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GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
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Impacts of Decarbonization, Policy, and Climate Scenario Uncertainty on Load Forecasts

Casey Burleyson, Nathalie Voisin, and the GODEEEP team

U.S. DEPARTMENT OF ENERGY BATTELLE

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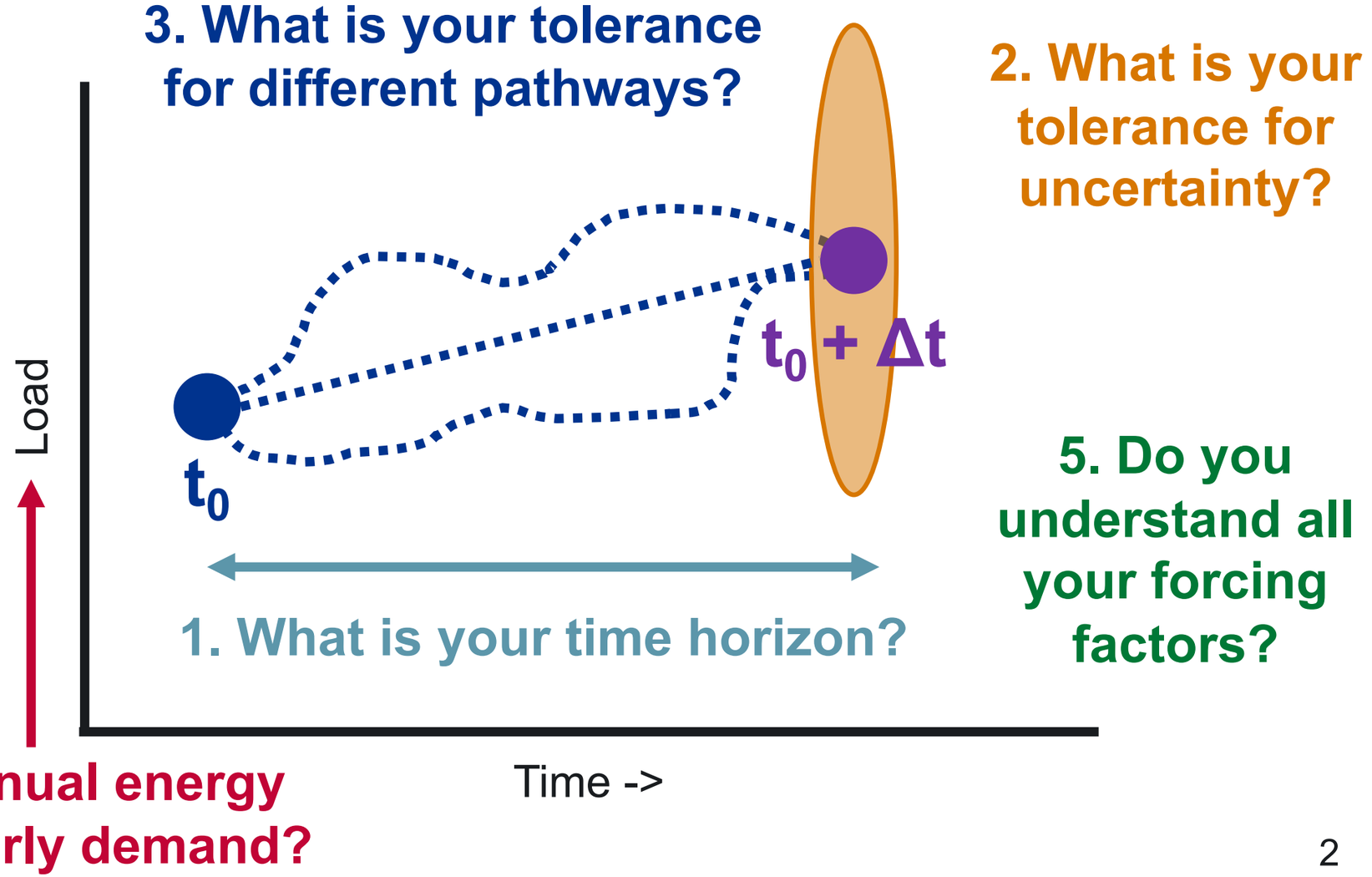
Fundamental Projection Problems

1. What is your time horizon?
2. What is your tolerance for uncertainty?
3. What is your tolerance for different pathways?
4. Annual energy or hourly demand?
5. Do you understand all your forcing factors?



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Forcing Factors

How many households will have solar panels?

How many electric vehicles will there be?

Will we have fusion energy in 2035?

Will people still need electricity in the future?

How many data centers will they build in my service area?

What will the generation technology mix look like?

What will be the federal policy on X?

What will the weather and climate look like in my service area?

How many people will live in my service area?

What does hydropower look like in a warmer world?

Forcing Factors

Fully Knowable

- Will people still need electricity in the future?
- Will we have fusion energy in 2035?

Reasonable Guesses

- What will the weather and climate look like in my service area?
- How many electric vehicles will there be?
- What will the generation technology mix look like?
- How many households will have solar panels?
- How many people will live in my service area?
- What does hydropower look like in a warmer world?

Completely Unknowable

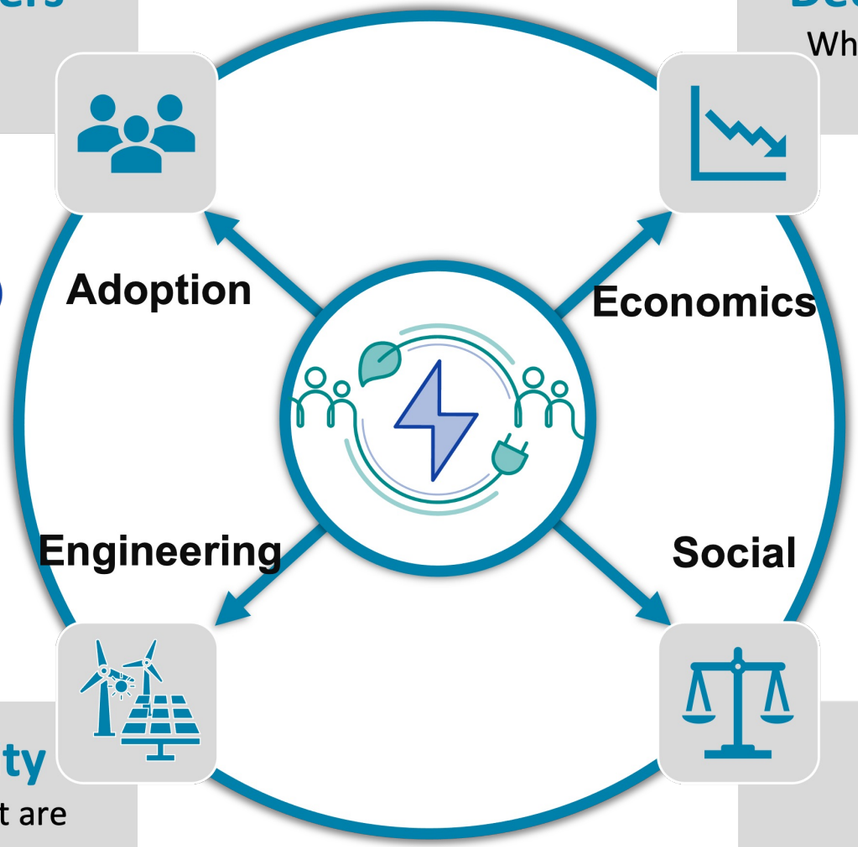
- What will be the federal policy on X?
- How many data centers will they build in my service area?

PNNL's GODEEEP Project

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform

Empowered Stakeholders
Transfer of methods, tools, datasets, and use cases

Decarbonization Pathways
Whole economy decarbonization with interactions across global markets



Resilience and Reliability
Infrastructure and operations that are responsive to climate change

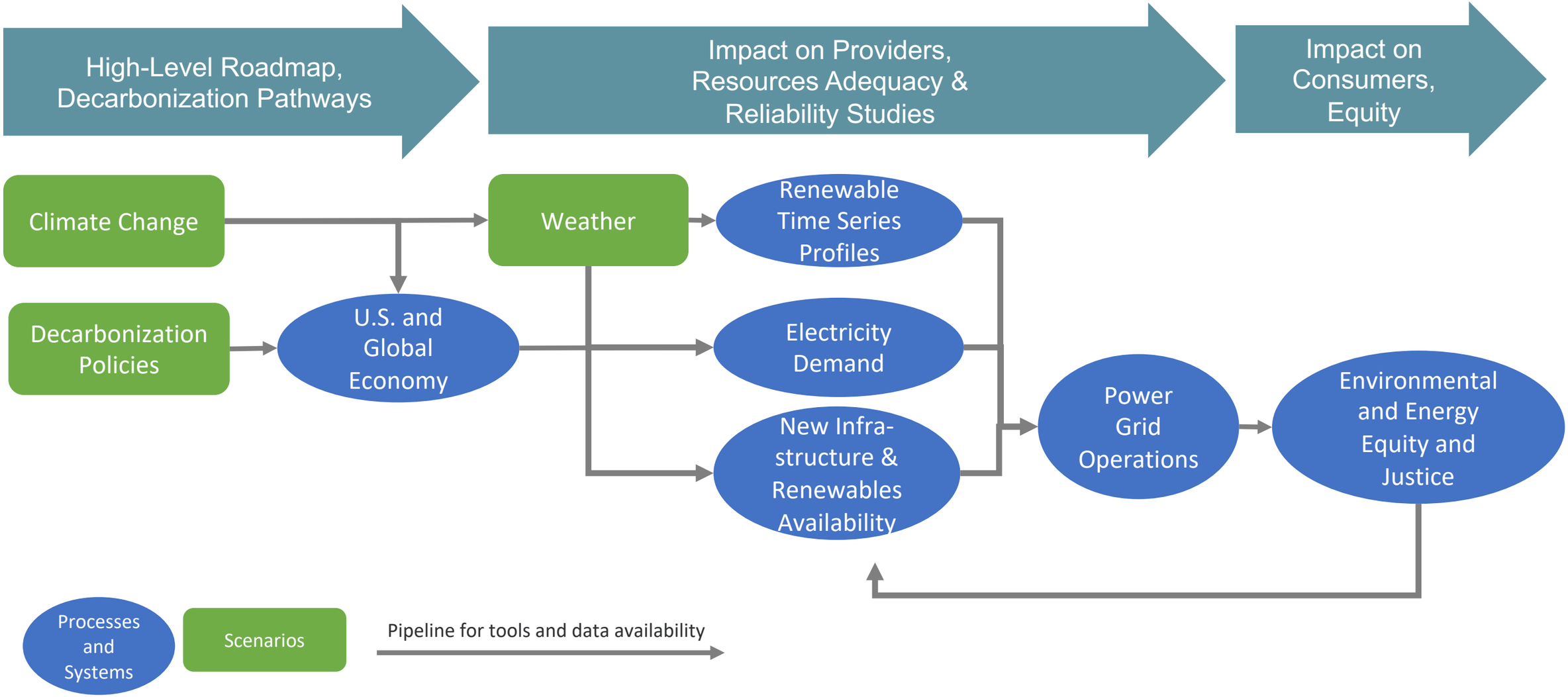
Justice and Equity
Environmental and energy equity impacts of decarbonization

A $4 million PNNL R&D project

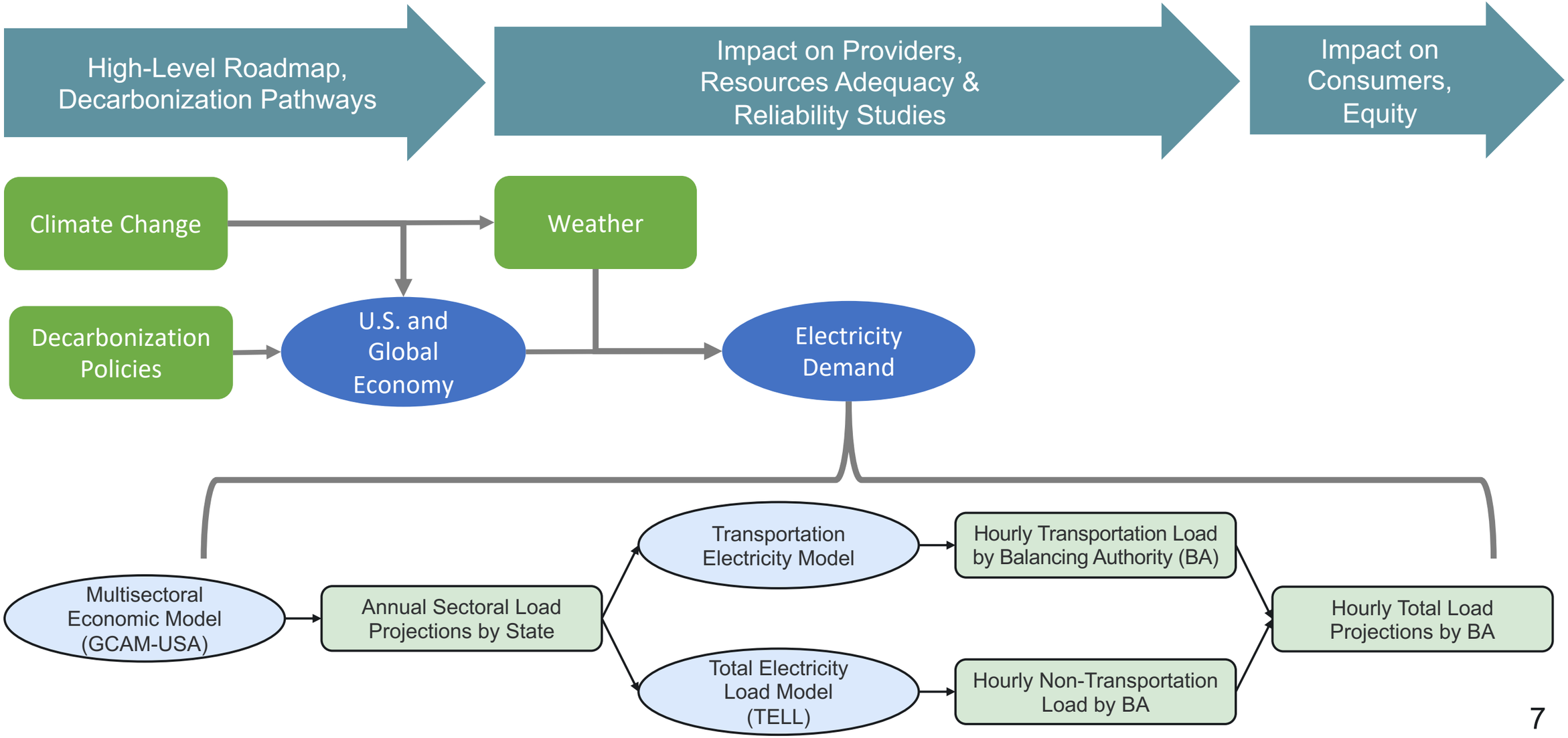
Coordinated research using staff expertise across renowned Climate and Bulk Electric Grid Programs in Fundamental and Applied Research across the Department of Energy's offices

- Atmospheric scientists
- Hydrologists
- Electrical engineers
- Social scientists
- Software engineers
- Stakeholder engagement experts

Consistent, Open-Source, End-to-End Framework with Intermediate Datasets and Tools for Flexible Customization



Climate and Decarbonization Impacts on Hourly Load Projections



GODEEEP Scenarios

Name	Decarbonization Goal	CCS	IRA	Population	Climate Impact
bau_climate	None	No	No	SSP2	RCP 8.5 - Hotter
bau_ira_ccs_climate	None	Yes	Yes	SSP2	RCP 8.5 - Hotter
nz_climate	Net Zero by 2050	No	No	SSP2	RCP 8.5 - Hotter
nz_ccs_climate	Net Zero by 2050	Yes	No	SSP2	RCP 8.5 - Hotter
nz_ira_ccs_climate	Net Zero by 2050	Yes	Yes	SSP2	RCP 8.5 - Hotter

Acronyms

BAU – Business as Usual

CCS – Carbon Capture Sequestration

HDD/CDD – Heating/Cooling Degree Days

IRA – Inflation Reduction Act

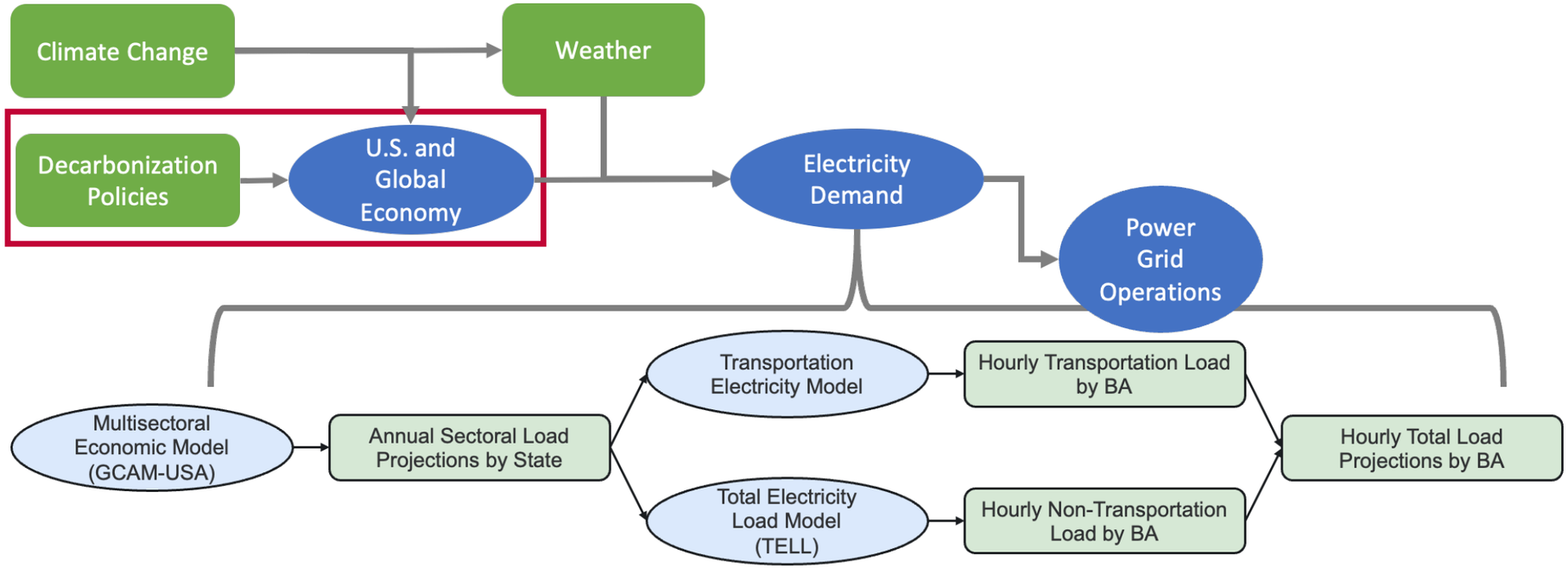
NZ – Net Zero

RCP – Representative Concentration Pathway

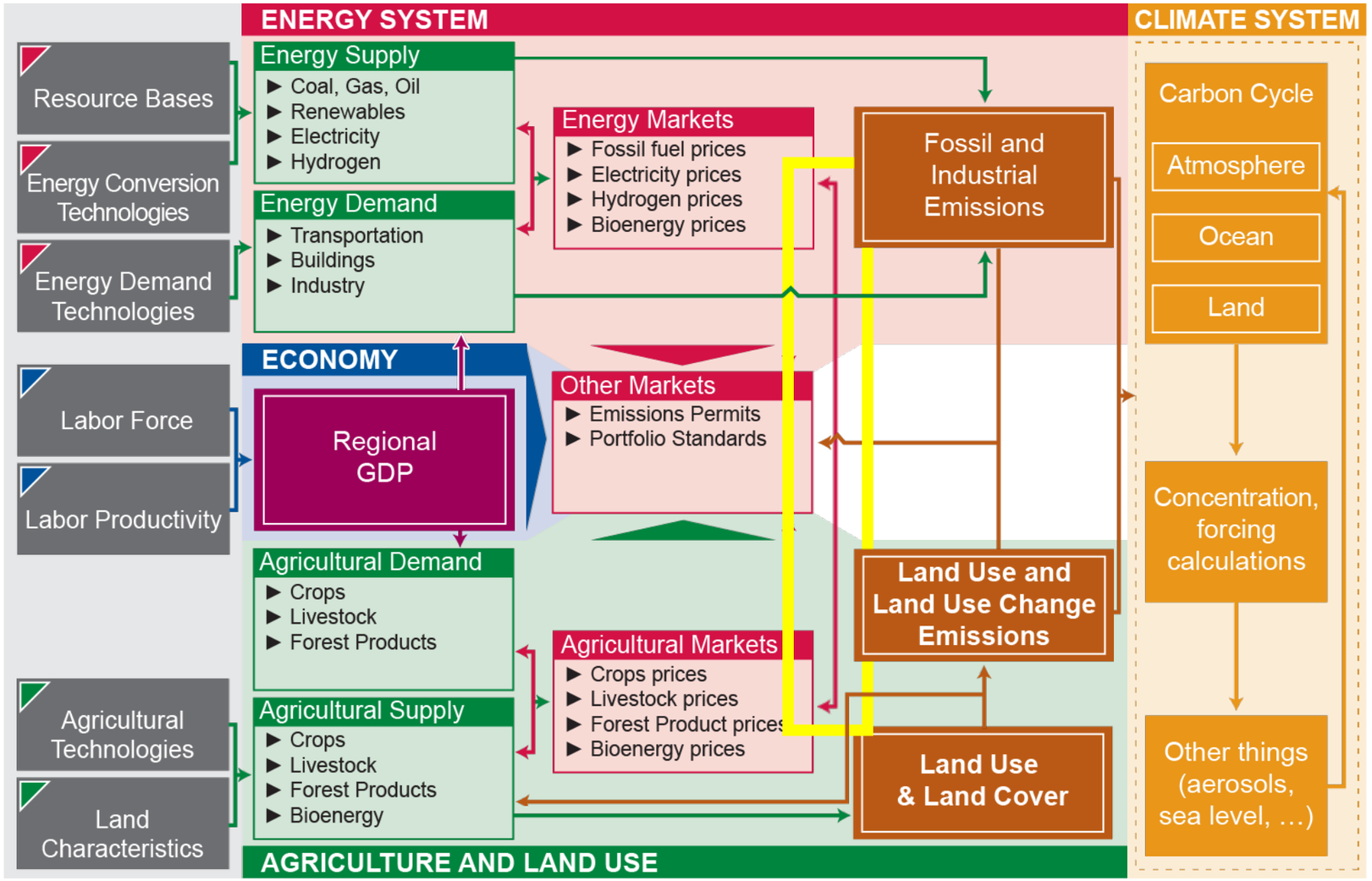
SSP – Shared Socioeconomic Pathway

Global Change Analysis Model with U.S. State-Level Representation (GCAM-USA)

- GCAM-USA provides a “boundary-condition” of the long-term transitions towards net-zero, such as energy demand and fuel mix across sectors and states
- GCAM-USA’s long-term projection will help drive utility-grade grid operations models to translate the large-scale projections into “on the ground” realizations of future grids, with quantifiable measurements of grid operations reliability and resilience

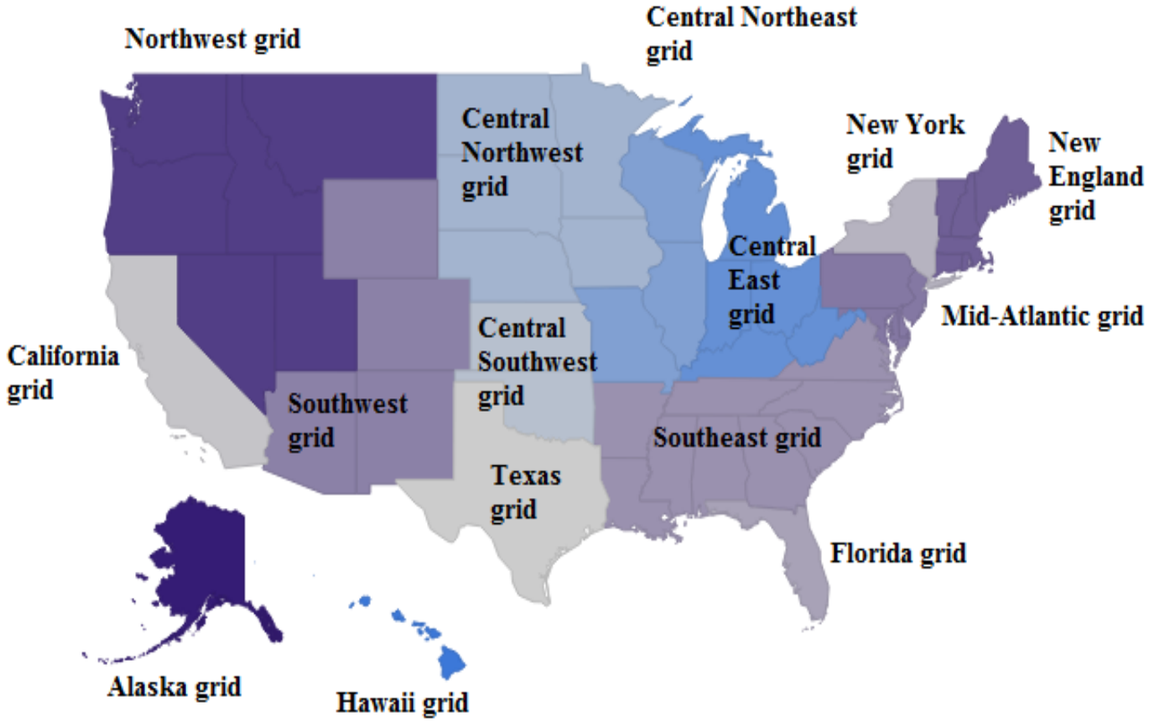


GCAM-USA Links Economic, Energy, Land-Use, Water, and Climate Systems

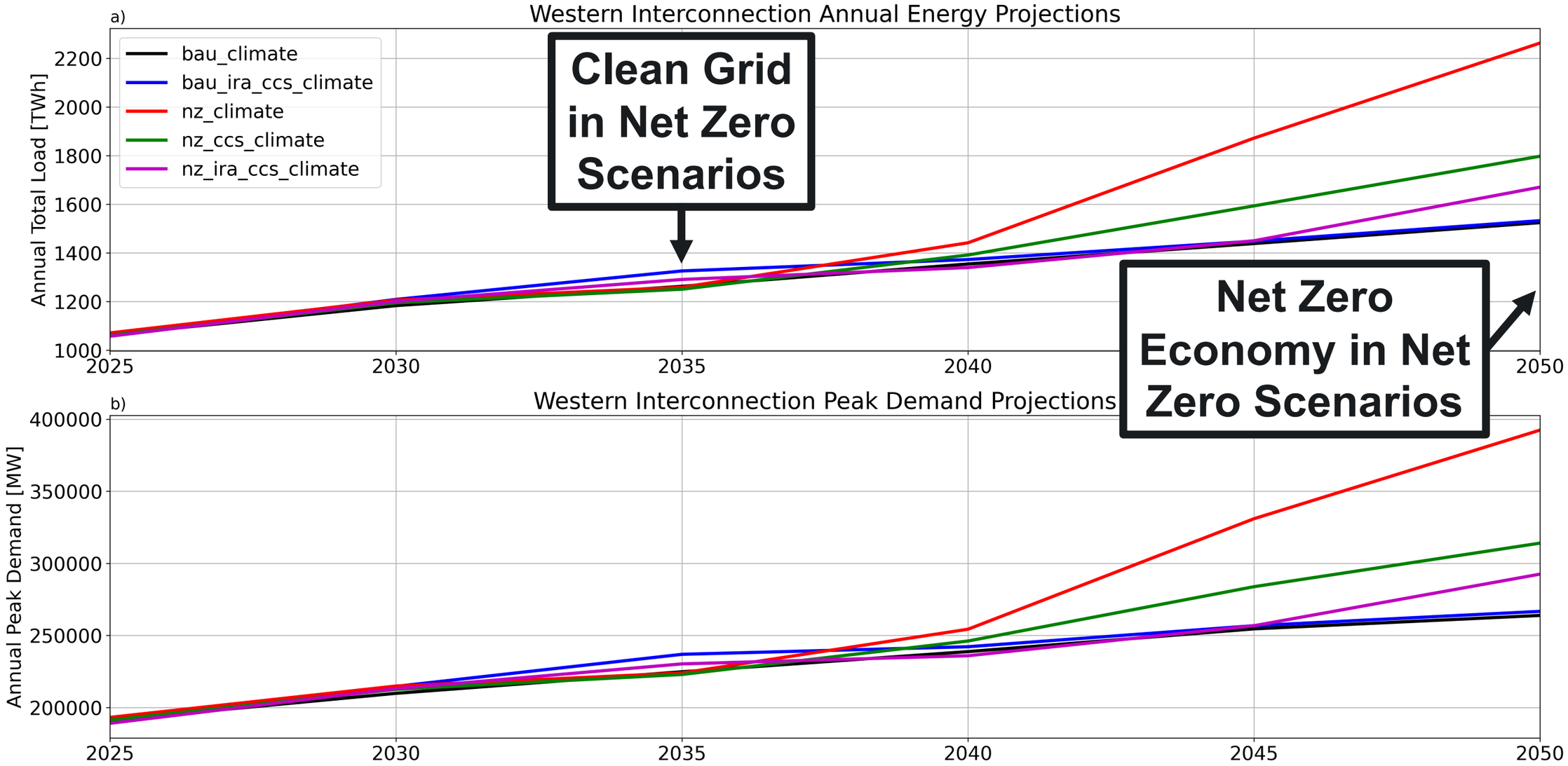


GCAM-USA Projects Annual Electricity Generation and Demand for Each State

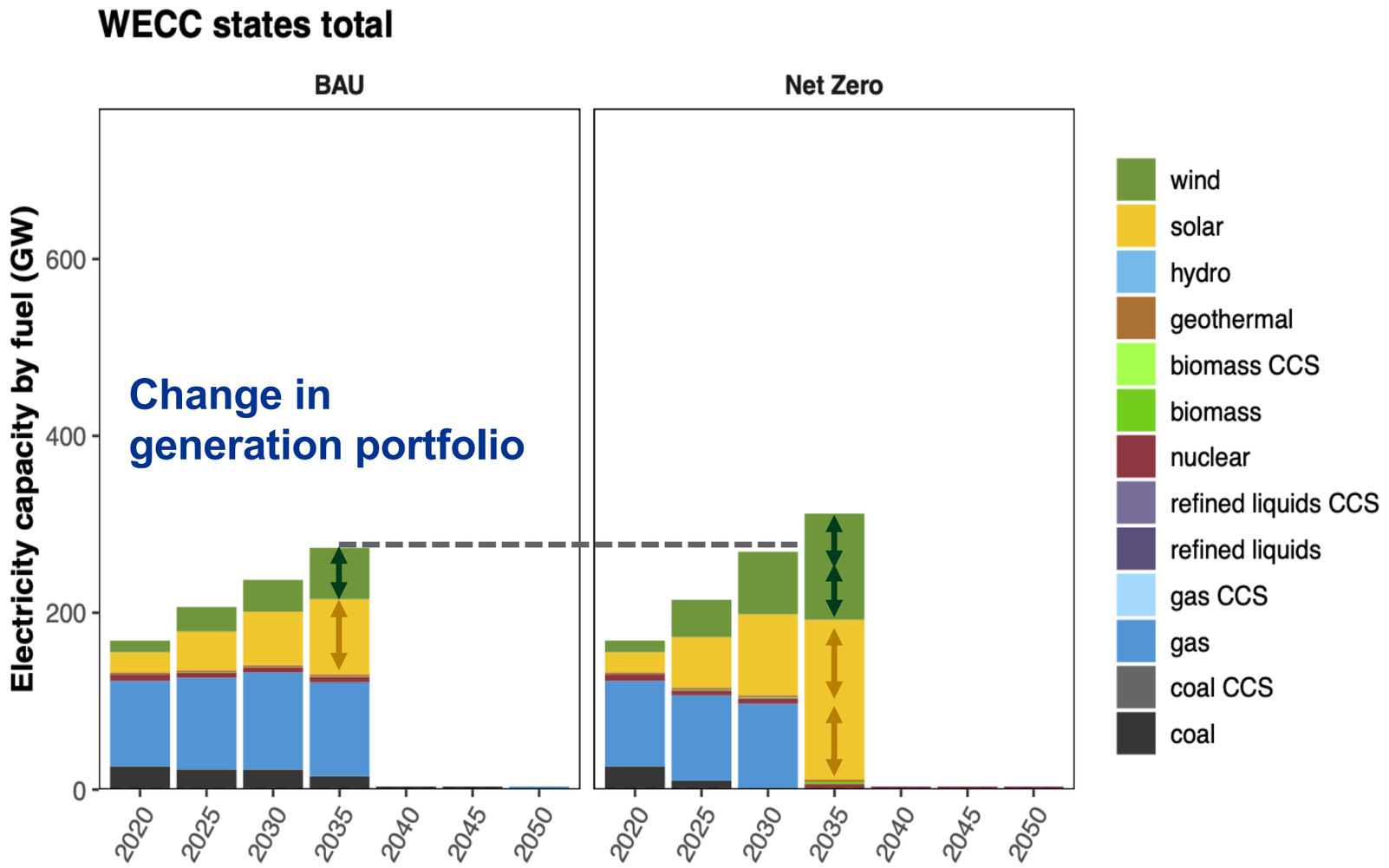
- Achieving net-zero entails **economy-wide** transitions, such as unprecedented electric capacity expansion
- Electricity load is sensitive to many factors (demand, climate, economics, fuel prices, etc.)
- A holistic understanding of electricity generation and demand is important to understand the **co-evolution** of cross-sector dynamics
- GCAM-USA endogenizes cross-sector linkages, such as energy flow, energy prices, food prices, water, and land
- Electricity trade in fifteen grid (NERC) regions



Projections of Electricity Demand



Change in Generation Mix Before 2035 - Changes in Demand After 2035



Ou, Yang, & Iyer, Gokul. (2023). GCAM-USA Decarbonization Pathways for GODEEEP (2.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7838872

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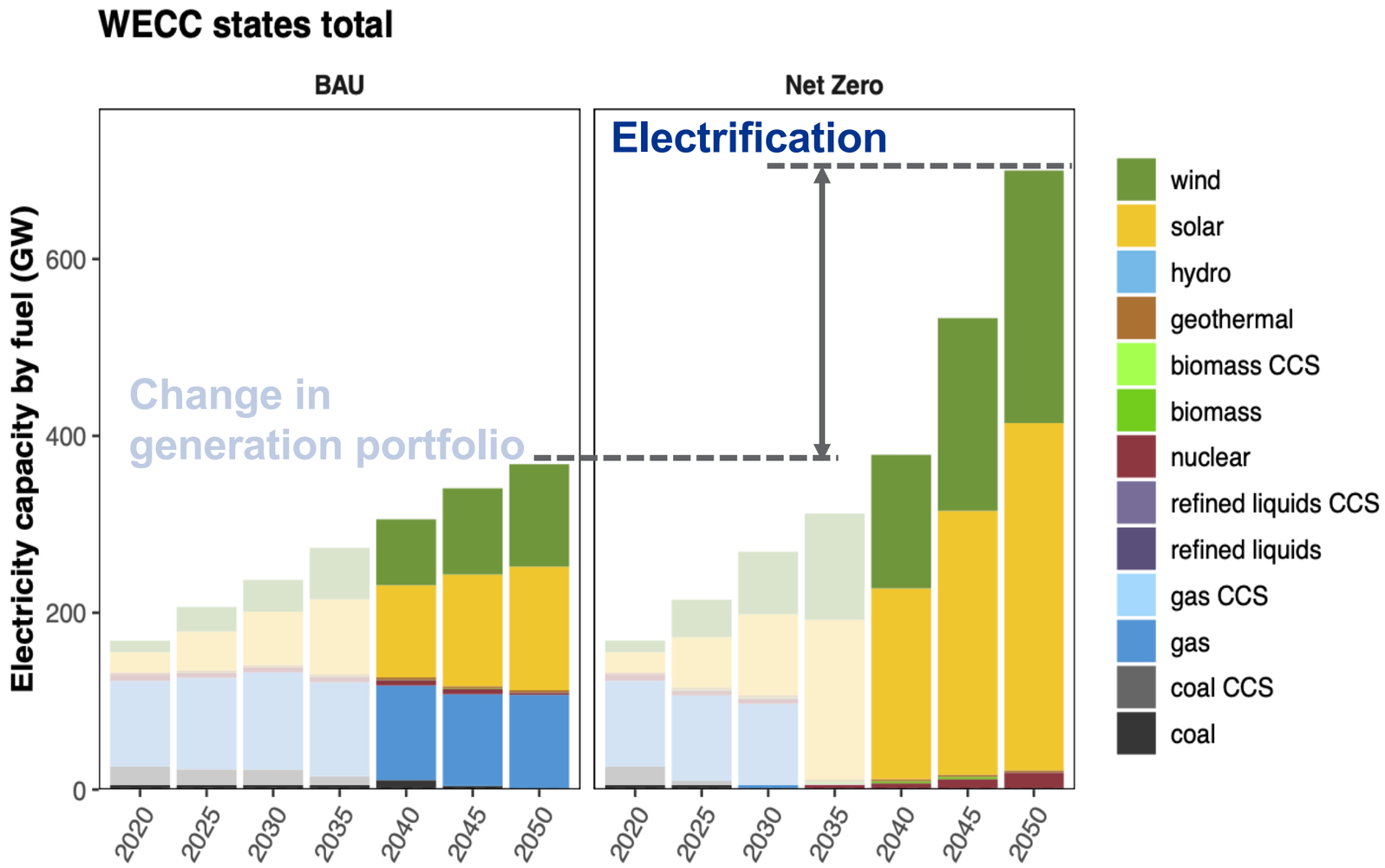

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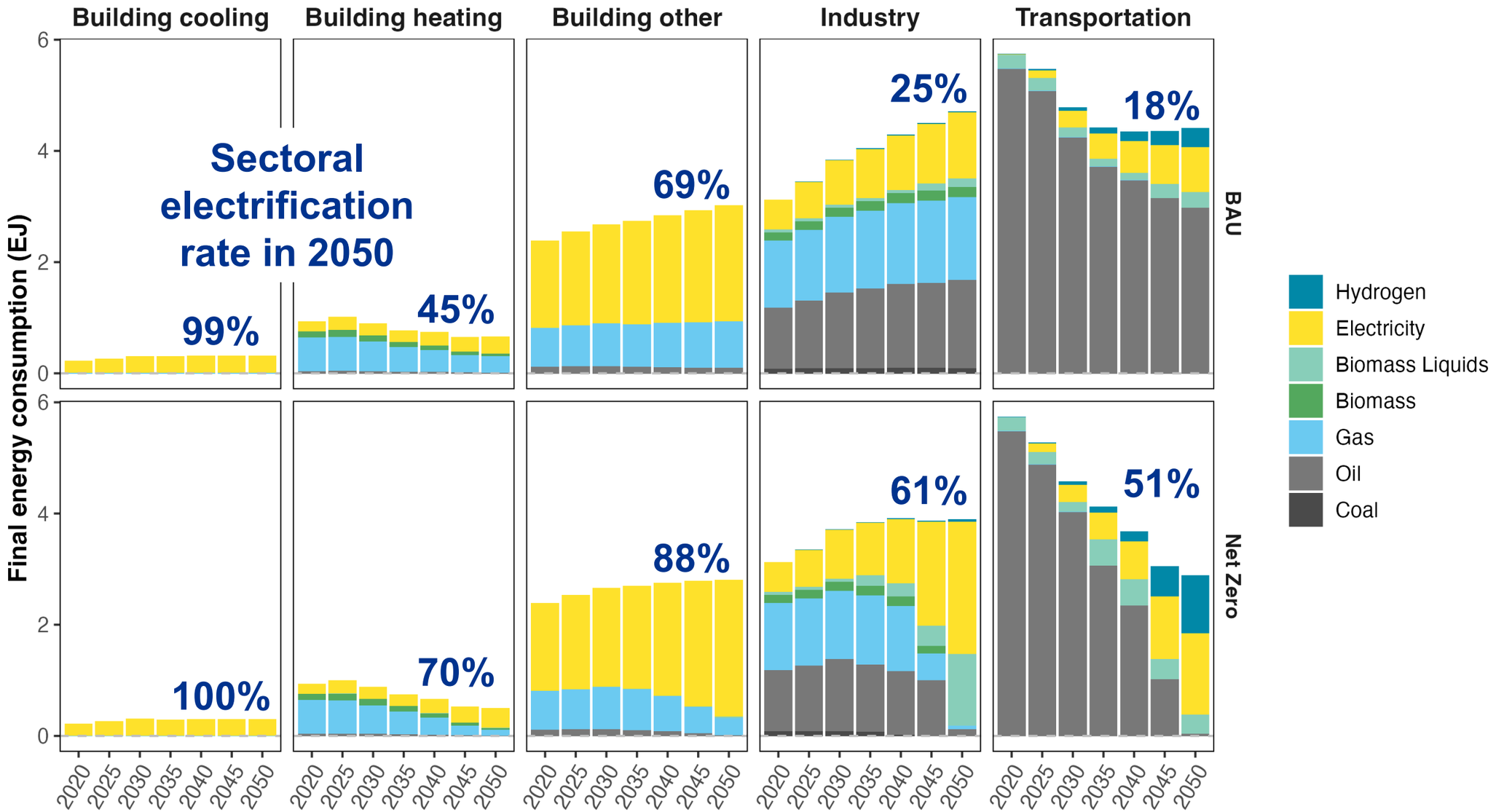
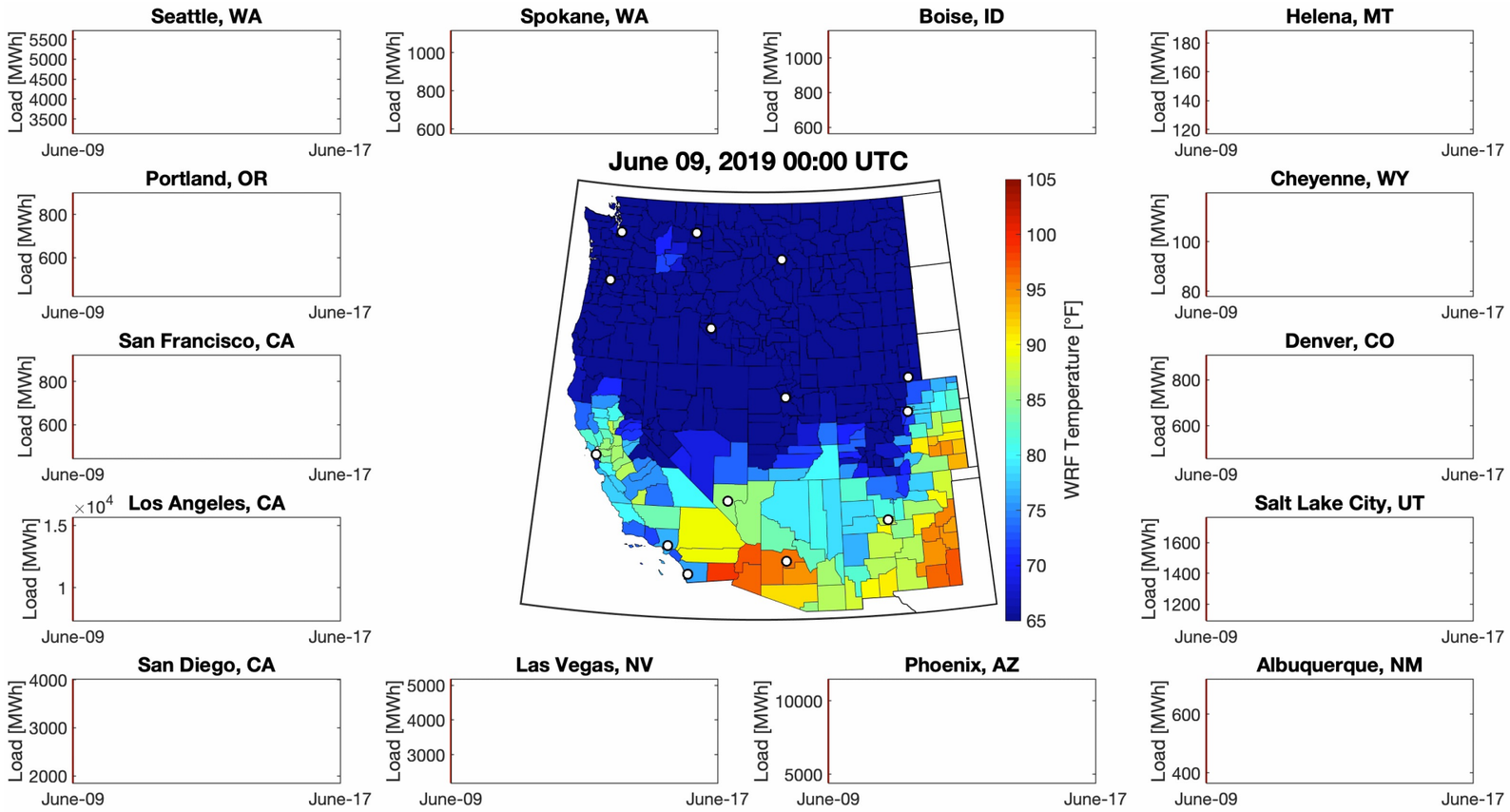
Clean-Energy Transition Across Demand Sectors



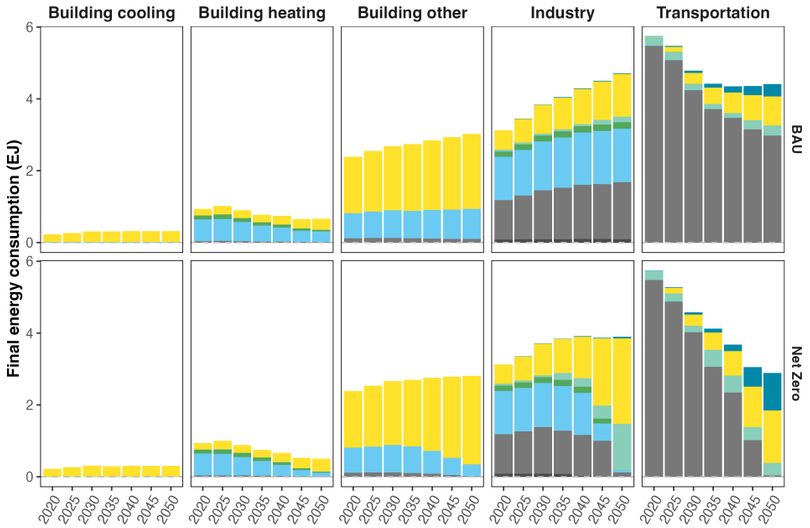
PNNL's Total ELectricity Loads (TELL) Model

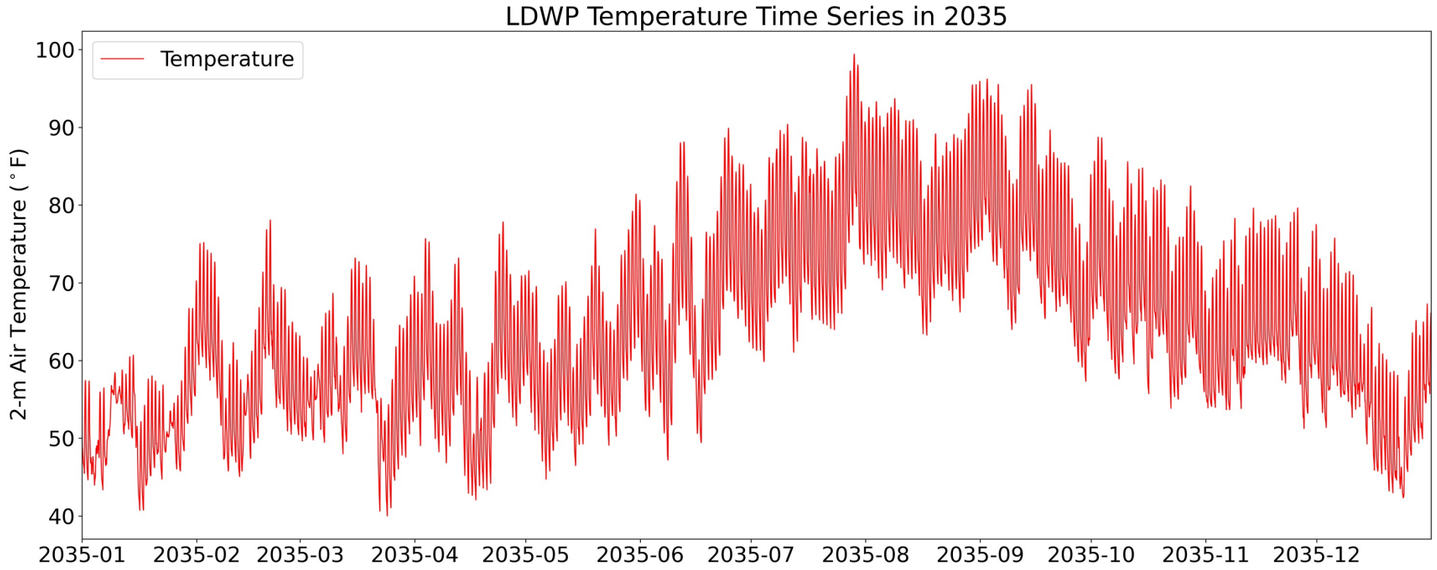
- Projects the evolution of hourly electricity demand in response to changes in weather and climate
- Based on a series of machine learning models trained on historical loads and meteorology
- Output is projections of **hourly electricity demand** at the county-, state-, and **BA-scale** that are conceptually and quantitatively consistent
- Released as an extensively documented open-source code base: https://github.com/IMMM-SFA/tell

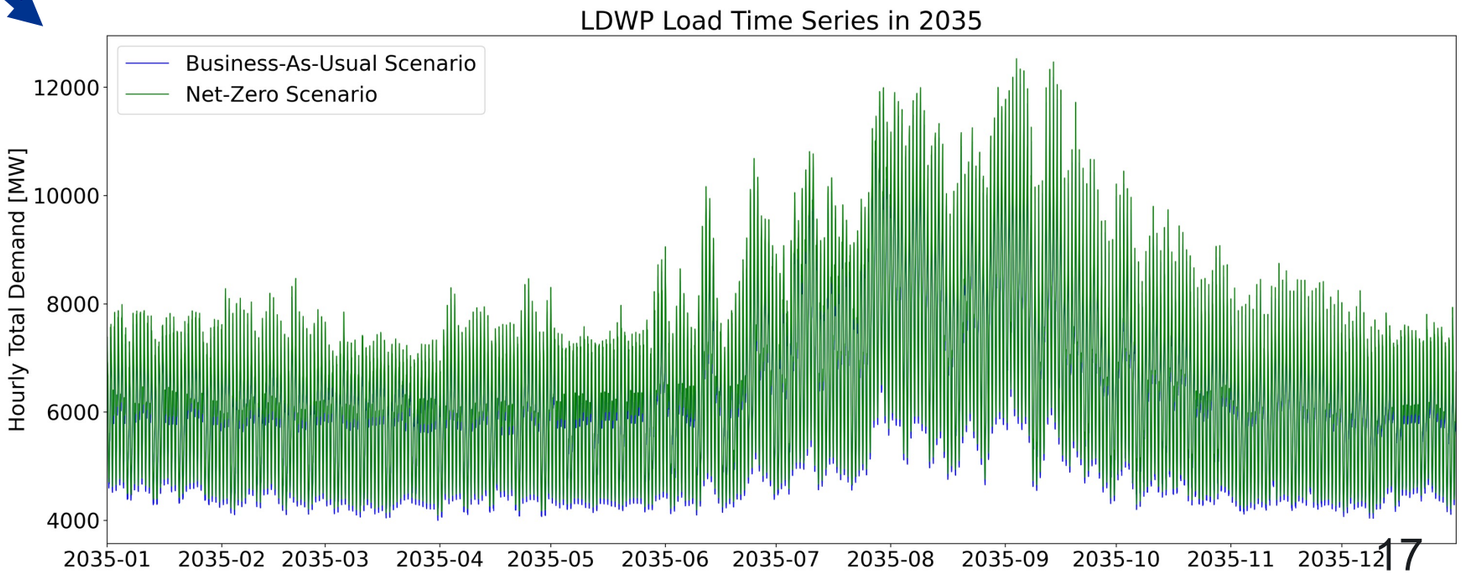


McGrath, C., C. D. Burleyson, Z. Khan, A. Rahman, T. Thurber, C. R. Vernon, N. Voisin, and J. S. Rice, 2022: tell: a Python package to model future electricity loads. Journal of Open-Source Software, 7(79) 4472, https://doi.org/10.21105/joss.04472

Result Snapshot: Hourly Load Time Series







Burleyson, Casey, Thurber, Travis, Acharya, Samrat, & Ghosal, Malini. (2023). Total Load Profiles by Balancing Authority in the Western United States for GODEEEP (v1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8067472

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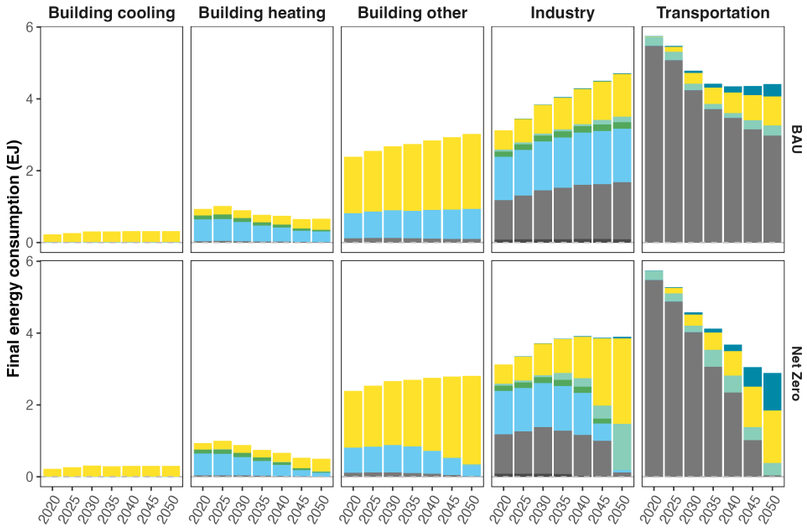

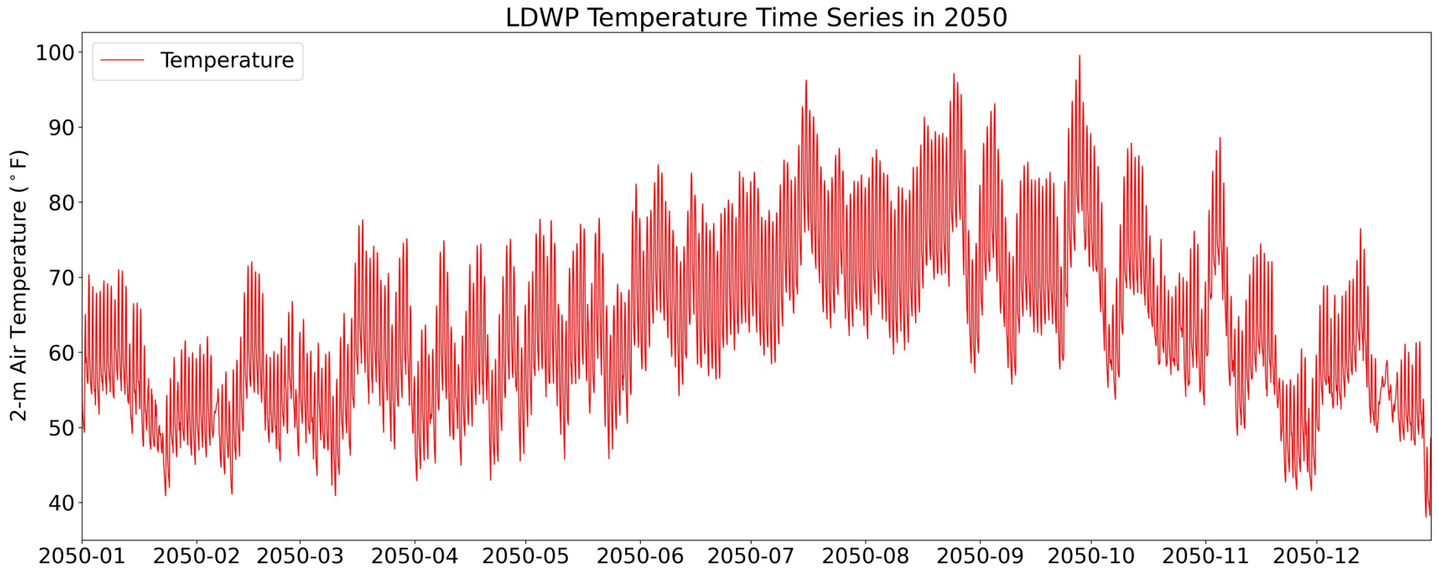

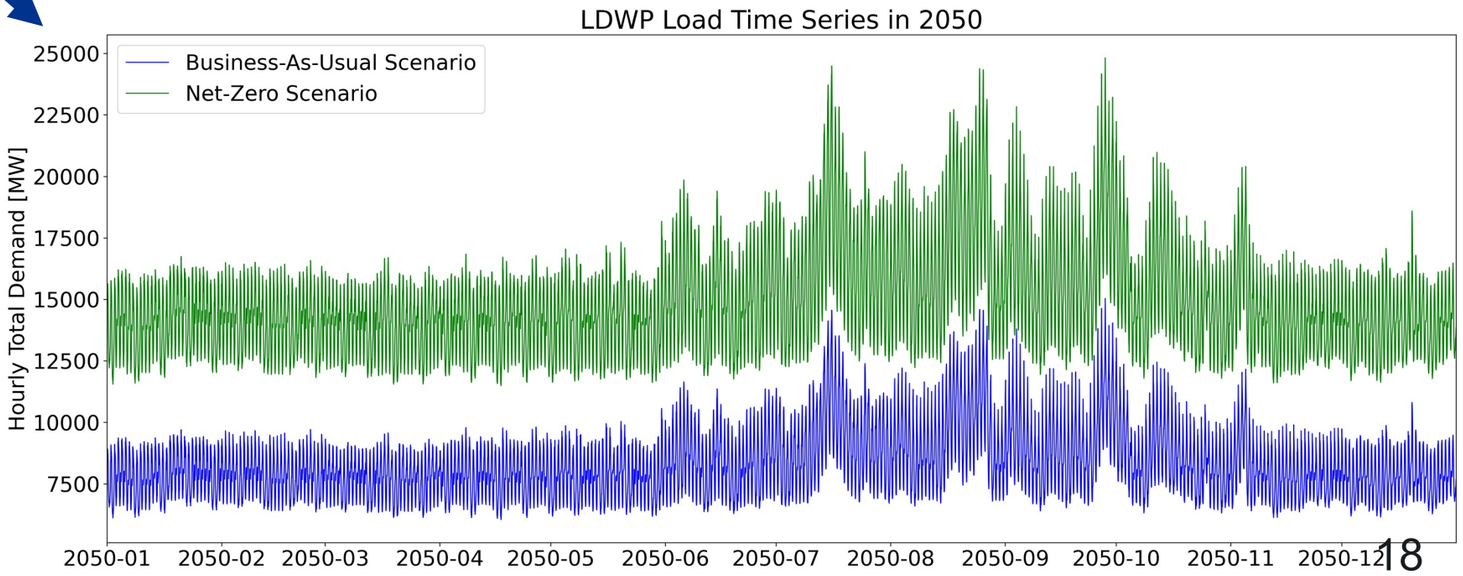

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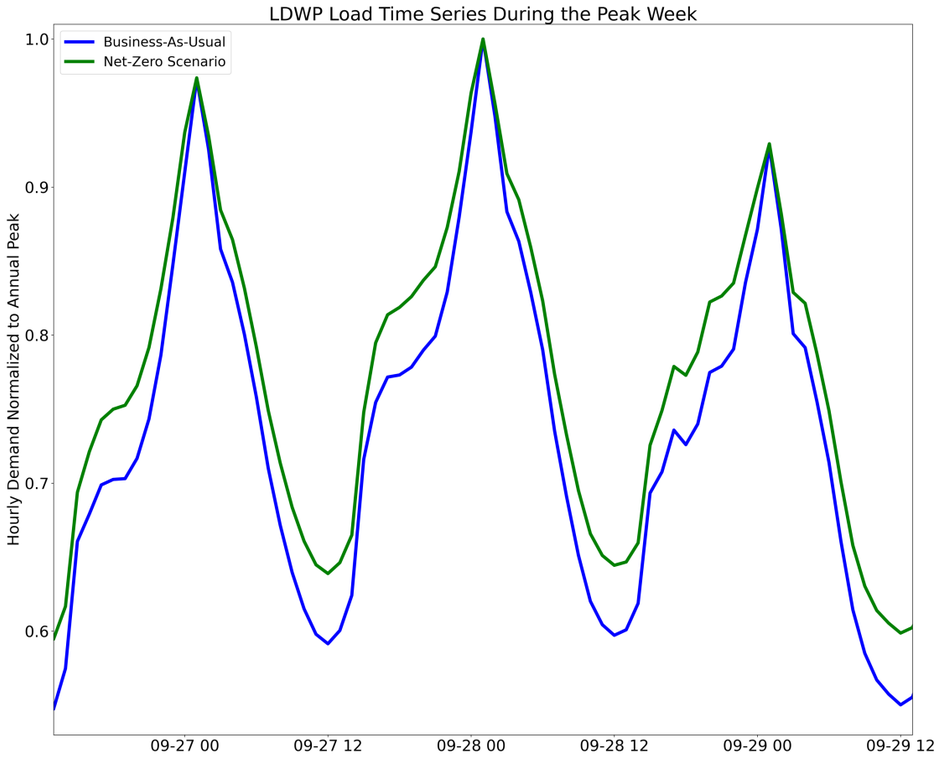
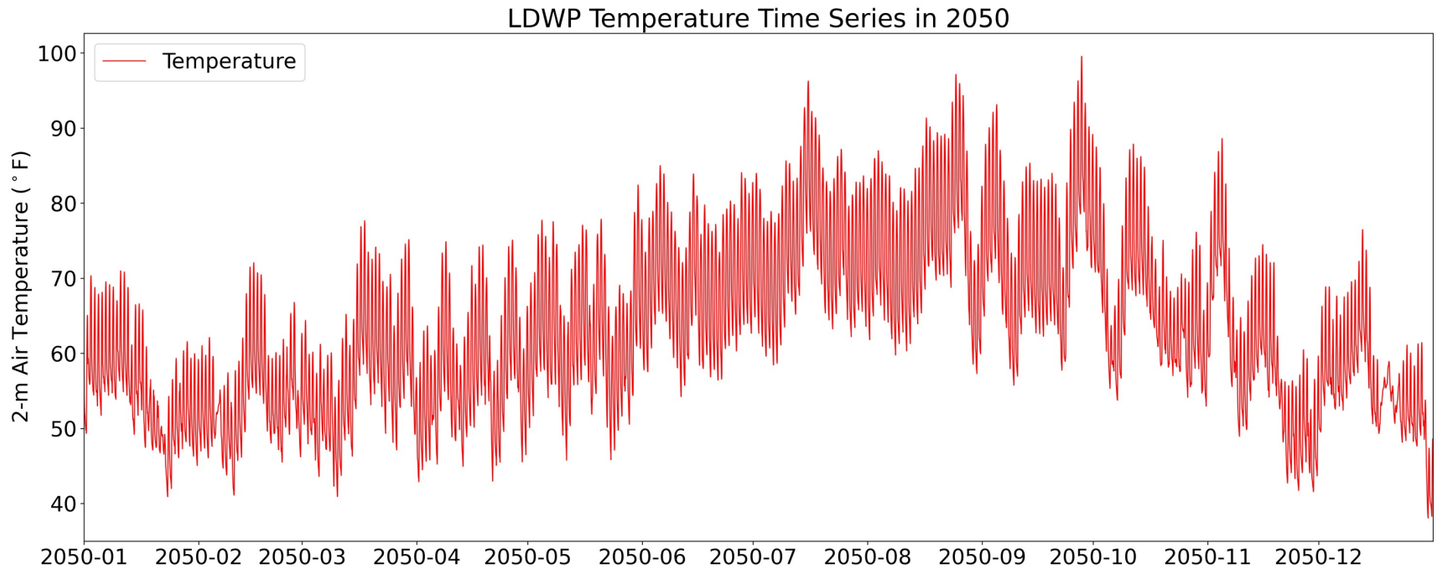
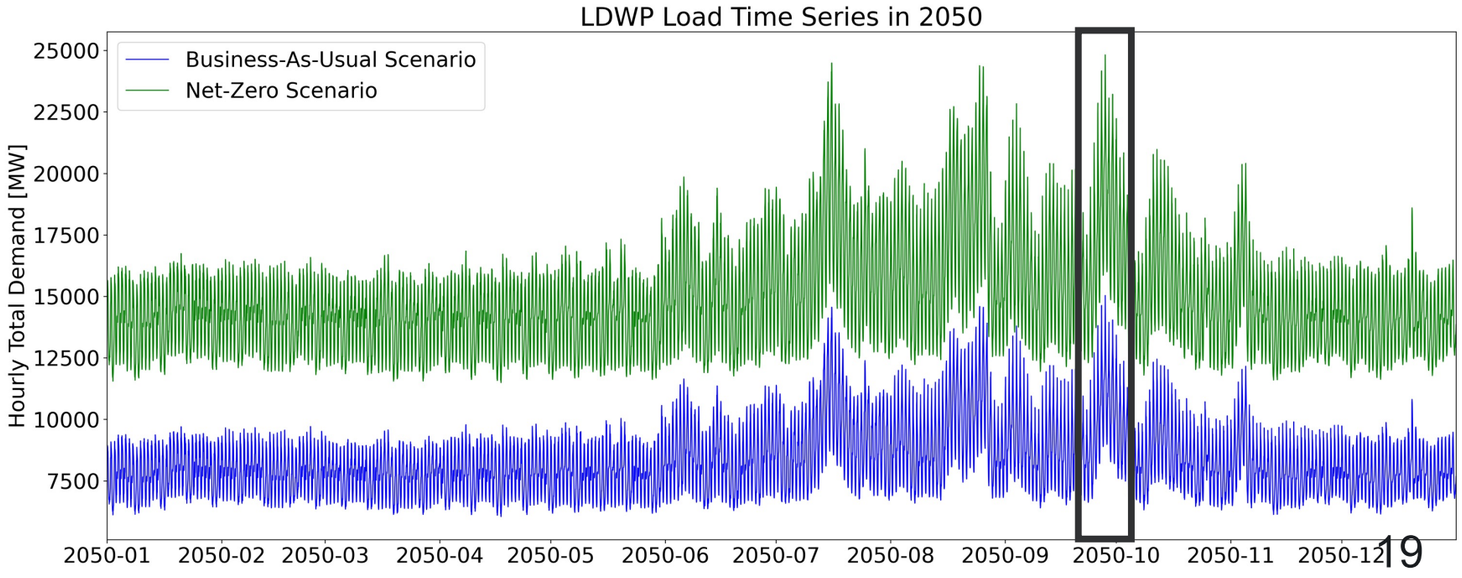


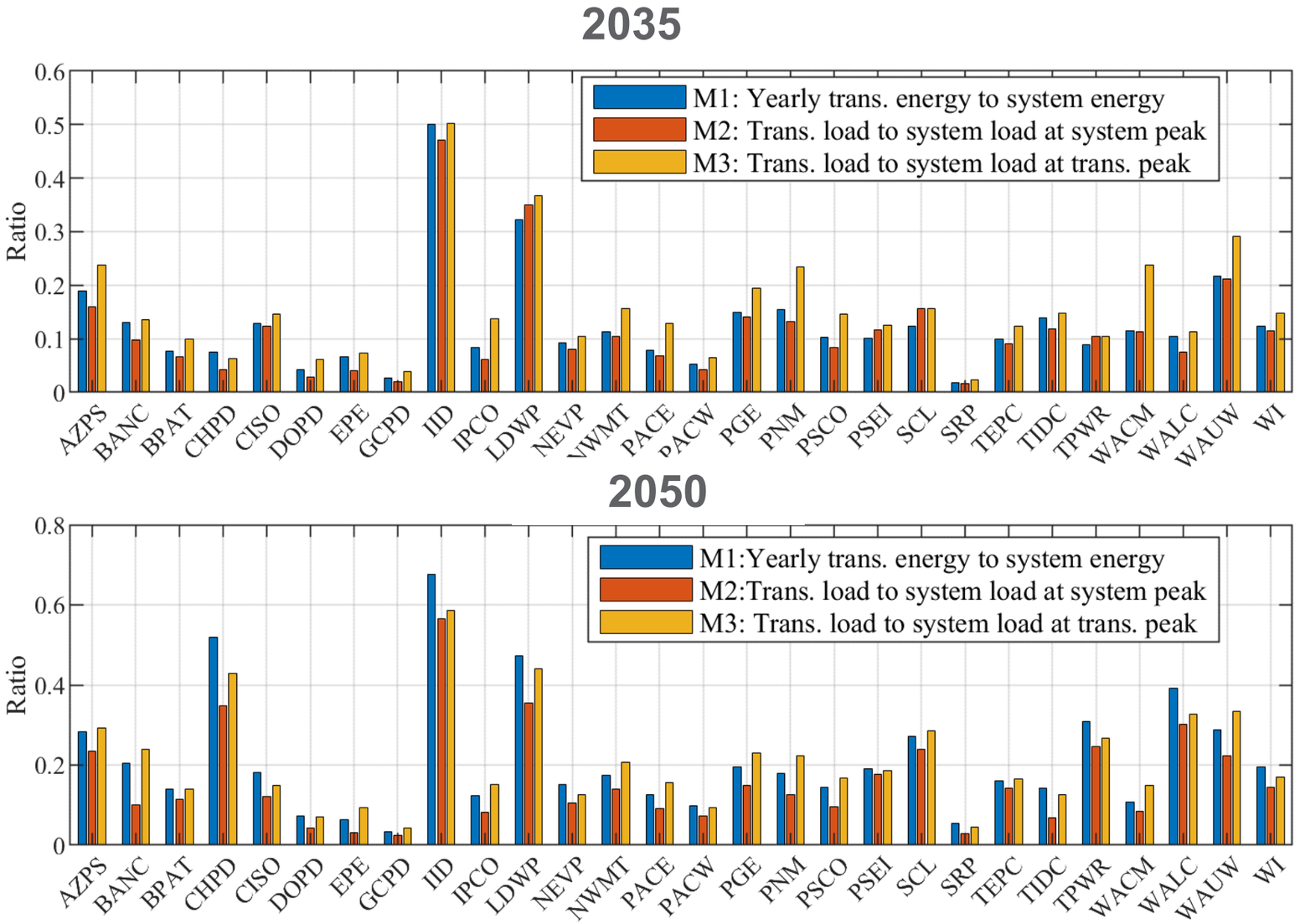
Peak Days





Result Snapshot: Transportation Demand

- Transportation load affects various BAs differently
- Approximately 10–20% of the system's peak load is impacted by transportation load for overall Western Interconnect
- BAs with predominantly residential and moderate climate regions experience more significant peak load penetration from transportation
- The peaks for transportation load and system load do not coincide



GODEEEP Data and Code

Key Datasets

- **Climate Forcing**
  - *Burleyson, C., Thurber, T., & Vernon, C. (2023). Projections of Hourly Meteorology by Balancing Authority Based on the IM3/HyperFACETS Thermodynamic Global Warming (TGW) Simulations (v1.0.0) [Data set]. MSD-LIVE Data Repository. https://doi.org/10.57931/1960530*
- **GCAM-USA Decarbonization Pathways**
  - Ou, Yang, & Iyer, Gokul. (2023). GCAM-USA Decarbonization Pathways for GODEEEP (2.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7838872
- **Total Electricity Load Profiles by Balancing Authority**
  - Burleyson, Casey, Thurber, Travis, Acharya, Samrat, & Ghosal, Malini. (2023). Total Load Profiles by Balancing Authority in the Western United States for GODEEEP (v1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8067472
- **Transportation Electrification Load Profiles by Balancing Authority**
  - Acharya, Samrat, Thurber, Travis B, & Ghosal, Malini. (2023). Transportation Electrification Load Profiles by Balancing Authority in the Western United States for GODEEEP (v1.0.1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8065137

Code

- https://github.com/GODEEEP and https://github.com/IMMM-SFA/tell

Webinars

- https://godeeep.pnnl.gov/webinars/

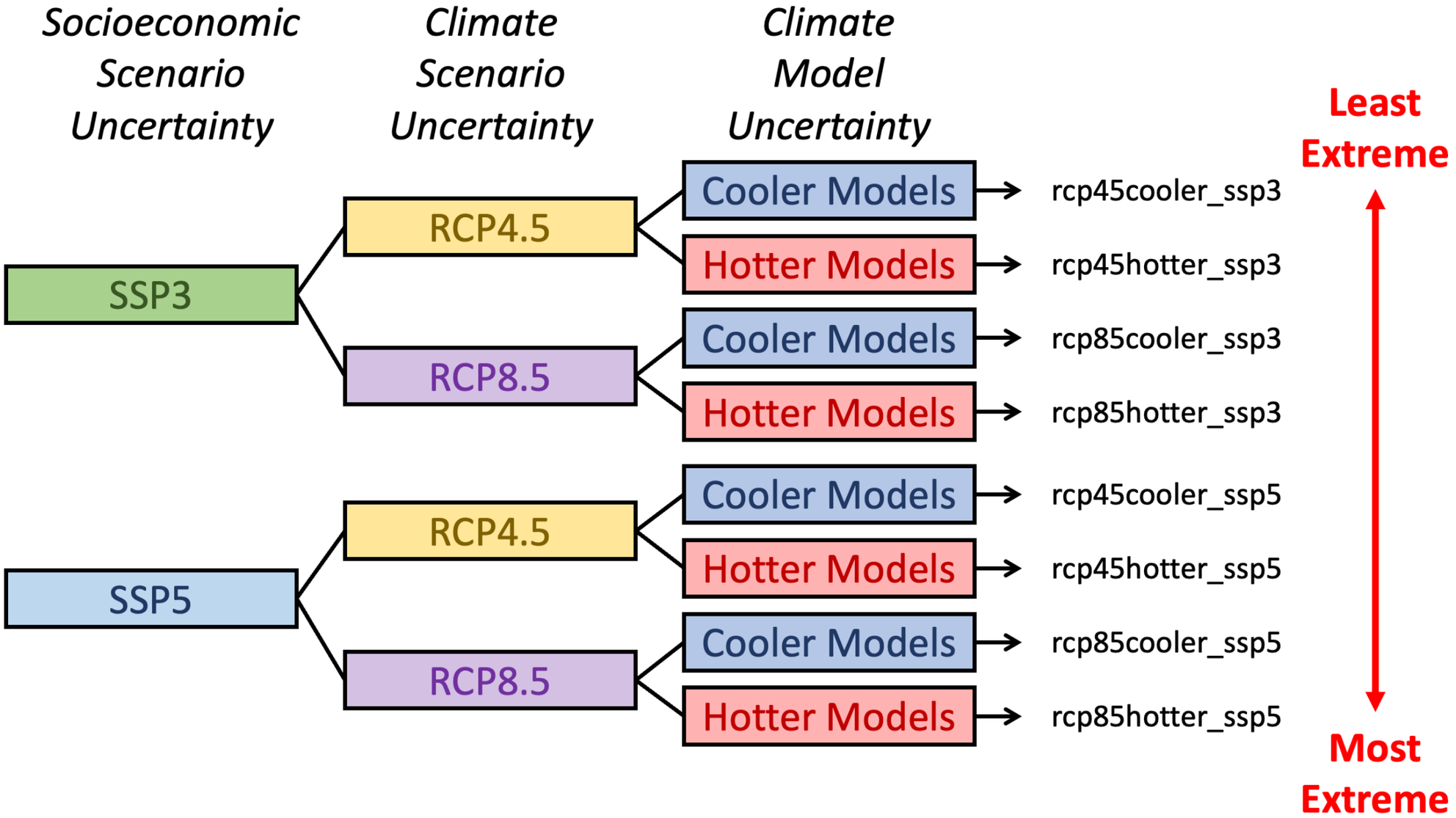
Scenario Divergence Study

- This research explores two basic questions: When do future electricity demand projections start to meaningfully diverge and what are the key drivers of that divergence?

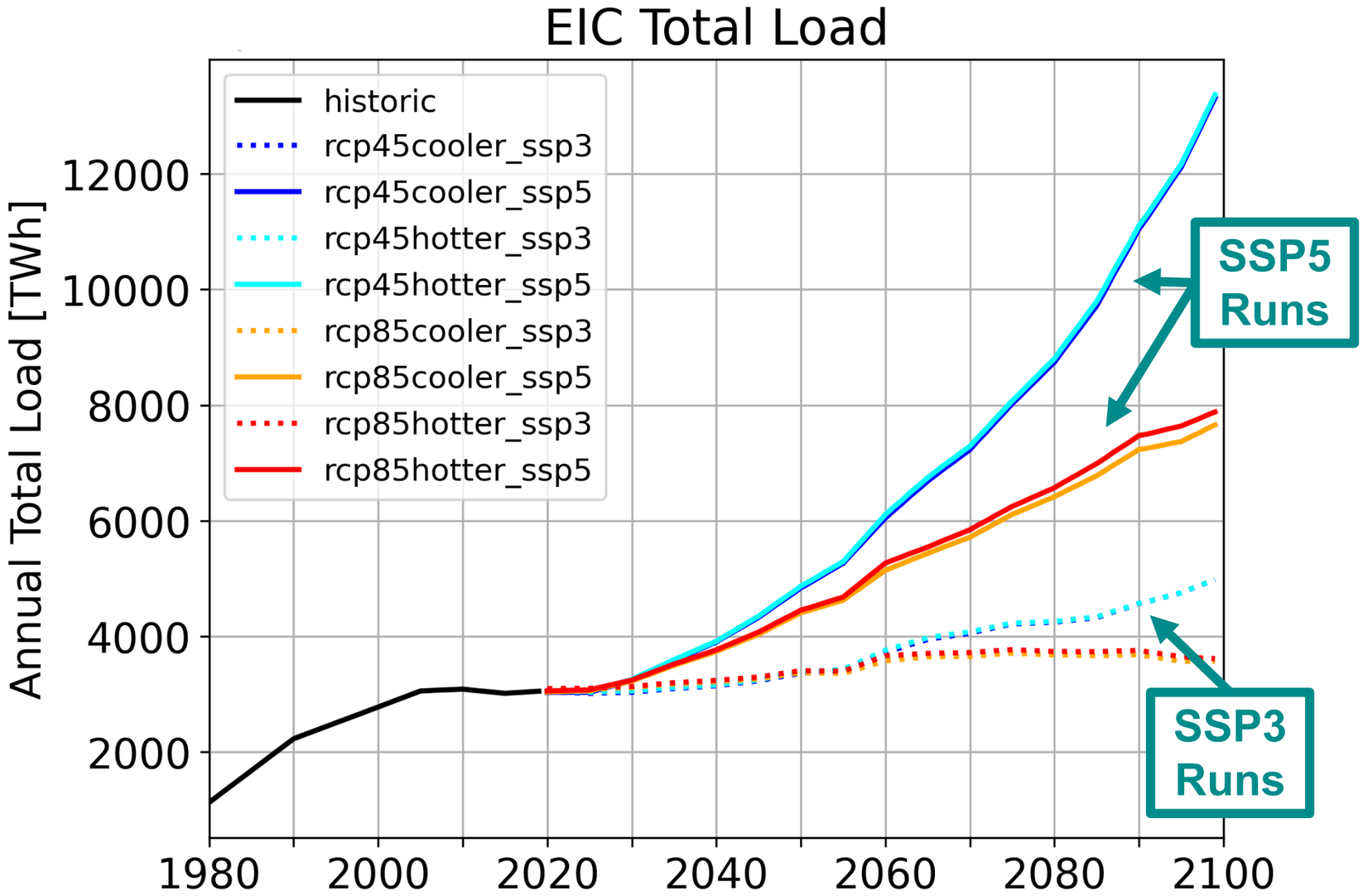
- These questions are important for demand-driven investment decisions in the energy sector, which are typically made using a 15- to 30-year time horizon. If future climate and socioeconomic projections do not lead to distinctly different demands within the first 30 years, then it may not matter which pathway we are likely on.

Burleyson, C. D., M. Kulshresta, Z. Khan, N. Voisin, and J. S. Rice, 2023: When do different scenarios of projected electricity demand start to meaningfully diverge? Submitted to *Applied Energy*.

Constructing a Meaningful Spread of Scenarios



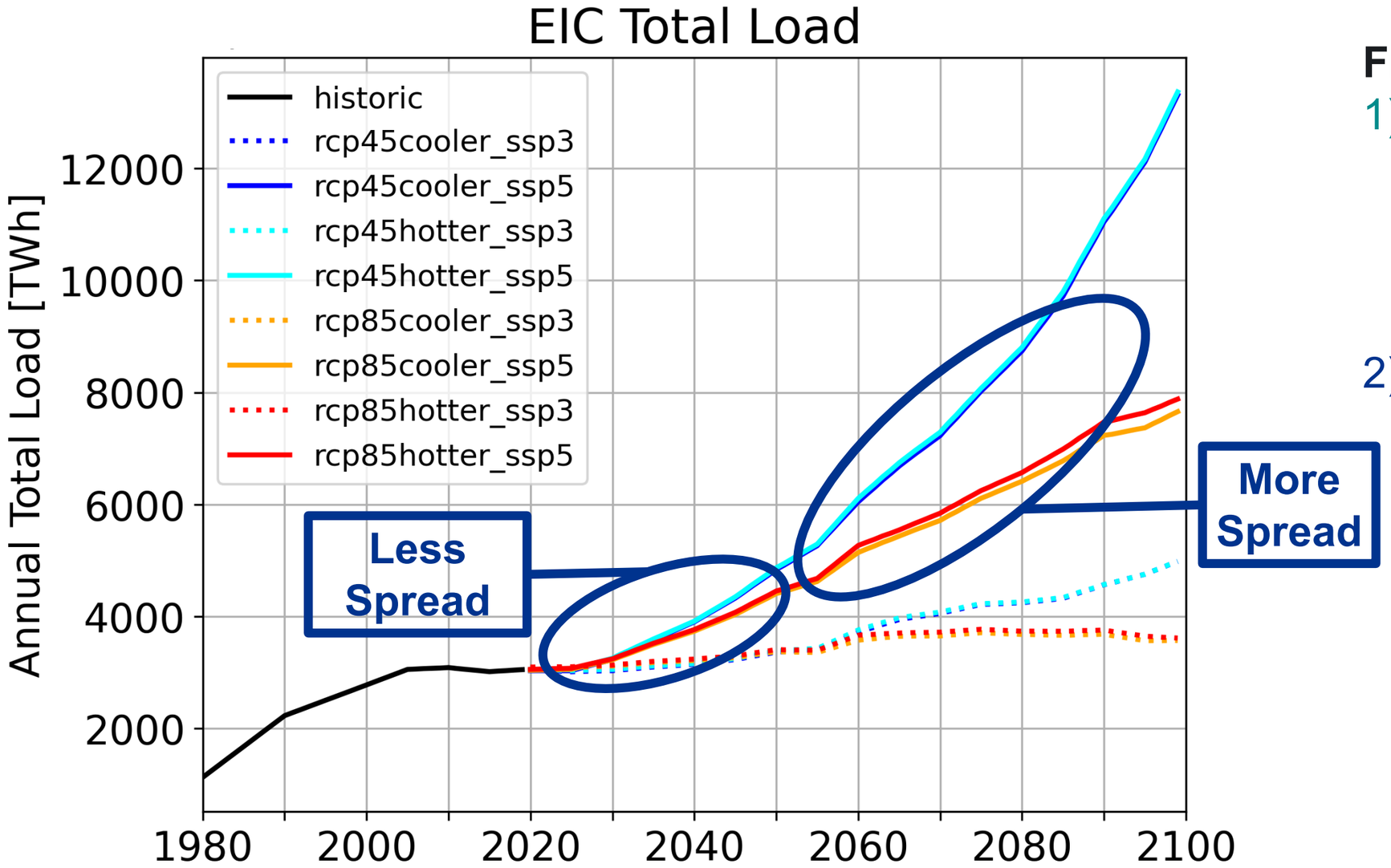
Scenario-Driven Demand Divergence



Findings

1) SSP5 demand projections are immediately and significantly higher than the SSP3 projections.

Scenario-Driven Demand Divergence



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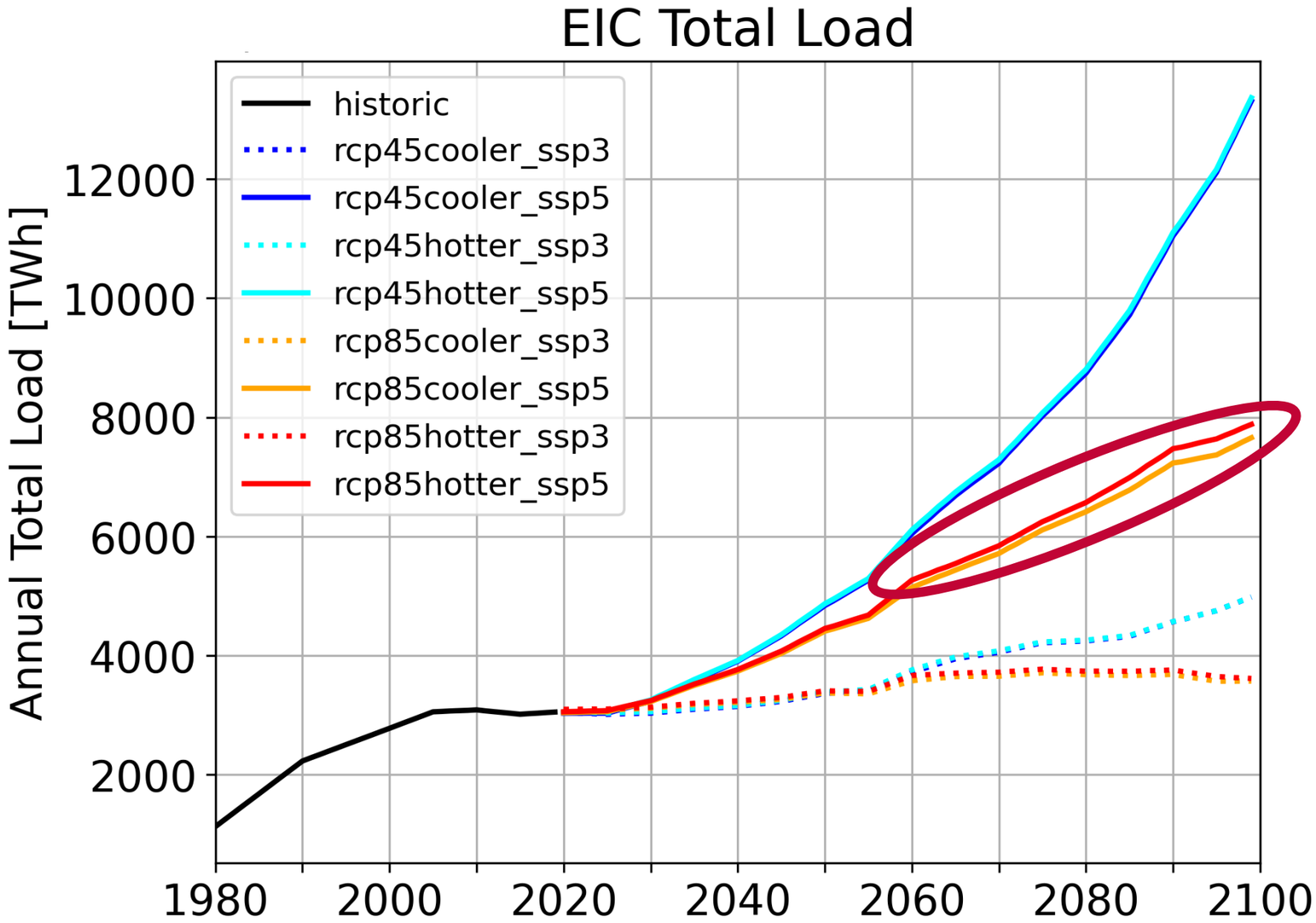
1) SSP5 demand projections are immediately and significantly higher than the SSP3 projections.
2) Spread across the climate scenarios is small for the first 20-30 years but then starts to increase in the latter 50 years.

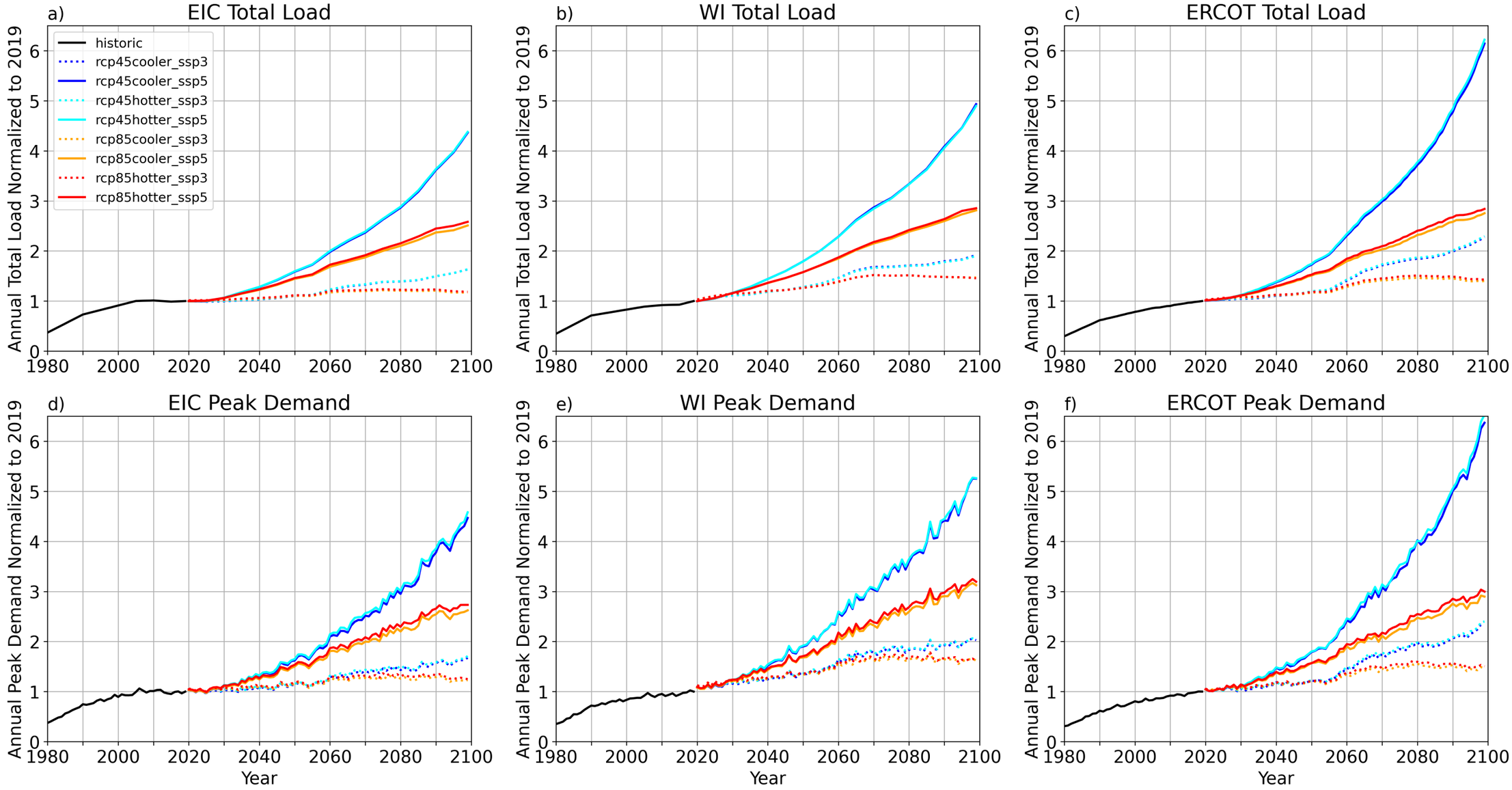
Scenario-Driven Demand Divergence



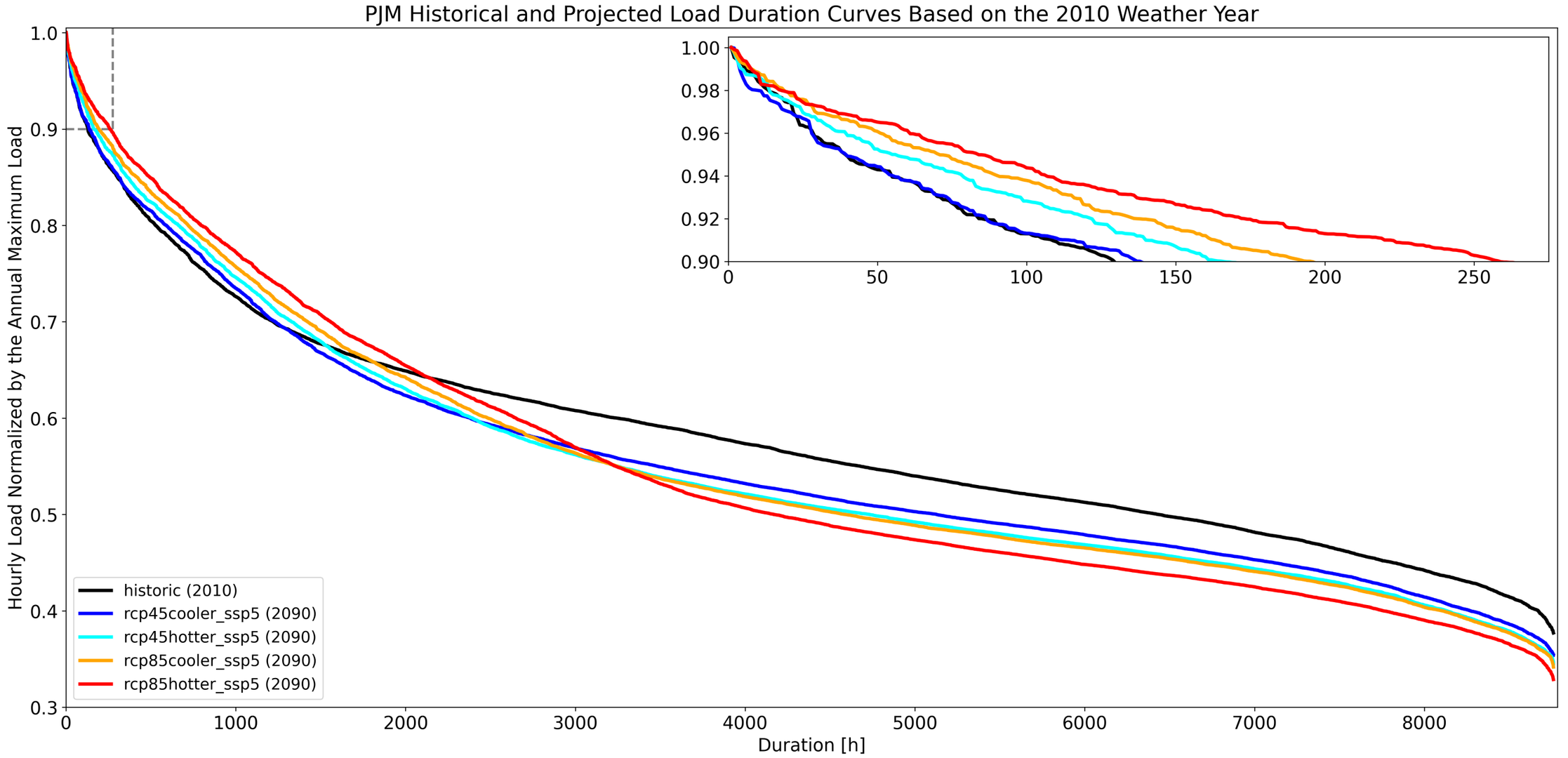
Findings

1) SSP5 demand projections are immediately and significantly higher than the SSP3 projections.
2) Spread across the climate scenarios is small for the first 20-30 years but then starts to increase in the latter 50 years.
3) Climate model sensitivity is very small even at the end of the century.

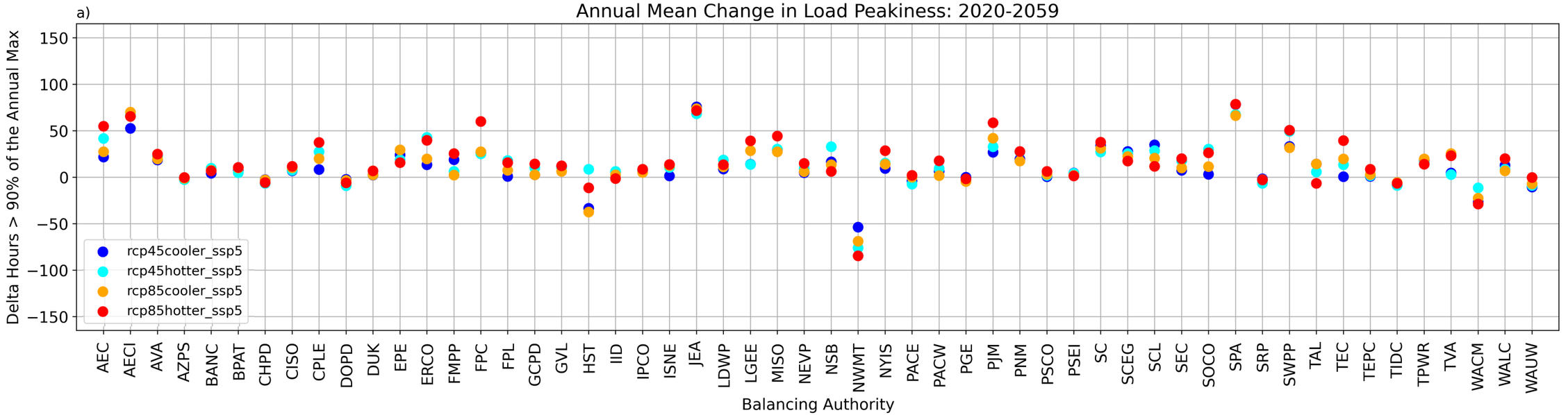
Results Are Consistent Across Interconnections



Change in Load Peakiness Calculation

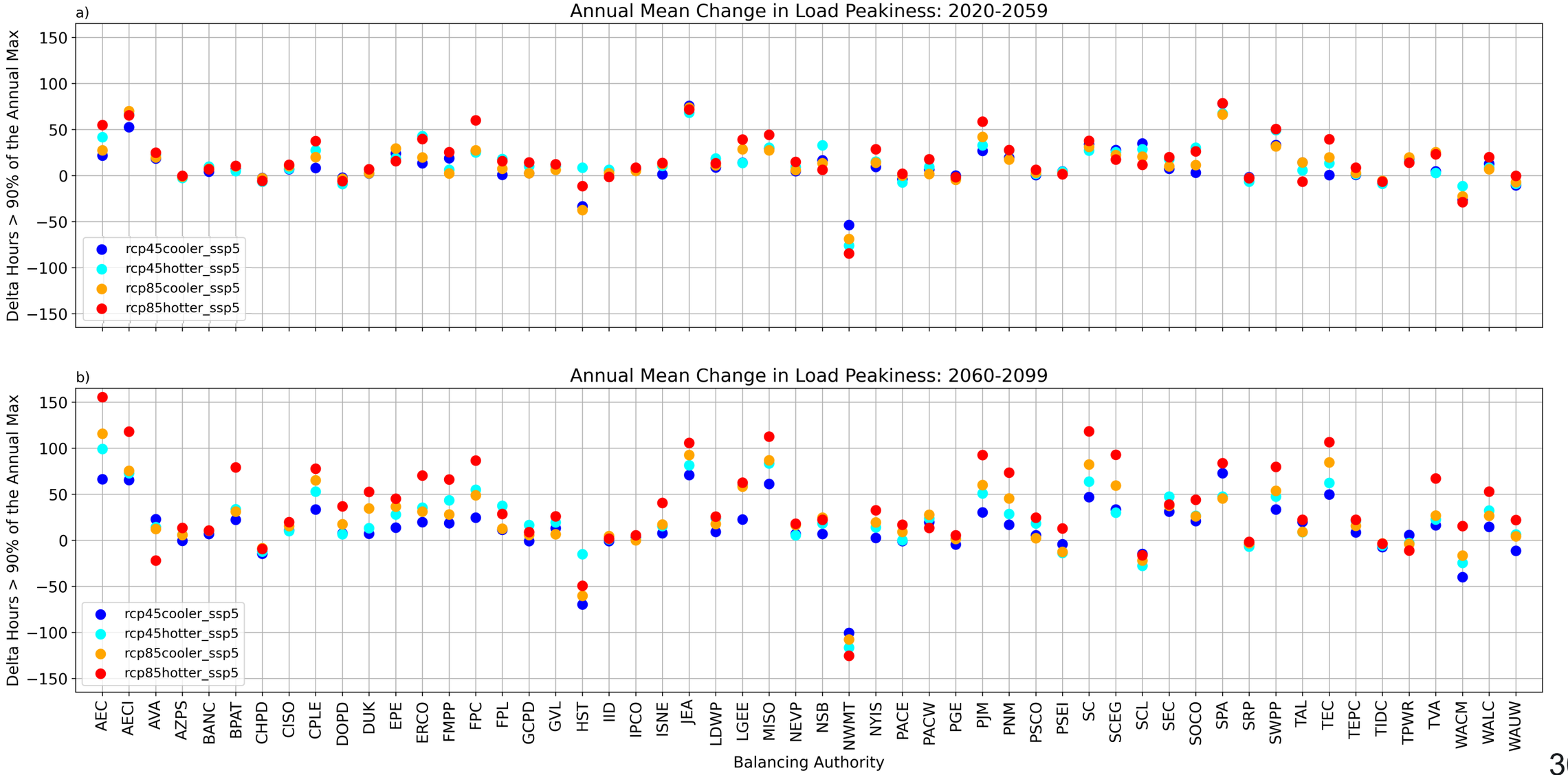


Loads Become Peakier



Loads become “peakier” over time (e.g., more hours closer to the annual peak value), but the various climate scenarios give roughly the same magnitude of increase for the first forty years.

Loads Become Peakier



Key Messages and Results

- We are translating scientific understanding into actionable power-system relevant data and insights for use in long-term planning.
- Innovations:
  - Combining global economic model with bottom-up technology-specific transportation model to create load projections for multiple decarbonization scenarios.
  - Exploring scenario uncertainty: When does it matter what climate model you use?
- Results:
  - Clean grid mandates modify the generation mix. Net zero mandates dramatically modify the total demand for electricity.
  - Transportation electrification modifies the load shapes in important ways. We would expect similar signals with the electrification of building heating.
  - In order of relative importance for electricity demand:
    - Climate policy uncertainty: Tied to when policies take effect
    - Socioeconomic scenario uncertainty: Matters almost immediately
    - Climate scenario uncertainty: Matters within 25-30 years
    - Climate model uncertainty: Matters only after 50+ years