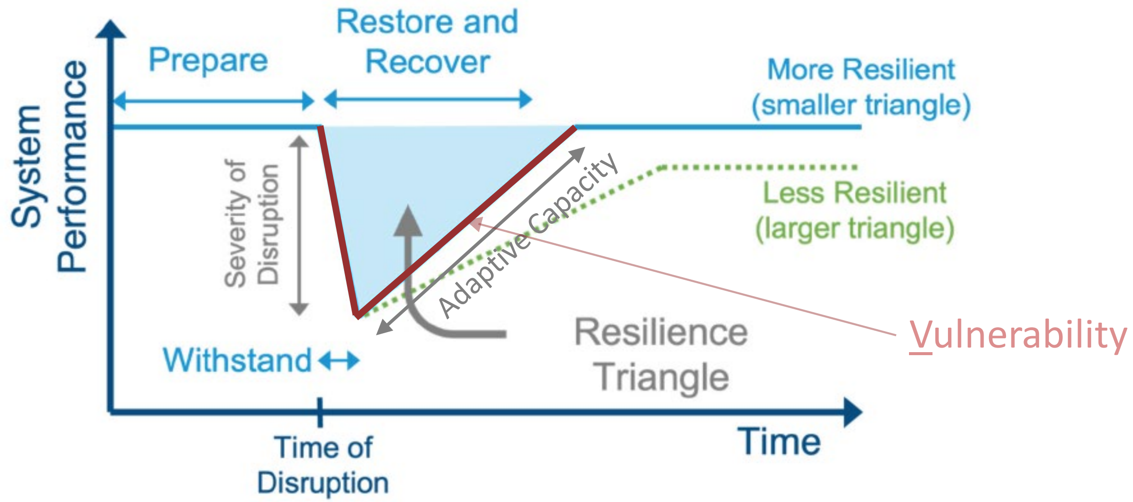
Applicable Hazards → Design Parameters → Future Projections → Vulnerable SSCs → Susceptible SSCs → Decisioning

What can we do to Plan, Prepare and Respond to these impacts?

Natural Hazard Risk and Resiliency

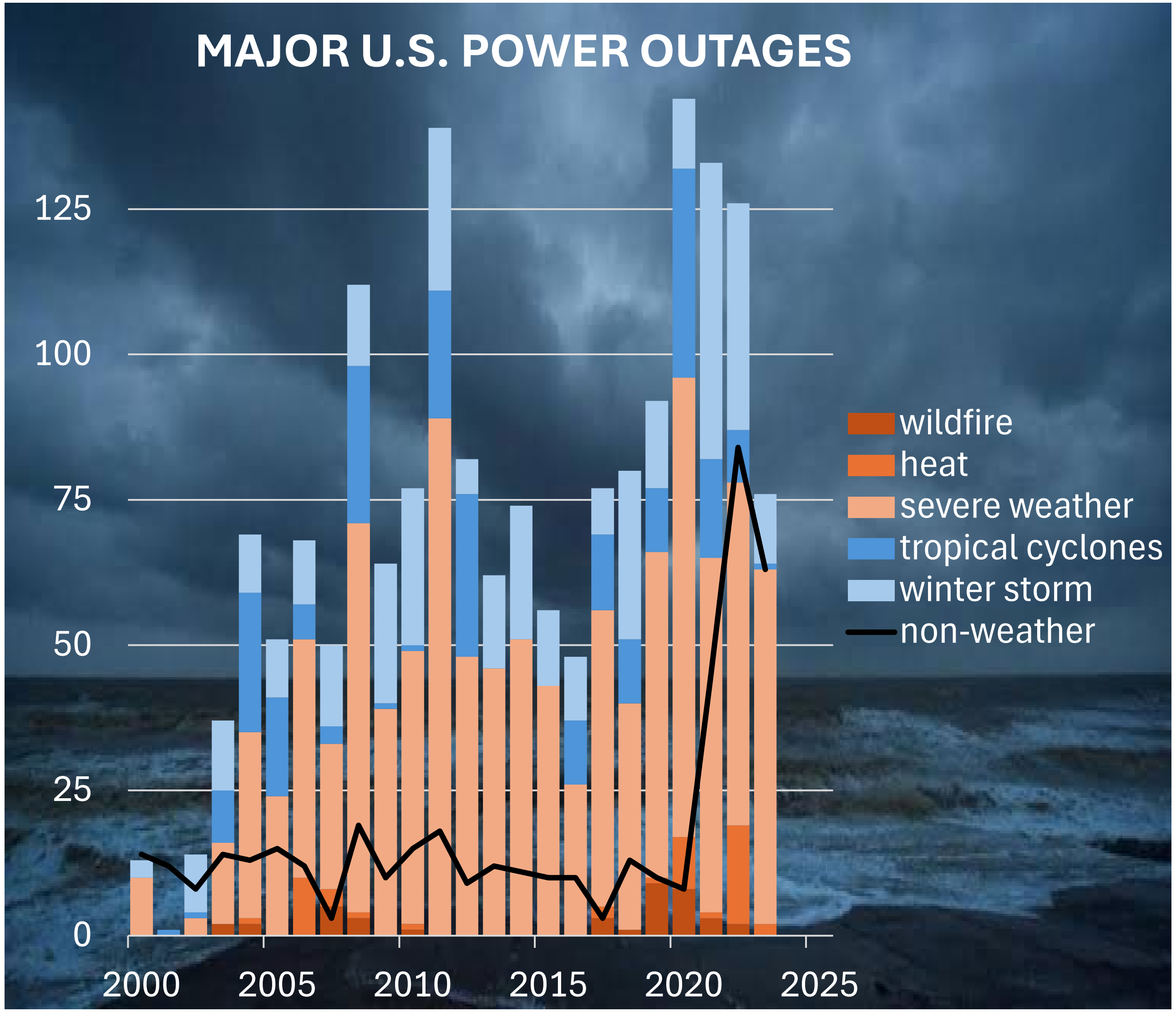
- Future hazard events may not be bounded by the historical record — climate change is shifting frequencies, magnitudes, and patterns
- Situational awareness — knowing local conditions, plant design margins, and hazard trends — is the foundation of resilience
- Resilience requires both robustness (withstanding the event) and adaptive capacity (recovering and improving afterward)
- Seasonal readiness is no longer sufficient — forward-looking assessments identify signposts of future change before they become crises
- The goal: understand where existing margins remain adequate and where targeted adaptation is warranted — ***before conditions demand it***

EPRI Climate READi



What operational risk do changing hazards pose to nuclear plants?

Extreme weather is the leading cause of major power outages in most regions of the world



- More frequent or intense weather events like tropical cyclones, heatwaves, floods, and severe storms challenge grid reliability, along with rising costs and awareness of consequences
  - Direct damage to grid infrastructure, including power lines, substations, and equipment
  - Significant economic disruption from power outages
  - Social costs including health and fatalities
- The economic toll of a single extreme weather events can be disproportionately severe for some vulnerable regions

Notable extreme weather events like 2017 Hurricane Maria in Puerto Rico and 2021 Texas Winter Storm demonstrate widespread and costly grid failures

Source: left: EPRI analysis of U.S. Form OE-417 reports, right: IEA (2020), Power Systems in Transition www.iea.org/reports/power-systems-in-transition

Key Climate Variables Impacting Nuclear Plant Operation

AMBIENT AIR TEMPERATURE

Rising temperatures could impact plant power output through reduced thermal efficiency.

Source: Linnerud, 2011

EXTREME STORM EVENTS

- High Winds (Hurricanes, Tornados, Derechos)
- Water Stress (Flooding, Drought)
- Extreme Temperatures
- Lightning

SEA LEVEL RISE

Rising sea levels could increase flooding risks from storm surges and exacerbate coastal erosion.

Source: Fourth U.S. National Climate Assessment (NCA4), 2018

COOLING WATER

Cooling water temperature and water availability are related to ambient air temperature and to other climate changes.

There is significant variability in plant design, margin available , and Technical Specification temperature limits.

Nuclear Plants Are Designed for Extreme Hazards — But Conditions Are Evolving

Nuclear plants have significant inherent resilience built into their design

- **Robust design** basis for extreme floods, winds, seismic events, and temperature extremes
- **Defense-in-depth** provides multiple barriers against external event impacts
- Decades of **operating experience** have refined procedures for severe weather response

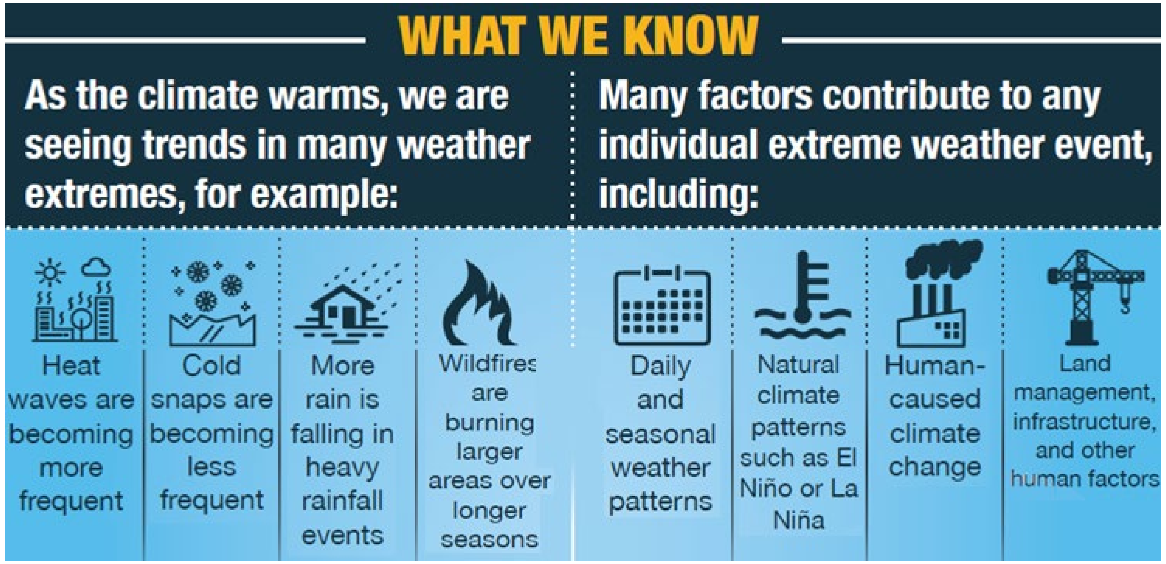
The challenge: operating and design assumptions based on historical climate records may no longer represent future conditions

- Our probabilistic assessments use historical frequency data — climate change shifts those frequencies (what was a once in 1000-year event is now a 500-year event)
- Equipment qualification envelopes may be approached or exceeded more frequently
- Long plant lifetimes (60-80 years) mean plants will operate through additional climate change

The goal is to understand where margins remain adequate and where adaptation is warranted.

Climate Change and Extreme Weather

- How warming will impact extreme weather is not always clear
  - We have the most confidence in projected changes in temperature extremes
  - Other extremes, like wind speeds and hurricanes are less confident
- Natural variability is the biggest driver of extreme weather
  - The weather, not climate change, drives extreme events
  - A warmer world can make some extremes more likely (extreme heat) and some extremes less likely (extreme cold)
    - However, extreme cold records may be broken in the future



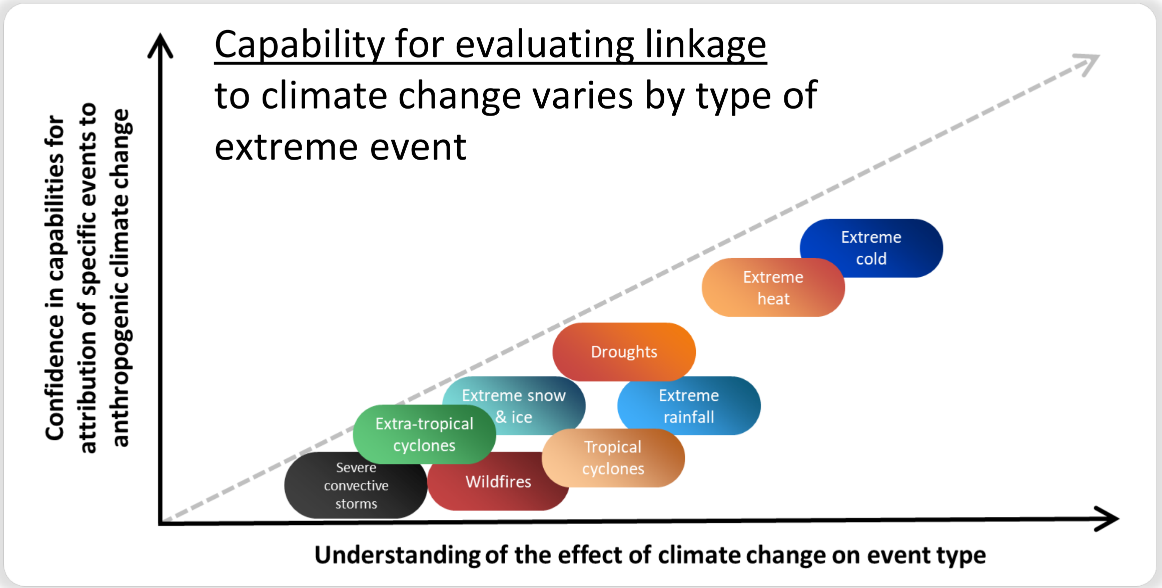
WHAT WE KNOW

As the climate warms, we are seeing trends in many weather extremes, for example:

- Heat waves are becoming more frequent
- Cold snaps are becoming less frequent
- More rain is falling in heavy rainfall events
- Wildfires are burning larger areas over longer seasons

Many factors contribute to any individual extreme weather event, including:

- Daily and seasonal weather patterns
- Natural climate patterns such as El Niño or La Niña
- Human-caused climate change
- Land management, infrastructure, and other human factors



Capability for evaluating linkage to climate change varies by type of extreme event

Source: Adapted from US National Academy of Sciences

Graphics adapted from NAS (2016)

Components of Uncertainty in Climate Projections

- **Natural variability** is generally the biggest component of uncertainty in the near-term
  - I.e., weather drives the chaos, not climate change
- **Model** choice is the second largest component of variability in the near-term
  - Models are different on purpose. Each model has different physics and parameterizations (approximations) that contribute to this uncertainty.

- **Climate Scenarios** are generally the largest component of uncertainty in the long-term
- **Downscaling** is a major component of uncertainty in locations with microclimates (mountains, coastal, etc.)

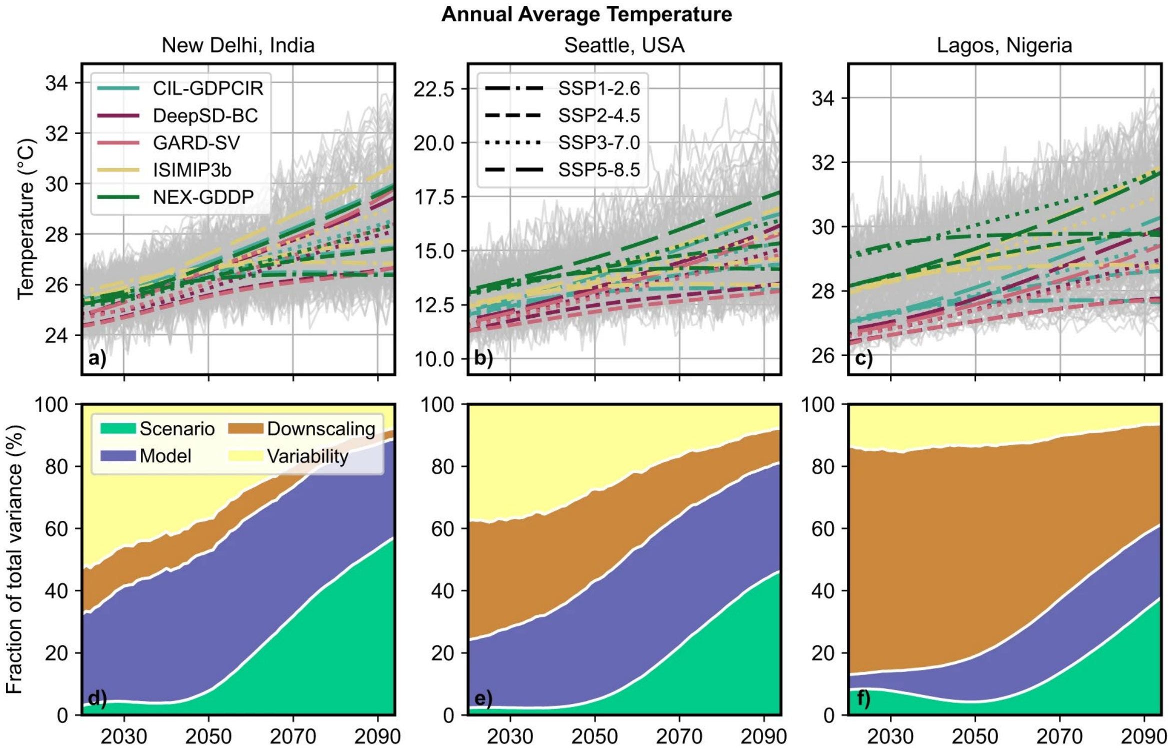


Figure: Lafferty, D. C., & Sriver, R. L. (2023)

Timeframe of Assessment

- The timeframe determines the tools for the assessment
- What is of interest?
  - Becoming more ***resilient*** to present day climate so you can mitigate/recover more quickly from extreme weather
  - Incorporating future climate information into long-term ***planning***

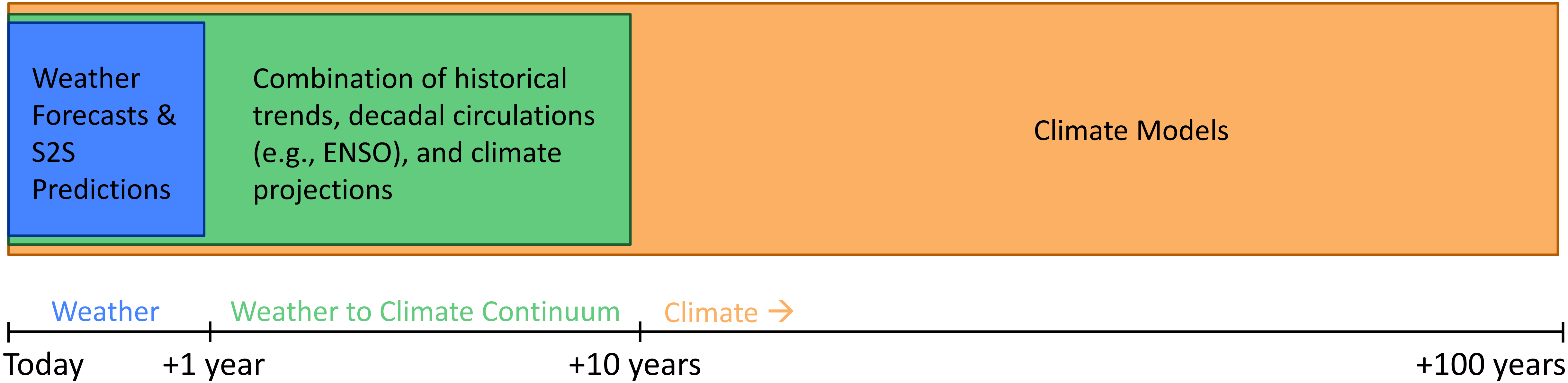
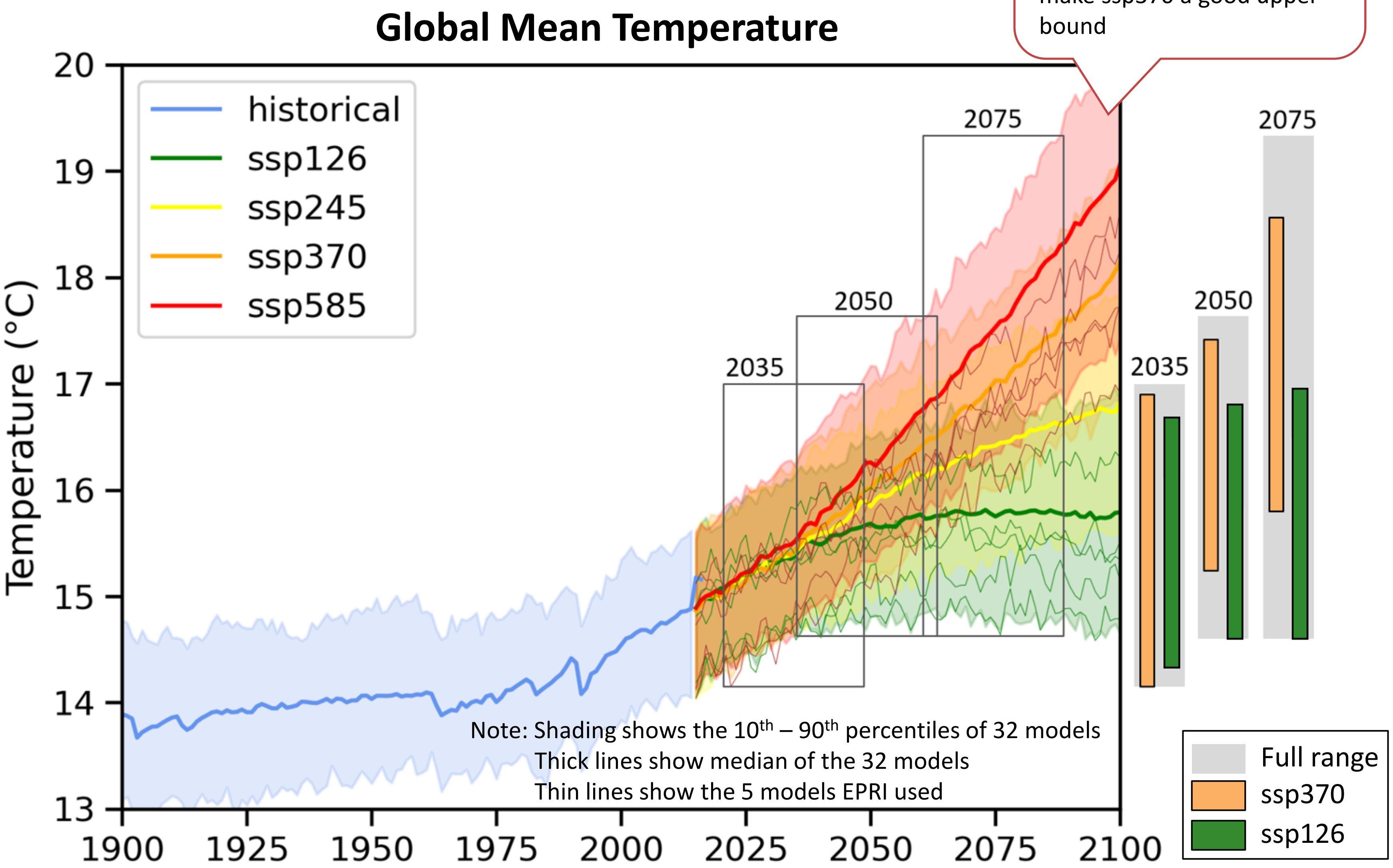


Figure adapted from: Argonne National Laboratory

Climate Model and Scenario Selection

Example at the Site Level

- Don’t need to use every model and scenario
  - Often infeasible
  - Information overload
- Model subsets can be used
  - Chosen by global response
  - Need to sample from the model and scenario space effectively
  - ‘Space’ refers to the full range of projections available
- We often use 5 climate models and two scenarios (ssp126 and ssp370)
  - These 5 models, outlined in the ISI-MIP project, are geared towards impact assessments
  - The 2 scenarios are chosen as bounds



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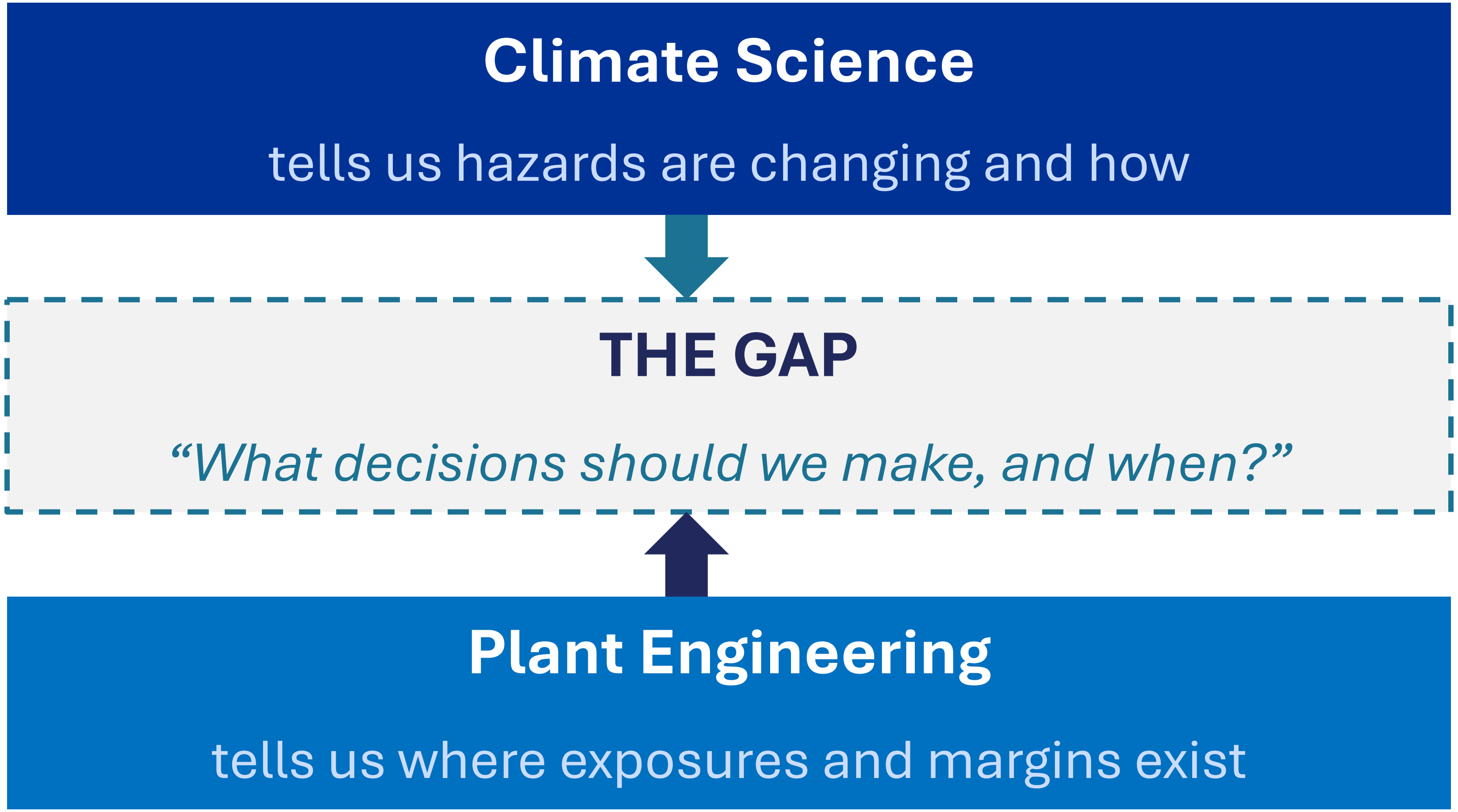
Thin lines show the 5 models EPRI used

What Does This Uncertainty Means for Plant Decision Making

- Near-term projections (2030–2040) carry narrower uncertainty — *long-term projections (2060–2080) diverge significantly* across models and scenarios
- For plants with 20 - 40-year remaining license periods, or new builds, this divergence directly affects long-lived capital decisions — *you are committing today for a future you cannot precisely predict*
- Waiting for certainty is not a strategy — it is a choice to have no strategy
- The answer is decisions that are *robust across a range of plausible futures* — which is exactly what the decision frameworks ahead are designed to support

The Gap We Are Addressing – Current Studies



Climate Science

tells us hazards are changing and how

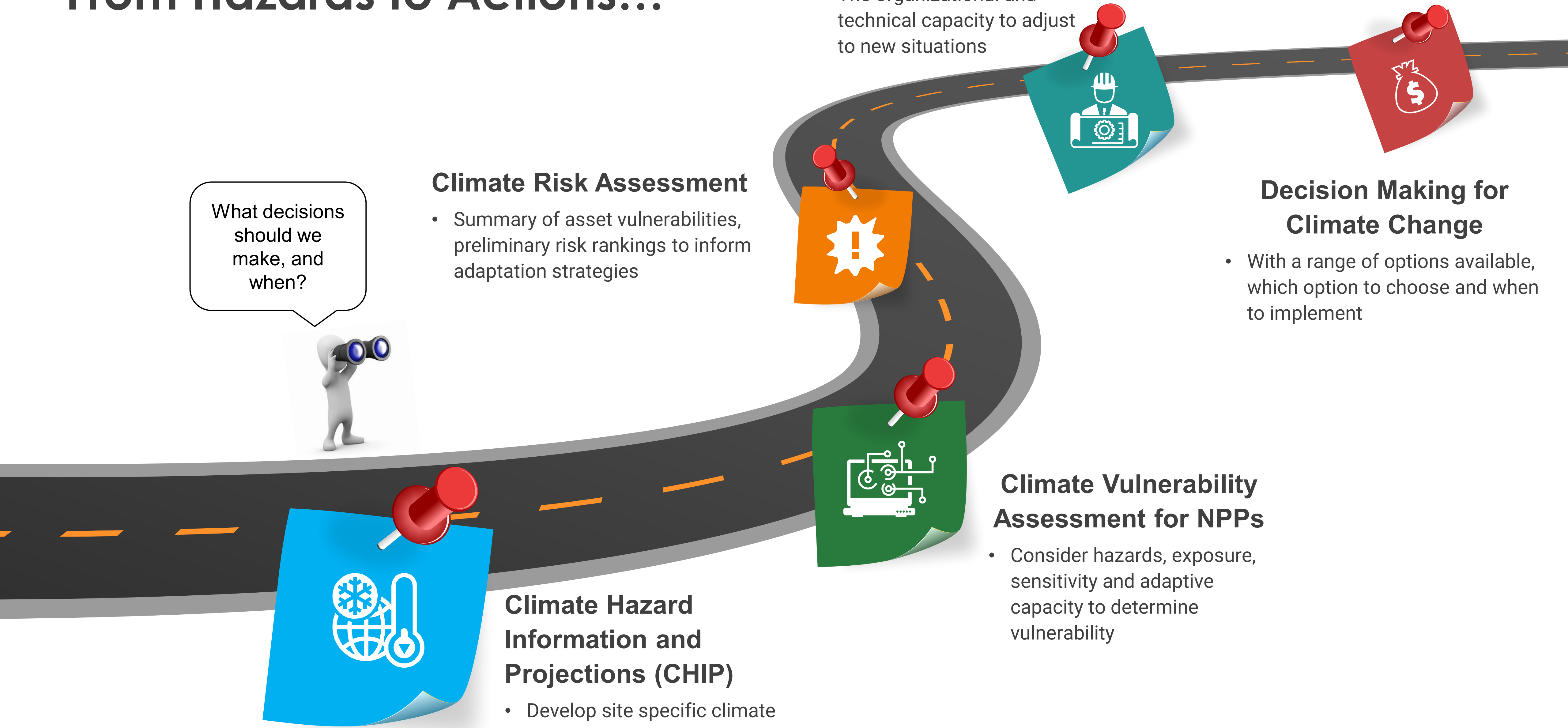
THE GAP

“What decisions should we make, and when?”

Plant Engineering

tells us where exposures and margins exist

From Hazards to Actions…



Climate Hazard Information and Projections (CHIP)

- Develop site specific climate hazards considering effects of future climate changes

Climate Vulnerability Assessment for NPPs

- Consider hazards, exposure, sensitivity and adaptive capacity to determine vulnerability

Climate Risk Assessment

- Summary of asset vulnerabilities, preliminary risk rankings to inform adaptation strategies

Adaptation Strategies

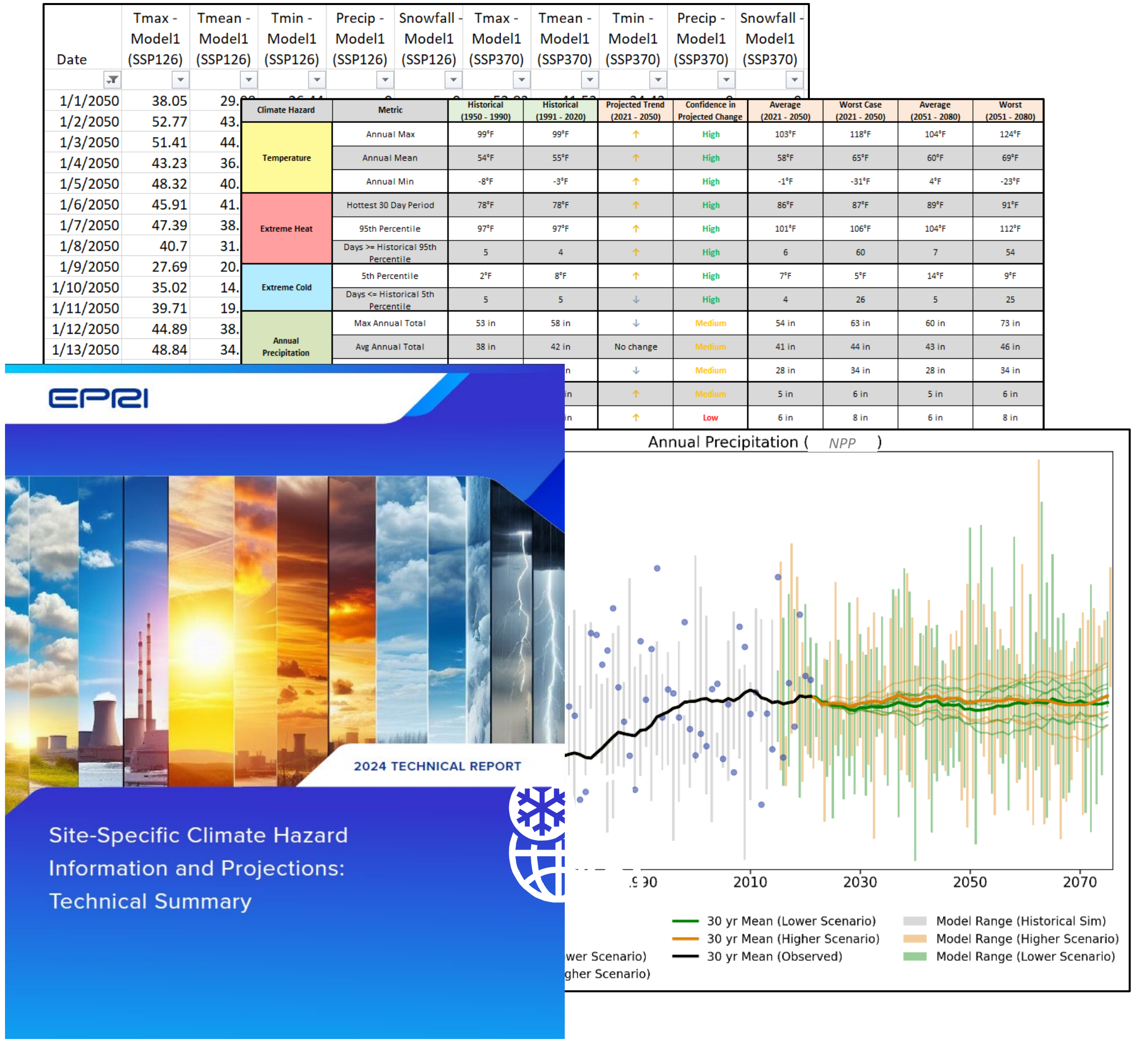
- The organizational and technical capacity to adjust to new situations

Decision Making for Climate Change

- With a range of options available, which option to choose and when to implement

Hazard Assessment – Forward Looking

Site-Specific Climate Hazard Information and Projections (CHIP)



Date	Tmax - Model1 (SSP126)	Tmean - Model1 (SSP126)	Tmin - Model1 (SSP126)	Precip - Model1 (SSP126)	Snowfall - Model1 (SSP126)	Tmax - Model1 (SSP370)	Tmean - Model1 (SSP370)	Tmin - Model1 (SSP370)	Precip - Model1 (SSP370)	Snowfall - Model1 (SSP370)
1/1/2050	38.05	29.								
1/2/2050	52.77	43.								
1/3/2050	51.41	44.								
1/4/2050	43.23	36.								
1/5/2050	48.32	40.								
1/6/2050	45.91	41.								
1/7/2050	47.39	38.								
1/8/2050	40.7	31.								
1/9/2050	27.69	20.								
1/10/2050	35.02	14.								
1/11/2050	39.71	19.								
1/12/2050	44.89	38.								
1/13/2050	48.84	34.								

Climate Hazard	Metric	Historical (1950 - 1990)	Historical (1991 - 2020)	Projected Trend (2021 - 2050)	Confidence in Projected Change	Average (2021 - 2050)	Worst Case (2021 - 2050)	Average (2051 - 2080)	Worst (2051 - 2080)
Temperature	Annual Max	99°F	99°F	↑	High	103°F	118°F	104°F	124°F
	Annual Mean	54°F	55°F	↑	High	58°F	65°F	60°F	69°F
	Annual Min	-8°F	-3°F	↑	High	-1°F	-31°F	4°F	-23°F
Extreme Heat	Hottest 30 Day Period	78°F	78°F	↑	High	86°F	87°F	89°F	91°F
	95th Percentile	97°F	97°F	↑	High	101°F	106°F	104°F	112°F
	Days >= Historical 95th Percentile	5	4	↑	High	6	60	7	54
Extreme Cold	5th Percentile	2°F	8°F	↑	High	7°F	5°F	14°F	9°F
	Days <= Historical 5th Percentile	5	5	↓	High	4	26	5	25
Annual Precipitation	Max Annual Total	53 in	58 in	↓	Medium	54 in	63 in	60 in	73 in
	Avg Annual Total	38 in	42 in	No change	Medium	41 in	44 in	43 in	46 in
			n	↓	Medium	28 in	34 in	28 in	34 in
			in	↑	Medium	5 in	6 in	5 in	6 in
			in	↑	Low	6 in	8 in	6 in	8 in

2024 TECHNICAL REPORT

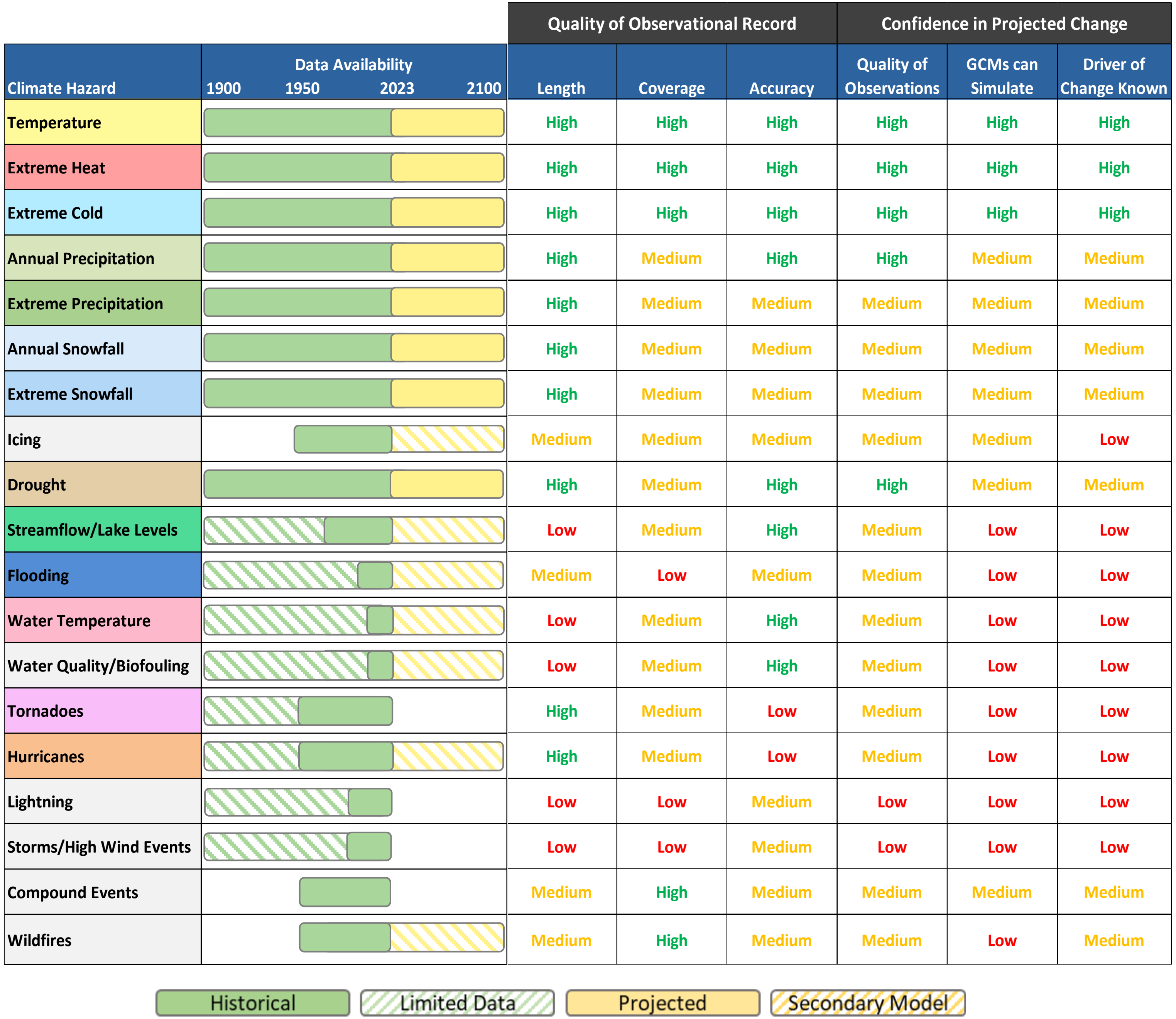
Site-Specific Climate Hazard Information and Projections: Technical Summary

- Identify site specific natural hazards and how they may change in the future
- Are local physical conditions changing?
- Not all hazards have projections
- All hazards have uncertainty
  - Natural Variability – biggest component
  - Model Choice – different physics
  - Climate Scenarios – long term uncertainty
  - Downscaling – locations specific / microclimates
- Provide engineers with usable information to assess operating/design envelop

Identifying Hazards for the Assessment

Where can we create actionable insights?

- Not all hazards have projections
- All projections have uncertainty, some hazards more than others
- Some hazards may not be worth assessing right now



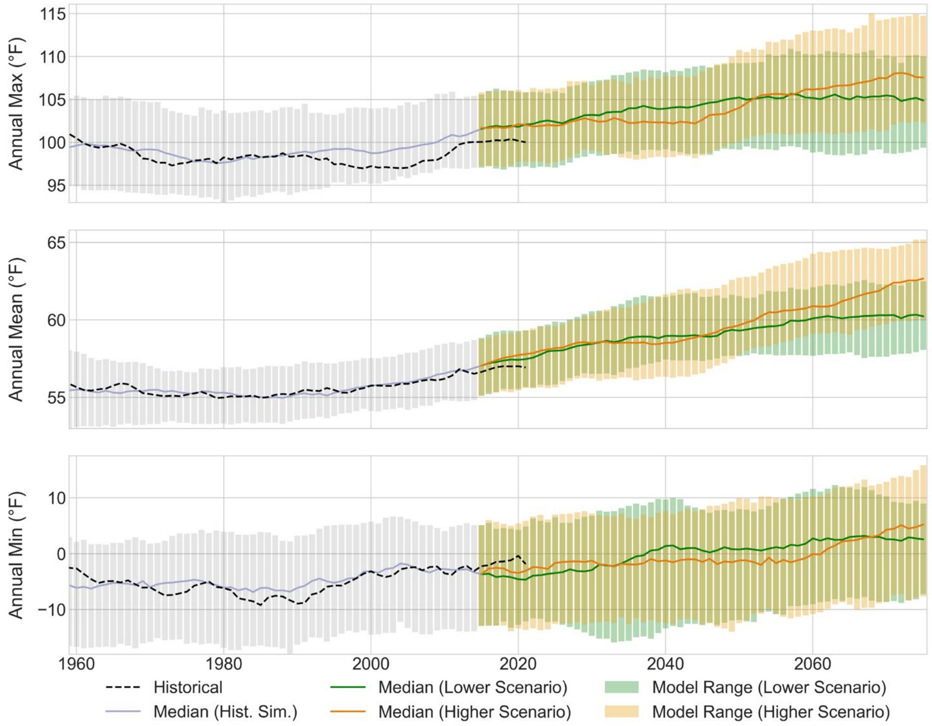
Climate Hazard	Data Availability 1900 1950 2023 2100	Quality of Observational Record			Confidence in Projected Change		
		Length	Coverage	Accuracy	Quality of Observations	GCMs can Simulate	Driver of Change Known
Temperature	🟩🟨	High	High	High	High	High	High
Extreme Heat	🟩🟨	High	High	High	High	High	High
Extreme Cold	🟩🟨	High	High	High	High	High	High
Annual Precipitation	🟩🟨	High	Medium	High	High	Medium	Medium
Extreme Precipitation	🟩🟨	High	Medium	Medium	Medium	Medium	Medium
Annual Snowfall	🟩🟨	High	Medium	Medium	Medium	Medium	Medium
Extreme Snowfall	🟩🟨	High	Medium	Medium	Medium	Medium	Medium
Icing	🟩▧	Medium	Medium	Medium	Medium	Medium	Low
Drought	🟩🟨	High	Medium	High	High	Medium	Medium
Streamflow/Lake Levels	▨🟩▧	Low	Medium	High	Medium	Low	Low
Flooding	▨🟩▧	Medium	Low	Medium	Medium	Low	Low
Water Temperature	▨🟩▧	Low	Medium	High	Medium	Low	Low
Water Quality/Biofouling	▨🟩▧	Low	Medium	High	Medium	Low	Low
Tornadoes	▨🟩	High	Medium	Low	Medium	Low	Low
Hurricanes	▨🟩▧	High	Medium	Low	Medium	Low	Low
Lightning	▨🟩	Low	Low	Medium	Low	Low	Low
Storms/High Wind Events	▨🟩	Low	Low	Medium	Low	Low	Low
Compound Events	🟩	Medium	High	Medium	Medium	Medium	Medium
Wildfires	🟩▧	Medium	High	Medium	Medium	Low	Medium

🟩 Historical ▨ Limited Data 🟨 Projected ▧ Secondary Model

Finding from Recent Studies

Dominant Hazards

- **Extreme heat** (air + water temperature) is the most broadly impactful hazard across all sites
  - **Water temperatures** projected to increase through at least 2075 under scenarios
  - Ultimate heat sink (UHS) technical specification limits could be challenged with increasing frequency
- **Biological fouling** worsens with warmer water — indirect pathway to cooling system degradation



Additional Hazards

- **Wind variability and recirculation** — site-specific but consequential (warm discharge redirected to intake)
- **Precipitation, drought, flooding** — generally stable to moderately worsening; significant uncertainty
- **Sea level rise** — adequate near-term margins at coastal sites, but modest SLR can non-linearly amplify storm flooding

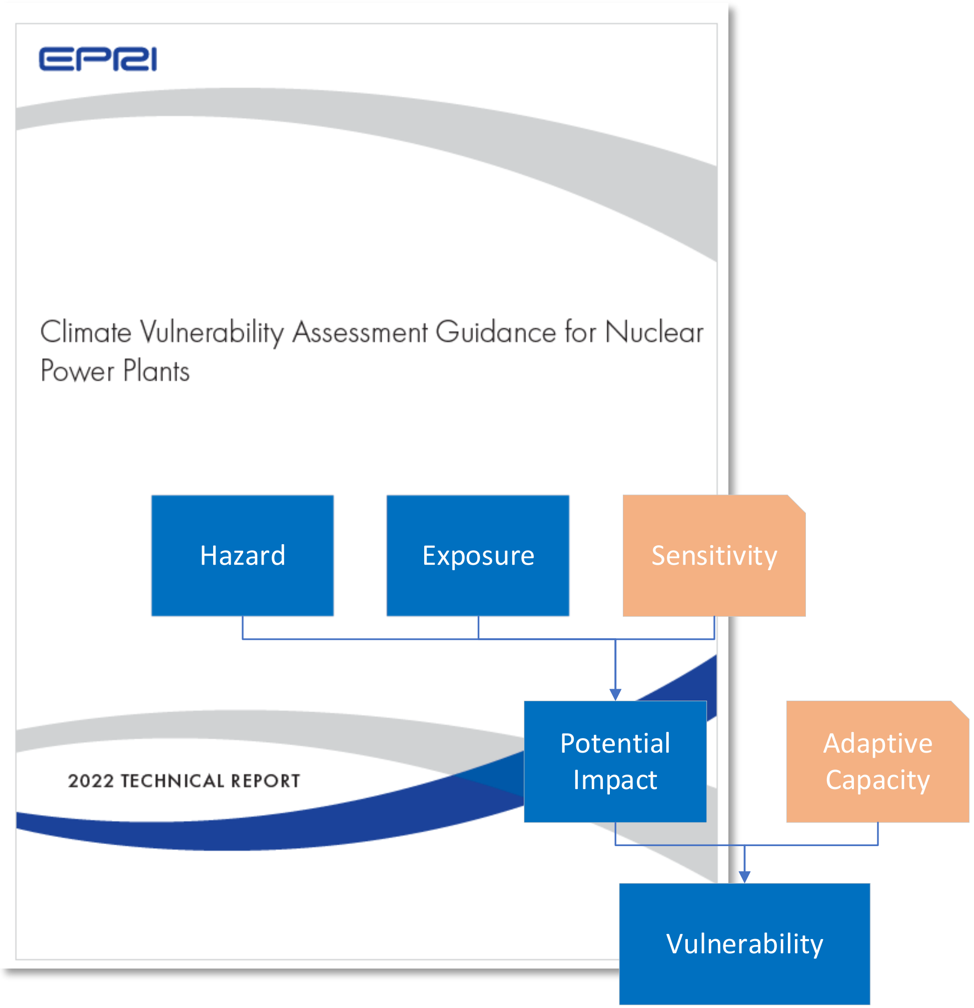
Vulnerability Assessments - The Foundation

Climate Vulnerability Assessment (CVA) is the structured first step in climate resilience planning

- Step 1 — Hazard characterization: Identify climate-sensitive hazards relevant to the site (heat, flood, drought, wind, wildfire)
- Step 2 — Exposure assessment: Determine which plant systems, structures, and components are exposed to each hazard
- Step 3 — Sensitivity analysis: Evaluate how each exposed element responds to changes in hazard intensity or frequency
- Step 4 — Adaptive capacity review: Assess existing margins, procedures, and design features that provide resilience
- Step 5 — Vulnerability identification: Identify where operating and design margins are challenged to new hazards

CVA outputs: a prioritized map of where climate change may reduce margins or create new challenges

- Many plants and organizations globally have initiated or completed CVAs in recent years



Climate Vulnerability Assessment Guidance for Nuclear Power Plants

2022 TECHNICAL REPORT

Common Vulnerability Patterns and Margin Adequacy

Where Margins Are Narrowing

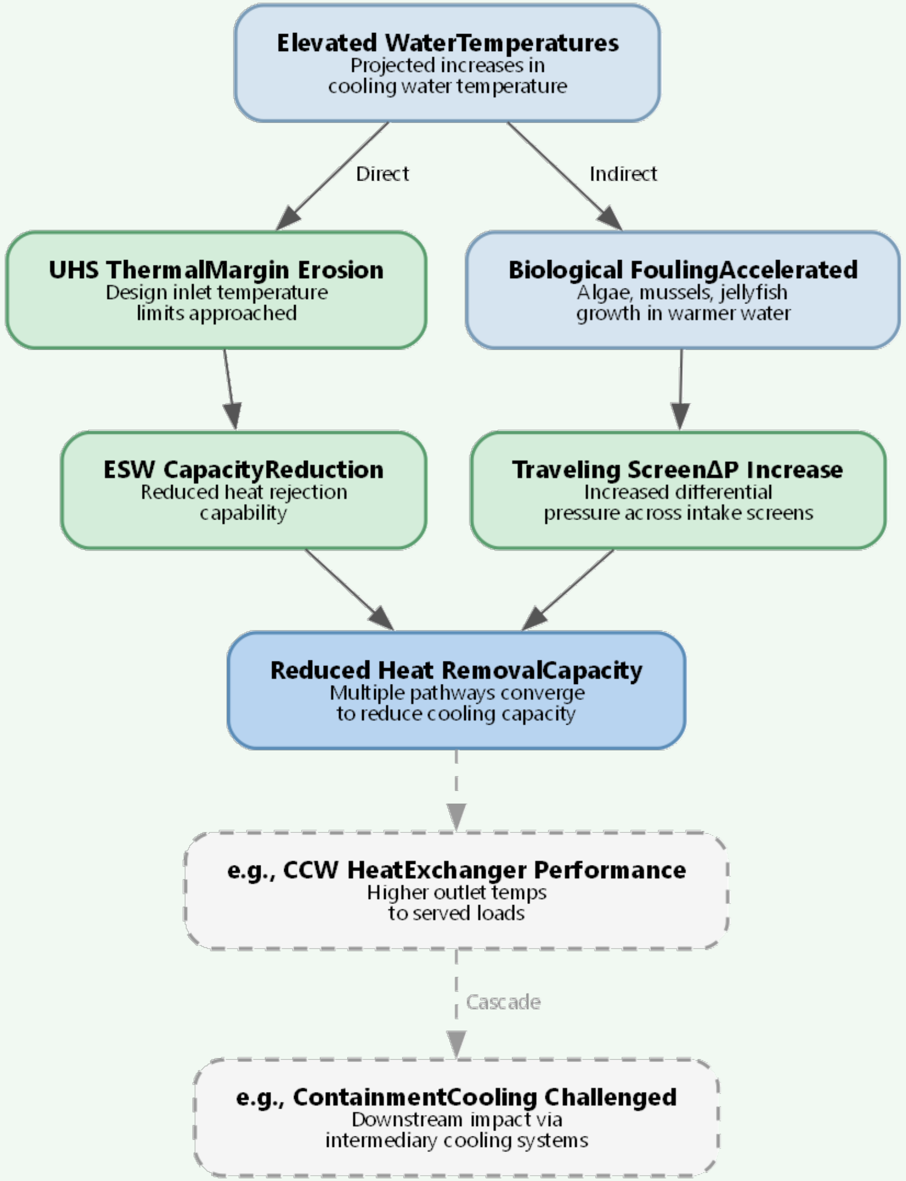
- **Cooling-system thermal margins** (UHS, ESW, CCW) — most commonly identified vulnerability
- **HVAC systems** — compound stressor from rising air temperature + humidity
- Most sites retain adequate margins under near-term conditions
- Margins narrow under mid-century (~2050) projections

Margin Model

- Design margin = gap between analyzed design limit and operating limit
- Climate-driven increases in operating parameters progressively reduce available margin

Cascading Effects Are Significant

- Indirect pathways propagate margin reductions across system boundaries
- Example cascade:
  - Warmer water → biofouling →
  - increased screen ΔP →
  - reduced flow to RCP seals, instrument air, chilled water
- Cascading effects were among the most consequential vulnerabilities identified



Elevated Water Temperatures
Projected increases in cooling water temperature

Direct

Indirect

UHS Thermal Margin Erosion
Design inlet temperature limits approached

Biological Fouling Accelerated
Algae, mussels, jellyfish growth in warmer water

ESW Capacity Reduction
Reduced heat rejection capability

Traveling Screen ΔP Increase
Increased differential pressure across intake screens

Reduced Heat Removal Capacity
Multiple pathways converge to reduce cooling capacity

e.g., CCW Heat Exchanger Performance
Higher outlet temps to served loads

Cascade

e.g., Containment Cooling Challenged
Downstream impact via intermediary cooling systems

Lessons Learned — What Worked Well

Process Strengths

- **Structured site walkdowns** — identified vulnerabilities not evident from desktop analysis
  - Wind recirculation, new biological issues, solar heating, drainage pathways discovered in the field
- **Cross-functional teams** — operations, engineering, and licensing staff brought irreplaceable knowledge
- **Direct operator engagement** — often more actionable than systematic condition report reviews

Benefits

- **Consistent deliverable structure** — six-deliverable framework provided clarity and common language across sites
- **Collaborative, multi-site campaign** — challenges at early sites directly informed improvements at later ones
- **Standardized templates and evaluation criteria** — improved consistency across assessments


Applicable Hazards → Design Parameters → Future Projections → Vulnerable SSCs → Susceptible SSCs → Decisioning

The coordinated nature of the campaign created a compounding cycle of improvement — challenges identified at one site informed more efficient approaches at subsequent sites.

Where the US Industry Stands — and What Comes Next

- US industry completed climate vulnerability assessments in 2025, using EPRI and INPO guidance and CHIP hazard projection data
- CVAs are complete — the harder work now begins: translating vulnerability findings into threat strategies and prioritized decisions
  - Key open questions: what responses are needed and when? How does long-term operation and power uprate affect future resilience margins?
- *Critical research underway to identify solutions that return operating margin to plants under projected future conditions*

From Vulnerability Assessment to Risk-Informed Decision Making

A vulnerability assessment tells you where you may have a problem. A decision framework tells you what to do about it and when.

The expanded framework moves through five stages:

1. ***Climate hazard characterization*** — what hazards, what trajectories, what uncertainty
2. ***Exposure and vulnerability assessment*** — what plant elements are affected and how sensitive are they
3. ***Risk evaluation*** — translate vulnerability into consequence likelihood and severity
4. ***Adaptation strategy*** — identify operational and infrastructure responses
5. ***Decision framework*** — structure choices about adaptation timing, type, and investment level

The critical addition beyond traditional CVA: explicit treatment of uncertainty and structured decision logic

- Climate projections carry inherent uncertainty across emissions scenarios, regional climate models, and timescales
- Risk-informed decisions must account for this uncertainty rather than defaulting to a single assumed future

Scenario-Based Climate Futures: A Practical Framework

Rather than a single projection, evaluate plant adaptation strategies across representative climate futures

- Representative scenario set (illustrative) – "best estimate"
- Baseline / Moderate change: Near-term continuation of observed trends; modest temperature and precipitation shifts
- Hot and dry: Significant warming with reduced summer precipitation; stress on cooling water availability
- Hot and wet: Significant warming with increased precipitation intensity; elevated flooding and storm risk
- Extreme heat: High-end temperature trajectory; severe heat wave frequency and duration
- Severe warming stress test: Upper-bound scenario for testing the limits of current adaptive capacity

Purpose: Test whether a proposed adaptation strategy performs acceptably across all representative futures

- Strategies that require knowing exactly which future occurs are fragile; strategies robust across scenarios are preferred
- This approach is consistent with many published guidance on climate change and infrastructure

Climate Model and Scenario Selection

Example at the Site Level

- Don’t need to use every model and scenario
  - Often infeasible
  - Information overload
- Model subsets can be used
  - Chosen by global response
  - Need to sample from the model and scenario space effectively
  - ‘Space’ refers to the full range of projections available
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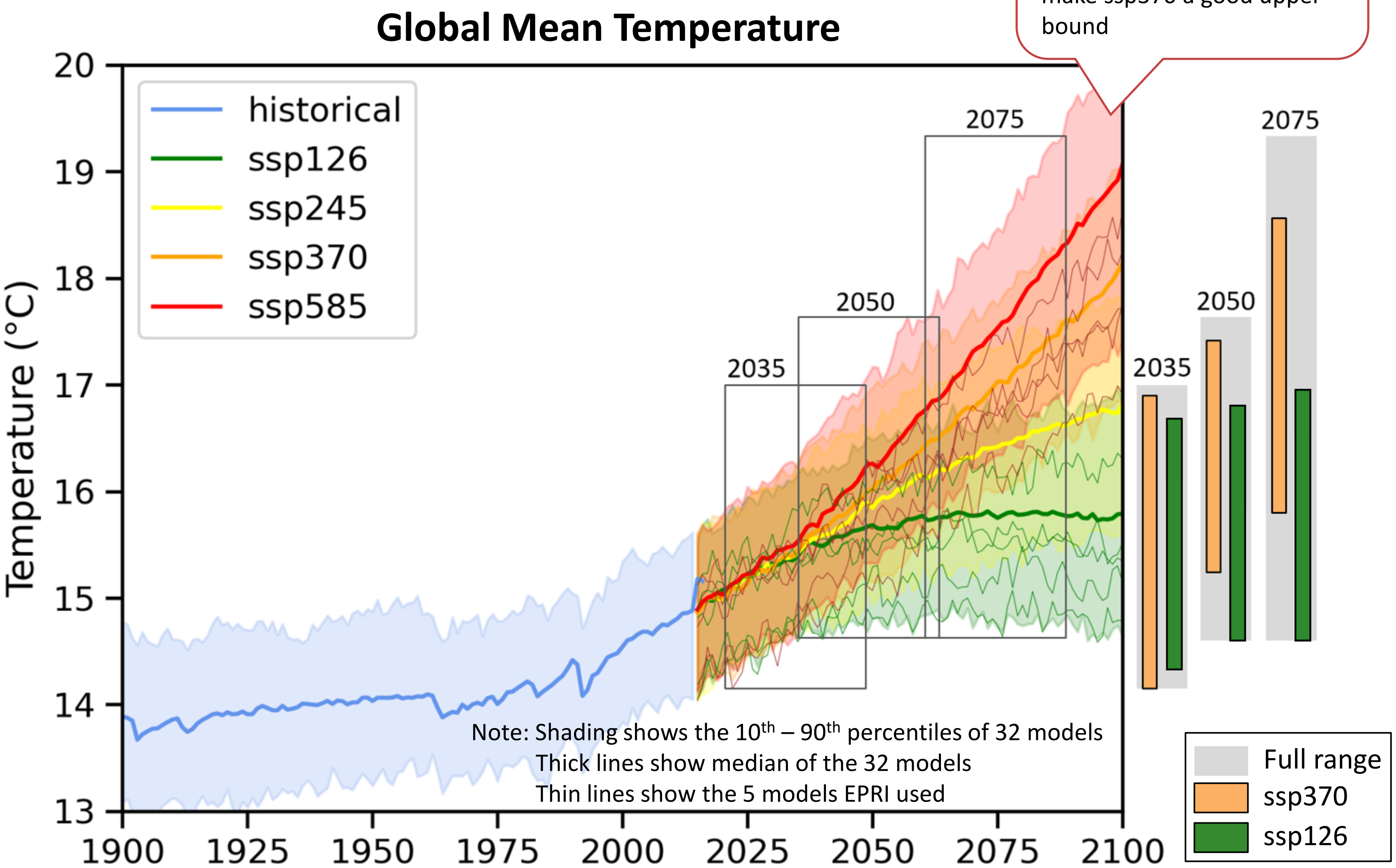

Global Mean Temperature

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Note: Shading shows the 10th – 90th percentiles of 32 models
Thick lines show median of the 32 models
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Decision Making Under Deep Uncertainty (DMDU)

DMDU provides a structured approach to making good decisions when the future cannot be predicted precisely

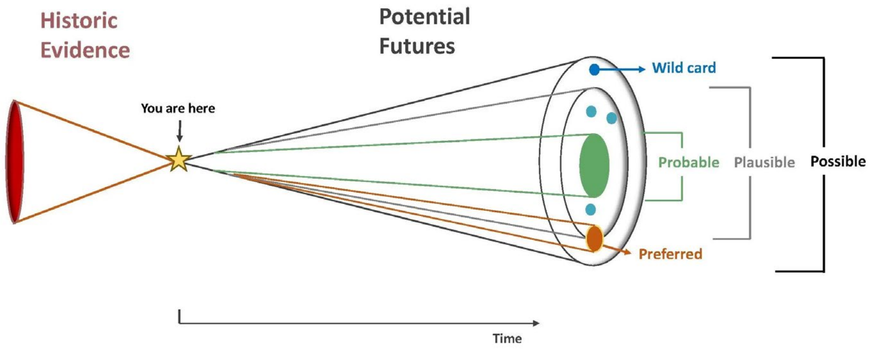
- **Core principle**: Rather than optimizing for one expected future, identify strategies that perform acceptably across many futures

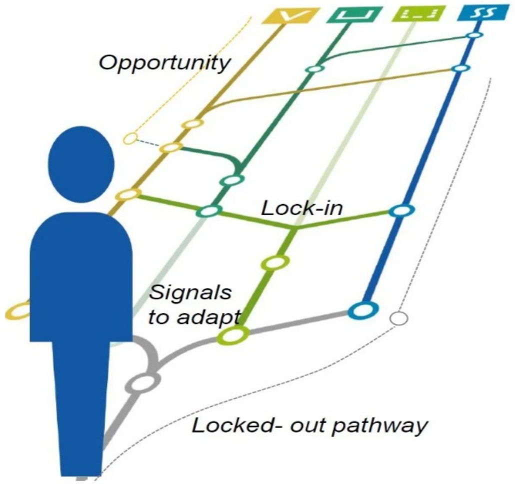
Key DMDU principles applicable to nuclear plant climate resilience:

- **Explore multiple plausible futures** — use scenario-based analysis rather than single-point projections
- **Identify robust strategies** — prefer actions that avoid severe regret across a wide range of outcomes
- **Develop adaptive pathways** — stage decisions with built-in decision triggers rather than committing to irreversible actions now
- **Monitor and update** — treat monitoring as a decision support tool, not just an operational requirement

DMDU is already familiar in nuclear risk management

- PRA sensitivity studies, cliff-edge effect analysis, and importance measures all reflect DMDU-compatible thinking
- Climate resilience extends these existing frameworks into a longer-horizon planning context





How EPRI Is Applying DMDU to Real Plant Decisions

The challenge for plant decision makers

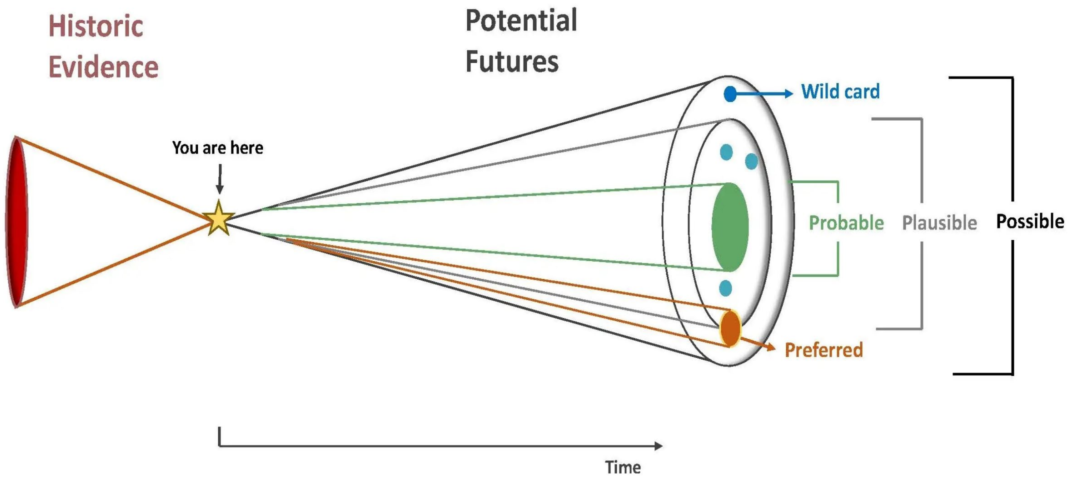
- How do you choose siting and design options that remain acceptable across a wide range of plausible future climate hazards *without betting on a single forecast — and with a clear basis for stakeholders?*

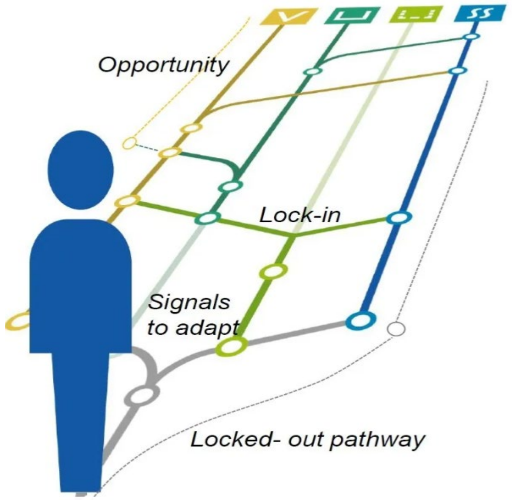
EPRI's approach

- Robust Decision Making (RDM) stress-tests design and siting alternatives across thousands of plausible climate futures — selecting options that minimize regret and defining adaptive upgrades with pre-specified triggers

Pilot Demonstration

- Coastal surge/SLR vs riverine/PMF vs drought/heat





Adaptive Pathways: Staging Decisions Over Time

Adaptive pathways avoid the false choice between “act now on everything” and “wait for certainty”

- ***Core concept***: Define a sequence of decision points triggered by observable conditions, not arbitrary timelines

Example adaptive pathway for cooling system resilience:

- ***Now*** — Enhance monitoring: Install intake temperature trending, increase meteorological data collection
- ***Trigger A*** (if intake temps exceed X for Y consecutive days): Implement enhanced operational protocols, evaluate supplemental cooling options
- ***Trigger B*** (if exceedance frequency increases): Initiate engineering studies for cooling system upgrades
- ***Trigger C*** (if studies confirm inadequacy): Implement infrastructure modifications

Advantages of the adaptive pathway approach

- Avoids premature commitment of capital to solutions that may not be needed under moderate climate futures
- Avoids delayed response by pre-defining what conditions trigger action — removing ambiguity at decision time
- Preserves flexibility to incorporate improved climate projections and new technologies as they emerge

Monitoring is not just compliance — it is the early warning system that activates the pathway

Operational Adaptation: The First Line of Climate Resilience

Operational adaptations are faster to implement and more flexible than infrastructure investments – they are the immediate first line of response

Heat wave response

- Pre-defined decision trees for cooling system optimization at elevated ambient and river temperatures
- Proactive power reductions before reaching technical specification limits
- Enhanced monitoring and reporting during heat events

Water management

- Seasonal operating protocols that anticipate low-flow and high-temperature periods
- Coordination with river basin authorities and downstream users during drought conditions

Enhanced monitoring

- Real-time intake temperature trending with early warning thresholds
- 72-hour to 14-day weather forecasting integration
- Biological monitoring for intake biofouling risk (jellyfish, algae, invasive species)

Workforce and logistics planning

- Extreme weather staffing protocols and pre-positioning of critical materials and equipment

Infrastructure Hardening: Long-Term Structural Responses

Infrastructure investments address vulnerabilities that operational procedures alone cannot manage

Flood protection

- Flood barrier systems (berms, deployable gates, door seals) to protect safety-related areas
- Drainage system upgrades to handle increased precipitation intensity
- Elevation of critical electrical equipment and emergency diesel fuel supplies

Cooling system resilience

- Supplemental cooling capacity (dry cooling, supplemental towers) to manage elevated heat sink temperatures
- Intake modifications to handle biological fouling (screens, traveling water improvements)
- Alternate water supply connections for drought resilience

Electrical infrastructure

- Transformer enclosures and flood barriers for switchyard protection
- Enhanced backup power capacity and fuel storage for extended grid separation events
- Hardened communication systems for extreme weather conditions

Planning horizon for infrastructure: typically 5-15 years from decision to implementation

Intake Resilience through Informed Decisions

- Biological fouling at intake structures is an emerging and underappreciated operational risk — and a concrete example of where monitoring-driven resilience pays off
- Cooling system performance depends directly on the uninterrupted flow of water through intake structures — any blockage translates immediately to heat sink degradation
- Recent increases in bio-diversity and propagation have challenged intake structures
- Jellyfish are notoriously difficult to identify in advance of reaching an intake structure
- A technology for identifying jellyfish movement patterns and propagation conditions would be beneficial for other bio-monitoring applications

Technology for monitoring and forecasting could be applied to other flora and fauna

Jellyfish Bloom Detection and Forecasting at Intakes

- Once-through cooling systems are increasingly vulnerable to disruptions caused by jellyfish blooms
  - Clog intake structures
  - Damage intake screening equipment
  - Force partial or complete shutdowns
- Warm and nutrient/salinity profiles shift creating conditions conducive to more frequent and larger bloom patterns
- Detecting jellyfish in the water column is challenging
  - Gelatinous, translucent bodies blend into the surrounding water
  - Distribution is often patchy and unpredictable
  - A successful forecasting system must integrate advanced sensor technologies capable of directly detecting jellyfish or identifying the environmental precursors indicating the probability of bloom

- The ability to anticipate these events could greatly improve operational resilience

The Research Agenda: Closing the Gap Between Knowledge and Action

- CVAs are done — the work ahead is understanding what solutions exist, what research is still needed, and what the timeline for action looks like
  - *Heat transfer performance degradation* — how do elevated UHS temperatures affect equipment margins, and what design interventions recover that margin?
  - *Material degradation* — how do extreme temperature and precipitation cycles affect long-term component qualification envelopes?
  - *Intake reliability* — what sensor technologies and forecasting systems can give operators early warning of biological and debris fouling events?
- New plant design — how should advanced reactor siting and design processes account for the climate conditions of 2060–2100, not just today?
- The goal: identify solutions that return operating margin to plants on a timeline that matches the projected pace of climate change — before conditions demand emergency responses

International Cooperation: Accelerating Climate Resilience

No single plant, utility, or country has all the answers — international collaboration accelerates learning

IAEA contributions

- Safety standards and guides addressing climate change impacts on nuclear installations
- Technical cooperation programs in conducting climate vulnerability assessments
- Knowledge sharing on observed operational impacts and effective adaptation measures
- Peer review missions that include climate resilience as an assessment dimension

This Technical Meeting is itself an example of the value of international exchange

- Sharing operator experience builds collective knowledge
- What one plant learns from a heat wave, flood, or biological intake event can protect plant worldwide

EPRI's role in the international research community

- Development of climate vulnerability assessment methodologies applicable across reactor types and climates
- Research on advanced cooling technologies, biological intake management, and climate scenario frameworks
- Collaboration with IAEA, NEA, and member utilities to develop practical guidance for plant decision makers

The path forward requires sustained collaboration across regulators, operators, researchers, and international bodies

TOGETHER…SHAPING THE FUTURE OF ENERGY®

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Climate Risk and Resilience

Program 262

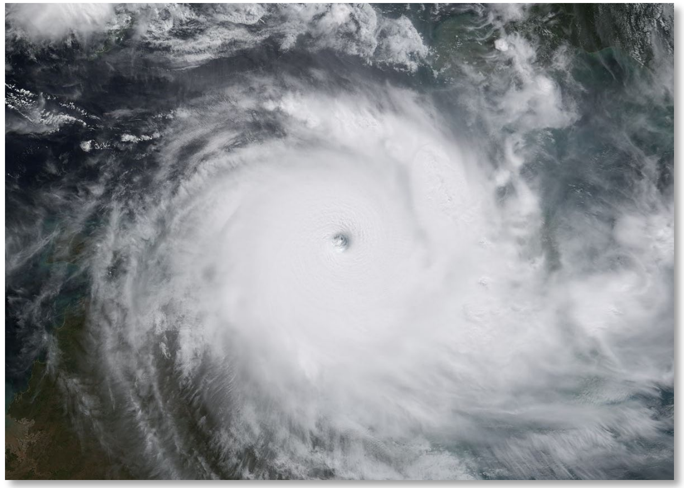
December 2025

Laura Fischer, Program Manager
lfischer@epri.com
Energy Systems and Climate Analysis Group

P262: Climate Risk and Resilience

Laura Fischer
lfischer@epri.com

Assessing, communicating, & managing climate-related risk



Promote Climate-Informed Planning

- Demonstrate how to integrate climate data and link modeling tools
- Assess hazard trends

Steward and Advance EPRI Frameworks

- Future home of Climate READi™ and SMARTargets™
- Lead future framework development

Climate Risk Assessments and Metrics

- Support company-specific assessments
- Inform development of risk & resilience metrics

Policy, Compliance, and Disclosure

- Research and insights to inform policy, regulatory filings, standards setting, and disclosure

EPRI helps members evaluate and manage climate-related risk and improve climate resilience

Program 262 Structure

Program under ESCA launches Jan 1, 2026

P262: Climate Risk and Resilience

Physical Risk

P262-A Physical Climate Risk and Resilience

Future of Climate READi + Climate Resilience Analysis Research + P201-E (physical risk)

Transition Risk

P262-B Transition Risk and Risk Management, Climate Disclosure, and Target Setting

Formerly P201-E (transition risk, target setting, global perspectives) + Future of SMARTargets

Bringing the two types of climate risk together

P262A will tackle risk and resilience from several angles

With technical advances in…

Climate Data Knowledge and Relevance

Understand, quantify, and model complex hazards

Track and evaluate new data sources for power system applications

Study tradeoffs and limitations in climate data use

Benchmark climate extremes for planning across scales

Method and Analysis Needs

Address needs within a specific tool or process to better handle climate risk

Develop, evaluate, and compare novel capabilities and implementation options within tools

Provide and refine inputs for asset vulnerabilities, loads, and scenarios

Investment Decision Making

Explore robust decision-making approaches under deep uncertainty

Demonstrate use of decision criteria for valuing resilience, including societal impacts, health, and equity

Evaluate sensitivities to data and modeling scoping decisions

Integrated Modeling Capabilities

Improve understanding of full-system resilience across generation, transmission, distribution, and customers

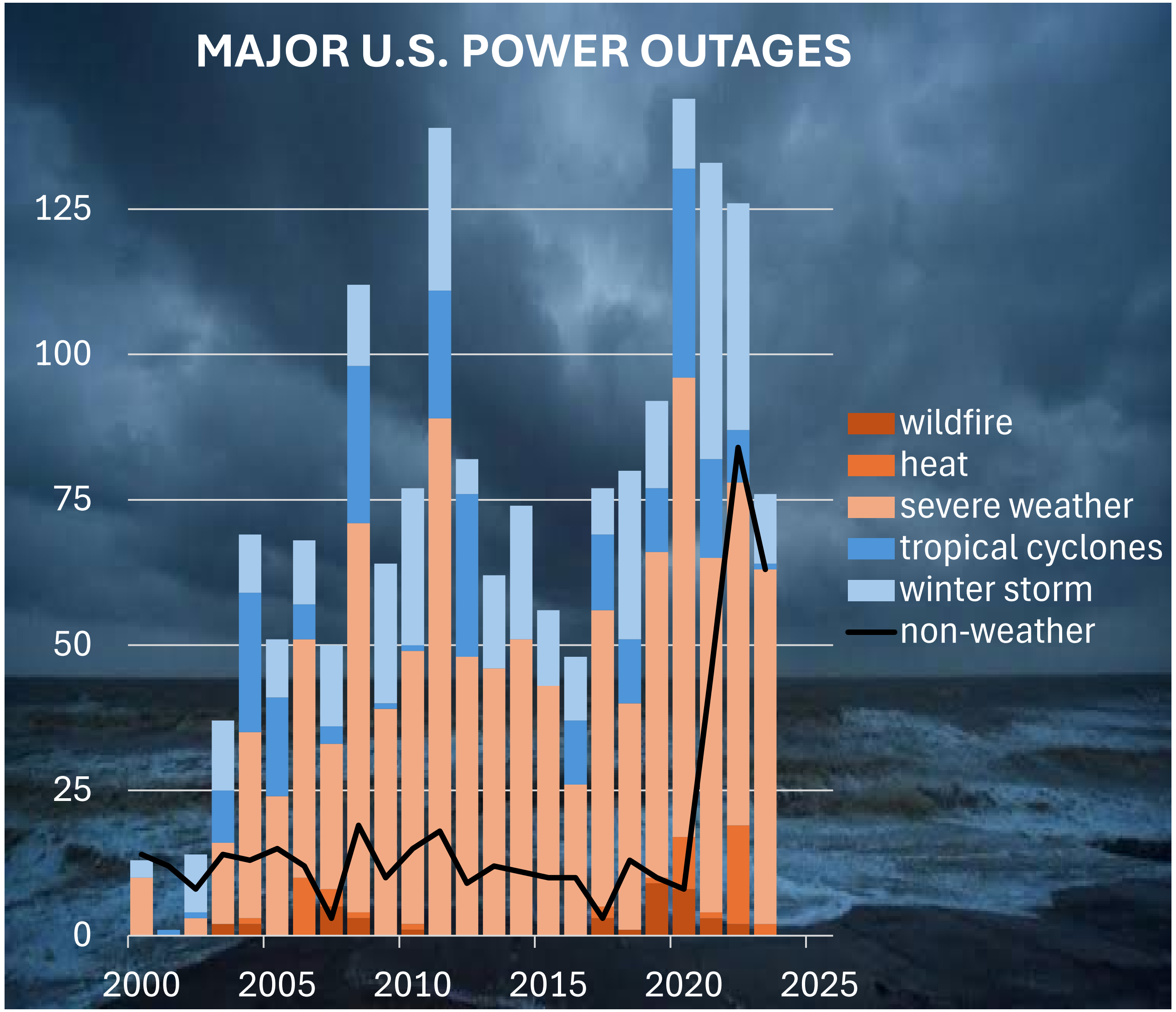
Streamline touchpoints between tools for consistent climate data, load, and technology assumptions

Explore coordinated planning among stakeholders or regions

Foundational Efforts:

- Climate READi Framework Coordination
- Education and Outreach
- Climate Data Services
- CRAG Engagement
- Tracking Climate Risk Developments

Extreme weather is the leading cause of major power outages in most regions of the world

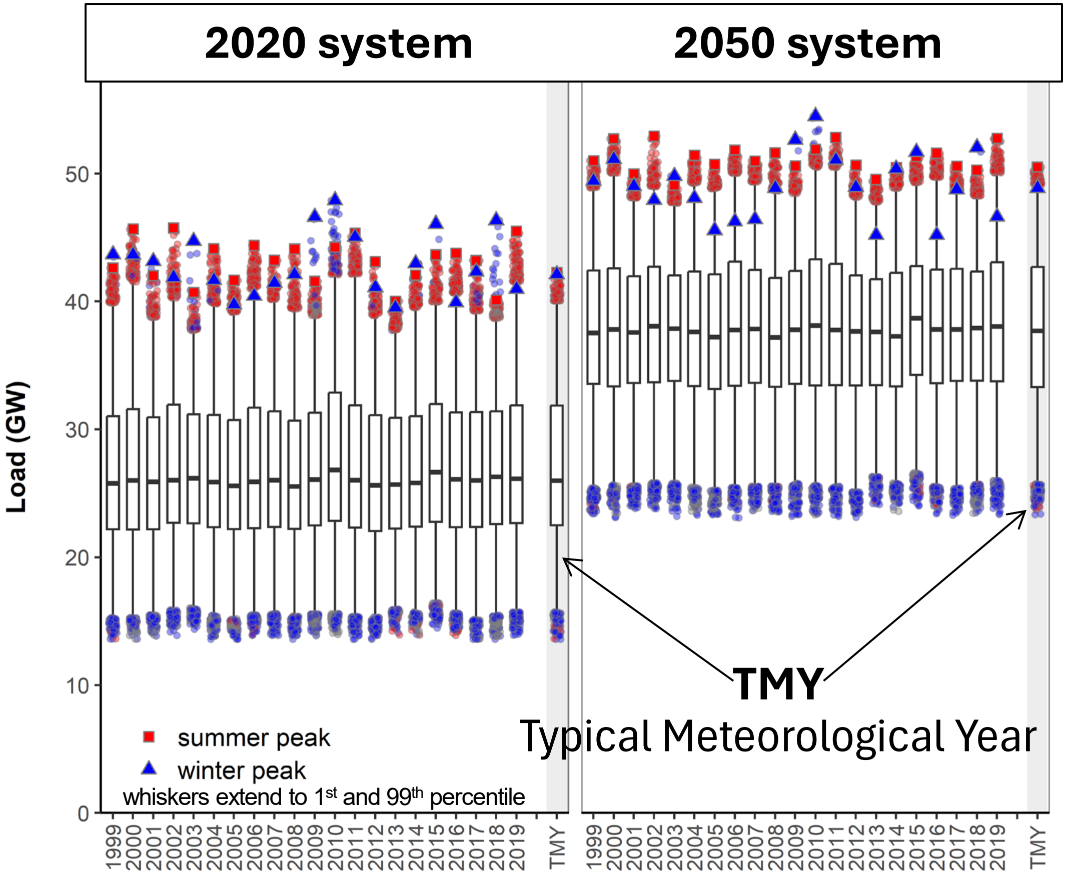


- More frequent or intense weather events like tropical cyclones, heatwaves, floods, and severe storms challenge grid reliability, along with rising costs and awareness of consequences
  - Direct damage to grid infrastructure, including power lines, substations, and equipment
  - Significant economic disruption from power outages
  - Social costs including health and fatalities
- The economic toll of a single extreme weather events can be disproportionately severe for some vulnerable regions

Notable extreme weather events like 2017 Hurricane Maria in Puerto Rico and 2021 Texas Winter Storm demonstrate widespread and costly grid failures

Source: left: EPRI analysis of U.S. Form OE-417 reports, right: IEA (2020), Power Systems in Transition www.iea.org/reports/power-systems-in-transition

Planning for a single or “typical” year underestimates extreme hours that challenge reliability, from both demand and supply



1. **Interannual weather variability over 20 year periods** exposes potential peaks that are missing from standard Typical Meteorological Years (TMYs)

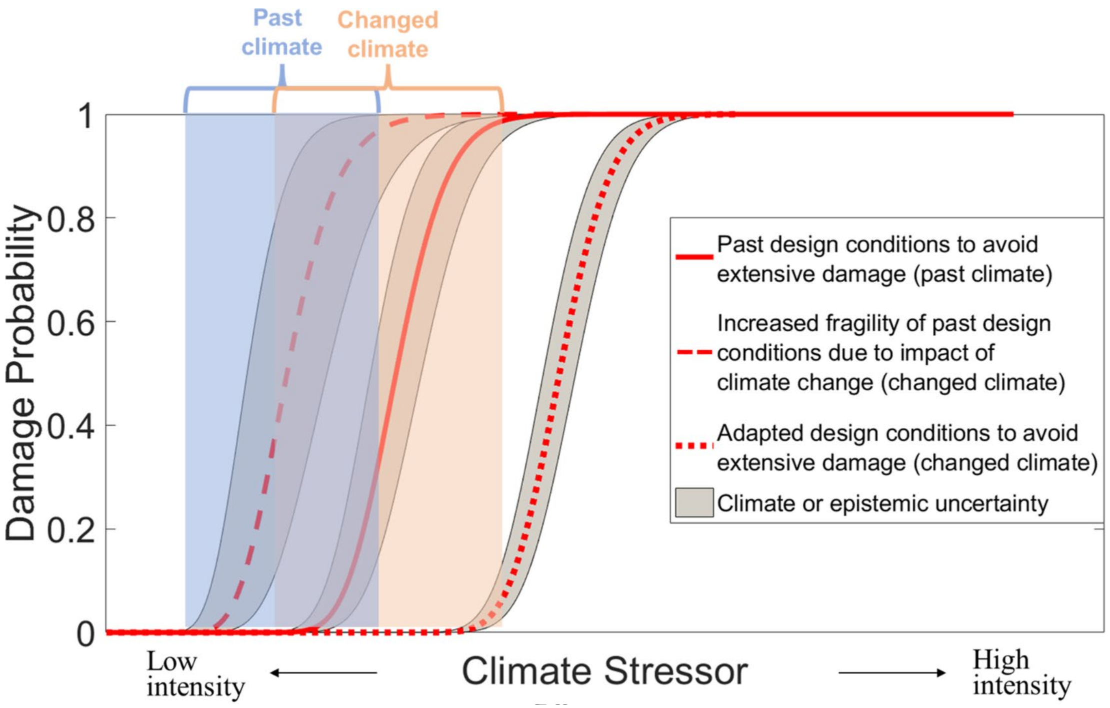
2. **Climate warming** will intensify summer peaks and reduce total winter heating demand in most regions

3. Integrated models are key to resolve technology and policy factors like **AI-driven data center growth and end-use efficiency** that also influence customer demand

Extreme events and weather variability are best captured with 20+ years of synchronous data; EPRI’s READi Framework highlights value of internally-consistent data across planning models

Simulated demand based on end-use mix of 2020 (left) and 2050 (center) plus climate weather (right). Distribution of hourly load assuming 1999-2019 meteorology and TMY (right side each panel).

Asset vulnerabilities include outages, capacity derates, efficiency losses, shortened life spans, and increased maintenance requirements, among others

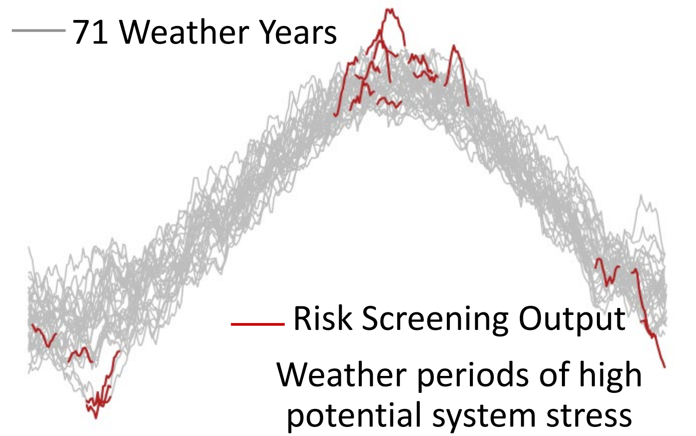


Technology	Weather Condition			Capacity Derating	Impact
Wind (Onshore)	100m Windspeed	>	23m/s	100%	High speed cutout
Solar PV	Temperature	>	95°F	22%	Heat derating
Gas Combined Cycle	Temperature	>	87°F	11%	Heat derating
Gas turbine	Temperature	<	10°F	33%	Cold derating
Gas turbine	Temperature	<	0°F	43%	Cold derating
Gas turbine	Temperature	<	-20°F	100%	Temperature Limit
Gas turbine	10m Windspeed Precipitation	>= >	26m/s 0.2in	10%	Tropical Storm

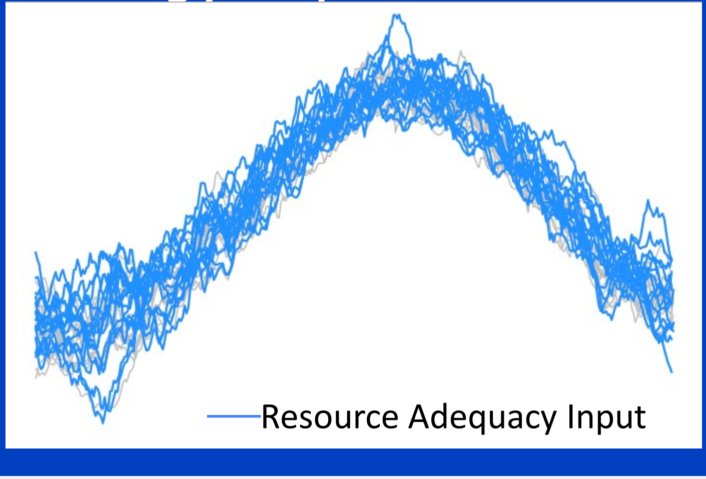
Grid vulnerability to weather stress depends on uncertain consequences, summarized as “fragility curves” in system models

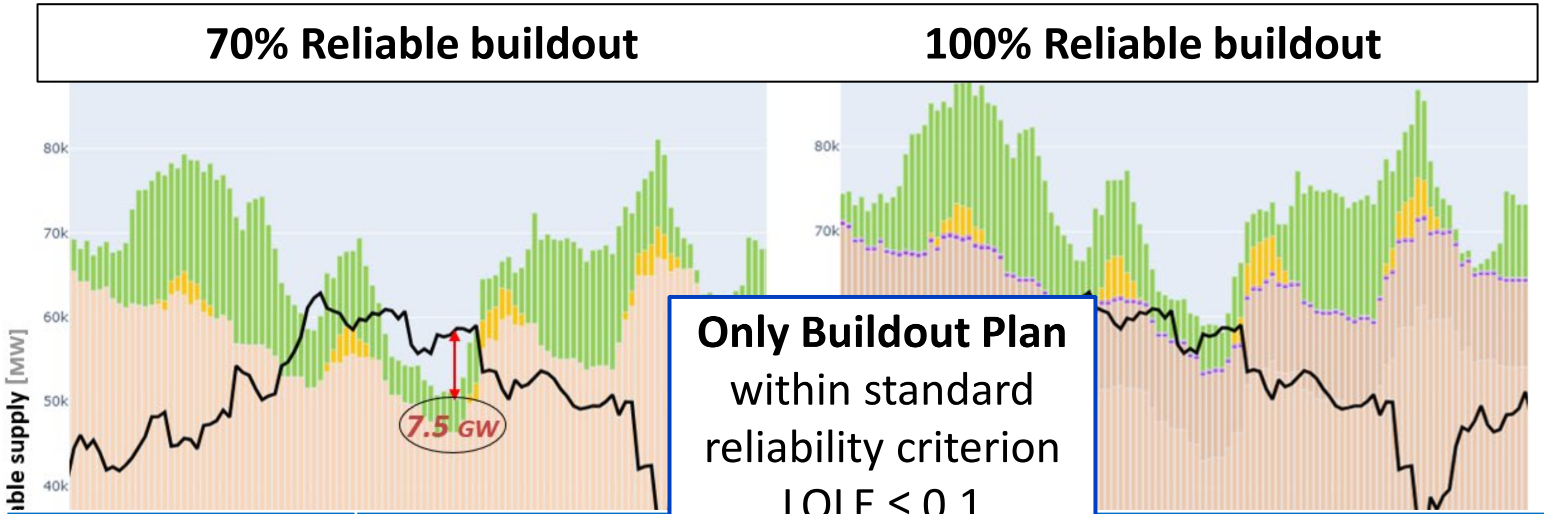
Climate-informed RA ingests a large state space of weather data and random fragility/failures; provides a distribution of expected performance

Weather data is screened for grid stress,



Resulting years passed to RA model




70% Reliable buildout | **100% Reliable buildout**

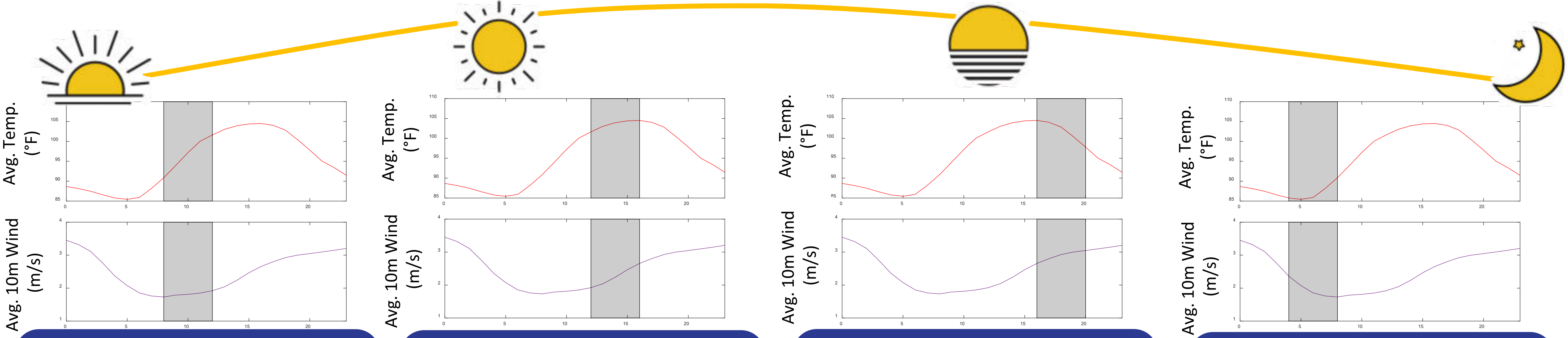
Only Buildout Plan within standard reliability criterion LOLE ≤ 0.1

CapEx Buildout Plan	**Resource Adequacy Result** Loss Of Load Expectation [days/year]	**Resource Adequacy Result** Expected Unserved Energy [MW/year]
100% Reliable	0.08	7.8
90% Reliable	0.46	1,840
70% Reliable	3.06	18,990

38 times more days w. load shedding expected

Only 7.8MW expected unserved energy (vs 19 GW)

Grid “stress” depends on factors beyond temperature

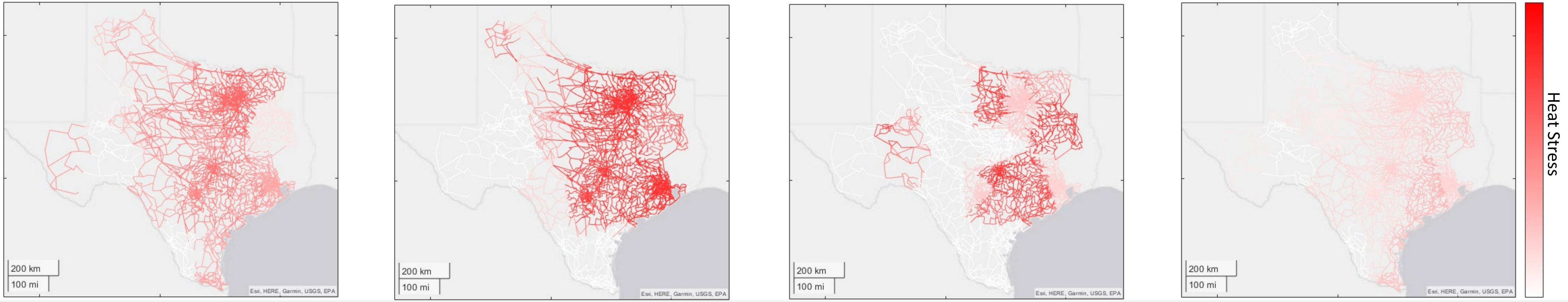


Rising temperatures, low wind to dissipate heat from lines

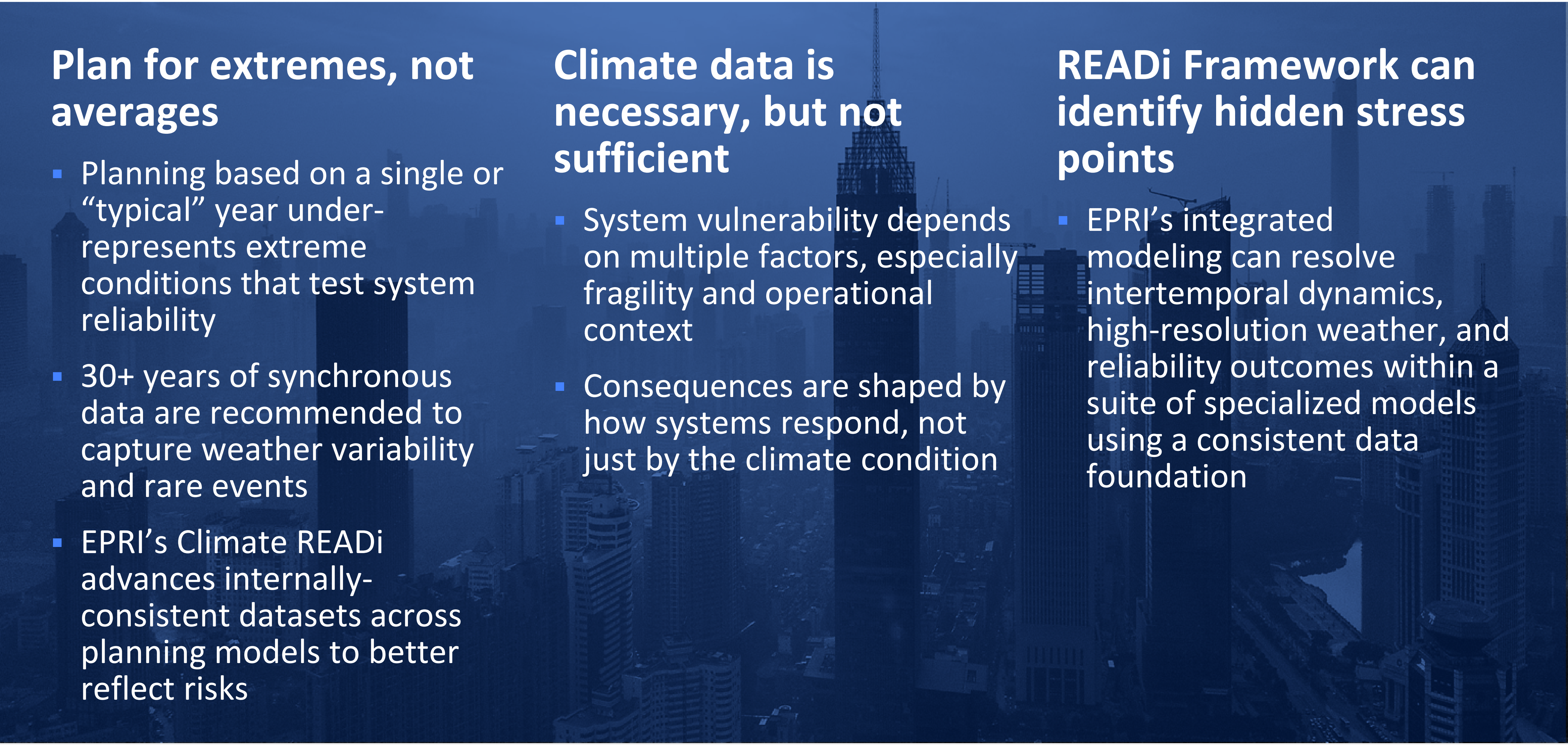
High temperatures, low wind to dissipate heat from lines

Temperatures still elevated, but offset by some western wind

Lower temperatures, wind decreasing



Key Messages



Plan for extremes, not averages

- Planning based on a single or “typical” year under-represents extreme conditions that test system reliability
- 30+ years of synchronous data are recommended to capture weather variability and rare events
- EPRI’s Climate READi advances internally-consistent datasets across planning models to better reflect risks

Climate data is necessary, but not sufficient

- System vulnerability depends on multiple factors, especially fragility and operational context
- Consequences are shaped by how systems respond, not just by the climate condition

READi Framework can identify hidden stress points

- EPRI’s integrated modeling can resolve intertemporal dynamics, high-resolution weather, and reliability outcomes within a suite of specialized models using a consistent data foundation

P262B will help you tackle transition risk and engage

Opportunities for technical analyses, resources, and guidance…

Transition risk assessment and management

- Methodology and tool development
- Third-party methodology perspectives
- Transition planning and economy wide transition support
- Scientific basis development

Risk Disclosure and Approaches

- Risk disclosure requirements tracking, technical perspectives, support
- Stakeholder education for informed expectations and dialogue

GHG Targets and Strategies

- Methodology and tool development
- Third-party methodology perspectives
- Scientific basis development – for alignment with science and international goals

Global Climate Science and Policy

- Global transitions futures assessment
- Global policy and science development tracking and perspectives

Suite of activities:

Company bi-lateral consultations

Development tracking and perspectives

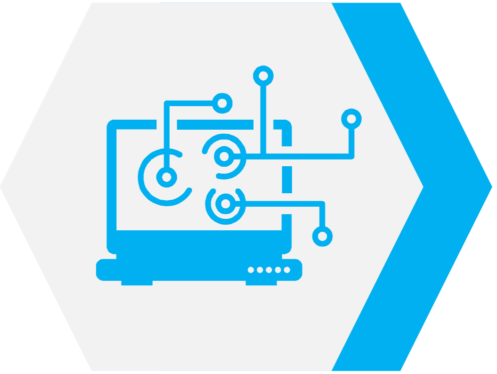
Educational outreach

Technical analysis

Frontier topics educational series

The P262 Approach

Diverse tactics to support corporate climate risk assessment



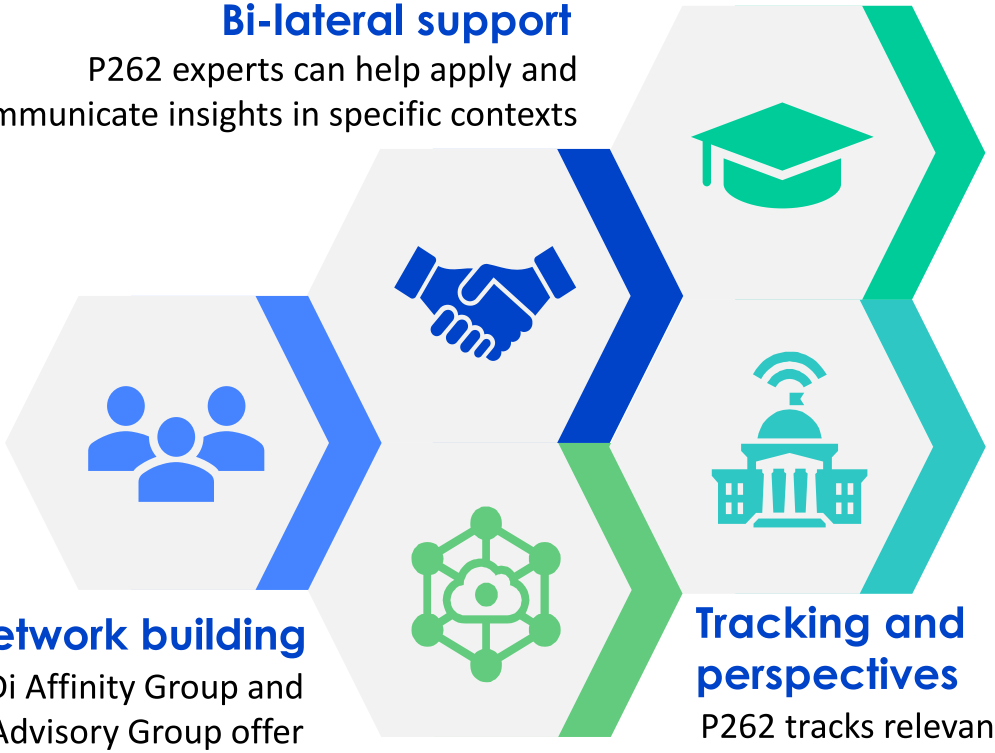
Technical analyses

P262 delivers technical analyses and guidance related to climate risk assessment

Technical insights leveraged to support internal and external engagement across the industry

⇄

Insights from engagement can inform future technical analyses



Collaboration

P262 leverages subject matter expertise from across EPRI for more comprehensive analyses

Network building

Climate READi Affinity Group and Stakeholder Advisory Group offer additional technical expertise

Bi-lateral support

P262 experts can help apply and communicate insights in specific contexts

Educational outreach

P262 insights and materials support internal and external stakeholder briefings

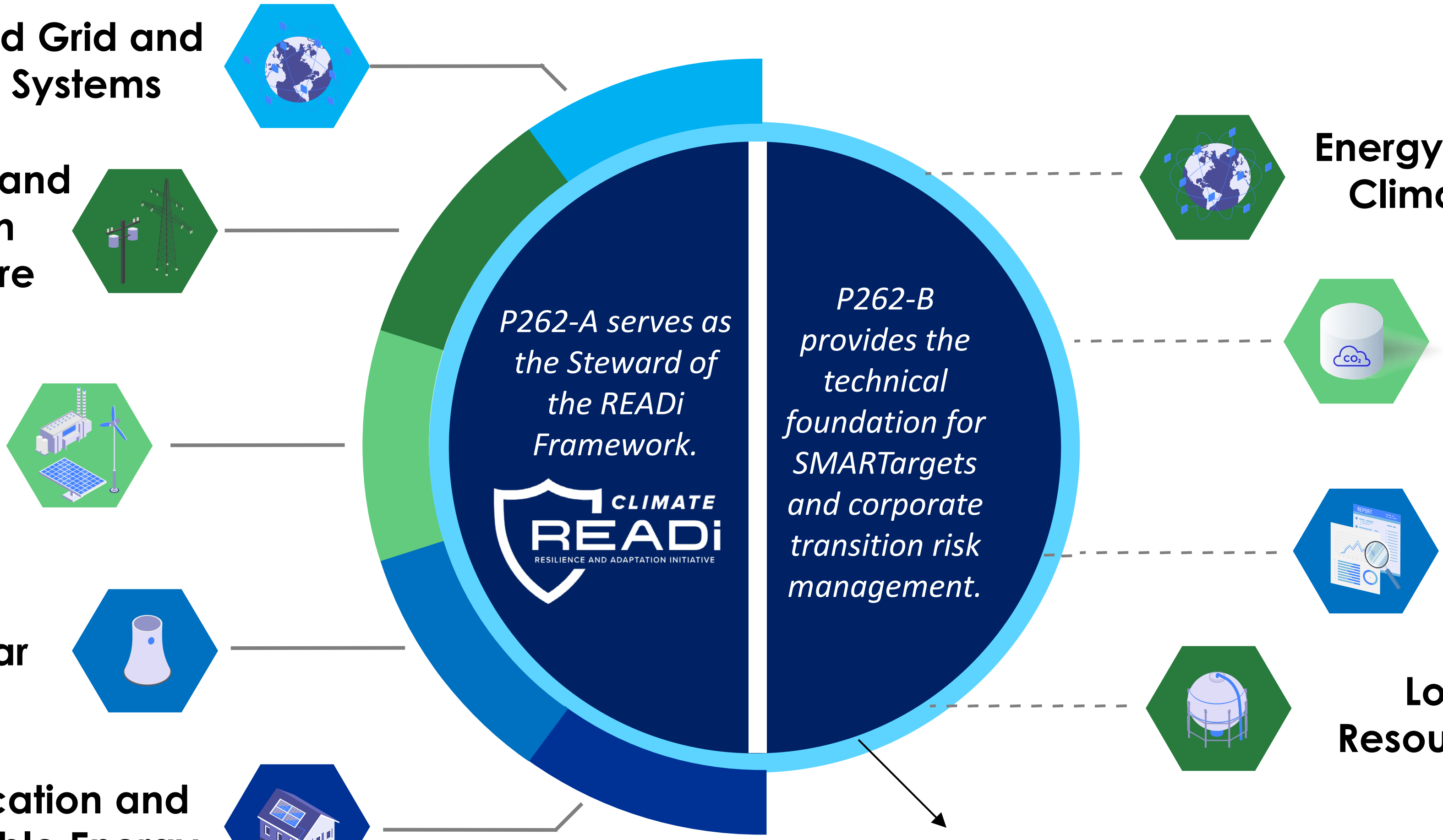
Tracking and perspectives

P262 tracks relevant science and policy developments and contextualizes weather events

Data-driven | Science-based | Technically rigorous | Power system-informed

The P262 Approach

Collaboration to expand expertise and promote synergistic research



Integrated Grid and Energy Systems

Transmission and Distribution Infrastructure

Generation

Nuclear

Electrification and Sustainable Energy Systems

P262-A serves as the Steward of the READi Framework.

P262-B provides the technical foundation for SMARTargets and corporate transition risk management.

Energy, Environmental and Climate Policy Analysis

Greenhouse Gas Emissions Accounting

Strategic Sustainability Science

Low Carbon Resources Initiative

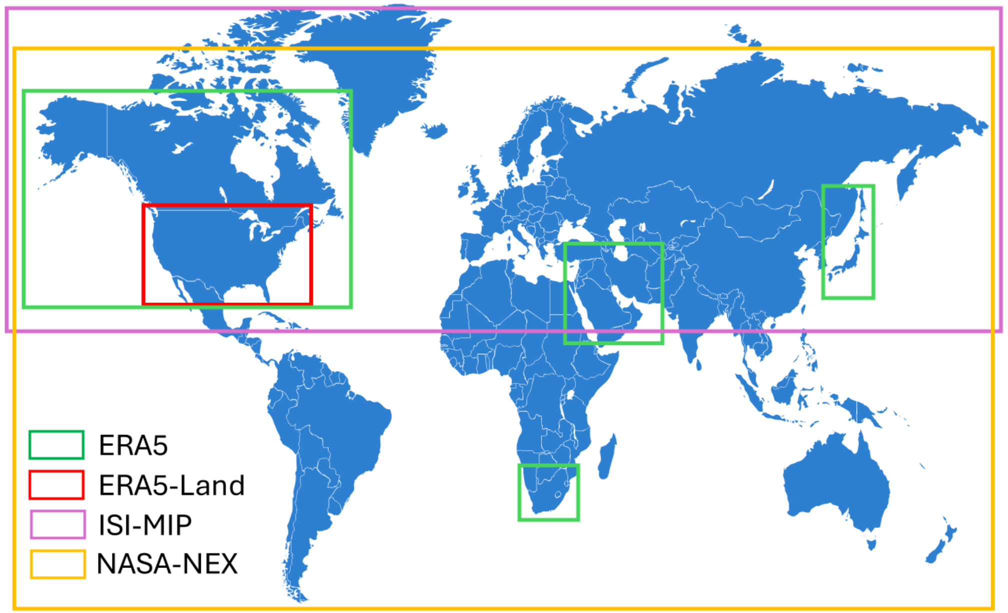
P262 A&B also intend to pursue joint projects.

Together, P262-A and P262-B can advance integrated decarbonization and climate resilience planning.

The P262 Approach

Investment in climate data infrastructure to support localized assessment and climate-informed modeling

Figure shows only cloud optimized datasets.
Additional data available for other regions.



EPRI's Climate Data Repository (CDR)

Cloud-based repository of power system relevant historical and projected climate data

Cloud computing platform for large computations

EPRI uses the CDR:

To provide quick and robust analyses via datasets have been cloud-optimized and put into a consistent format for ease of use

As a building block for future services, including the climate analysis toolkit

Time Period

1940 - 2025	2015 - 2100
Historical	Projected

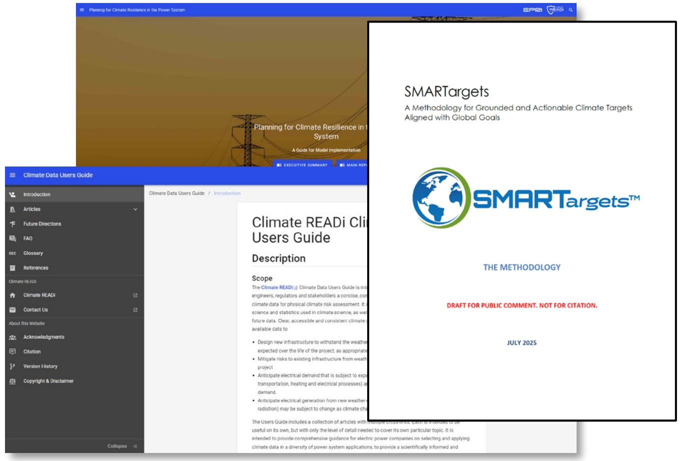
Variables	
2m air temperature	snowfall
10m wind speed	mean sea level pressure
100m wind speed	surface pressure
10m wind direction	relative humidity
100m wind direction	dewpoint
10m wind gusts	cloud cover
precipitation	surface roughness
precipitation type	shortwave radiation

Not every variable is available for every dataset

Click on the images to access the publications.

The P262 Approach (1 of 2)

Delivering insights to diverse stakeholders through multiple channels


Planning for Climate Resilience in the Power System

Planning for Climate Resilience in t
System

A Guide for Model Implementation

EXECUTIVE SUMMARY

MAIN REP

Climate READi Cli
Users Guide

Description

Scope

The Climate READi Climate Data Users Guide is int
engineers, regulators and stakeholders a concise, co
climate data for physical climate risk assessment. It
science and statistics used in climate science, as we
future data. Clear, accessible and consistent climate
available data to

- Design new infrastructure to withstand the weathe expected over the life of the project, as appropriat
- Mitigate risks to existing infrastructure from weath project
- Anticipate electrical demand that is subject to exp transportation, heating and electrical processes) a demand.
- Anticipate electrical generation from new weather radiation) may be subject to change as climate cha

The Users Guide includes a collection of articles with useful on its own, but with only the level of detail needed to cover its own particular topic. It is intended to provide comprehensive guidance for electric power companies on selecting and applying climate data in a diversity of power system applications, to provide a scientifically informed and

SMARTargets

A Methodology for Grounded and Actionable Climate Targets Aligned with Global Goals

SMARTargets™

THE METHODOLOGY

DRAFT FOR PUBLIC COMMENT. NOT FOR CITATION.

JULY 2025


Climate-Driven Variability of Co-Located Wind and Solar Generation

CLIMATE READi

INTRODUCTION

Falling capital costs, supportive policies, and prime co-located wind and solar resources are making joint projects increasingly viable and economical. Facilities that combine both wind and solar technology are attractive because their time-varying generation can often be anti-correlated across several timescales, with wind generation often greatest at night and in the winter when solar generation is relatively low. This anti-correlation results in more consistent generation from a combination wind and solar facility than from either alone. While such a relationship can be anticipated from the general climatology of wind and solar generation, it leaves open the degree of consistency in generation and revenue from electricity sales (or averted electricity purchases) that should be expected from month to month, since the atmospheric dynamics governing variability on scales from several days to several weeks are quite different from those governing the day-night and summer-winter variability.

This research summary presents three main findings from recent EPRI analysis of the variability of co-located wind and solar generation:

1. Wind and solar generation have covariance patterns that are a strong function of location, averaging period, and season of the year.
2. There are large parts of the US where wind and solar generation have reliable, spatially coherent tendencies to be relatively high or low when temperature is warm or cold.
3. These patterns have implications for power system interconnection and capacity expansion strategies.

The Climate READi Research Initiative

EPRI launched the Climate Resilience and Adaptation Initiative (Climate READi) in 2022 to help prepare the power system for the effects of climate change. This globally focused project prioritizes collaboration to mitigate physical climate risk, ensure resilient energy investment, and enable robust planning that is responsive to unique local conditions, technically rigorous, and focused on equity and worker health and safety.

STUDY OVERVIEW

In this study, 73 years (1950-2022) of wind speed and solar radiance data from the ERA5 reanalysis data set was evaluated to determine the monthly variability of wind and solar generation, both separately and in combination. Business operations tend to rely on a monthly scale to understand how combining wind and solar generation infrastructure at a single site might impact the reliability of income streams at different locations around the continental United States. The timeseries of monthly generation is shown below in Figure 1 to better understand the frequency of months with generation relative to the climatologically expected generation. This analysis was performed at all 1723 locations around the continental United States in areas with existing wind farms as of November 2023 (using the U.S. Wind Turbine Database, provided by the U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory via https://eerscmap.usgs.gov/uswtdb), and on a subset of seven locations intended to represent a cross-section of rural communities:


EPRI

Leveraging Machine Learning t
Future Tornado Activity in the U

READi Insights

KEY TAKEAWAYS

- Machine learning can effectively reproduce historical tornado patterns with limited inputs.
- The capability of machine learning to project future conditions is generally limited by the climate models representation of large-scale circulation patterns.
- Projections using machine learning suggest an increase in tornado activity in the Midwest and a shift in tornado timing toward early spring and winter.

INTRODUCTI

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any country in the w
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and improving prep

While the impact of
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EPRI

TECHNICAL BRIEF

Net-Zero Climate Targets are not for Everyone

ABSTRACT

Net-zero climate targets are being discussed and even requested; however, there is very little scientific discussion of net-zero strategies for local decision-makers such as regions, cities, and corporations. With stakeholders calling for net-zero targets, there is need for scientific guidance. This brief addresses this issue and, using available resources and illustrative analysis, generates foundational insights for more informed dialogue and development of local strategies and policies, which are critical for realistic, actionable solutions. Across analyses, the article finds evidence that net-zero is not for everyone. It is essential to consider differences in decarbonization opportunities and enabling conditions that will help balance the challenges of decarbonization and facilitate greater ambition. Companies, policy-makers, stakeholders, and researchers will find this brief to be of value given its insights regarding potential local low-carbon strategies and transitions and opportunities for progress managing the climate.

Net-zero greenhouse gas emissions targets have emerged as a popular climate change management goal for countries, cities, regulators, and corporations. Net-zero CO_2 emissions by 2050 is, far and away, the most common target discussed. There is also growing public and stakeholder expectations that net-zero targets should be set and pursued by all, with net-zero increasingly referenced and being demanded of public and private sector decision-makers. Net-zero has become a default for climate strategy discussions, with the names of organizations, initiatives, and methodologies communicating stakeholder expectations, e.g., Net Zero Climate, Net Zero Coalition, Net Zero Tracker, Science Based Targets Initiative Corporate Net-Zero Standard (SBTi, 2021, 2023), and Moody's Ratings' Net Zero Assessment (Moody's Ratings, 2024).

Despite the enthusiasm, there has been surprisingly little discussion about the science of net-zero strategies, especially for local decision-making, such as by cities and corporations. What does the science say and are net-zero expectations and strategies aligned with the science, or should they be revised? This brief explores the science on sub-global net-zero strategies—first drawing insights from published resources, and then, evaluating company level net-zero strategies using a simple illustrative analysis.

- If your applications can support open scientific / engineering publications, you can access it for free.
- Of course, the codes need to be properly prepared to leverage the full power of the modern high-performance computing system (i.e., CPU-GPU hybrid system).
- We will demonstrate our usage as an example to inspire further applications.

Public Educational Webcast Series

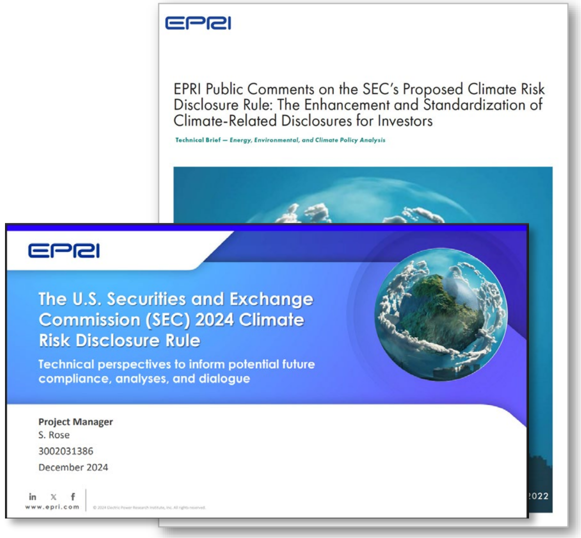
Options for Estimating the Global Economic Impacts of Climate Change and the Social Cost of Carbon Module-by-Module

Technical analysis and guidance	Story Maps	Insights / Tech Briefs	Presentations / Briefings / Events
Web-based or PDF reports provide guidance on various stages of climate risk assessment	Narratives with compelling visuals to reach diverse audiences	Short-form pieces that distill research results into headline findings and key messages	Communicating science, insights, and methods to stakeholders. Hosting webcasts and workshops.

The P262 Approach (2 of 2)

Delivering insights to diverse stakeholders through multiple channels

Click on the images to access the publications.



EPRI Public Comments on the SEC's Proposed Climate Risk Disclosure Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors

Technical Brief — *Energy, Environmental, and Climate Policy Analysis*

The U.S. Securities and Exchange Commission (SEC) 2024 Climate Risk Disclosure Rule

Technical perspectives to inform potential future compliance, analyses, and dialogue

Project Manager
S. Rose
3002031386
December 2024

www.epri.com

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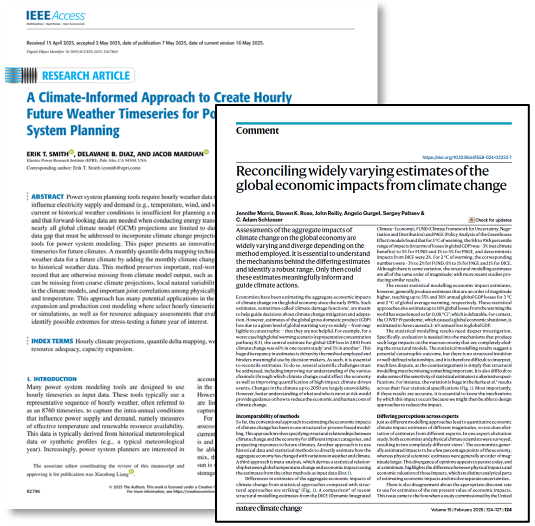
Formal comments and perspectives

Comments focus on evaluating technical aspects of proposed rules and/or regulations (e.g., SEC Rule, TCFD)



IEEE Access

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RESEARCH ARTICLE

A Climate-Informed Approach to Create Hourly
Future Weather Timeseries for Po
System Planning

ERIK T. SMITH, DELAVANE B. DIAZ, AND JACOB MARDIAN
Electric Power Research Institute (EPRI), Palo Alto, CA 94304, USA
Corresponding author: Erik T. Smith (esmith@epri.com)

ABSTRACT Power system planning tools require hourly weather data t
influence electricity supply and demand (e.g., temperature, wind, and s
current or historical weather conditions is insufficient for planning a r
and that forward-looking data are needed when conducting energy trans
nearly all global climate model (GCM) projections are limited to dai
data gap that must be addressed to incorporate climate change projecti
tools for power system modeling. This paper presents an innovative
timeseries for future climates. A monthly quantile delta mapping techni
weather data for a future climate by adding the monthly climate chang
to historical weather data. This method preserves important, real-wor
record that are otherwise missing from climate model output, such as
can be missing from coarse climate projections, local natural variabilit
in the climate models, and important joint correlations among physically
and temperature. This approach has many potential applications in the
expansion and production cost modeling where select hourly timeserie
or simulations, as well as for resource adequacy assessments that eval
identify possible extremes for stress-testing a future year of interest.

INDEX TERMS Hourly climate projections, quantile delta mapping, we
resource adequacy, capacity expansion.

I. INTRODUCTION

Many power system modeling tools are designed to use hourly timeseries as input data. These tools typically use a representative sequence of hourly weather, often referred to as an 8760 timeseries, to capture the intra-annual conditions that influence power supply and demand, namely measures of effective temperature and renewable resource availability. This data is typically derived from historical meteorological data or synthetic profiles (e.g., a typical meteorological year). Increasingly, power system planners are interested in

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Reconciling widely varying estimates of the global economic impacts from climate change

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Assessments of the aggregate impacts of climate change on the global economy are widely varying and diverge depending on the method employed. It is essential to understand the mechanisms behind the differing estimates and identify a robust range. Only then could these estimates meaningfully inform and guide climate actions.

Economists have been estimating the aggregate economic impacts of climate change on the global economy since the early 1990s. Such estimates, sometimes called 'climate damage functions', are meant to help guide decisions about climate change mitigation and adaptation. However, estimates of the global gross domestic product (GDP) loss due to a given level of global warming vary so widely – from negligible to catastrophic – that they are not helpful. For example, for a worst-case high global warming scenario (representative concentration pathway 8.5), the central estimate for global GDP loss in 2100 from climate change was 60% in one recent study[1] and 3% in another[2]. This huge discrepancy in estimates is driven by the method employed and hinders meaningful use by decision-makers. As such, it is essential to reconcile estimates. To do so, several scientific challenges must be addressed, including improving our understanding of the various channels through which climate change could affect the economy as well as improving quantification of high-impact climate-driven events. Changes in the climate up to 2050 are largely unavoidable. However, better understanding of what and who is most at risk would provide guidance on how to reduce the economic and human costs of climate change.

Incomparability of methods

So far, the conventional approach to estimating the economic impacts of climate change has been to use structural or process-based modelling. This approach involves specifying structural relationships between climate change and the economy for different impact categories, and projecting responses to future climates. Another approach is to use historical data and statistical methods to directly estimate how the aggregate economy has changed with variations in weather and climate. A third approach is meta-analysis, which derives a statistical relationship between global temperature change and economic impacts using the estimates from the other methods as input data (Box 1).

Differences in estimates of the aggregate economic impacts of climate change from statistical approaches compared with structural approaches are striking[3] (Fig. 1). A comparison[4] of recent structural modelling estimates from the DICE (Dynamic Integrated Climate–Economy), FUND (Climate Framework for Uncertainty, Negotiation and Distribution) and PAGE (Policy Analysis of the Greenhouse Effect) models found that for 3 °C of warming, the 5th to 95th percentile range of impacts (in terms of losses in global GDP) was −3% (net climate benefits) to 5% for FUND and 1% to 3% for PAGE, and deterministic impacts from DICE were 2%. For 2 °C of warming, the corresponding numbers were −3% to 2% for FUND, 0% to 1% for PAGE and 1% for DICE. Although there is some variation, the structural modelling estimates are all of the same order of magnitude; with more recent studies producing similar results.

The recent statistical modelling economic impact estimates, however, generally produce estimates that are an order of magnitude higher, reaching up to 55% and 38% annual global GDP losses for 3 °C and 2 °C of global average warming, respectively. These statistical approaches also estimate up to 10% global losses from the warming the world has experienced so far (1.08 °C)[5], which is debatable. For context, the COVID-19 pandemic, which caused a global economic shutdown, is estimated to have caused a 2–6% annual loss in global GDP.

The statistical modelling results need deeper investigation. Specifically, evaluation is needed into the mechanisms that produce such large impacts on the macroeconomy that are completely eluding the structural models. The statistical modelling results suggest a potential catastrophic outcome, but there is no structural intuition or well-defined relationships, and it is therefore difficult to interpret, much less dispute, as the counterargument is simply that structural modelling must be missing something important. It is also difficult to make sense of the sensitivity of statistical estimates to alternative specifications. For instance, the variation is huge in the Burke et al.[6] results across their four statistical specifications (Fig. 1). Most importantly, if these results are accurate, it is essential to know the mechanisms by which this impact occurs because we might then be able to design approaches to reduce the impact.

Differing perceptions across experts

Just as different modelling approaches lead to quantitative economic climate impact estimates of different magnitudes, so too does elicitation of estimates from different experts. In one expert elicitation study, both economists and physical climate scientists were surveyed, resulting in two completely different views[7]. The economists generally estimated impacts to be a few percentage points of the economy, whereas physical scientists' estimates were generally an order of magnitude larger. This divergence of opinions appears to persist today, and at a minimum, highlights the difference between physical impacts and economic valuation of those impacts, which are distinct analytical parts of estimating economic impacts and involve separate uncertainties.

There is also disagreement about the appropriate discount rate to use for estimates of the net present value of economic impacts. This issue came to the fore when a study commissioned by the United

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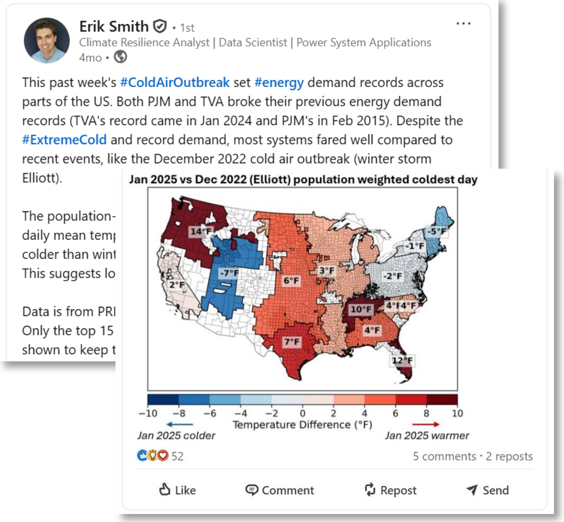

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This past week's #ColdAirOutbreak set #energy demand records across parts of the US. Both PJM and TVA broke their previous energy demand records (TVA's record came in Jan 2024 and PJM's in Feb 2015). Despite the #ExtremeCold and record demand, most systems fared well compared to recent events, like the December 2022 cold air outbreak (winter storm Elliott).

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daily mean temp
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This suggests lo

Data is from PRI
Only the top 15
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