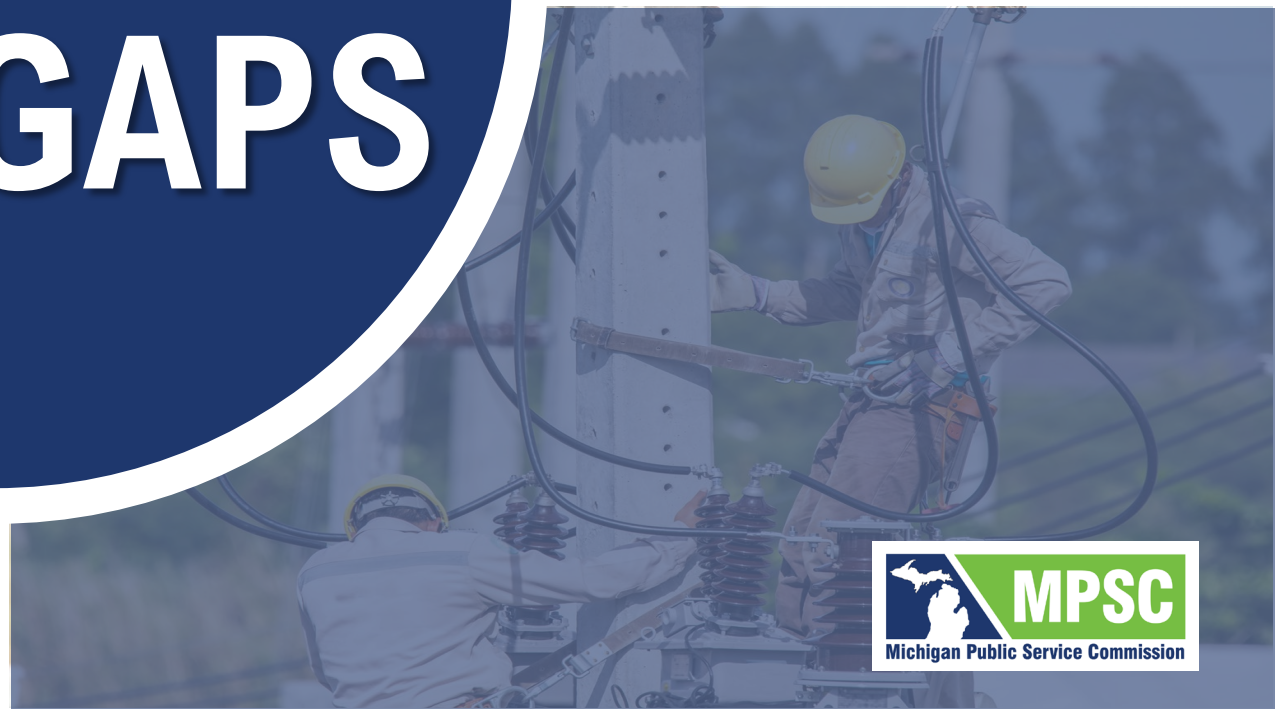
Session 1
IDENTIFY THE GAPS



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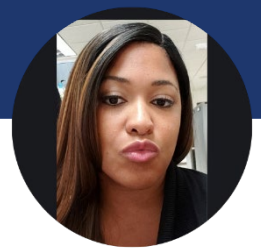

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Technical Conference
Day 2

Session One
Identify the Gaps

Speaker Topic:
Current Gaps: Do We Meet the Existing Standards?

November 5, 2021
9:05 a.m.

CURRENT GAPS: DO WE MEET THE EXISTING STANDARDS

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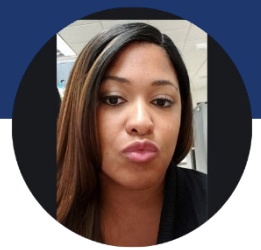

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01 Current reliability standards – storm restoration, etc.

02 Pending ruleset changes

03 Root cause of failures

04 Outage measurement and tracking – do metrics capture reality (SAIDI, etc)

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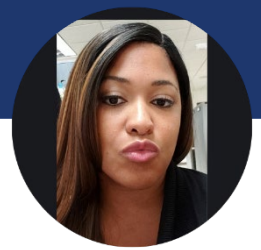

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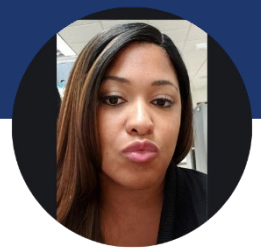
MI POWER GRID

- Focused, multi-year stakeholder initiative to maximize the benefits of the transition to clean, distributed energy resources for Michigan residents and businesses
- Engages utility customers and other stakeholders to help integrate new clean energy technologies and optimize grid investments for reliable, affordable electricity service
- Includes outreach, education, and regulatory reforms

Grid Security and Reliability Standards



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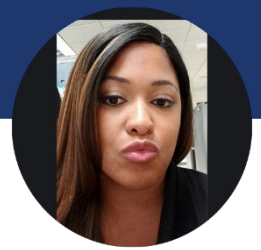
Workgroup Initiated 9/11/2019 → 4 Stakeholder Meetings Conducted 12/3/2019 – 3/12/2020 → Initial Report 7/31/2020 → Final Report 12/15/2020

MI POWER GRID: Emerging Technologies; Grid Optimization; Customer Engagement

- Workgroup initiated in September 2019 and held four stakeholder meetings as part of Phase I.
- Charged with recommending revisions to the Service Quality and Reliability Standards as well as the Technical Standards for Electric Service rulesets
- Identified gaps in existing rules and proposed solutions, including improvements in expected levels of performance, requiring automatic bill credits for customers who experience long-term or multiple outages, as well as strengthening cybersecurity monitoring and reporting.

Service Quality and Reliability Standards



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Workgroup Participants and Commenters

- Michigan's Attorney General
- Michigan's Utilities
- Michigan Fire Departments
- MEGA
- MECA
- MAUI
- State Rep. Yaroch
- New Energy Advisors
- CUB

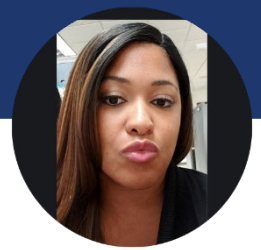
Issues Reviewed

- Adopting more IEEE Definitions
- Revising Wire Down Standby Times
- Outage Reporting Requirements
  - Emergency Response Plans, AAR's
    - Service Performance Rules to be transferred to Billing Ruleset
    - Modifying Annual Reporting Requirements for all utilities
    - Outage Credits and Thresholds
    - Electric Service Reliability

Timeline

- December 2019 to March 2020
  - Monthly whole group sessions to discuss common issues
  - Separate subgroup sessions:
    - Two Definitions and Outage Reporting Meetings
    - Three Wire Down Meetings
- January-August 2021
  - Internal review of proposed ruleset in preparation to move to rulemaking

Current Outage Reliability Requirements



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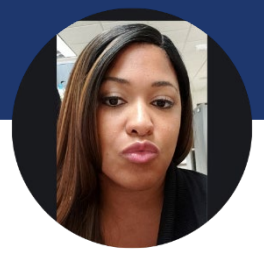
R 460.721: Duty To Plan to Avoid Unacceptable Levels

- An electric utility shall plan to operate and maintain its distribution system in a manner that will permit it to provide service to its customers without experiencing an unacceptable level of performance as defined by these rules.



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Current Outage Reliability Requirements

R 460.722: Unacceptable Levels of Performance

- It is unacceptable for a utility to fail to meet these interruption standards:
  - ✓ **Normal and Catastrophic conditions**: an electric utility shall restore service within 36 hours to not less than 90% of its customers experiencing service interruptions.
  - ✓ **Catastrophic conditions**: an electric utility shall restore service within 60 hours to not less than 90% of its customers experiencing service interruptions.
  - ✓ **Normal conditions:** an electric utility shall restore service within 8 hours to not less than 90% of its customers experiencing service interruptions.
  - ✓ **Repetitive Outages**: An electric utility shall not experience 5 or more same circuit repetitive interruptions in a 12-month period on more than 5% of its circuits.

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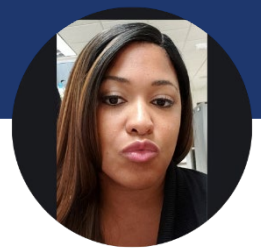
Root Cause of Failures – Rule 705



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R 460.3705 Interruptions of service; records; planned interruption; notice to commission.

Rule 705. (1) Each electric utility shall make a reasonable effort to avoid interruptions of service. When interruptions occur, service shall be restored within the shortest time practical, consistent with safety.

(2) Each electric utility shall keep records of sustained interruptions of service to its customers and shall make an analysis of the records for the purpose of determining steps to be taken to prevent recurrence of the interruptions. The records shall include the following information concerning the interruptions:

(a) Cause.

(b) Date and time.

(c) Duration.

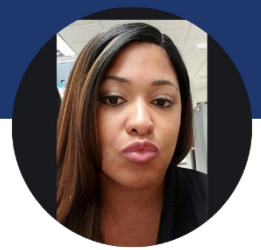
(3) Planned interruptions shall be made at a time that will not cause unreasonable inconvenience to customers and shall be preceded, if feasible, by adequate notice to persons who will be affected.

(4) Each electric utility or electric cooperative shall promptly notify the commission of any major interruption of service to its customers.

History: 1983 AACS; 1996 AACS.

Source: Michigan Technical Standards for Electric Service

Outage Reporting Requirements



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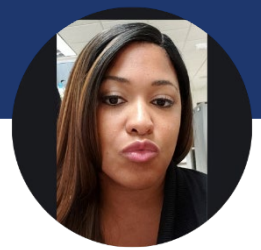
- Current Technical Standards ruleset requires notification to MPSC when a utility is experiencing a major interruption to their system ("catastrophic" 10%+).
- Some utilities provide pre-event notifications to alert Staff that inclement weather is expected in their territory.
- Outages are tracked by the utility and reported to the Commission once they reach reportable levels.

Outage Tracking



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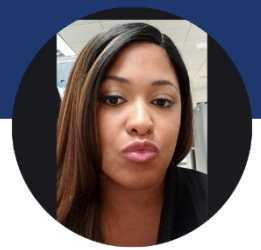
- Once the Commission is notified of an outage, the restoration process is tracked by Staff until the utility has restored the affected customers.
- Staff monitors the progress via reports from the utility and through the utility outage map.
- Staff may request AAR's from a utility to review restoration performance and takeaways.
- Staff tracks the utility performance via annual reports provided by each utility.
  - ✓ U-12270, U-16065, U-16066



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Current and Proposed Reporting Requirements

All Utilities (U-12270):

- Wire Down Relief
- Meter Read
- New Service Installation
- ~~Complaint Response*~~
- ~~Average Call Answer Time*~~
- ~~Call Blockage Factor*~~
- Outage Restoration—Normal
- Outage Restoration—Catastrophic
- Outage Restoration—All Conditions
- Same Circuit Repetitive Outage
- Outage Credits Paid
- SAIDI, SAIFI, CAIDI
  - ✓ 5 year rolling average
  - ✓ With and Without Major Event Days

Consumers Energy & DTE Energy Only:

- CEMI 0-10+
- CELID 60hrs and CELID 8hrs (excluding catastrophic events)
- $25.00 Outage Credit Directives
- List of their 10 worst performing circuits for the prior years in terms of SAIDI & SAIFI
- SAIDI and SAIFI excluding major events for the year
- Circuit name, number and location
- Length of circuit (miles)
- Number of customers served
- Substation name
- Last circuit trim
- List of outages and causes
- Corrective action plan to improve performance
- MAIFI (if possible)

*Proposed Transfer to Billing Rules

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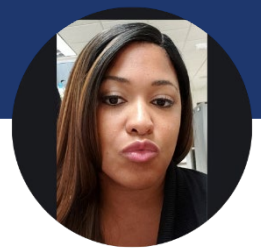
Outage Root Cause Analysis



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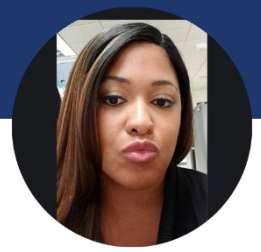
- Rule 705 contained within the Technical Standards require utilities to conduct an outage cause analysis.
- Utilities are also required to keep detailed records of outages.
- For utilities that do not meet MPSC annual reporting metrics, the utility must provide an explanation of how they will remedy the problem that caused them to miss the metric.
- For large scale outages, the Commission orders Staff to investigate the root cause of the outages and identify areas of improvement.

Proposed Service Quality Changes

- Updates to Definitions to align with industry standard IEEE Terminology.
- Require utilities to automatically issue outage credits to customers who qualify.
- Increase in the base outage credit amount to $35.00 and added $2.00 per hour multiplier for long duration outages.
- Automatic adjustments to the outage credit amount to account for inflation annually.
- New mandates for repetitive and momentary outages.



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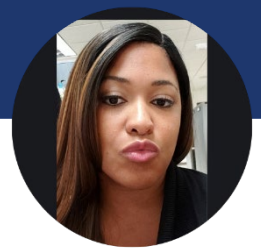
Overview: Outage Credit Threshold Revisions



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Unacceptable	Current		Revised	
Normal	*0-10%*	8 hrs	*0-1%*	8 hrs
Gray Sky			*1-10%*	24 hrs
Catastrophic	*10%+*	60 hrs	*10%+*	48 hrs
All Conditions		36 hrs		36 hrs
Outage Credit	**Current**		**Revised**	
Normal	*0-10%*	16 hrs	*0-1%*	16 hrs
Gray Sky			*1-10%*	48 hrs
Catastrophic	*10%+*	120 hrs	*10%+*	96 hrs

- Customers are eligible for outage credits when they experience long duration or repetitive outages.
- In the workgroup process, it was revealed that many utilities have events that are significant enough to push them out of “normal” operations, but are not classified as “catastrophic”.
- Staff created a “gray sky” category to capture these events for internal tracking as well as for customers to be eligible for the outage credit.

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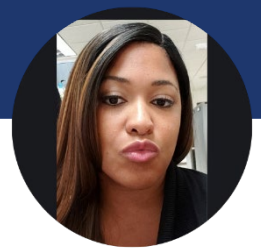

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Additional Information

- Customers who have additional questions regarding their outage credit eligibility and their bill should reach out to their utility provider.
- In addition, the Customer Assistance Division at the MPSC can assist customers who have additional questions or concerns. Customer Service Division can be reached at (517) 284-8100.

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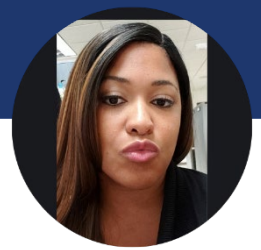

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Outage Measurement

Date	Storm Type	Customers Interrupted*	Storm Duration (Days)**	Storm Restoration (Days)**
11/17/2013	Wind Storm	719,854	5.5	6
12/21/2013	Ice Storm	388,950	8	6.9
09/05/2014	Wind Storm	414,699	7	7.2
12/24/2015	Wind Storm	181,627	4	4.2
03/07/2017	Wind Storm	1,103,539	7	7.1
07/06/2017	Wind Storm	181,620	4	4.2
04/15/2018	Ice Storm	288,976	5	5.3
05/04/2018	Wind Storm	254,867	4	4.5
08/26/2018	Wind Storm	255,763	7	6.9
02/06/2019	Ice Storm	231,891	4	5
07/19/2019***	Wind Storm	825,505	3	5.0

* Number of customers interrupted are cumulative when more than one utility reported the same storm.
** Storm duration and storm restoration are reflected as an average when more than one utility reported the same storm.
*** Preliminary numbers at the time of this report.
Source: MPSC

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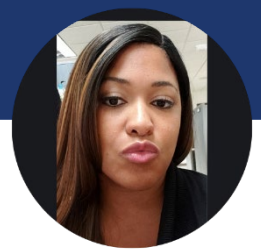

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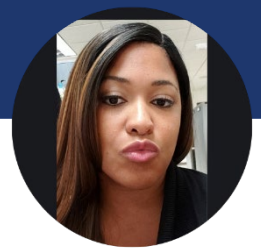
MPSC Rulemaking Process

Draft Rules	• Initial rules are drafted by the Regulatory Affairs Division or Staff
RFR Submitted & Approved by LSB	• The Request for Rulemaking (RFR) is drafted and submitted to the Michigan Office of Administrative Hearings and Rules (MOAHR) • Submit draft rules to the MPSC's Regulatory Affairs Officer (RAO) at MOAHR • Rules are informally approved by the Legislative Services Bureau (LSB) and MOAHR
Submit the RIS to the RAO	• A Regulatory Impact Statement (RIS) is drafted and submitted to the RAO • Recommended changes sent back
Issue Order #1	• Gives brief history of rule set • Sets dates for public hearing and for receipt of comments • Exhibit A: NOH; Exhibit B: Rules in strike/bold • ***MPSC STAFF CANNOT MAKE FURTHER CHANGES TO RULE SET***
Publicize and hold Public Hearing	• Public hearing notices must be published in at least three public newspapers • Must publish 10-60 days before a hearing date • RIS must be posted to MPSC website at least 10 days before public hearing
Issue Order #2	• Review verbal/written comments • MPSC responds to each, explaining reasoning for adoption or denial of the recommended change • Amend rules if, after discussing with Staff, public comments suggest valid rule changes • ~~RIS must be posted to MPSC website at least 10 days before public hearing~~
Submit JCAR Report	• Sent along with the order and a final version of the rules to RAO, who submits them to the Joint Committee on Administrative Rules (JCAR). • Wait for 15 joint session days.
Issue Order #3	• Formally adopts the rules and transmits them to MOAHR for filing with the Secretary of State • Prepare and submit Certificate of Adoption

Next Steps



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- Rulemaking is not a fast process and can be lengthy.
  - ✓ Ruleset hearing scheduled for December 9th
- The Commission will continue to monitor the outage performance of Michigan's utilities.
  - ✓ Rate Case Review (Tree Trimming/Storm Response)
  - ✓ Utility Five Year Distribution Planning Review
  - ✓ MI Power Grid Initiative
  - ✓ Michigan Technical Conference on Storms
- Customers who were affected by longer outages can apply for an outage credit through their utility.
  - ✓ DTE has announced that they will voluntarily credit eligible customers who experienced qualifying outages up to $100.

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Speaker Topic:
Better Planning Electric Power Systems for a Changing Climate

November 5, 2021
9:20 a.m.

Better Planning Electric Power Systems for a Changing Climate

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MPSC Technical Conference
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ASSET LAB

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Speaker Topic:
Better Planning Electric Power Systems for a Changing Climate

November 5, 2021
9:20 a.m.

Outline

- Pathways through which climate change can affect the electric power sector
- Expected climate change impacts in Michigan
- System-level consequences of climate change impacts in the power system
- New approaches for power system planning under a changing climate

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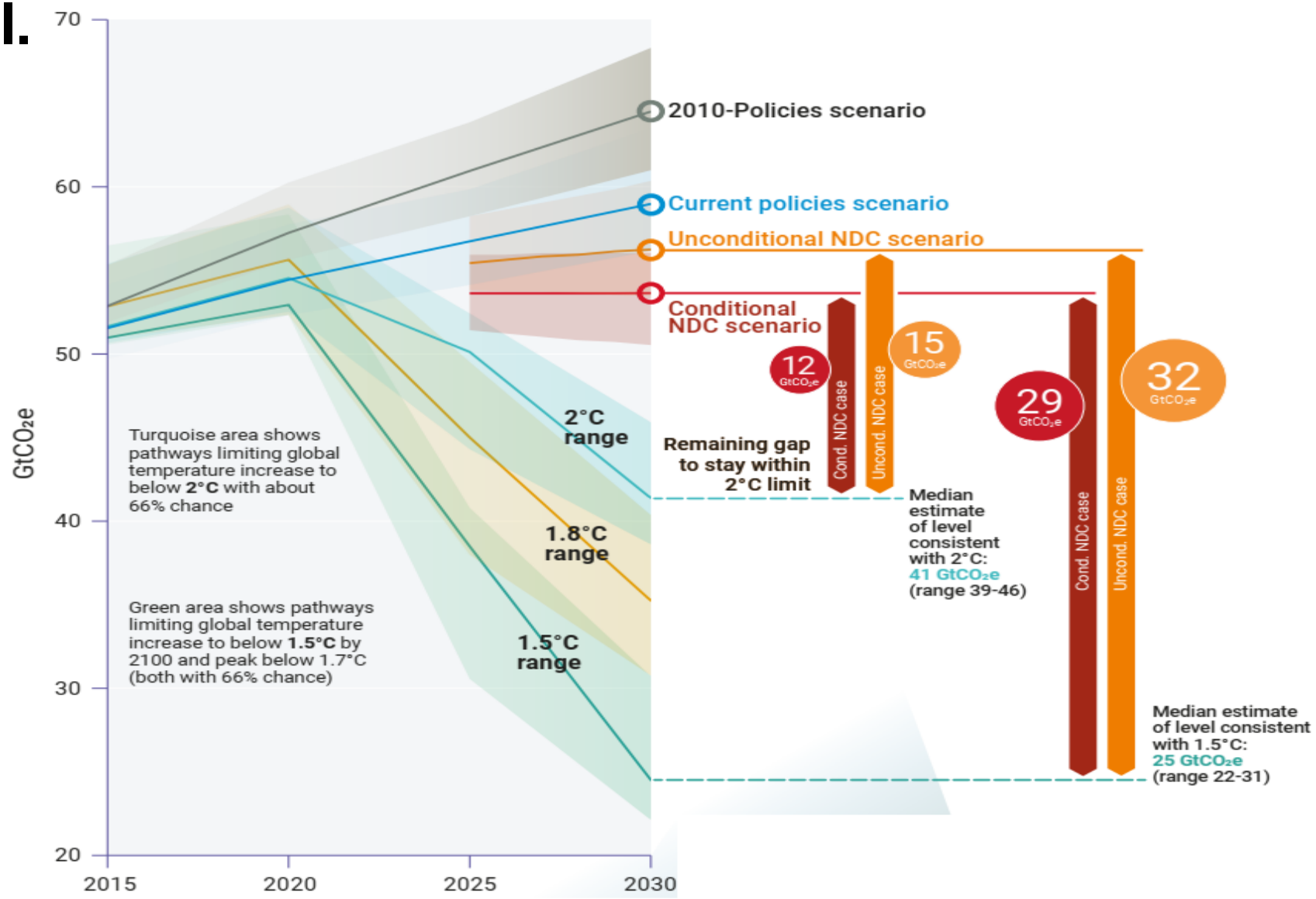
Efforts to mitigate climate change likely won't meet A 2ºC goal.



Source: UNEP, 2020

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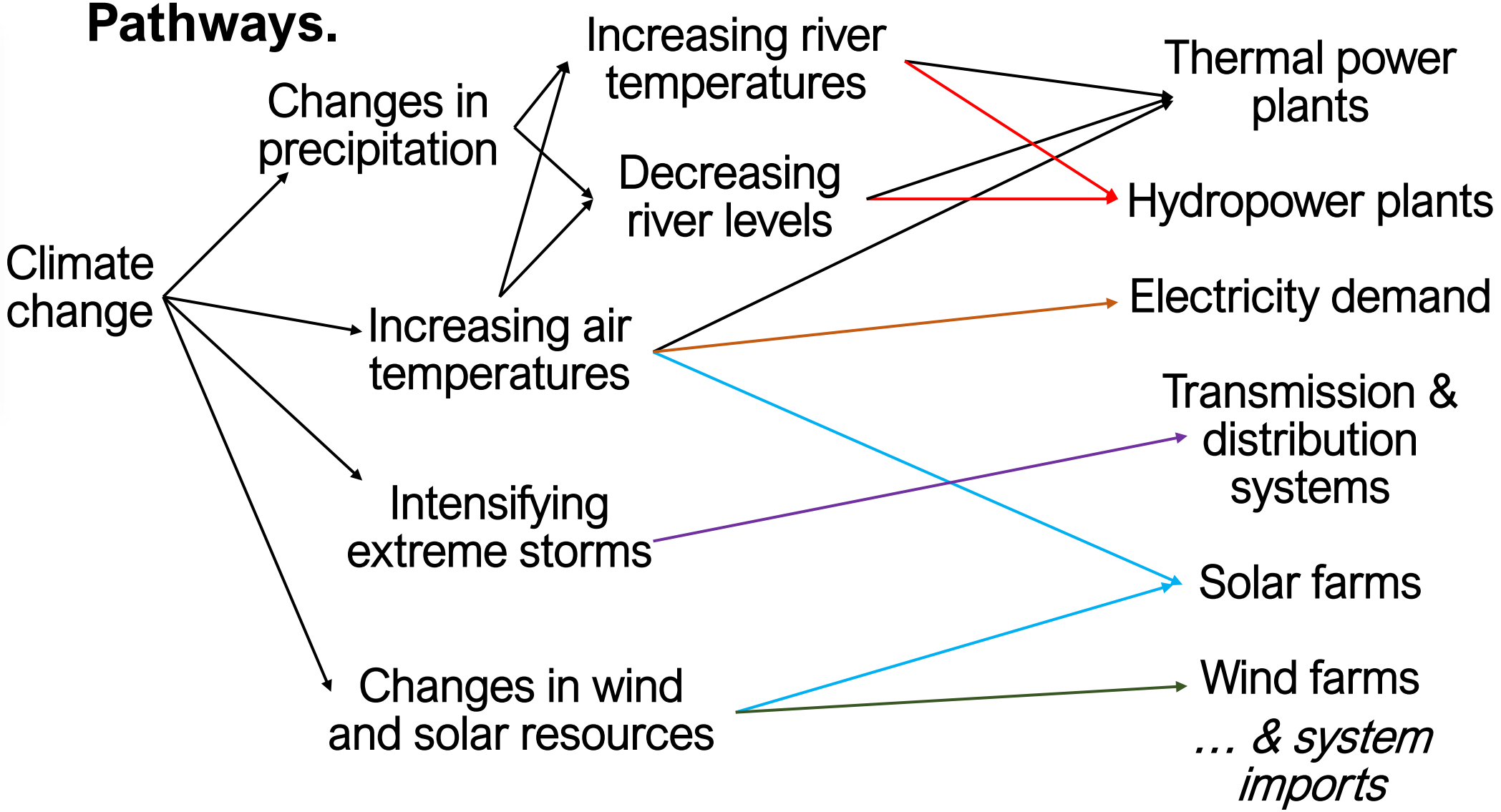
9:20 a.m.

Climate Change Might Affect Individual Parts **Of The Power System In Michigan Through Numerous Pathways.**



Craig et al., 2018, Renewable & Sustainable Energy Reviews

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MPSC
Technical Conference
Day 2

Session 1
Identify the Gaps

Speaker Topic:
Better Planning Electric Power Systems for a Changing Climate

November 5, 2021
9:20 a.m.

Outline

- Pathways through which climate change can affect the electric power sector
- **Expected climate change impacts in Michigan**
- System-level consequences of climate change impacts in the power system
- New approaches for power system planning under a changing climate

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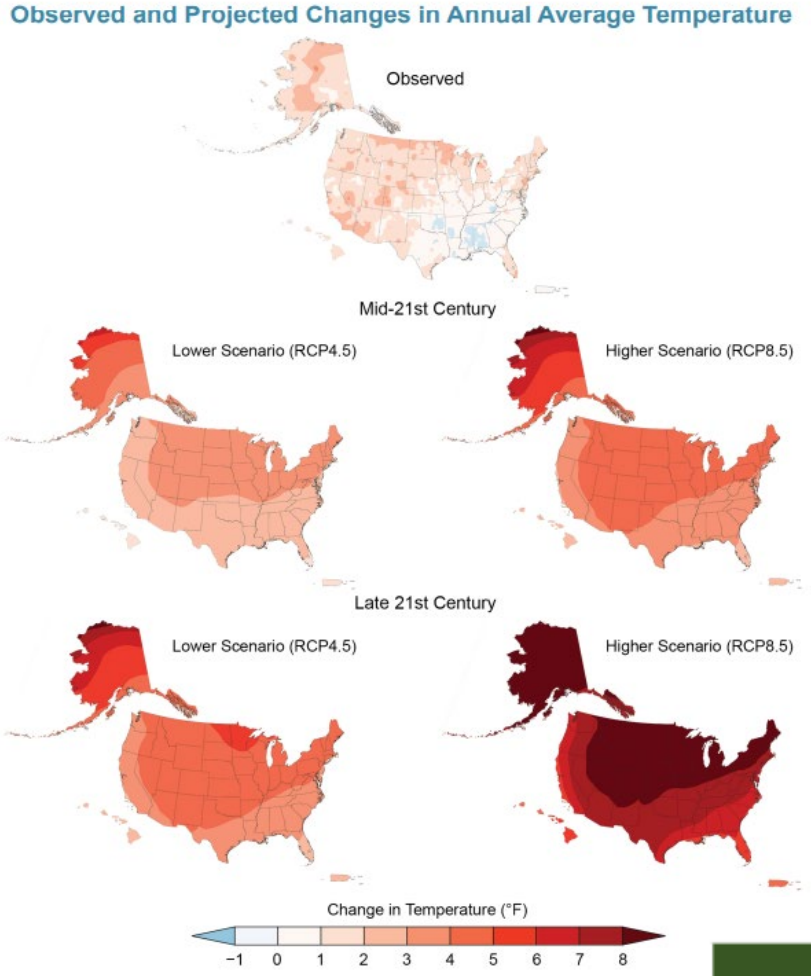
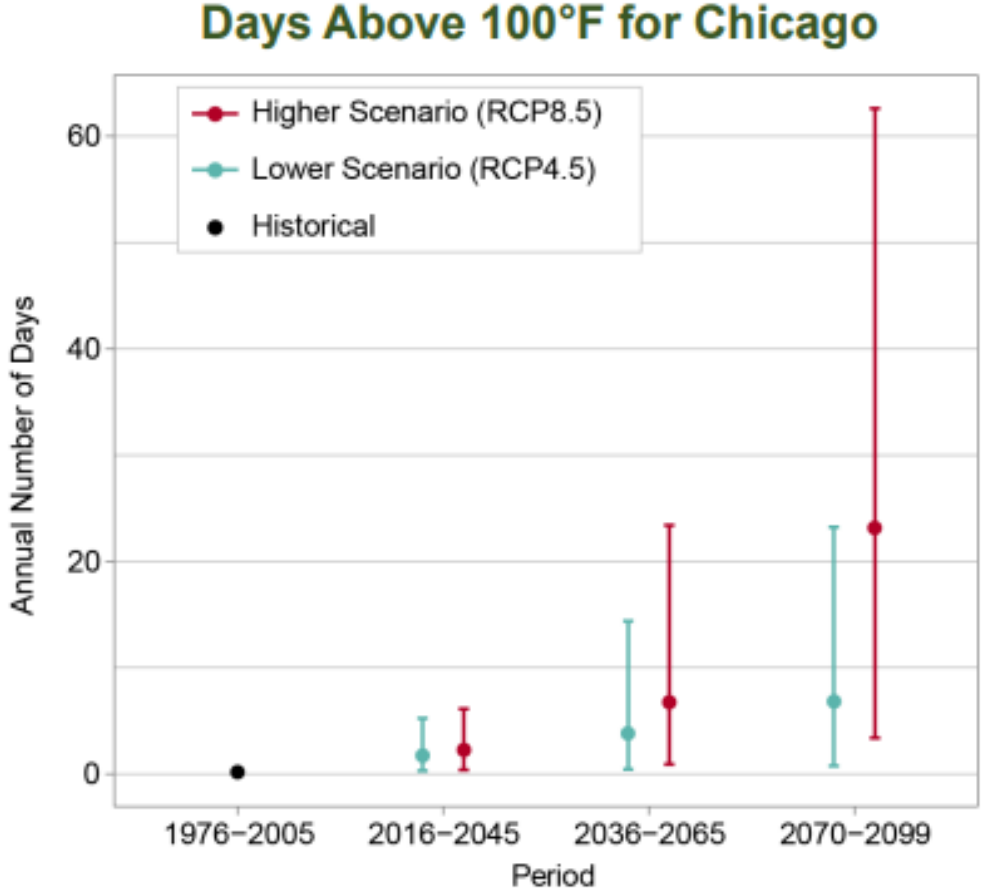
Climate Change Will Increase Average And Extreme Air Temperatures Across The Midwest





Average Annual 5-Day Maximum Temperature

Geographic Area	Modeled Historical (1976–2005)	Mid-21st Century (2036–2065) for Lower Scenario (RCP4.5)	Mid-21st Century (2036–2065) for Higher Scenario (RCP8.5)
Northern Minnesota	88°F	93°F	95°F
Southern Missouri	97°F	102°F	103°F

Figures 2.4 & 21.10 & Table 21.1,
U.S. Fourth National Climate Assessment

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Climate Change Will Likely Increase Average Annual And Heavy Precipitation Events Across The Midwest

- Average annual precipitation could increase by 1-5% through 2045 across Midwest, mostly in winter and spring.

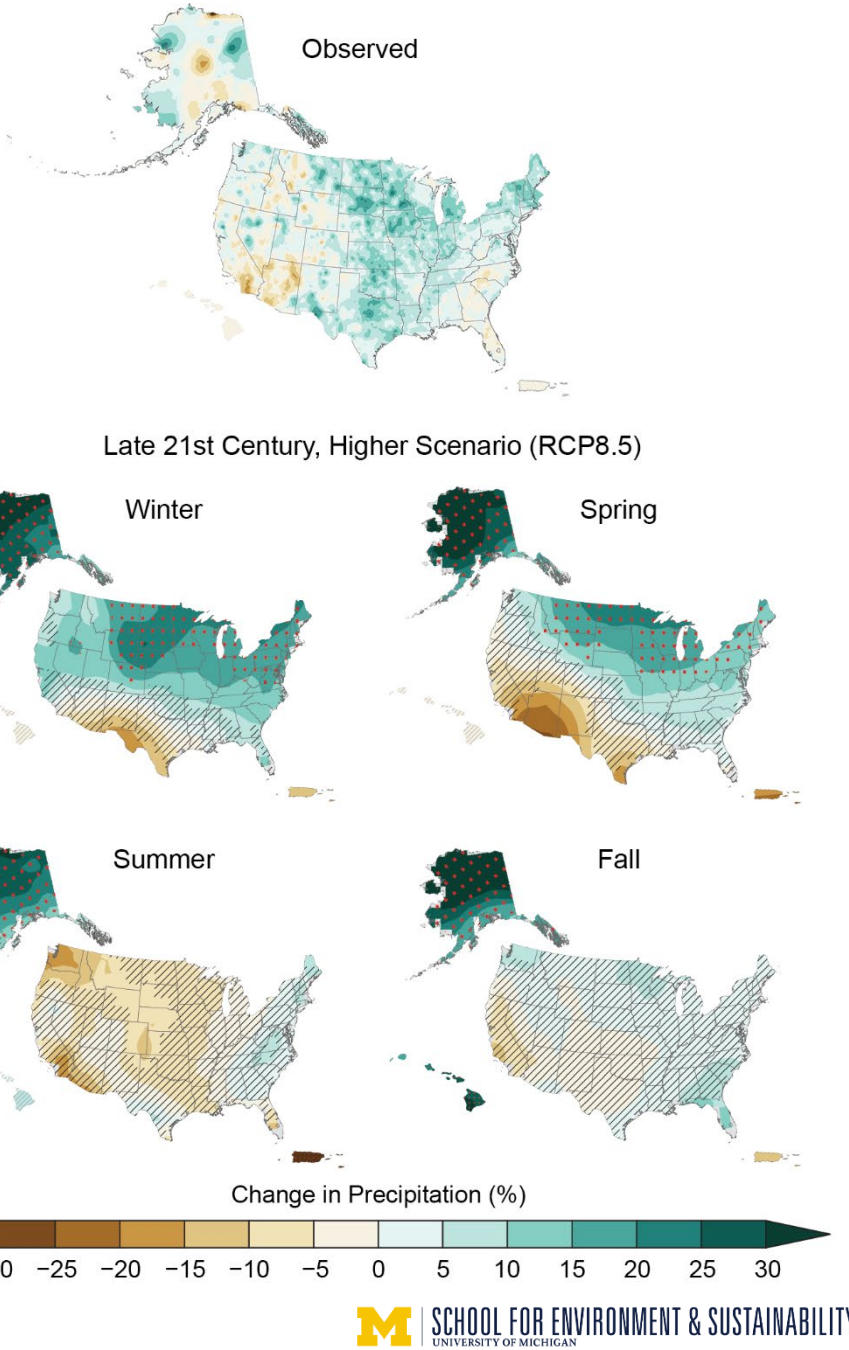

Figure 2.6, U.S. Fourth National Climate Assessment

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Climate change will likely increase average annual and heavy precipitation events across the midwest

- Average annual precipitation could increase by 1-5% through 2045 across Midwest, mostly in winter and spring.

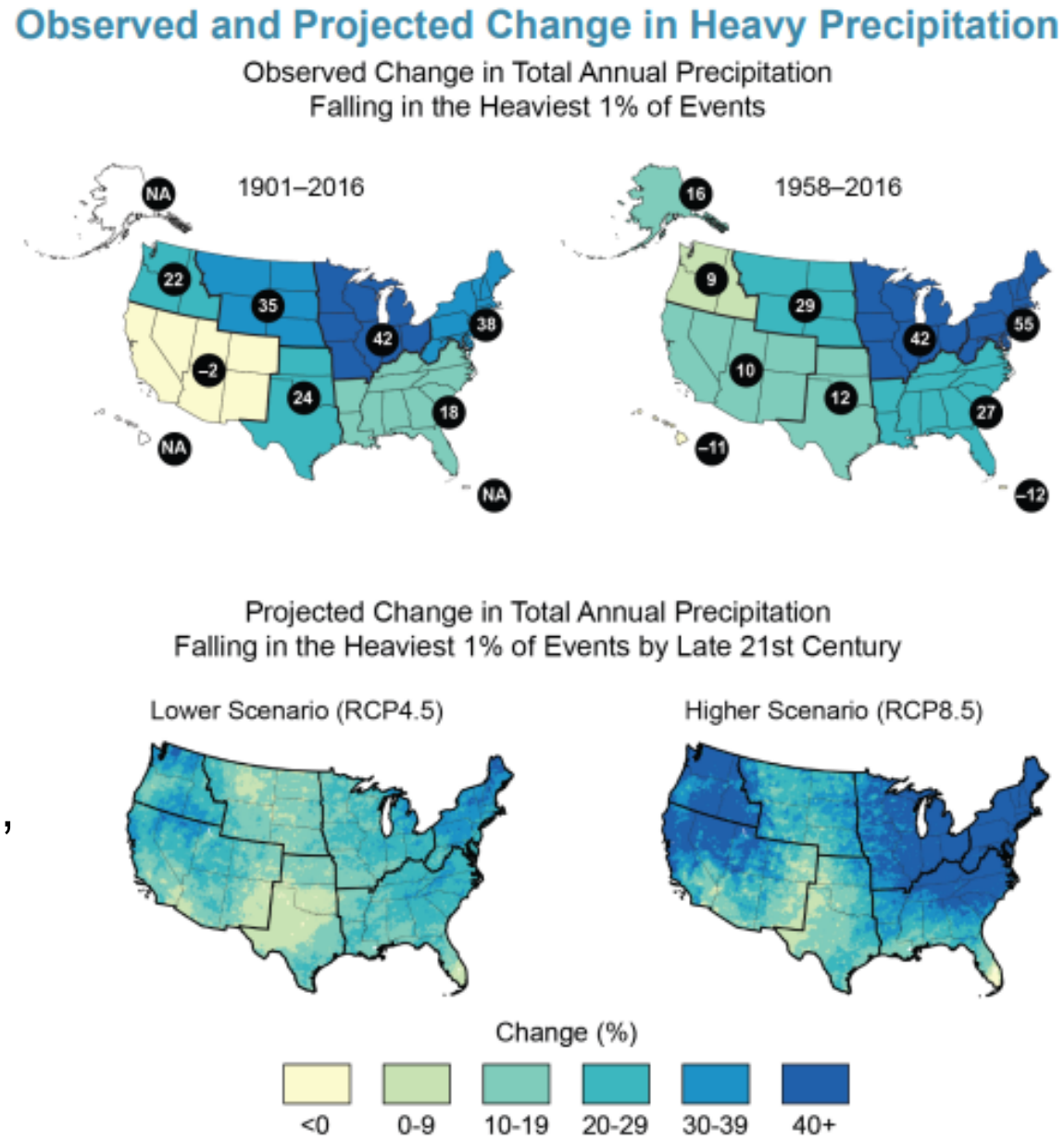

Figure 2.6, U.S. Fourth National Climate Assessment

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Climate Change Could Intensify Extreme Weather Events In The Midwest.

Modeling studies consistently suggest that the frequency and intensity of severe thunderstorms in the United States could increase as climate changes,[177,243,244,245] particularly over the U.S. Midwest and Southern Great Plains during spring.[177] There is some indication that the atmosphere will become more conducive to severe thunderstorm formation and increased intensity, but confidence in the model projections is low. Similarly, there is only low confidence in observations that storms have already become stronger or more frequent. Much of the lack of confidence comes from the difficulty in both monitoring and modeling small-scale and short-lived phenomena.

U.S. Fourth National Climate Assessment

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Drought conditions might be accompanied by greater temperatures, posing A compound threat.

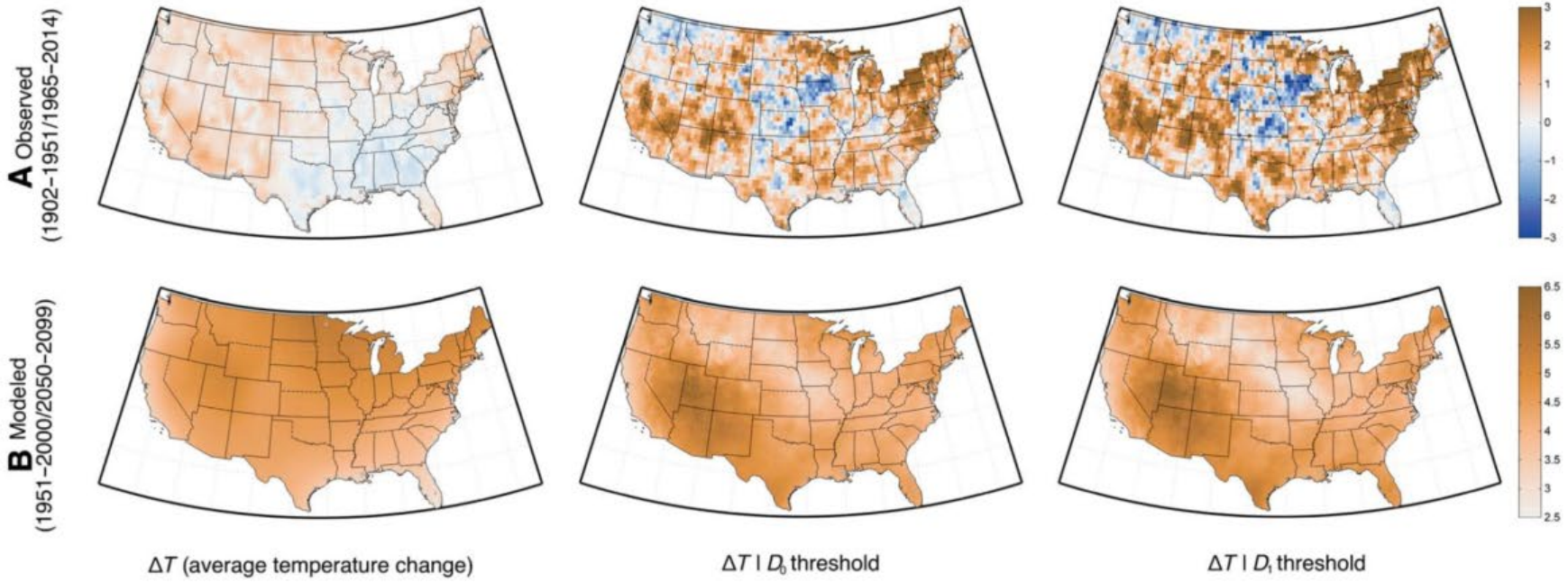

Fig. 1. Temperature shift associated with each dryness condition. Average temperature shift relating to each condition (including all wet and dry conditions, at or under the D_0 threshold, and at or under the D_1 threshold). (**A**) We compare the period of 1965–2014 relative to a baseline period of 1902–1951 with the observed CRU data. (**B**) We compare the future period of 2050–2099 relative to the historical baseline period of 1951–2000 with the CMIP5 model average ensemble.

Amplified warming of droughts in southern United States in observations and model simulations

Felicia Chiang[1]*, Omid Mazdiyasni[1], Amir AghaKouchak[1,2]

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Compound events are often the type of event we worry about most.

Table 1 | Non-exhaustive list of documented climate-related hazards for which drivers are dependent as well as combinations of dependent hazards with potentially large impacts

Hazard(s)	Climatic drivers	Reference(s)
Drought	Precipitation, evapotranspiration, historic evolution of soil moisture, temperature	35,77,78
Physiological heat stress	Temperature, atmospheric humidity, strongly dependent on diurnal cycle	56
Fire risk	Temperature, precipitation, relative humidity, wind, lightning	55,79
Storm risk	Wind speed, humidity, large scale atmospheric circulation	94,95
Coastal flood	River flow, precipitation, coastal water level, surge, wind speed	11,12,30
Flood risk at river confluences	Precipitation, water levels of contributing rivers, large-scale atmospheric circulation	31
Concurrent drought and heat	Temperature, precipitation, evapotranspiration, atmospheric humidity	7,35
Concurrent wind and precipitation extremes	Wind speed, precipitation, orography, large-scale atmospheric circulation	34
Concurrent heat and air pollution	Temperature, sulfur dioxide, NO_x, particulate matter (PM_{10})	6,76

Future climate risk from compound events

Jakob Zscheischler[1*], Seth Westra[2], Bart J. J. M. van den Hurk[3,4], Sonia I. Seneviratne[1], Philip J. Ward[4], Andy Pitman[5], Amir AghaKouchak[6], David N. Bresch[7,8], Michael Leonard[2], Thomas Wahl[9] and Xuebin Zhang[10]

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Several common themes are emerging from research on how climate change will affect power systems.

- A single climate-change-related event can impact demand, supply, and other infrastructure simultaneously.
  - For instance, extreme heat events can simultaneously reduce thermal and solar generation capacity; reduce transmission capacity; and increase electricity demand
- Climate change can shift risk profiles of power systems, including by exacerbating the risk of supply shortfalls.
- Incorporating climate change in long-term planning can mitigate this risk, including through adaptation investments.
  - Investments can be at existing assets or in new assets.
- Impacts of climate change on wind and solar plants are less certain and likely smaller than on demand and other supply-side assets.

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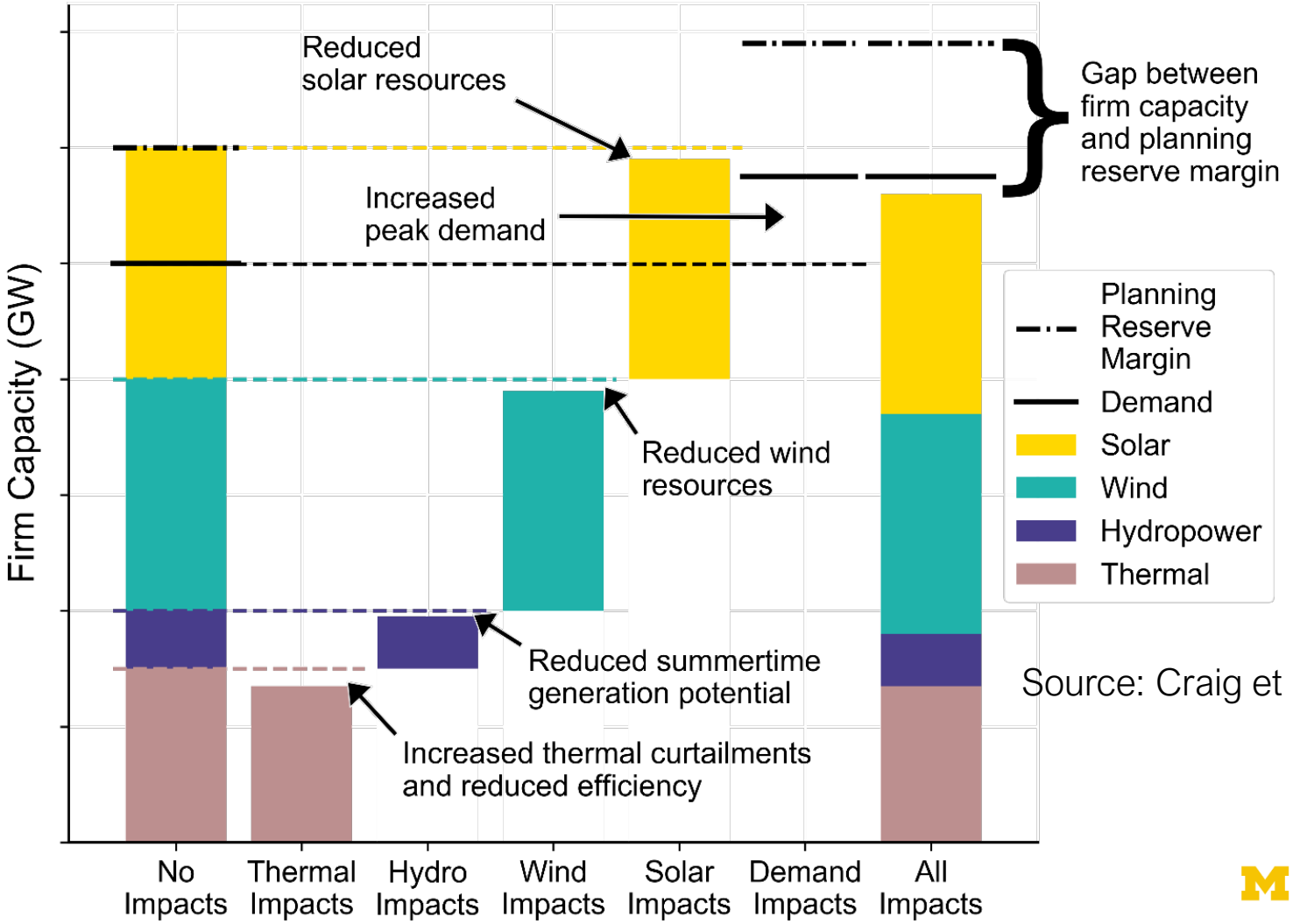
An emerging area of research considers consequences of climate change on power system planning

(Tarroja et al 2016, Ralston Fonseca et al 2021a, Abdin et al 2019, Perera et al 2020, Bennett et al 2021).



Source: Craig et al., 2018

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Climate change has already reduced system reliability in some regions!

California 2020: 491,000 customers lost power for up to 150 minutes during rolling blackouts.

FINAL

Root Cause Analysis
Mid-August 2020 Extreme Heat Wave

January 13, 2021

1. The climate change-induced extreme heat wave across the western United States resulted in demand for electricity exceeding existing electricity resource adequacy (RA) and planning targets.
2. In transitioning to a reliable, clean, and affordable resource mix, resource planning targets have not kept pace to ensure sufficient resources that can be relied upon to meet demand in the early evening hours. This made balancing demand and supply more challenging during the extreme heat wave.
3. Some practices in the day-ahead energy market exacerbated the supply challenges under highly stressed conditions.

California ISO

Prepared by:
System Operator
lities Commission
ergy Commission

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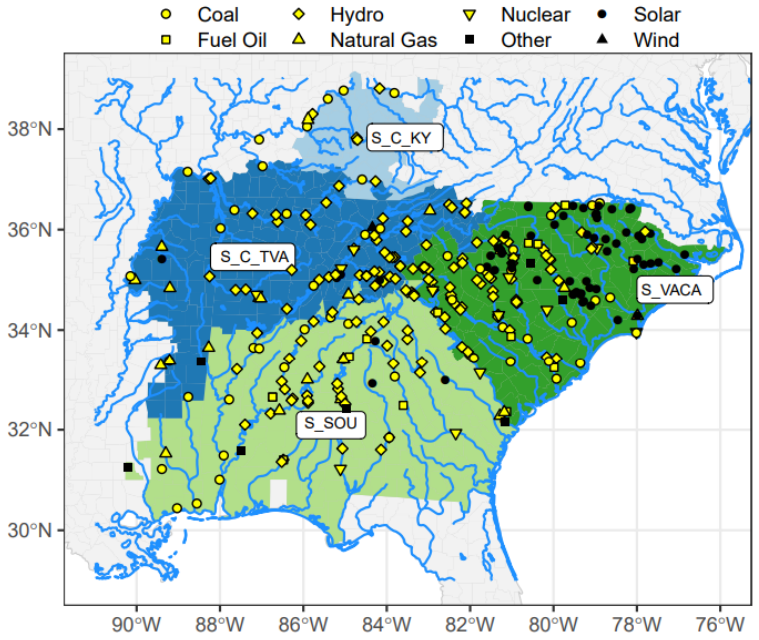
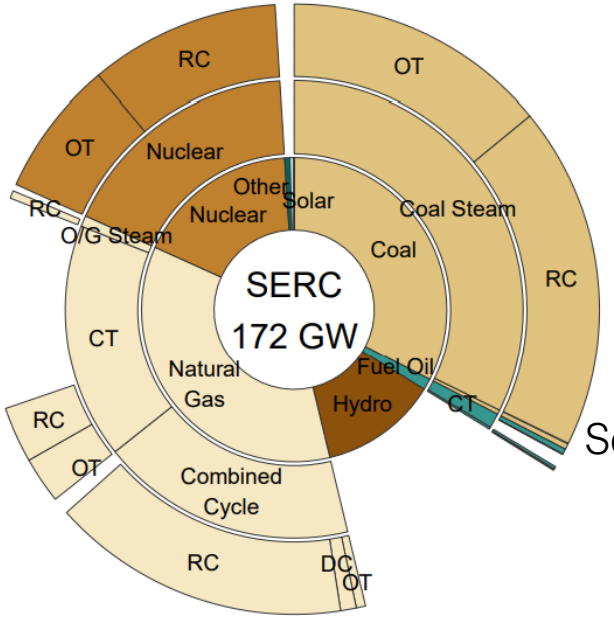
Research Deep Dive: What are the trade-offs between planning and operations under climate change?

1. If planners ignore climate change, how will their systems fare operationally under climate change?

2. If planners account for climate change, what are the excess costs if climate change does not occur?





Source: Fonseca et al., 2021, ES&T

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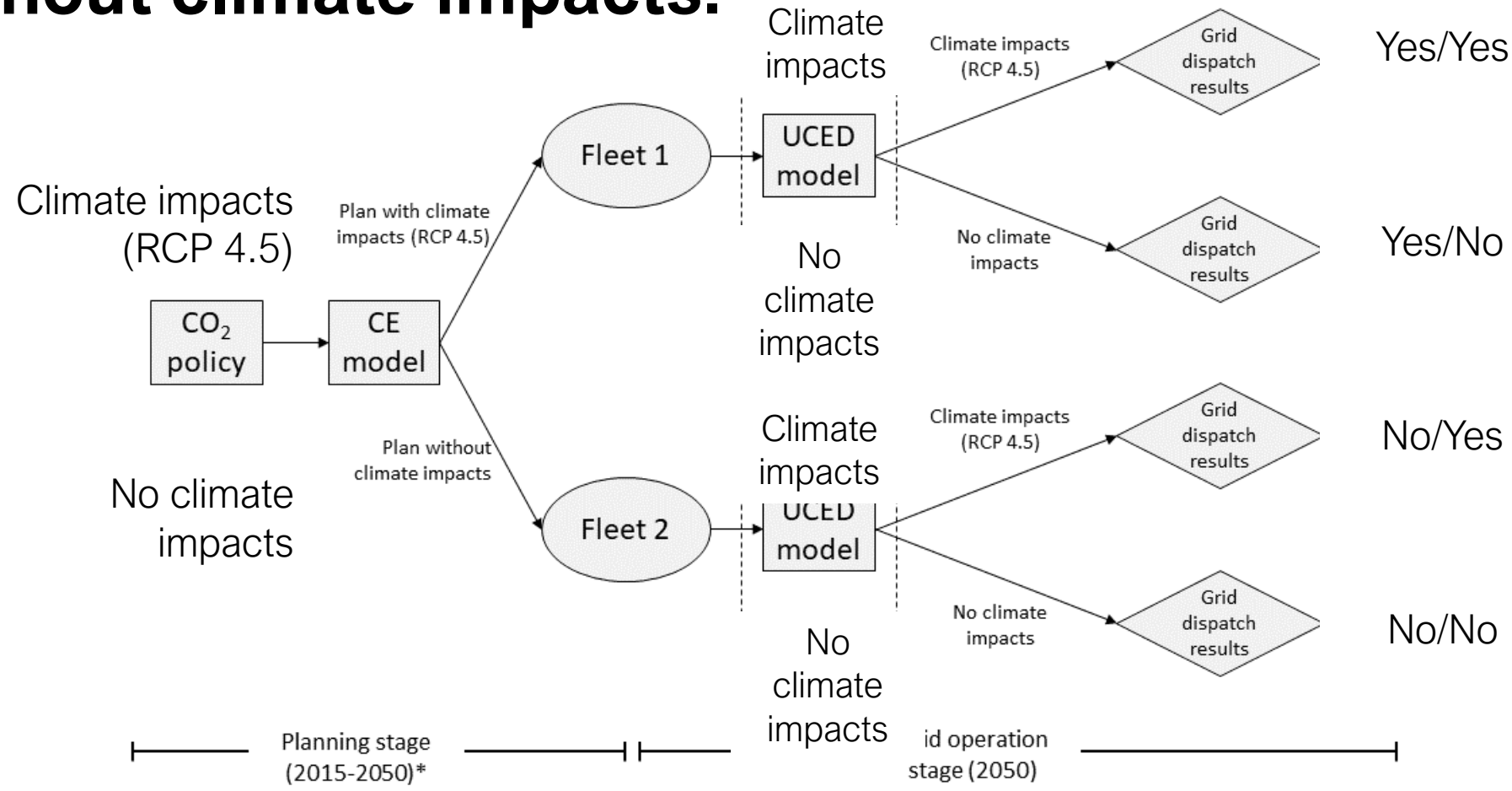
We run a planning (capacity expansion) model and operations (unit commitment and economic dispatch) model with and without climate impacts.



Source: Fonseca et al., 2021, ES&T

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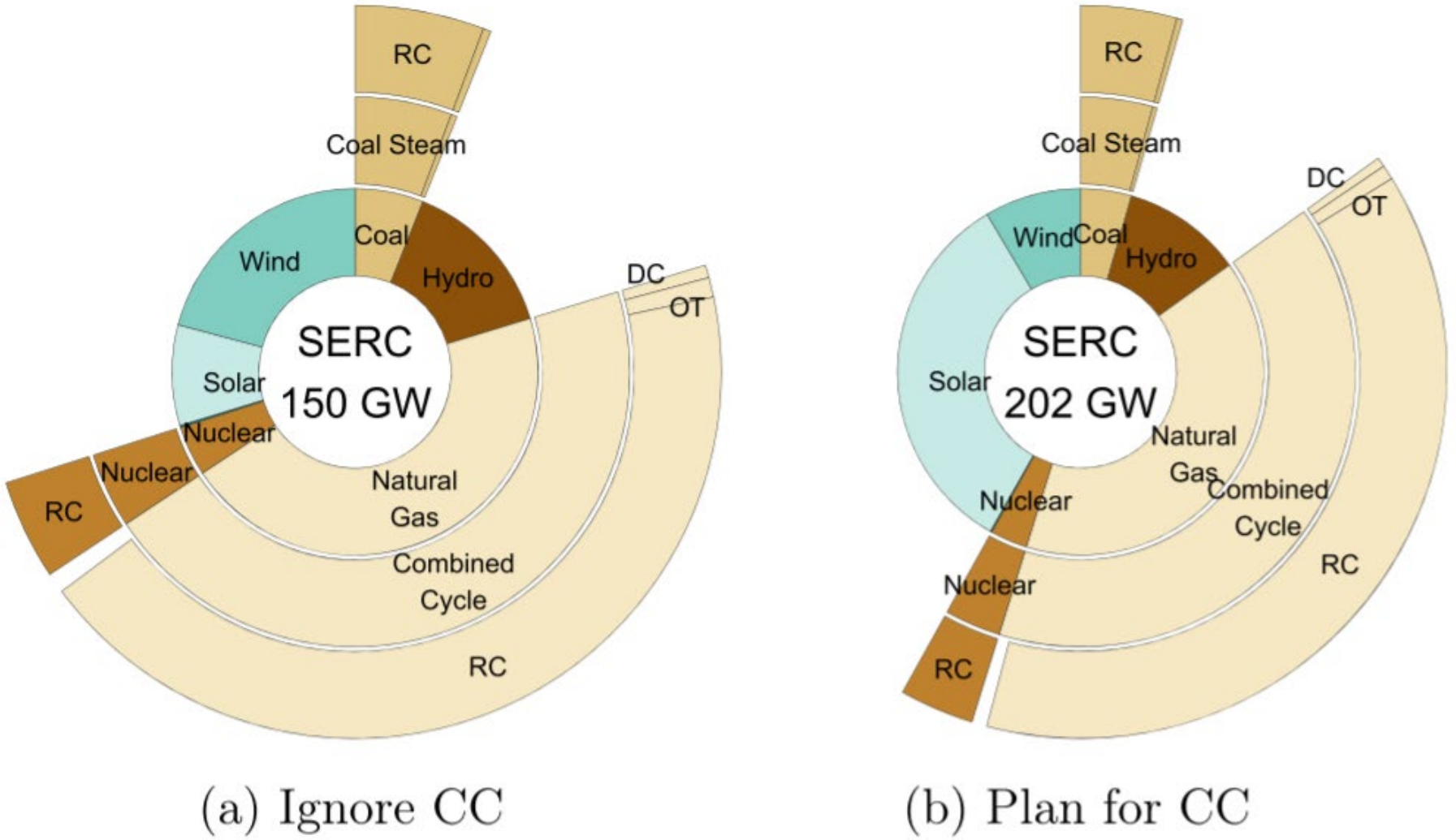
Including climate impacts in planning displaces natural gas with solar power investments.



Source: Fonseca et al., 2021, ES&T

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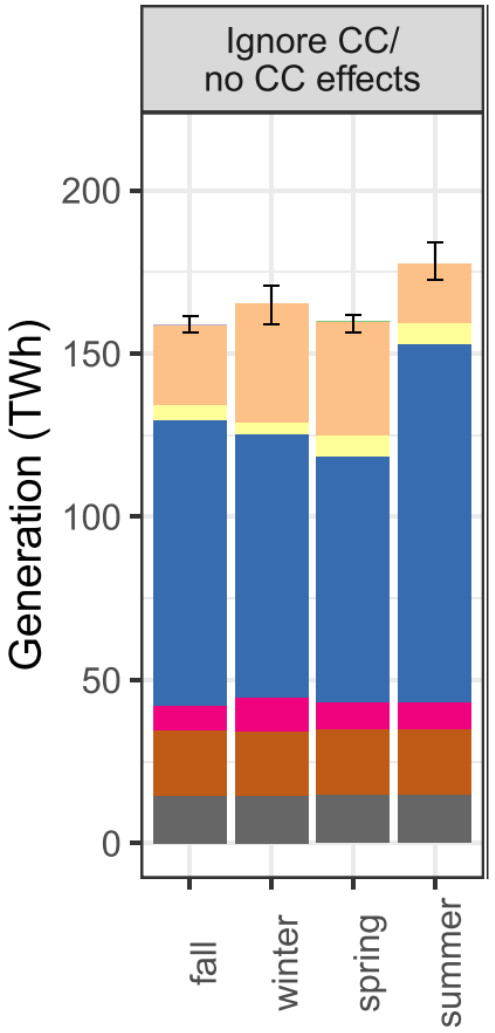
If we neglect climate change in the CE & UCED models, investments (mostly in NGCC) meet demand.



Source: Fonseca et al., 2021, ES&T

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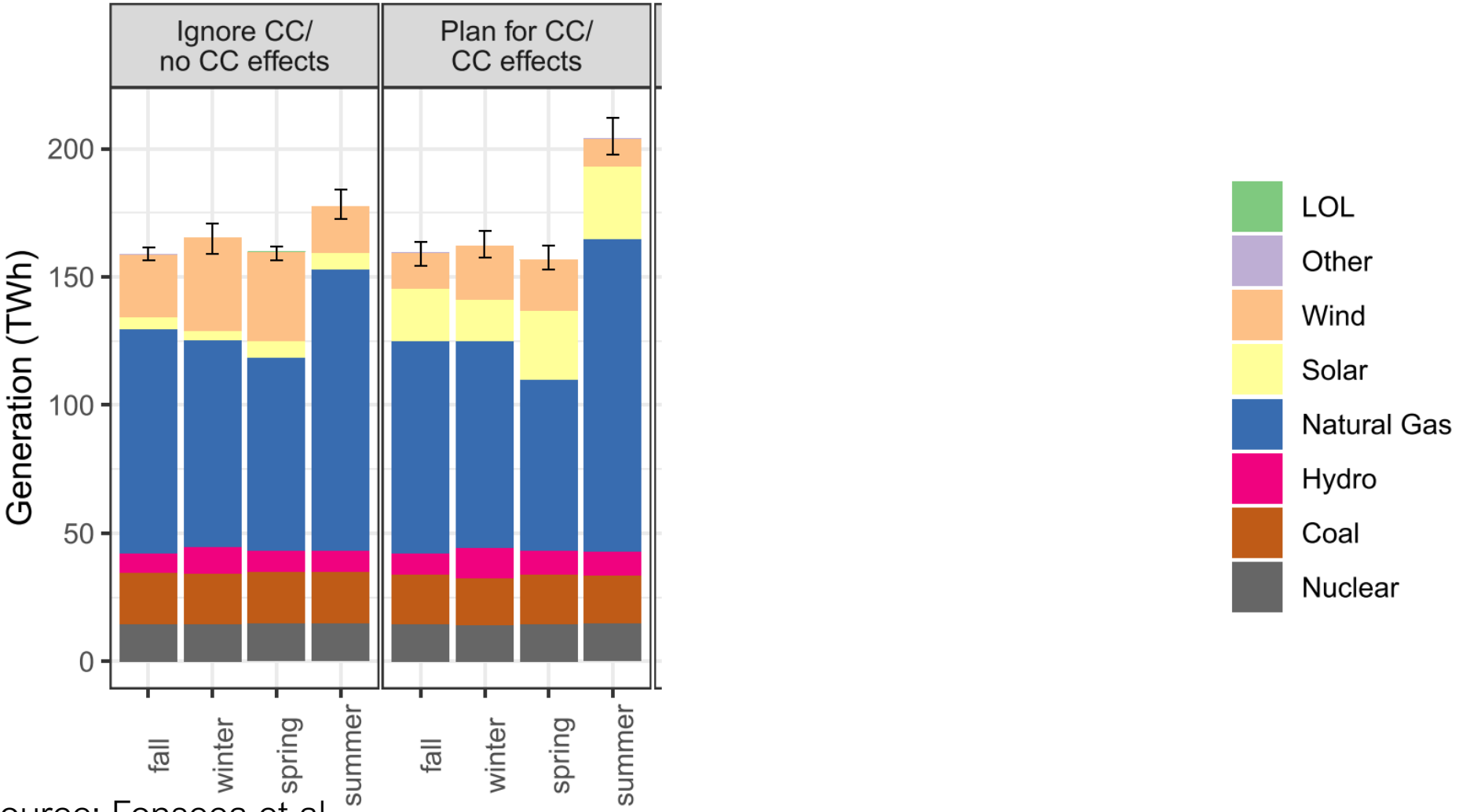
If we account for climate change in the CE & UCED models, investments in NGCC and solar meet elevated demand.



Source: Fonseca et al., 2021, ES&T

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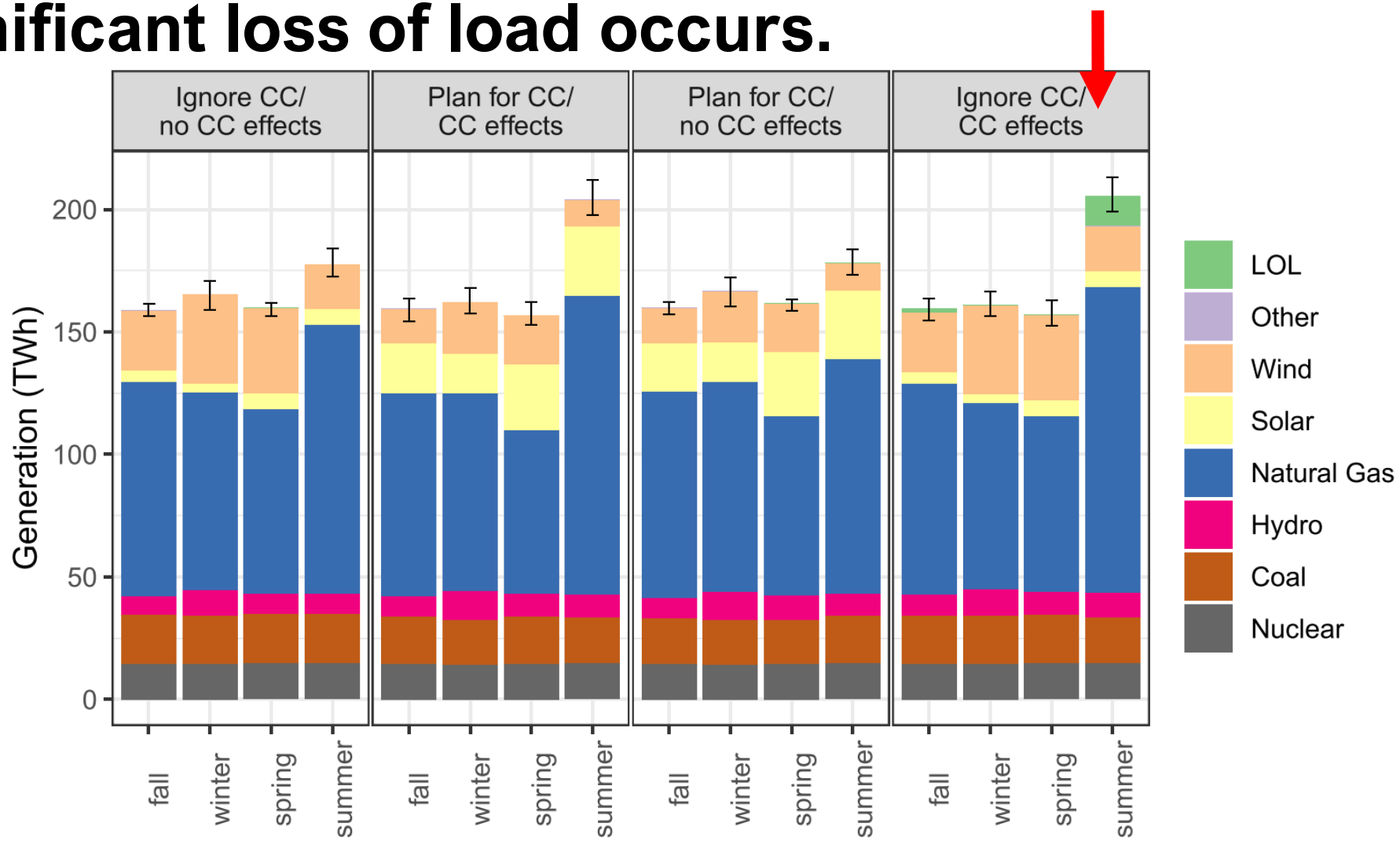
If we ignore climate change when planning but climate change then impacts operations, significant loss of load occurs.



Loss of load in Ignore CC/CC effects scenario occurs in roughly **1,000 hours per year** (12%) and occurs in large volumes (GWs).

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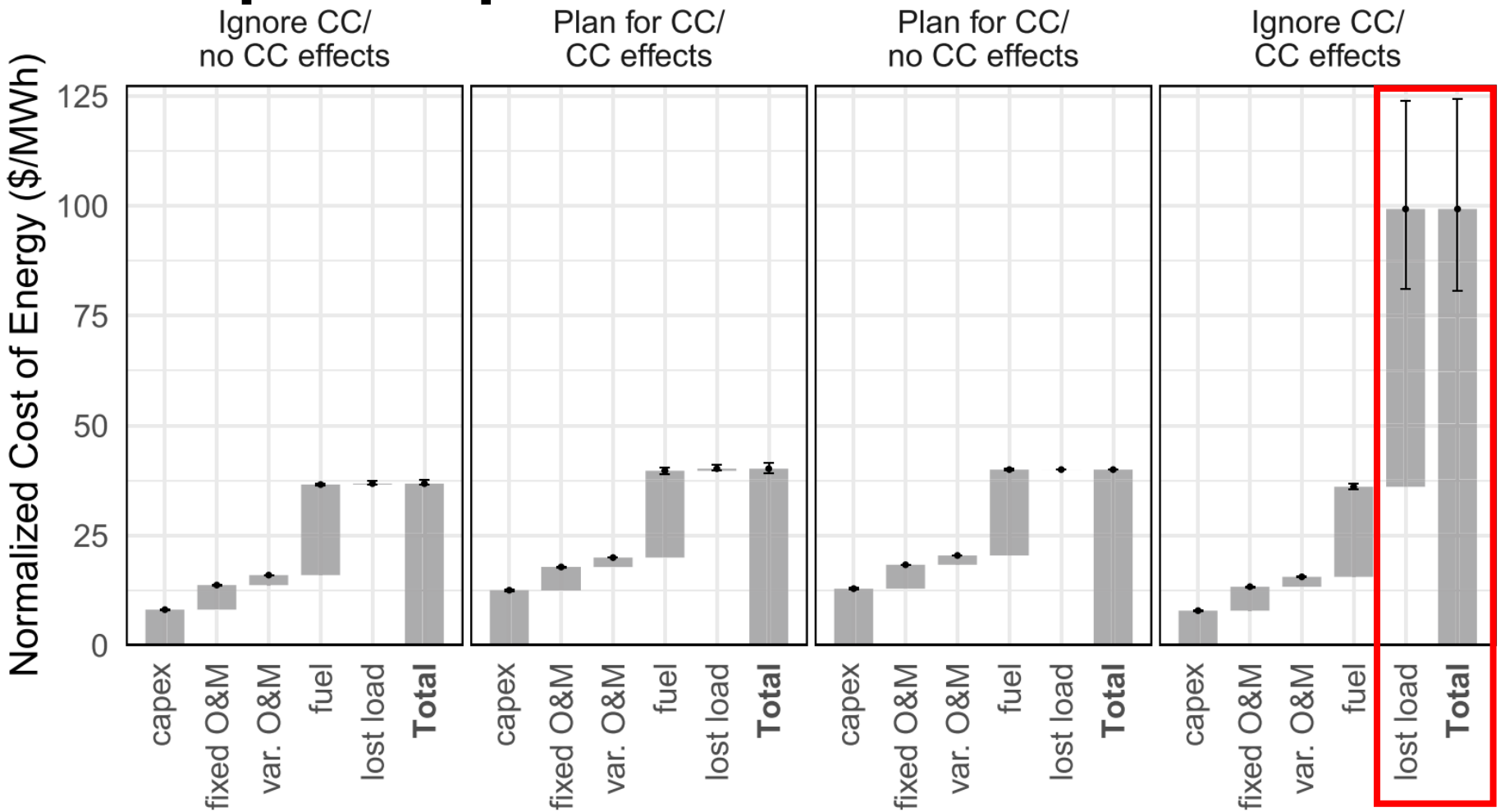
The only scenario with significantly greater energy costs is when we ignore climate change when planning but climate change then impacts operations.



Source: Fonseca et al., 2021, ES&T

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Due to the risk of significant lost load, we found planning for climate change has asymmetric costs and benefits (in the Southeast US).

- Cost of erroneously ignoring climate change: $59/MWh
- Cost of erroneously accounting for climate change: $3/MWh

- Lost load was driven by capacity under-investment and, to a lesser extent, thermal deratings.

- Planning for an 80% CO_2 emission reduction resulted in a system less vulnerable to climate impacts.

Source: Fonseca et al., 2021, ES&T

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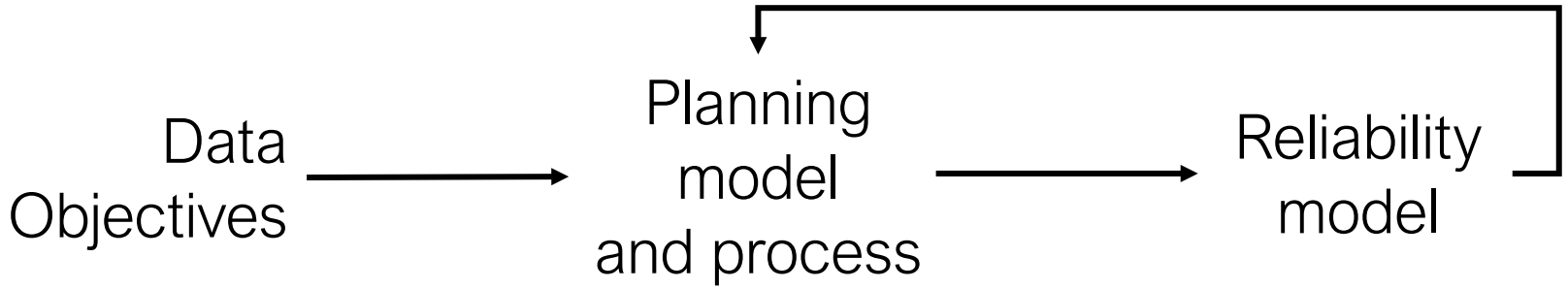
How can we better plan power systems for a changing climate?



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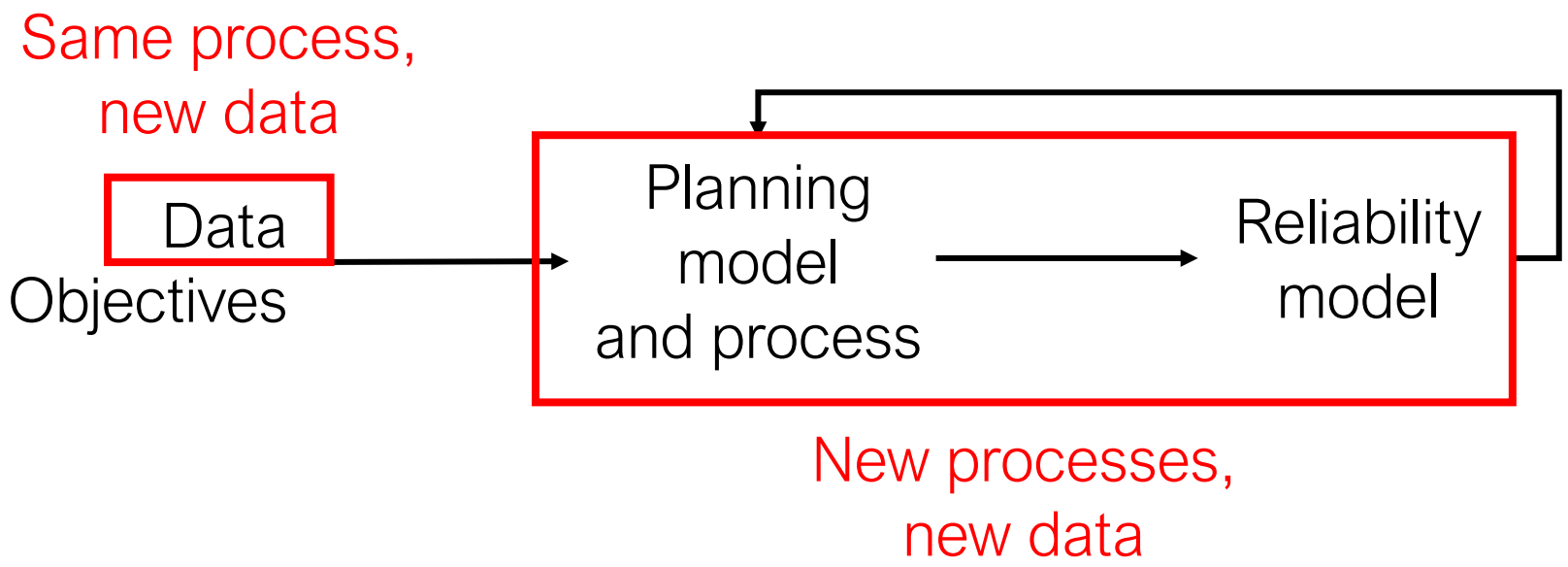

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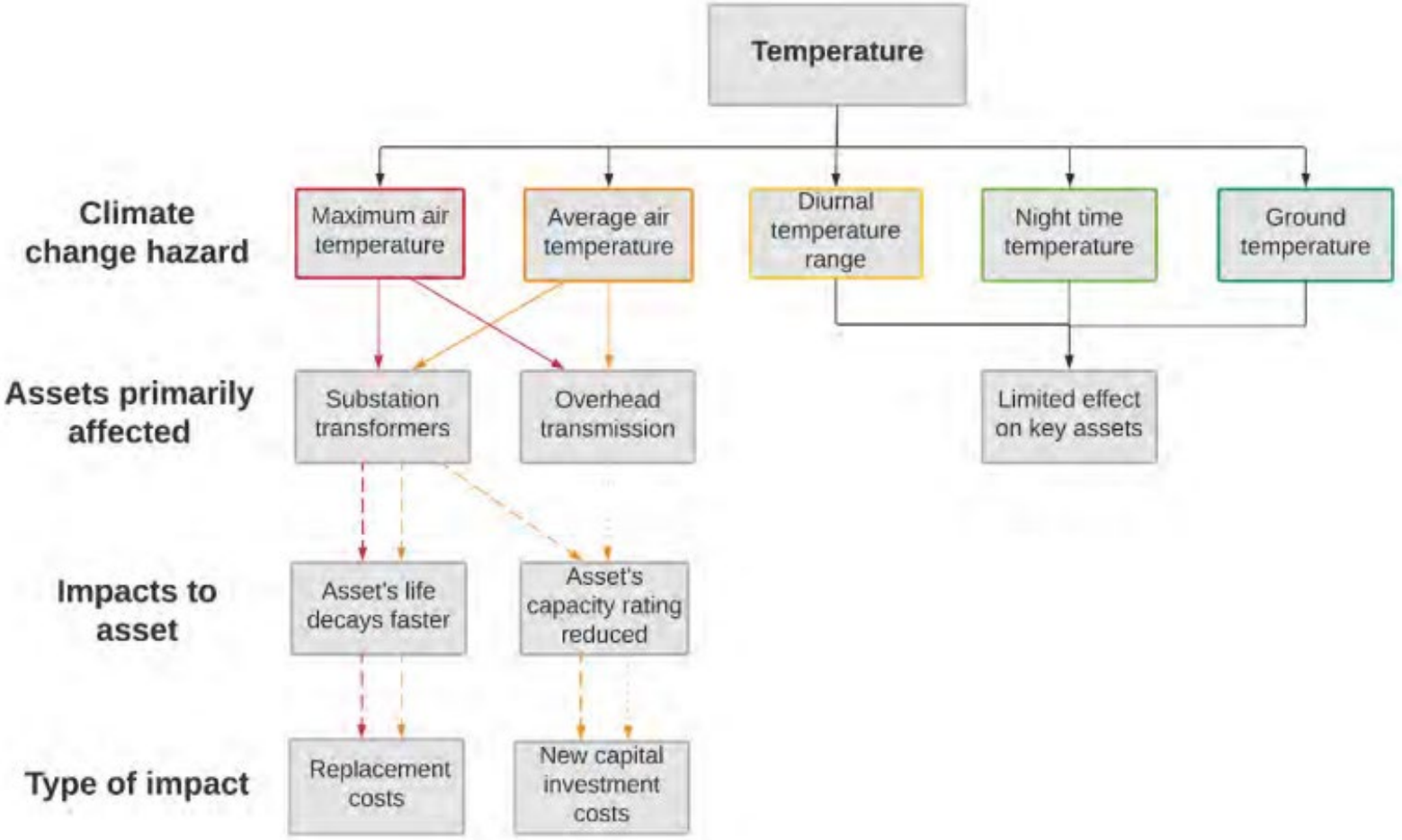
Same process, new data: update model inputs for future meteorology and hydrology

Figure 18 ■ Temperature-related impacts on Con Edison's electric system



Source: conEdison,
Climate Change Vulnerability Study (2019)

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How do we select new data capturing future potential conditions?

- There is no single future climate time series, so must use multiple time series from climate ensembles
  - Ensembles can include multiple models, multiple runs from a single model, or both
- To separate climate change from inter-annual variability, must use long (~30 year) time series
- Publicly-available climate data is not interchangeable with current planning data inputs
  - Lower resolution, missing variables
- Downscaling can improve resolution, but methods are computationally costly, not designed for power system data, and/or introduce new uncertainty

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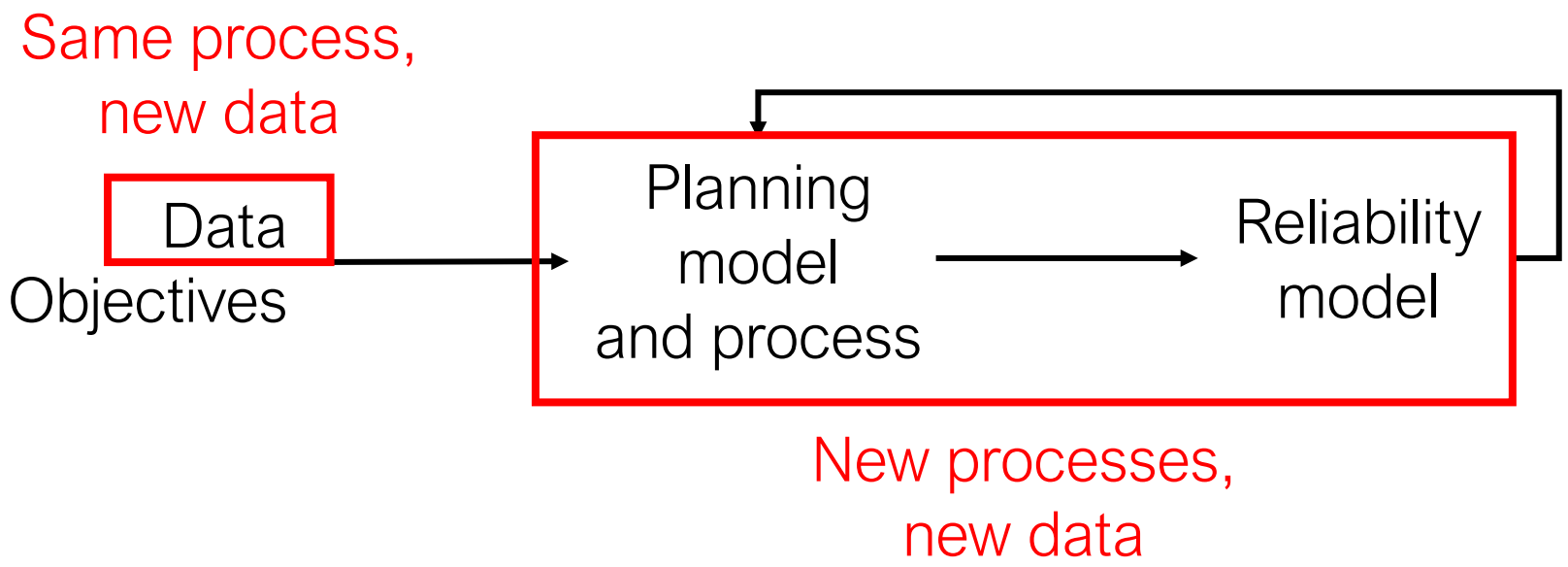

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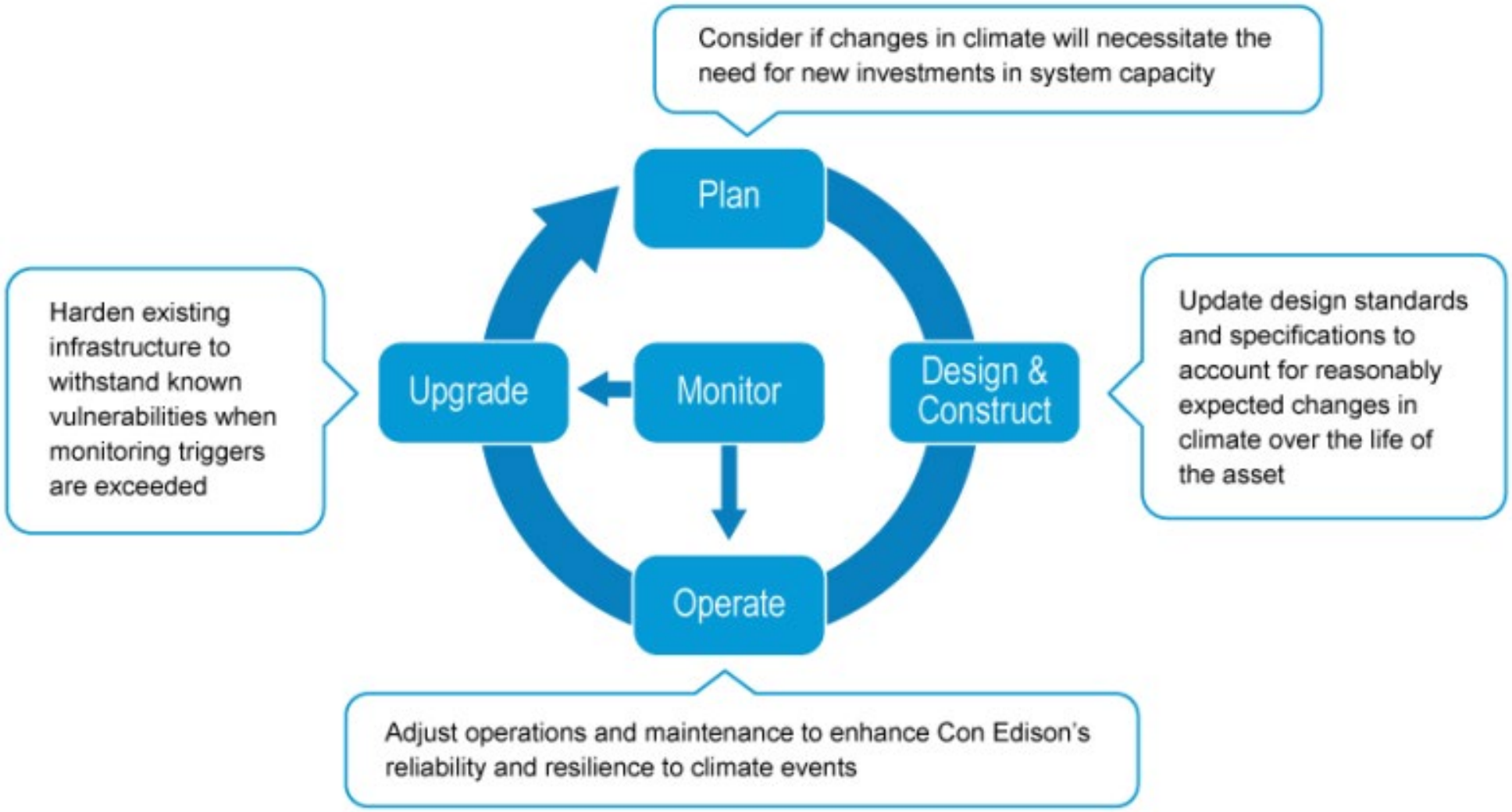
New process, new data: assess vulnerability of existing and new assets to climate change



Source: conEdison,
Climate Change Resilience & Adaptation (2021)

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New process, new data: assess vulnerability of existing and new assets to climate change

Key Areas	Summary of Process Updates	Key Findings
Load Forecasting	• Climate information will be included in future load forecasts for all commodities beginning in 2020. • Con Edison will incorporate anticipated temperature variable (TV)[9] increases into load forecasting, currently estimated at a 1-degree TV increase per decade beginning in 2030.	• The electric summer peak is expected to increase by 700 to 900 megawatts (MW) due to increased TV by 2050.
Load Relief	• Beginning in 2021, Con Edison will incorporate projected climate change-driven increases in load and reductions in power equipment ratings in the 10- and 20-year load relief plans.	• A relatively small impact on power transformers and network transformer ratings is expected due to ambient temperature rise between 2040 and 2050.
Reliability Planning	• Reliability modeling will use forward looking climate change-adjusted load forecasts and projected increases in TV. • In 2021, the Company will conduct a review of extreme event projections to determine whether additional model updates are warranted.	• Temperature increases and extended heat waves are expected to affect the reliability of distribution networks by 2030, absent adaptations.
Asset Management	• Con Edison processes will assess the extent to which expected future temperature changes impact ratings. • The Climate Change Planning and Design Guideline sets a flood design standard to account for increasing sea level rise, which applies to the electric, gas, and steam systems.	• The sea level projection exceeds the current design criterion of one foot of sea level rise by 2040.
Facility Energy Systems Planning	• Con Edison is updating designs to provide more flexibility for modifications during heating, ventilation, and air conditioning system replacement.	• Due to increases in temperature, the size of the cooling equipment in Con Edison's facilities may require an increase of up to 40% by 2040.
Emergency Response Activations	• Discussions are underway on how to incorporate heat, flooding, and precipitation projections into the weather and impact forecast model used to establish the Company's emergency response preparation to weather events. • The Company will plan for drills and exercises based on projected pathway criteria.	• Projected climate pathways could impact future weather and storm impact forecasts. • The Company will continue reviewing ways to incorporate climate change into a forward-looking model.
Worker Safety	• Con Edison will monitor climate change for impacts on worker safety. In 2022, the Company will consider whether additional heat stress protocols for climate change adaptation are warranted.	• An increase in temperature and heat index may exacerbate worker heat stress.

Source: conEdison, Climate Change Resilience & Adaptation (2021)

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Day 2

Session 1
Identify the Gaps

Speaker Topic:
Better Planning Electric Power Systems for a Changing Climate

November 5, 2021
9:20 a.m.

New process, new data: assess risk posed by climate change to assets

EUROPEAN COMMISSION

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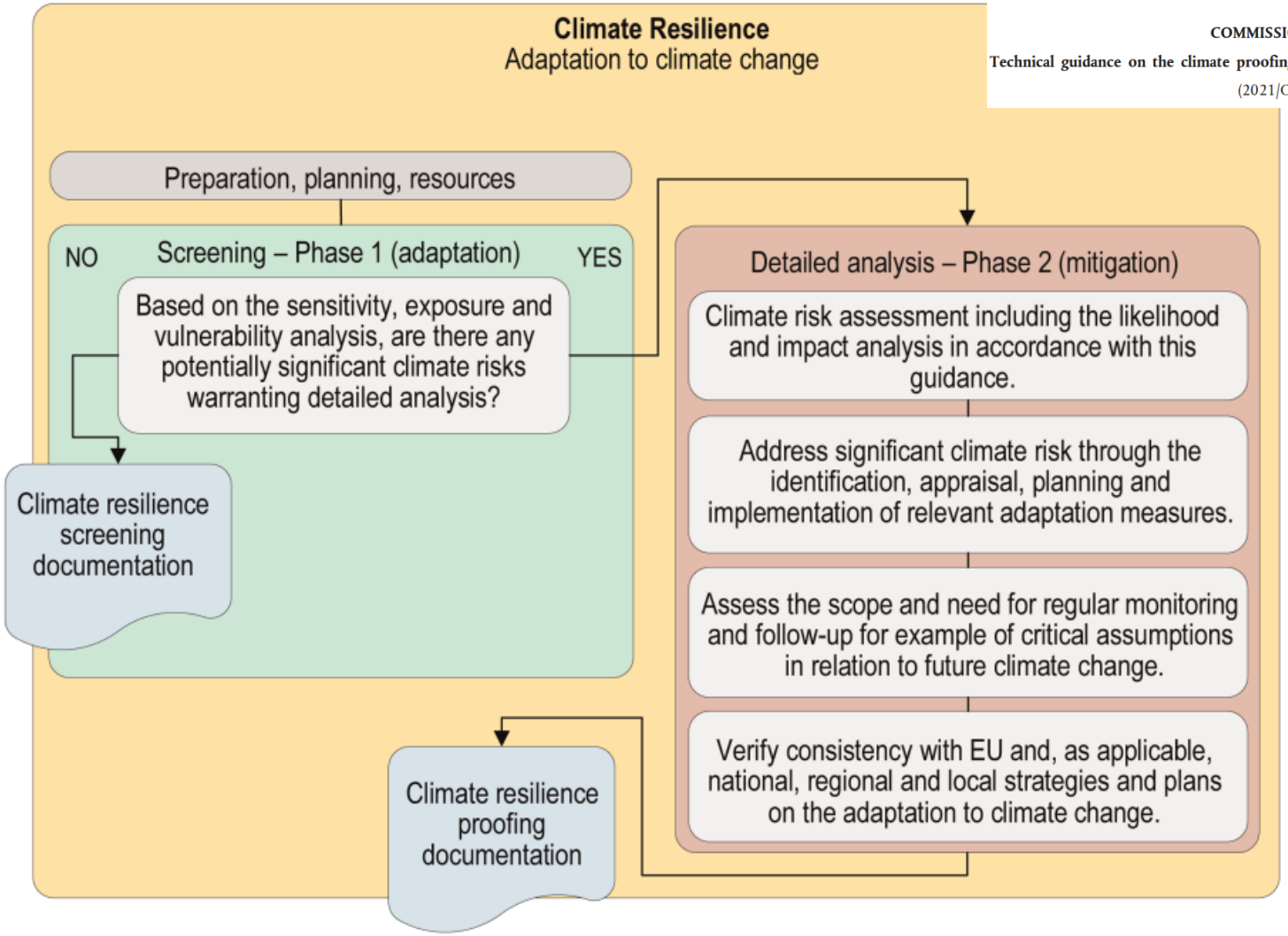
Technical guidance on the climate proofing of infrastructure in the period 2021-2027

(2021/C 373/01)



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Phase 1 (screening)

SENSITIVITY ANALYSIS

Indicative sensitivity table: *(example)*		Climate variables and hazards: Flood	Heat	...	Drought
Themes	On-site assets, ...	High	Low	...	Low
	Inputs (water, ...)	Medium	Medium	...	Low
	Outputs (products, ...)	High	Low	...	Low
	Transport links	Medium	Low	...	Low
	Highest score 4 themes	High	Medium	...	Low

The output of the sensitivity analysis may be summarised in a table with the sensitivity ranking of the relevant climate variables and hazards for a given project type, irrespective of the location, including critical parameters, and divided in e.g. the four themes.

EXPOSURE ANALYSIS

Indicative exposure table: *(example)*	Climate variables and hazards: Flood	Heat	...	Drought
Current climate	Medium	Low	...	Low
Future climate	High	Medium	...	Low
Highest score, current+future	High	Medium	...	Low

The output of the exposure analysis may be summarised in a table with the exposure ranking of the relevant climate variables and hazards for the selected location, irrespective of the project type, and divided in current and future climate. For both the sensitivity and exposure analysis, the scoring system should be carefully defined and explained, and the given scores should be justified.

VULNERABILITY ANALYSIS

Indicative vulnerability table: *(example)*		Exposure (current + future climate): High	Medium	Low
Sensitivity (highest across the four themes)	High	Flood		
	Medium		Heat	
	Low			Drought

Legend: Vulnerability level
High
Medium
Low

The vulnerability analysis may be summarised in a table for the given specific project type at the selected location. It combines the sensitivity and the exposure analysis. The most relevant climate variables and hazards are those with a high or medium vulnerability level, which are then taken forward to the steps below. The vulnerability levels should be carefully defined and explained, and the given scores justified.

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LIKELIHOOD ANALYSIS

Indicative scale for assessing the likelihood of a climate hazard (example):

Term	Qualitative	Quantitative (*)
Rare	Highly unlikely to occur	5 %
Unlikely	Unlikely to occur	20 %
Moderate	As likely to occur as not	50 %
Likely	Likely to occur	80 %
Almost certain	Very likely to occur	95 %

The output of the likelihood analysis may be summarised in a qualitative or quantitative estimation of the likelihood for each of the essential climate variables and hazards. (*) Defining the scales requires careful analysis for various reasons including e.g. that the likelihood and impacts of the essential climate hazards may change significantly during the lifespan of the infrastructure project among other due to climate change. Various scales are referred to in the literature.

IMPACT ANALYSIS

Indicative scale for assessing the potential impact of a climate hazard (example) — *Impacts:* / *Risk areas:*	Insignificant	Minor	Moderate	Major	Catastrophic
Asset damage, engineering, operational				■	
Safety and health					
Environment, cultural heritage		■			
Social		■			
Financial		■			
Reputation				■	
Any other relevant risk area(s)	■				
Overall for the above-listed risk areas				■	

The impact analysis provides an expert assessment of the potential impact for each of the essential climate variables and hazards.

RISK ASSESSMENT

Indicative risk table: *(example)*

Likelihood \ Overall impact of the essential climate variables and hazards (example)	Insignificant	Minor	Moderate	Major	Catastrophic
Rare					
Unlikely		Drought			
Moderate		Heat	Flood		
Likely					
Almost certain					

Legend: Risk level
- Low
- Medium
- High
- Extreme

The output of the risk analysis may be summarised in a table combining likelihood and impact of the essential climate variables and hazards. Detailed explanations are required to qualify and substantiate the assessment conclusions. The risk levels should be explained and justified.

New process, new data: rethink how we value adaptation investments in vulnerable areas

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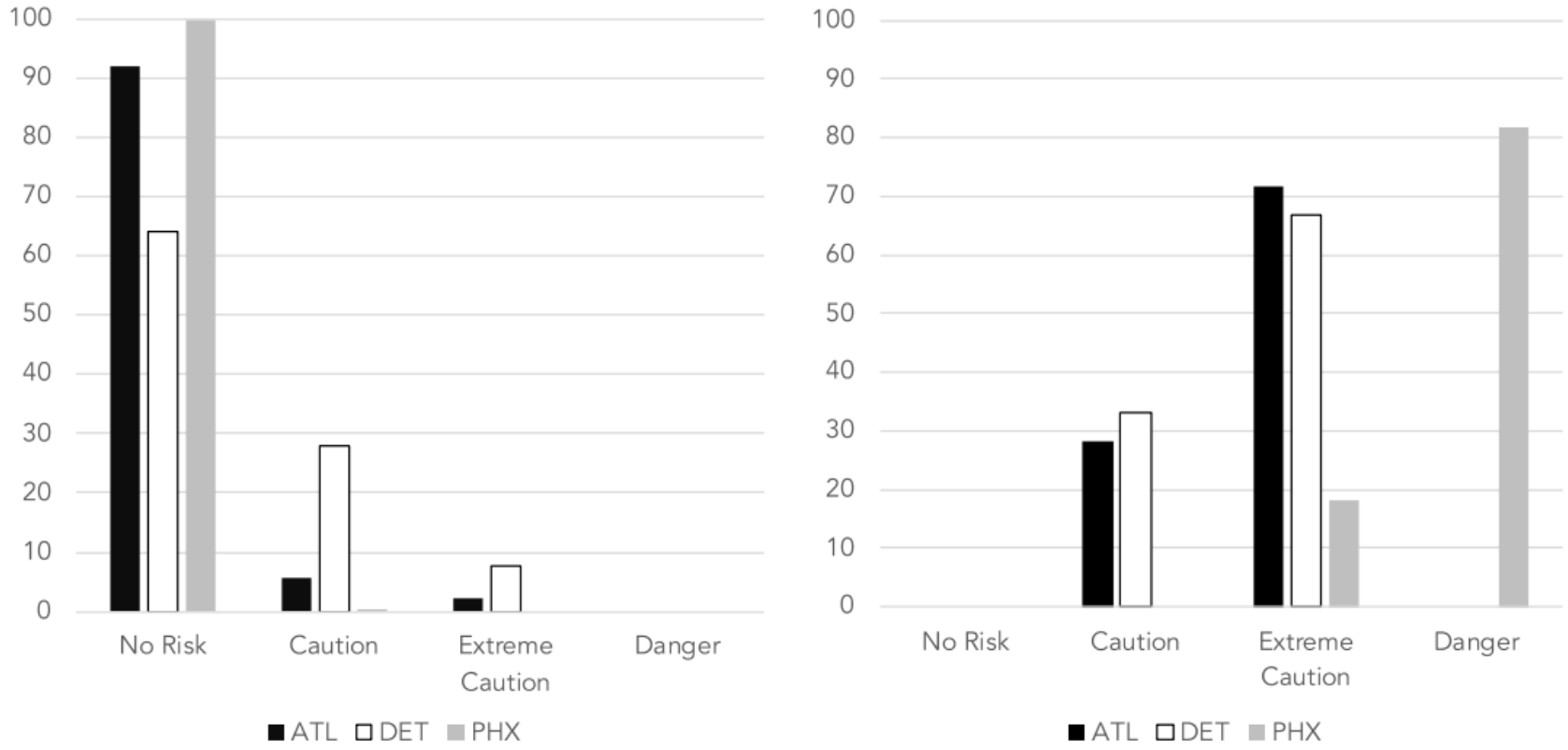

Figure 6. Percent (%) of residential structures categorized by heat index class during a simulated historical heat wave event (left panel) and a simulated concurrent heat wave and electrical grid failure event (right panel).

Compound Climate and Infrastructure Events: How Electrical Grid Failure Alters Heat Wave Risk

Brian Stone, Jr.,* Evan Mallen, Mayuri Rajput, Carina J. Gronlund, Ashley M. Broadbent, E. Scott Krayenhoff, Godfried Augenbroe, Marie S. O'Neill, and Matei Georgescu

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New process, new data: use robust decision making (RDM) to stress test plans to future climates

- RDM can stress-test power system plans to future potential realizations of climate change.
- RDM can identify trade-offs between investment decisions and objectives (cost, reliability, emissions reductions).
- RDM functions as a wrapper around existing planning processes.

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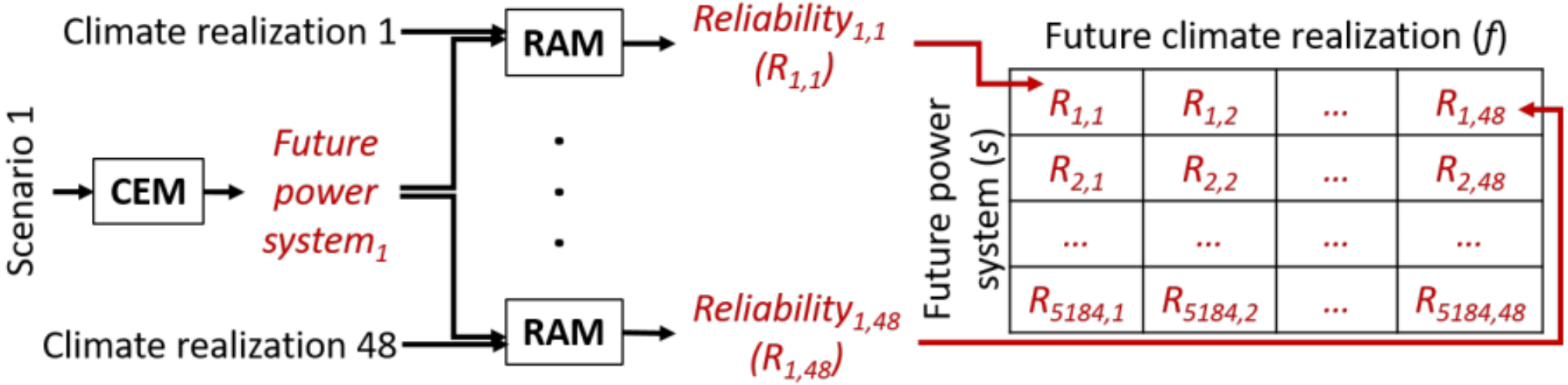

CEM = capacity expansion (planning) model; *RAM* = resource adequacy (reliability) model

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November 5, 2021
9:20 a.m.

Recap

- Pathways through which climate change can affect the electric power sector
- Expected climate change impacts in Michigan
- System-level consequences of climate change impacts in the power system
- New approaches for power system planning under a changing climate

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Thank you for your attention!

Please let me know what questions or comments you have.

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https://assetlab.org

ASSET LAB

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SUPPLEMENTAL SLIDES

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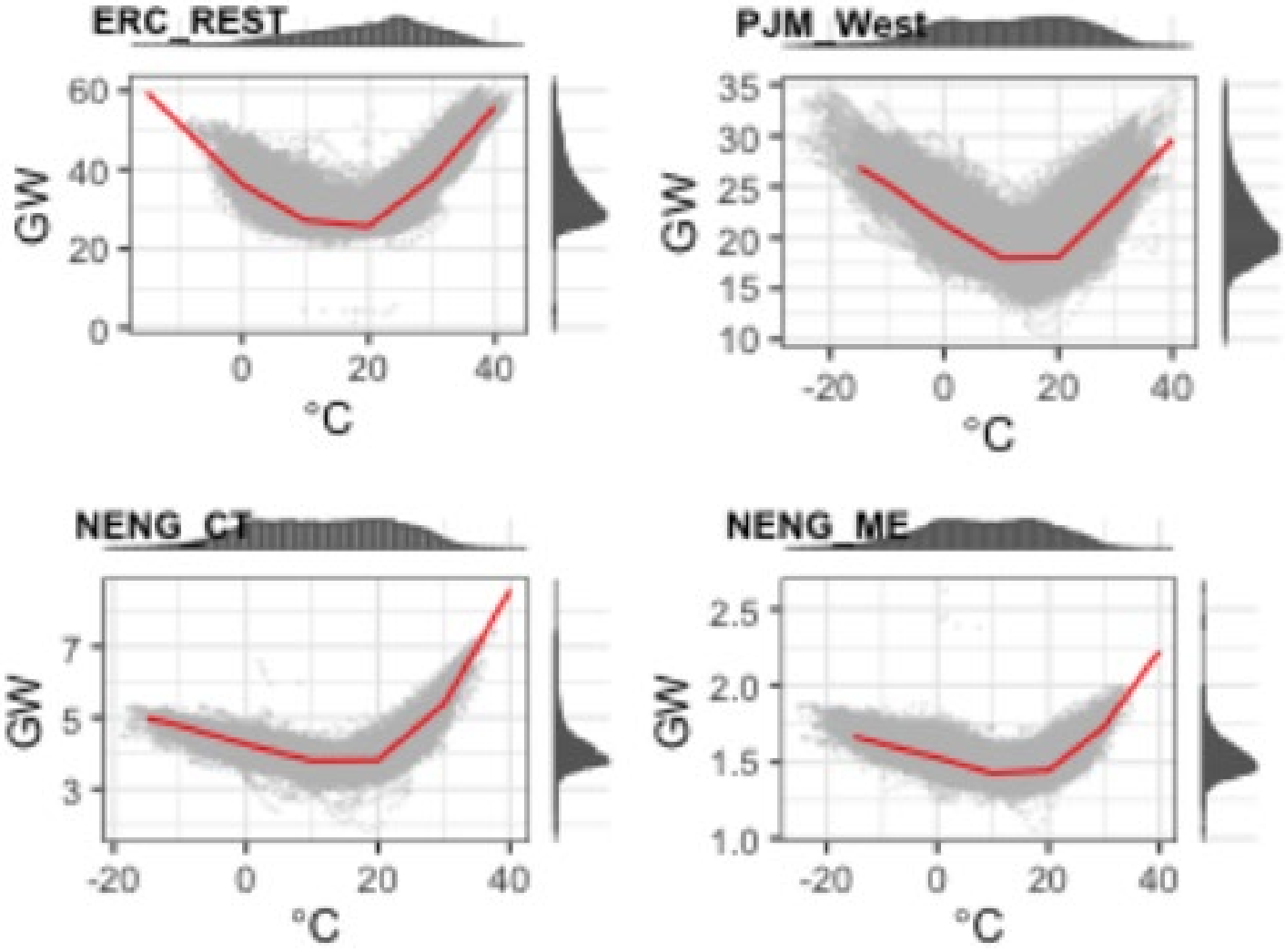
Climate change will affect demand through changes in ambient air temperatures and relative humidity. Strength of effect depends on air conditioning and electrified heating penetrations.



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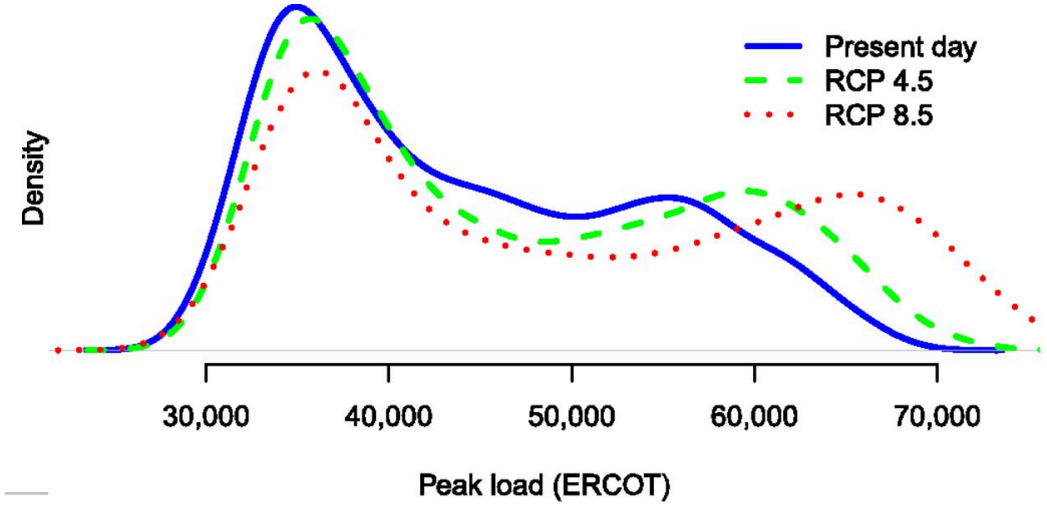
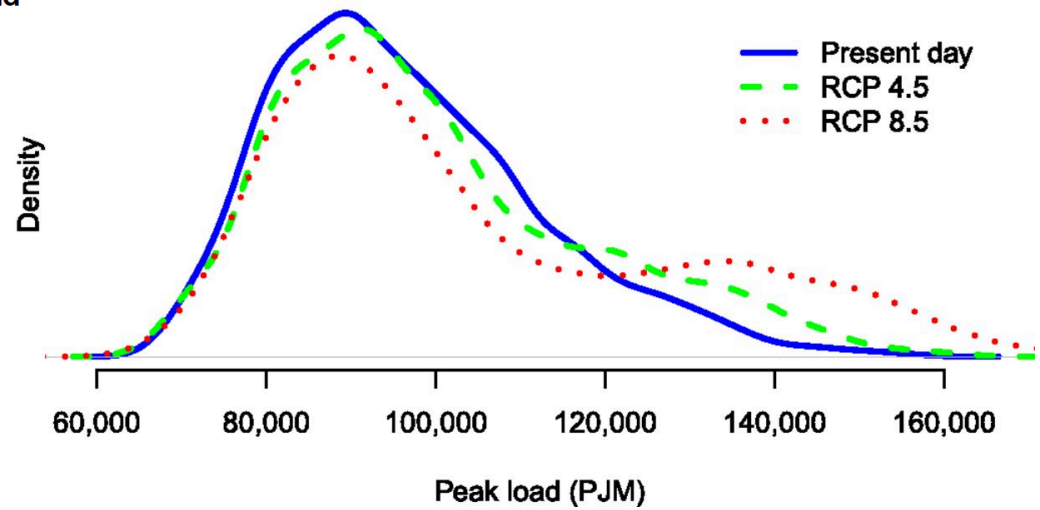
Climate change will increase peak demand by up to 20% (high agreement, robust evidence, high confidence).



Climate change is projected to have severe impacts on the frequency and intensity of peak electricity demand across the United States

Maximilian Auffhammer, Patrick Baylis, and Catherine H. Hausman



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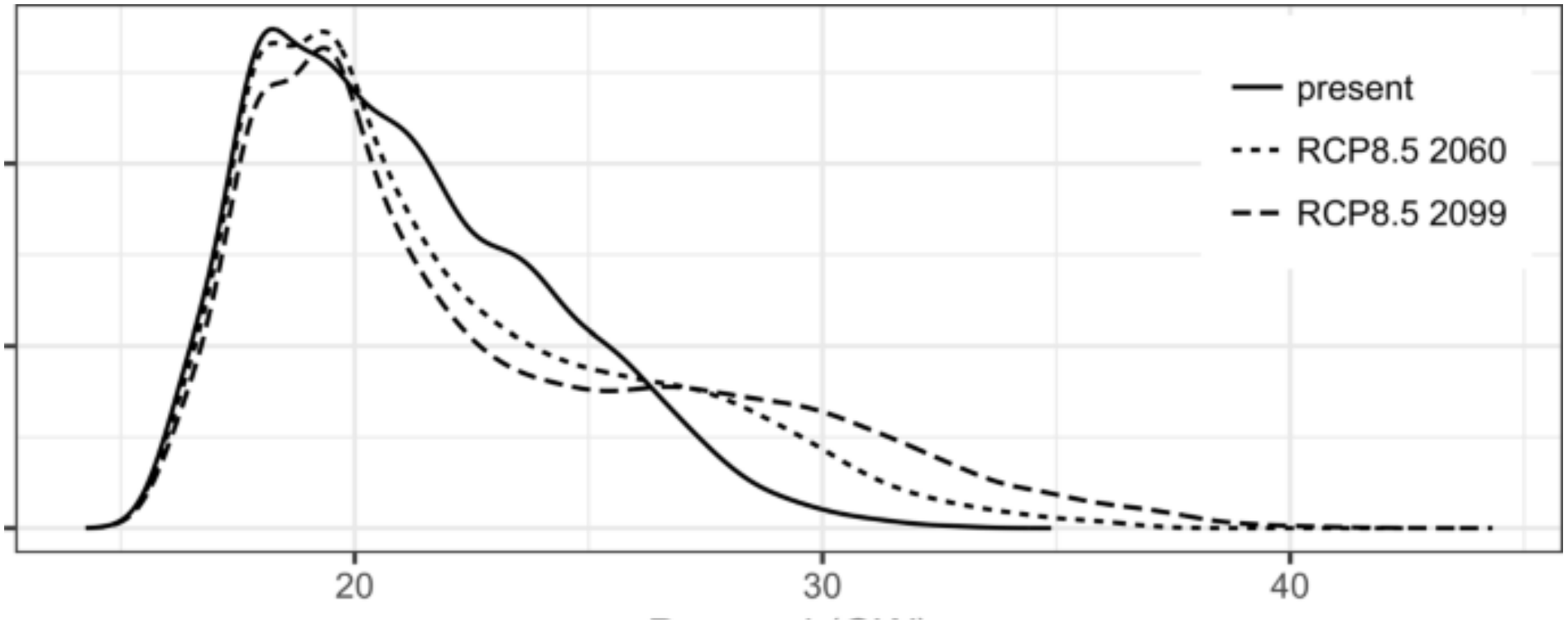

Demand in TVA (GW)

Seasonal effects of climate change on intra-day electricity demand patterns

Francisco Ralston Fonseca, Paulina Jaramillo, Mario Bergés & Edson Severnini

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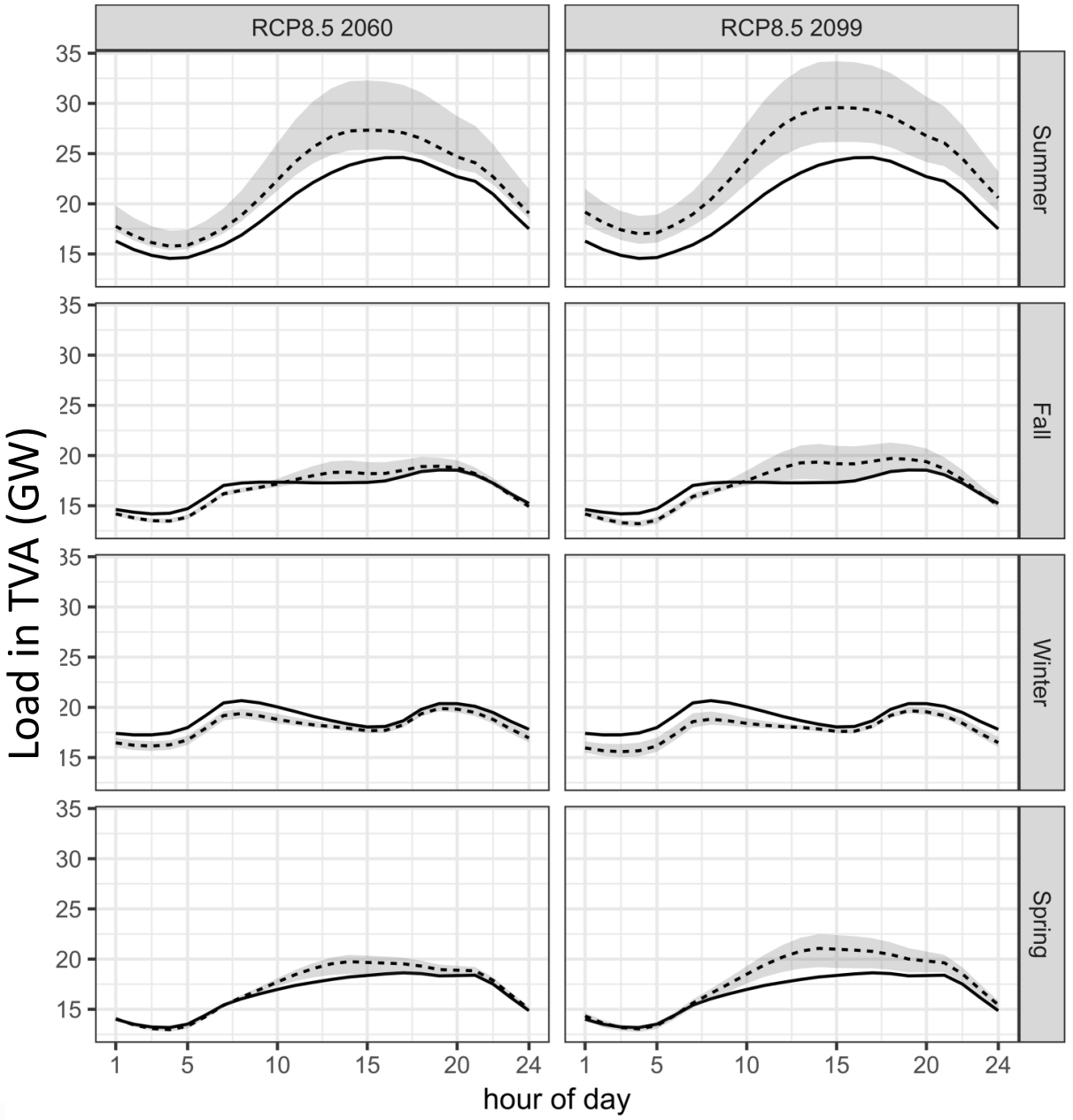
Climate change will have differentiated impacts on demand across space and time (seasons, time of day) (high agreement, robust evidence, high confidence).



Seasonal effects of climate change on intra-day electricity demand patterns

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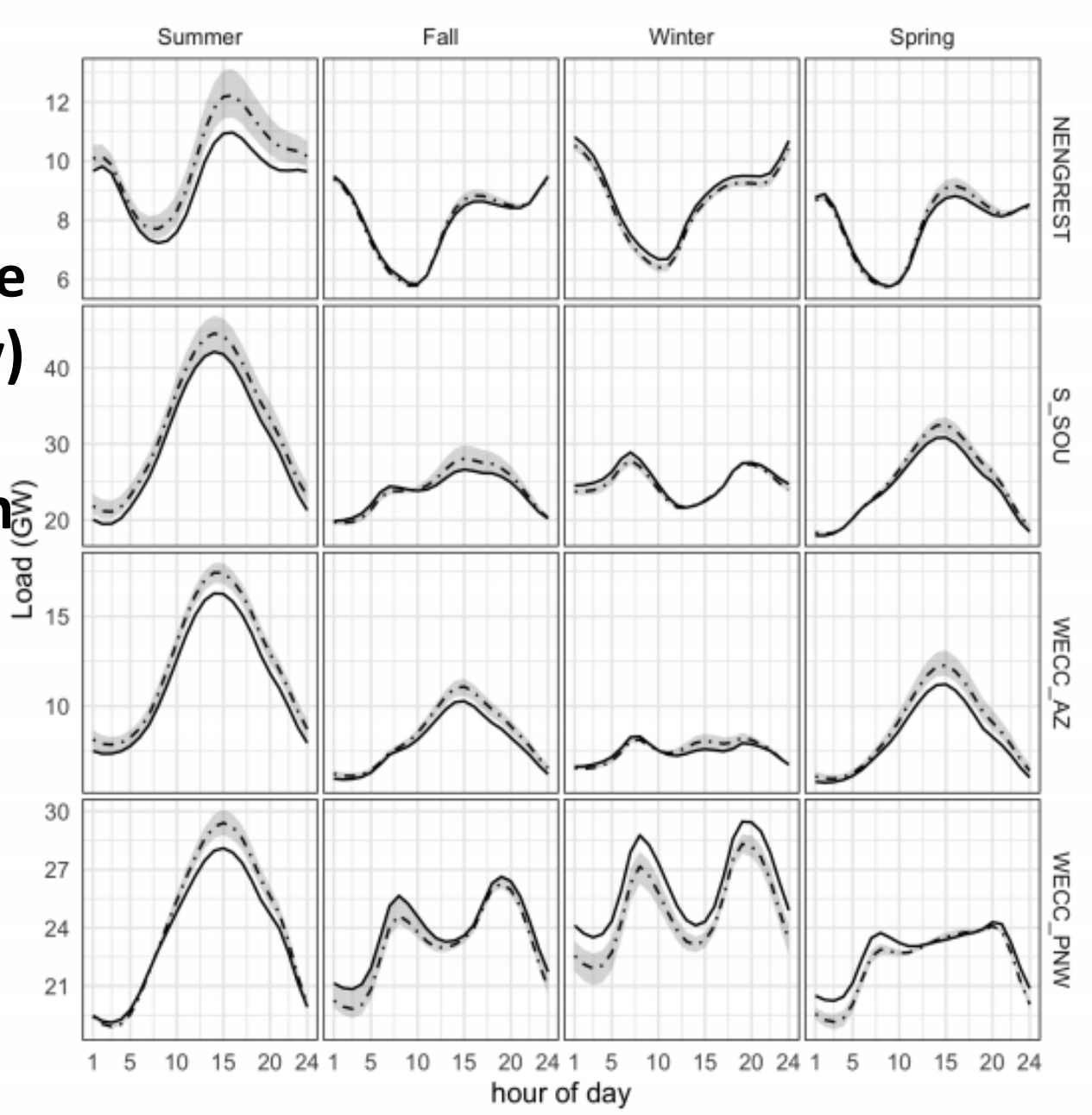

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Better Planning Electric Power Systems for a Changing Climate

November 5, 2021
9:20 a.m.

Climate change will reduce available capacity from thermal plants through three mechanisms.

1) Increased outages due to increasing ambient air temperatures.

2) Reduced efficiency due to increased ambient air temperatures and relative humidity.

3) Increased outages and reduced efficiency due to hydrological changes.

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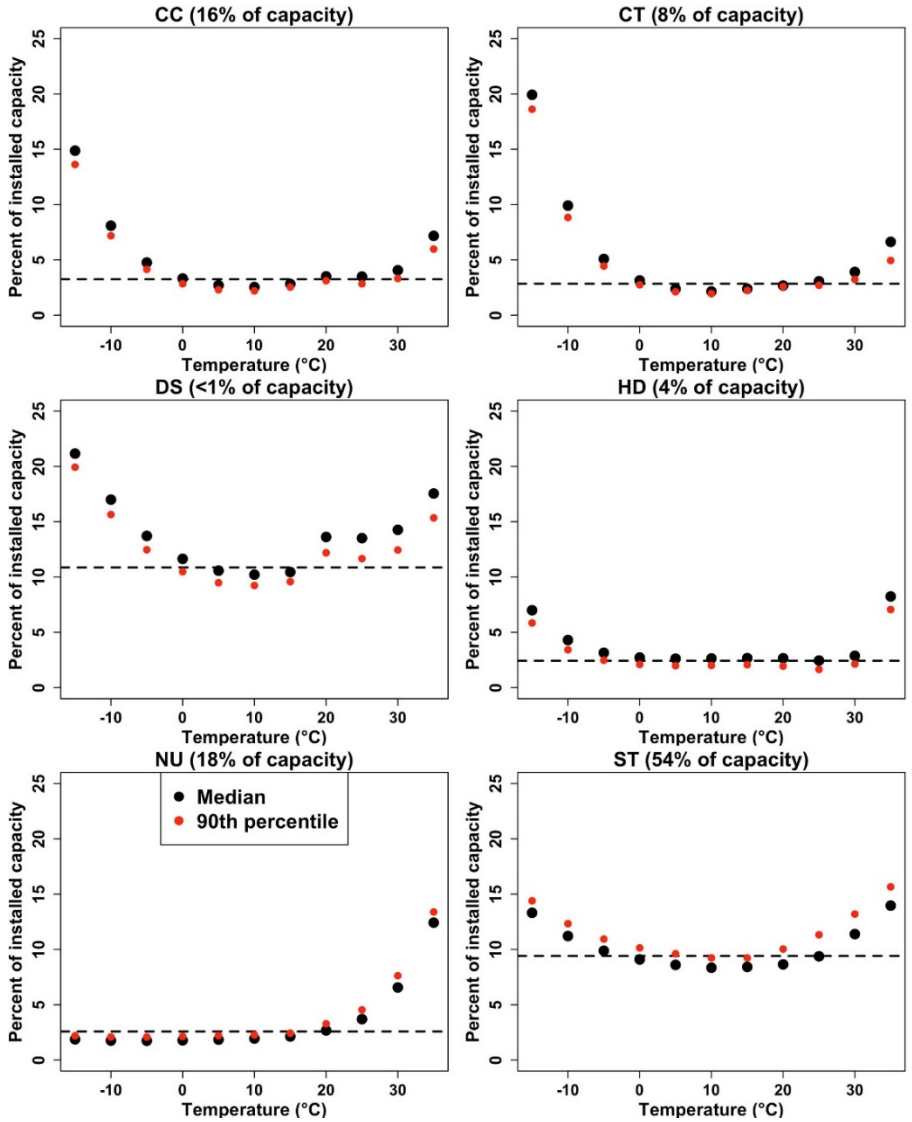
3) Increased outages and reduced efficiency due to hydrological changes.

CC is combined cycle, CT is simple cycle, DS is diesel, HD is hydroelectric and pumped storage, NU is nuclear, ST is steam turbine.

Murphy et al., "A time-dependent model of generator failures and recoveries captures correlated events and quantifies temperature dependence"



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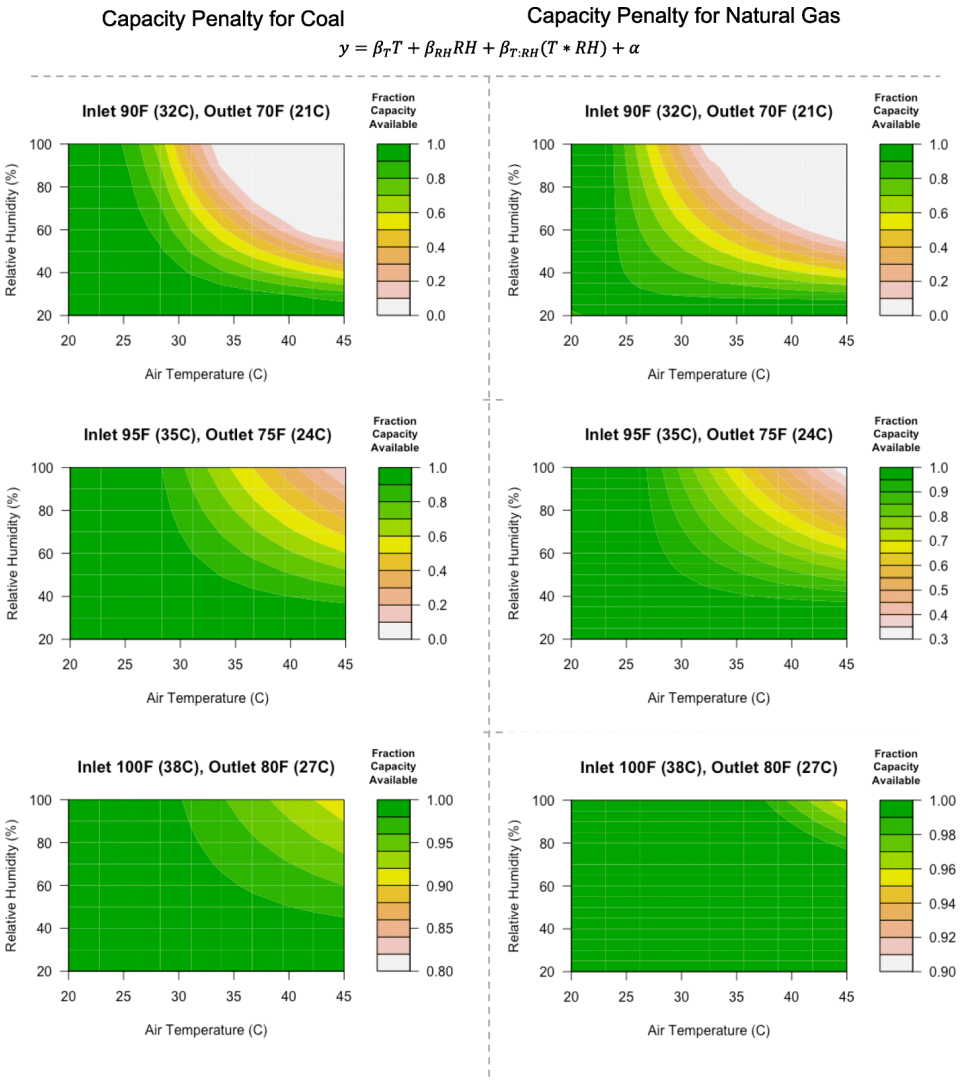

Fossil fuel–fired power plant operations under a changing climate

Aviva Loew, Paulina Jaramillo, Haibo Zhai, Rahim Ali, Bart Nijssen, Yifan Cheng & Kelly Klima

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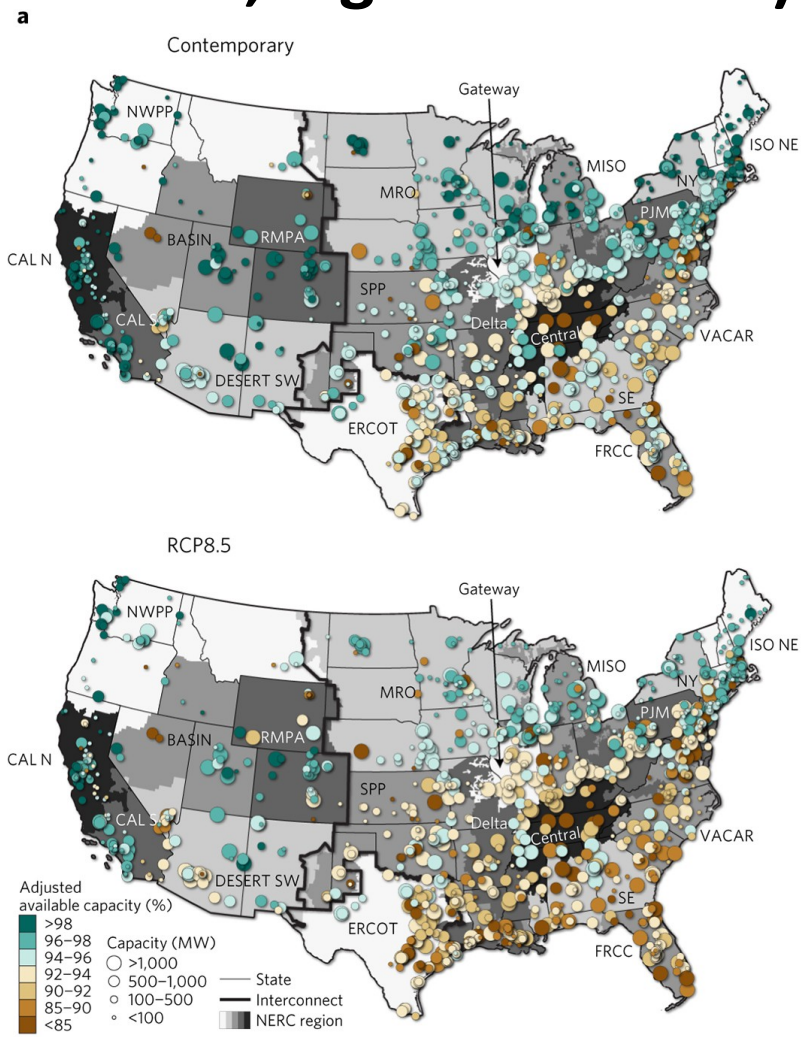
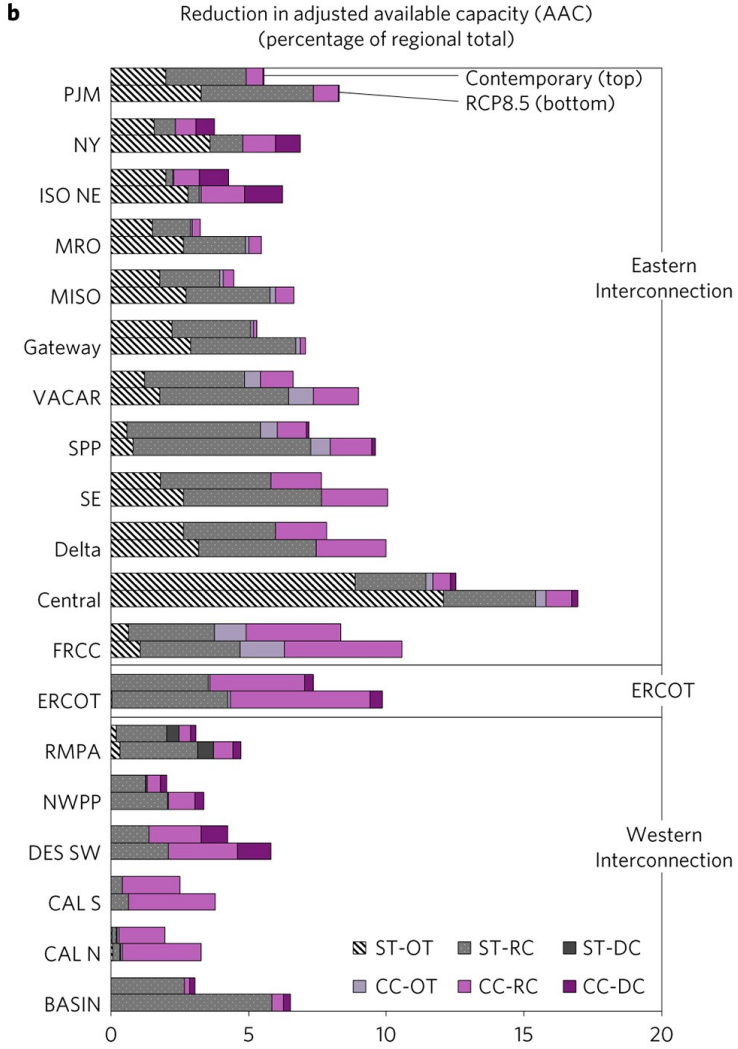
Climate change will reduce available capacity from thermal plants, particularly during summer (high agreement, robust evidence, high confidence).





Climate and water resource change impacts and adaptation potential for US power supply

Ariel Miara, Jordan E. Macknick, Charles J. Vörösmarty, Vincent C. Tidwell, Robin Newmark & Balazs Fekete

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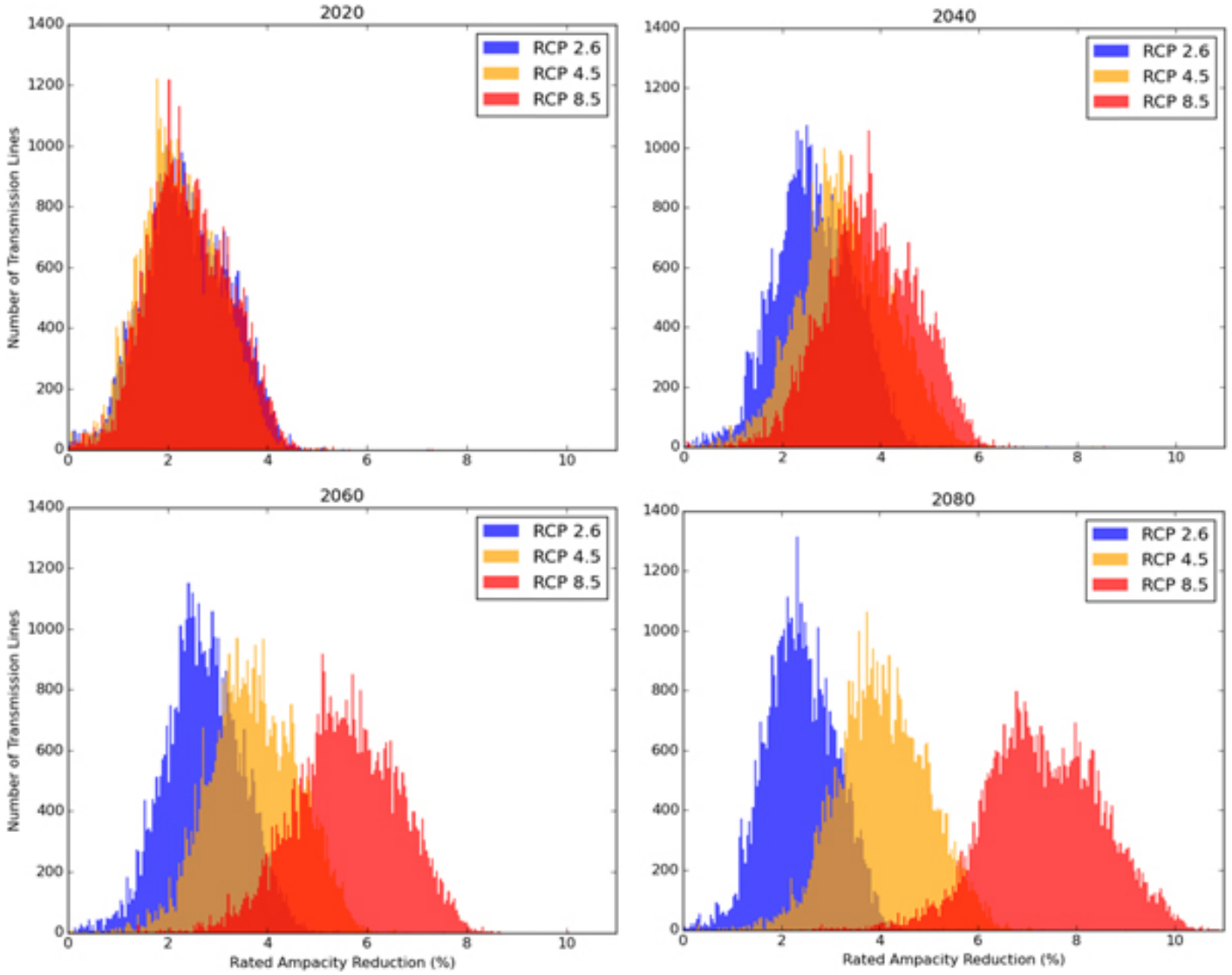
November 5, 2021
9:20 a.m.

Climate change will reduce transmission capacities through increased air temperatures (medium agreement, low evidence, medium confidence).

Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States

Matthew Bartos[4,1], Mikhail Chester[1], Nathan Johnson[2], Brandon Gorman[1], Daniel Eisenberg[1,3], Igor Linkov[3] and Matthew Bates[3]



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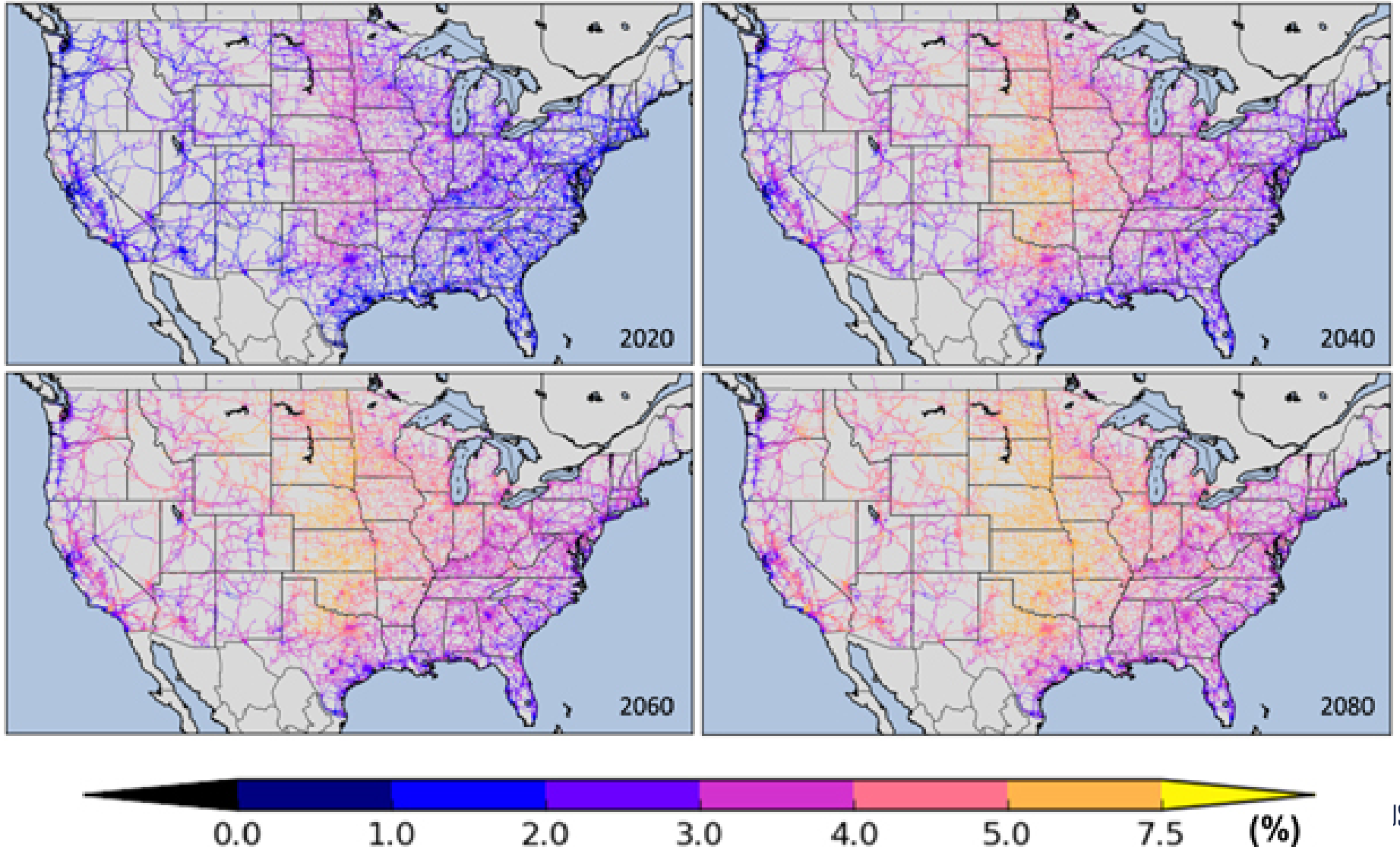

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9:20 a.m.

Climate change might alter hydropower, wind, and solar generation primarily through shifts in water, wind, and solar resources (low-medium agreement, low-medium evidence, low-medium confidence).

Changes will be highly heterogeneous across space and time.

Hydropower facilities in West are vulnerable to changes in snowpack.

Solar power is vulnerable to increasing air temperatures and wildfire smoke!

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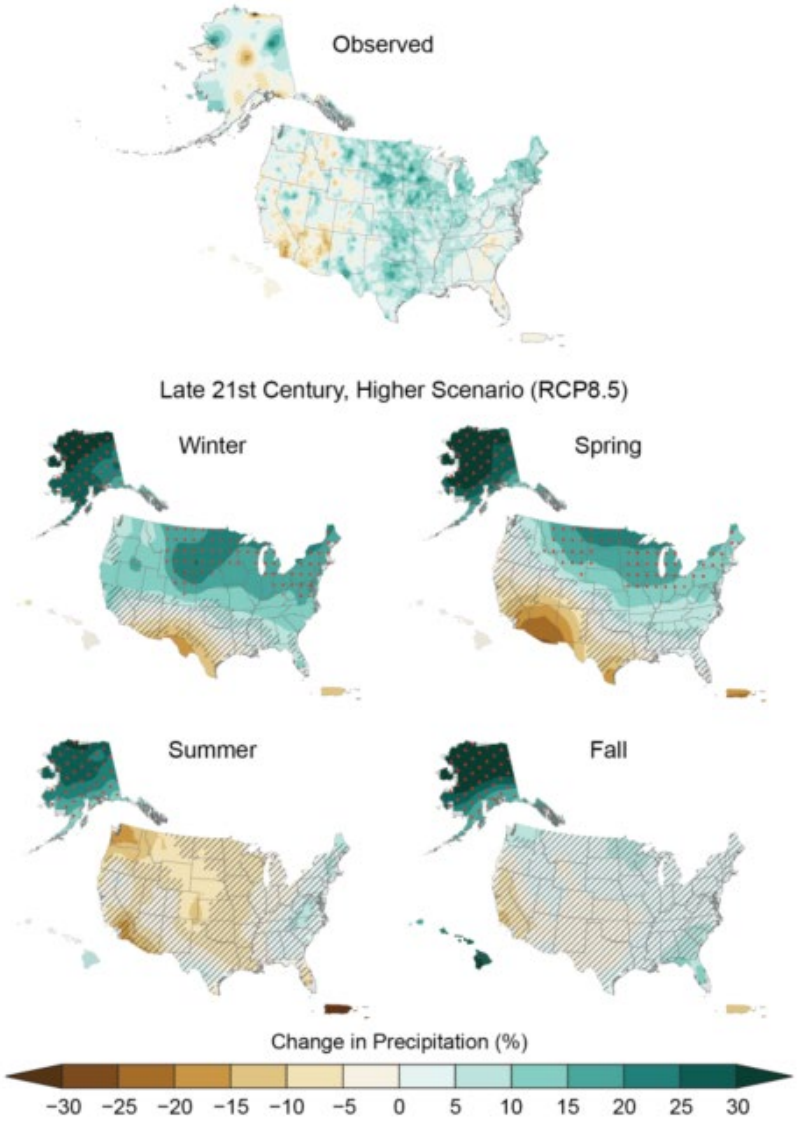
Climate change might alter hydropower potential (low-medium agreement, low-medium evidence, low-medium confidence).



Areas with red dots show where projected changes are large compared to natural variations; areas that are hatched show where changes are small and relatively insignificant.

Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II

2 Our Changing Climate

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Climate change might alter wind and solar generation (low-medium agreement, low-medium evidence, low-medium confidence).

- Estimating wind and solar resource changes requires **dynamical or statistical downscaling**
  - Remember, GCMs have low spatial and temporal resolution and limited cloud dynamics
- Dynamical downscaling is expensive (in terms of time and computing resources) and adds additional uncertainties
- Reduced form downscaling tools are starting to emerge

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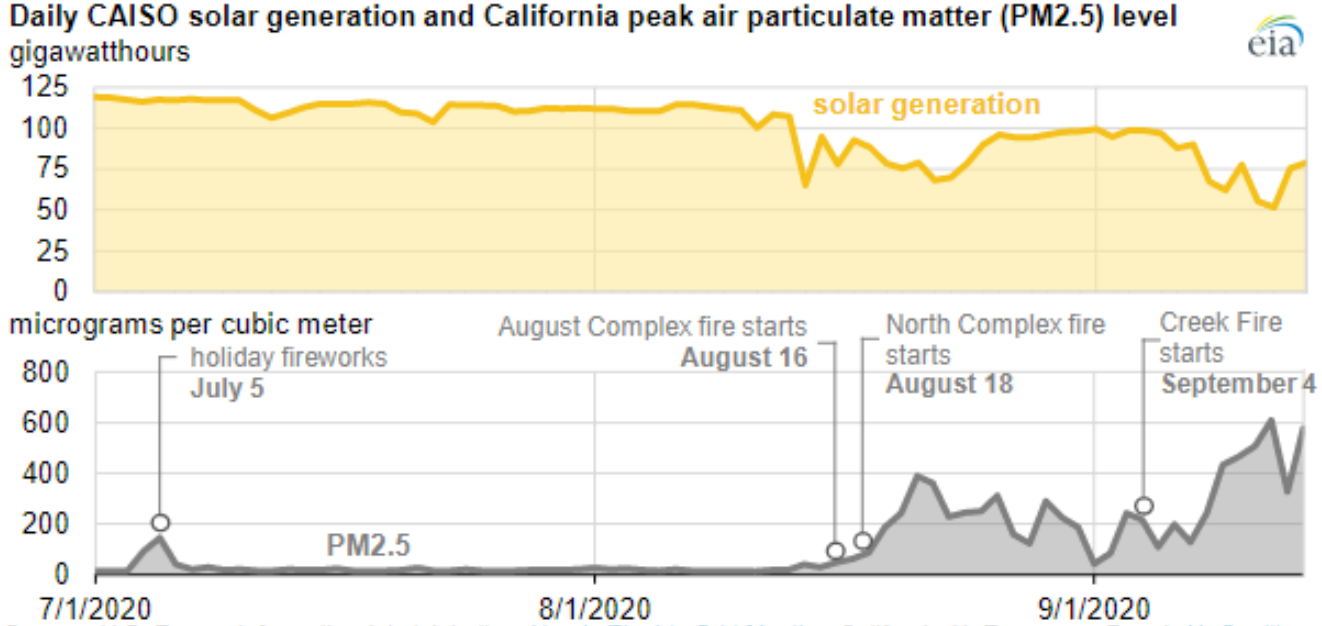
Some clear factors will reduce solar generation – wildfire smoke and increasing temperatures.

Smoke from California wildfires decreases solar generation in CAISO

Daily CAISO solar generation and California peak air particulate matter (PM2.5) level



Source: U.S. Energy Information Administration, Hourly Electric Grid Monitor; California Air Resources Board, Air Quality and Meteorology System
Note: CAISO=California Independent System Operator.

In the first two weeks of September 2020, average solar-powered electricity generation in the California Independent System Operator (CAISO), which covers 90% of utility-scale solar capacity in California, declined nearly 30% from the July 2020 average as wildfires burned across the state. Wildfire smoke contains small, airborne particulate matter particles that are generally 2.5 micrometers or smaller (referred to as PM2.5). This matter reduces the amount of sunlight that reaches solar panels, decreasing solar-powered electricity generation. As of September 28, California wildfires have burned an estimated 3.6 million acres in 2020, an area about the size of Connecticut.