INTEGRATED
MULTISECTOR
MULTISCALE
MODELING

POWER SYSTEMS ANALYSIS TO SUPPORT MSD RESEARCH:

BALANCING COMPUTATIONAL SPEED AND MODEL FIDELITY

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North Carolina State University

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Pacific Northwest National Laboratory | Baylor University | Berkeley Lab | Boston University | UC Davis University of California | Cornell University | NC State University | The University of North Carolina at Chapel Hill | Oak Ridge National Laboratory | Sandia National Laboratories

CRITICAL CHALLENGES FOR POWER SYSTEMS

Electricity systems must **expand and rapidly decarbonize** while also withstanding **extreme weather events** that are becoming more frequent and severe due to climate change.

Commonly explored via:

Capacity Expansion

- Long term optimal infrastructure planning
- ***What's the cheapest way to decarbonize by 2050?*** (NREL ReEDS; Princeton GenX, TEMOA)
- Uncertainty driven by **year-on-year, macro-trends** (climate, economy, technology)
- Constrained by "representative days"

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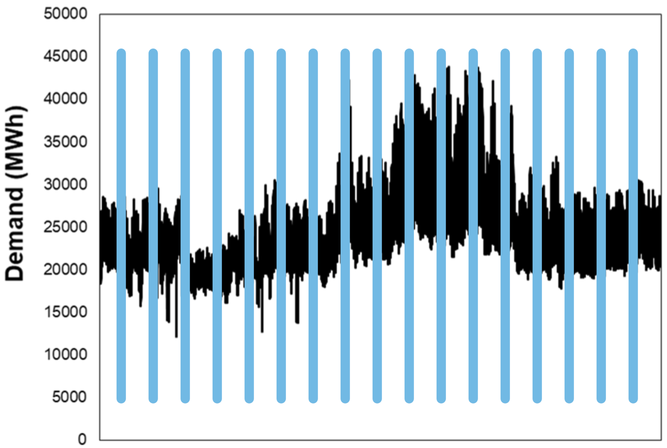

Small set of time slices, weather years

Limited or no transmission constraints

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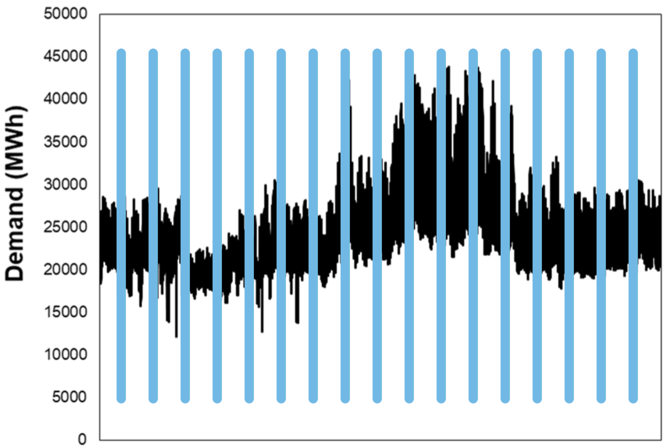


Small set of time slices, weather years

Limited or no transmission constraints

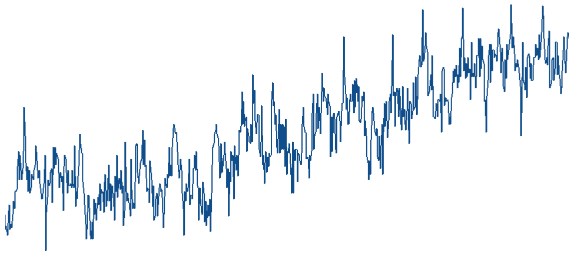
Operational Models

- Short term simulation/optimization, given set of grid infrastructure
- ***What's the cheapest way to operate the system over the next week?*** (Plexos, Gridview)

OPERATIONAL MODELS, IN A NUTSHELL

Hourly time series of everything

(demand, wind, solar, fuel prices, component outages)



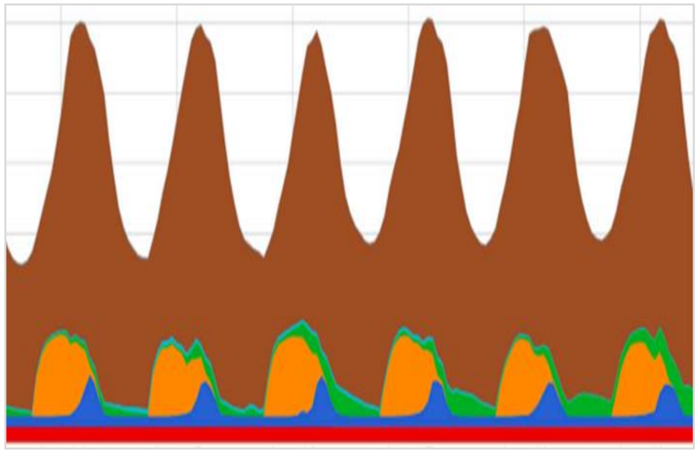
→

Rolling optimization
(LP, MILP)

Objective: minimize system wide cost of meeting demand

→

Optimal Generation Mix



Time

Plus: power flows, locational marginal prices, emissions (GHGs, criteria air pollutants)

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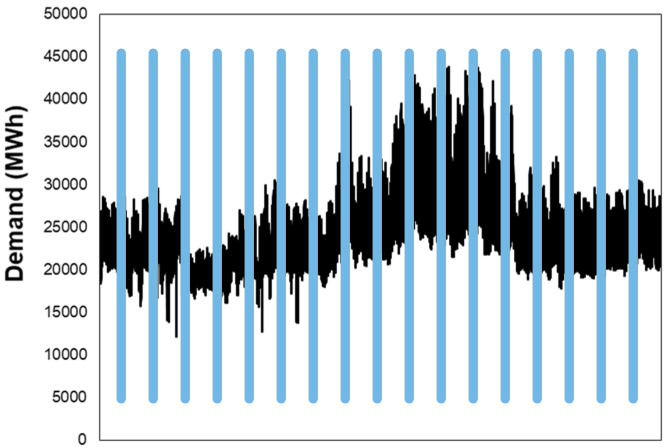

Small set of time slices, weather years

Limited or no transmission constraints

Operational Models

- Short term simulation/optimization, given set of grid infrastructure
- ***What's the cheapest way to operate the system over the next week?*** (Plexos, Gridview)
- Deterministic/stochastic → variability/uncertainty **driven by weather**
- Detailed operational constraints

CRITICAL CHALLENGES FOR POWER SYSTEMS

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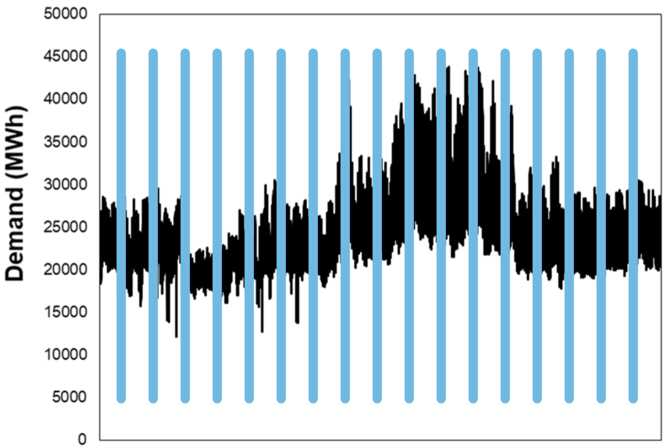

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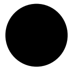
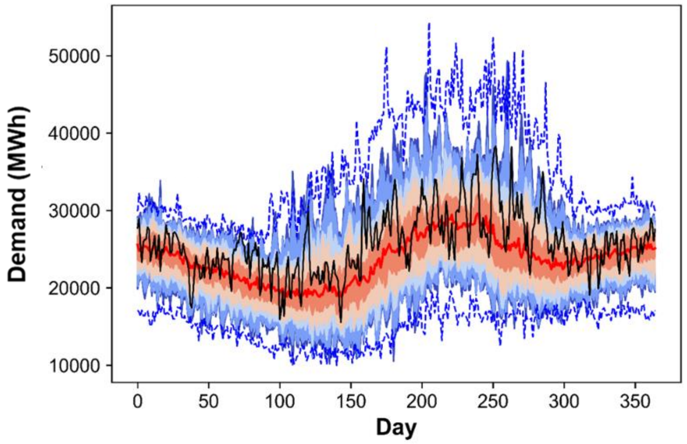
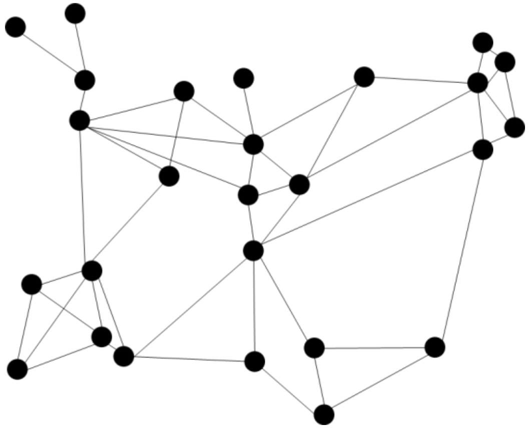


Operational Models

Stochastic ensemble



Network (full or reduced)



CRITICAL CHALLENGES FOR POWER SYSTEMS

Electricity systems must **expand and rapidly decarbonize** while also withstanding **extreme weather events** that are becoming more frequent and severe due to climate change.

Commonly explored via:

Capacity Expansion **Soft** → **Operational Models**

e.g., weather "stress testing" future decarbonization plans

CRITICAL CHALLENGES FOR POWER SYSTEMS

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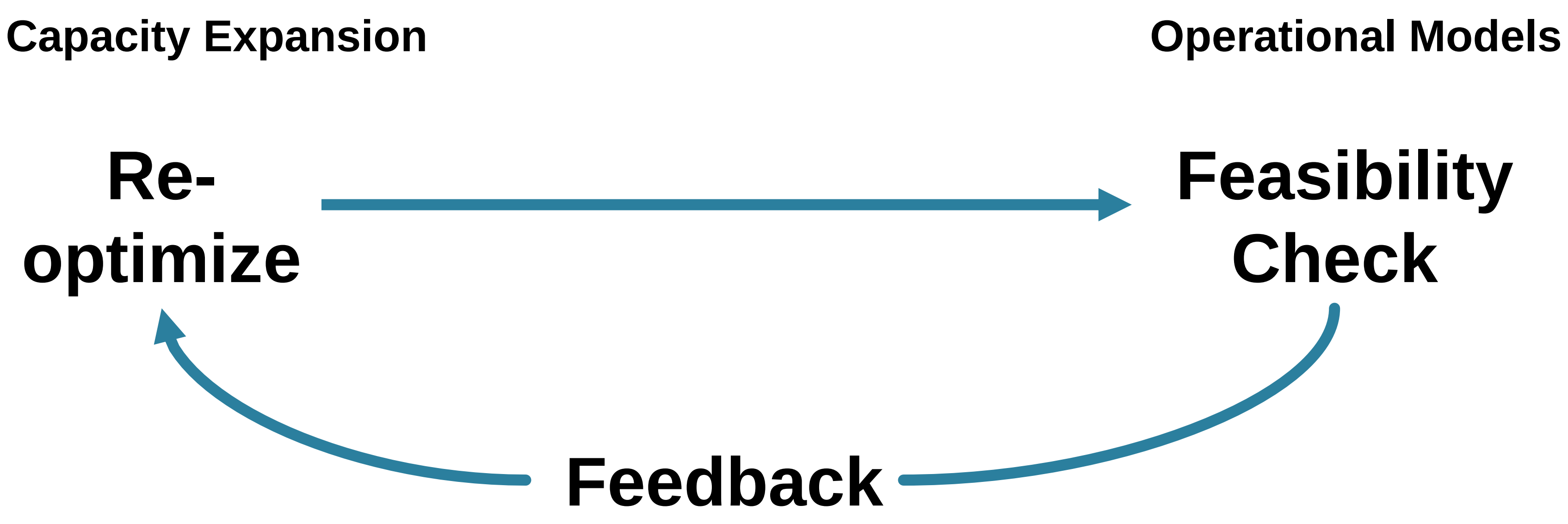
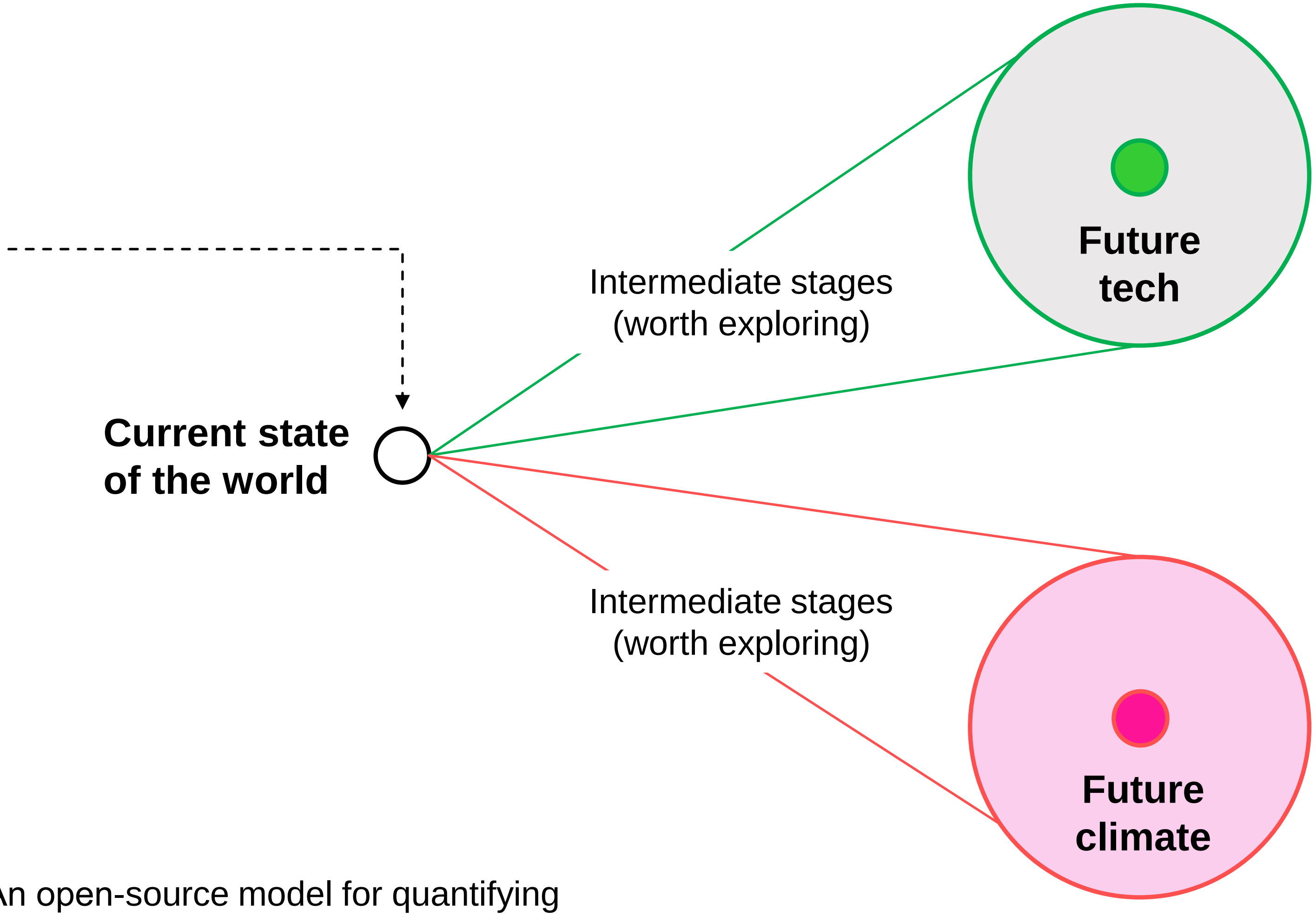
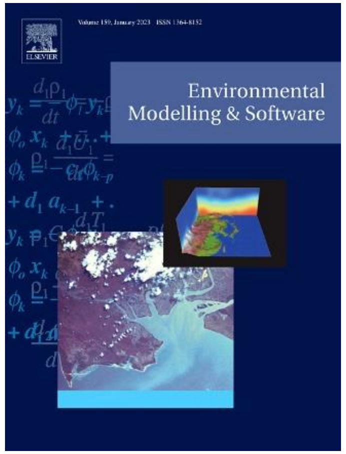


OPERATIONAL MODELS ARE COMPUTATIONALLY EXPENSIVE

800+ years* is a lower bound estimate of the simulation size needed to capture stationary weather uncertainty in the 2020 U.S. Western grid





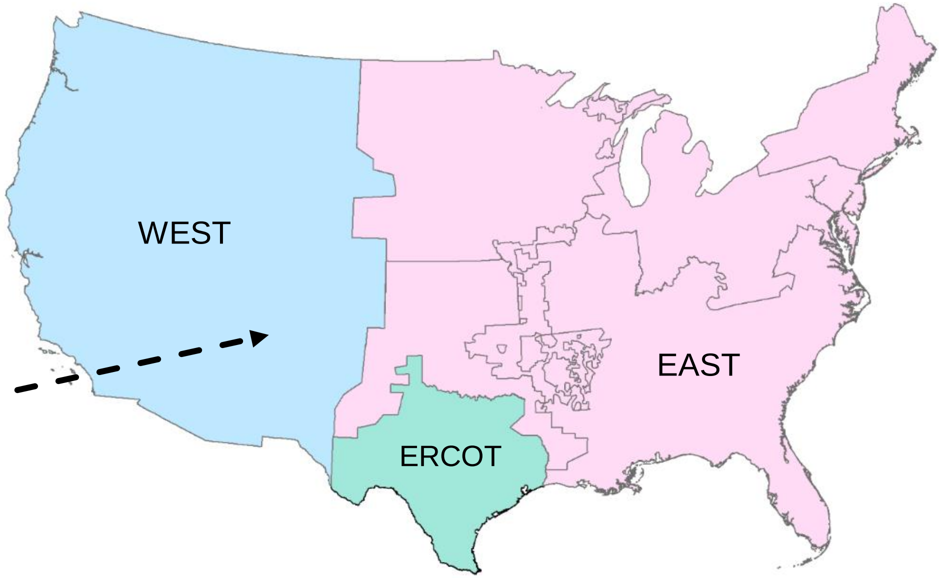
* **Su, Y** et al. (2020). “An open-source model for quantifying risks in bulk electric power systems from spatially and temporally correlated hydrometeorological processes”. ***Environmental Modelling and Software***. Vol. 126, April 2020, 104667.

BALANCING COMPUTATIONAL COSTS WITH MODEL FIDELITY

IM3 Phase 2 (*2021-2024*): Develop open-source software to assess the vulnerability and resilience of U.S. electric power systems to both short- and long-term influences, from local to continental scales.

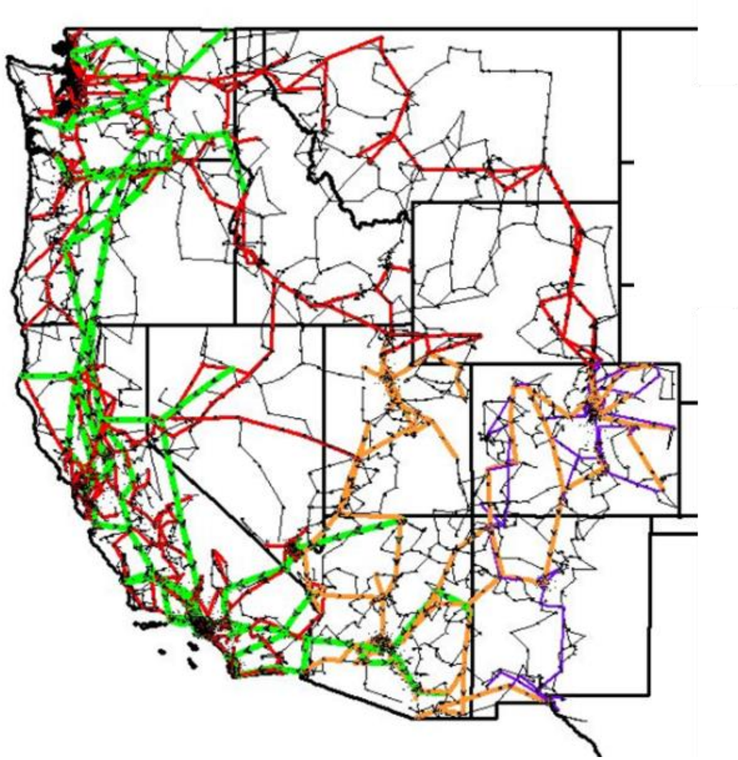
So, we built **GO** (grid operations).

- Leverages open-source datasets from **ARPA-E**, **EIA**, **EPA,** and **NERC.**
- Users can quickly instantiate direct current optimal power flow (DC OPF) models for the **three major electrical interconnections** and then calibrate them using historical grid performance data.



NETWORK REDUCTION

Original synthetic grid (10k nodes)



Developed with ARPA-E support by:
https://electricgrids.engr.tamu.edu/

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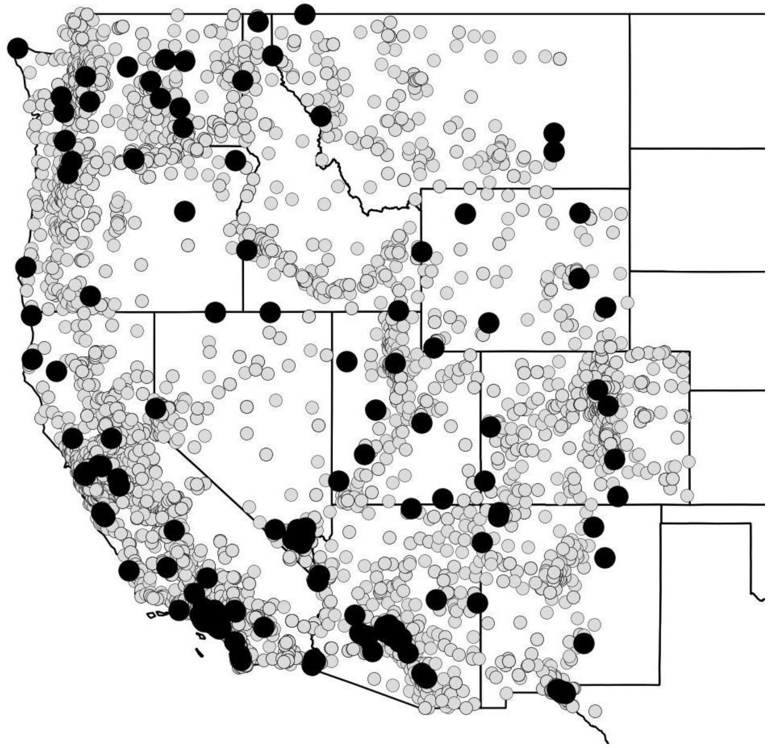
Key grid locations



Largest MW plants, load centers, and transmission nodes

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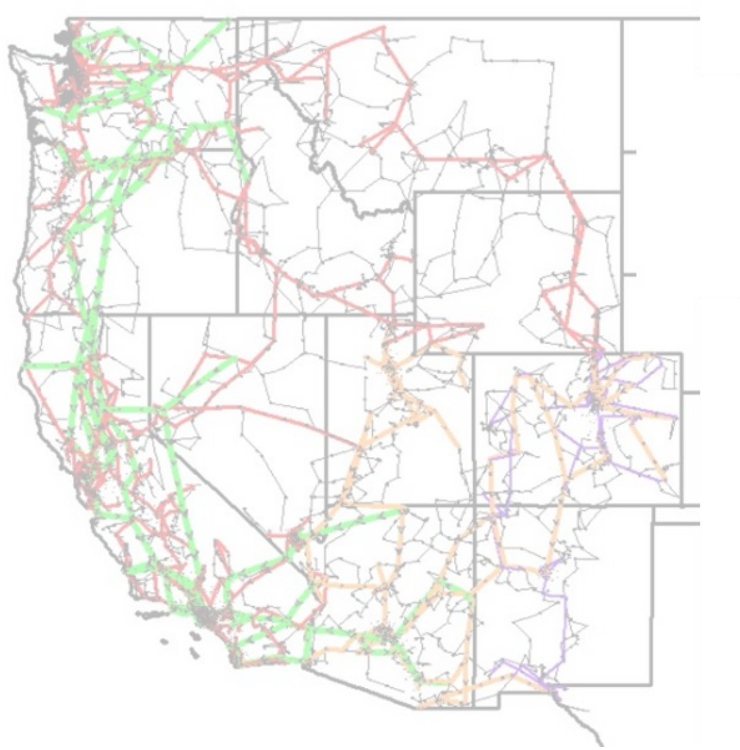

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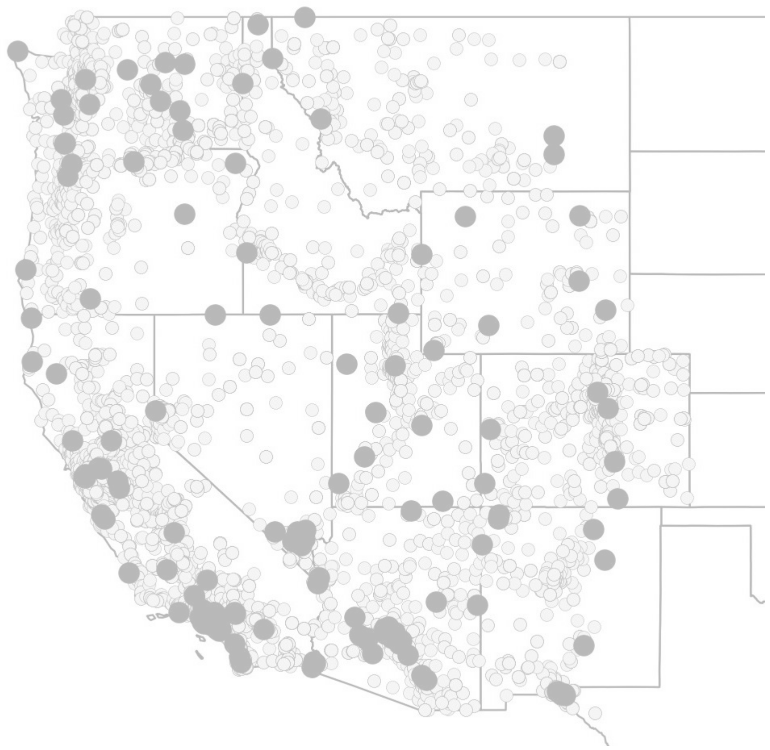
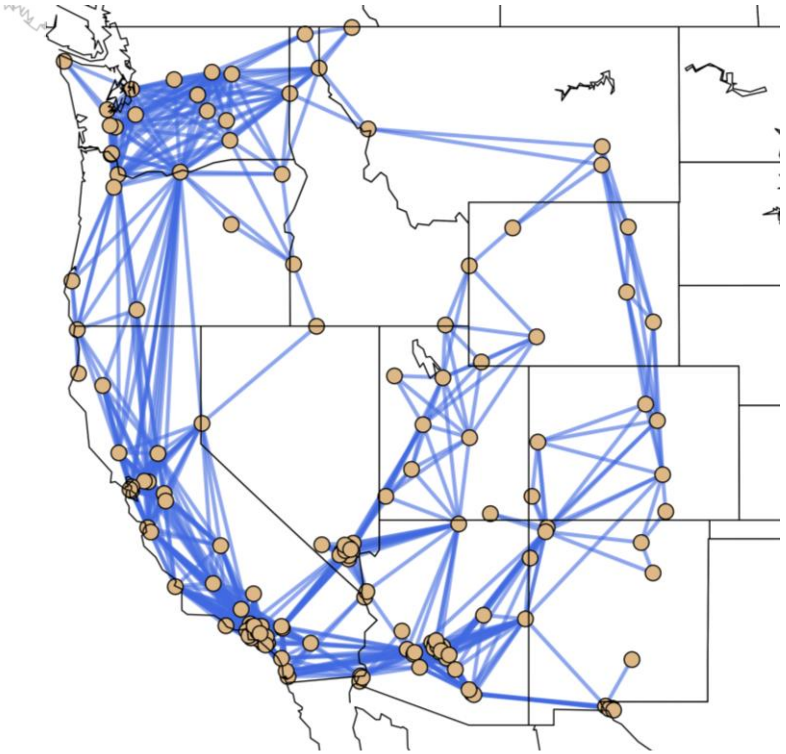


Largest MW plants, load centers, and transmission nodes

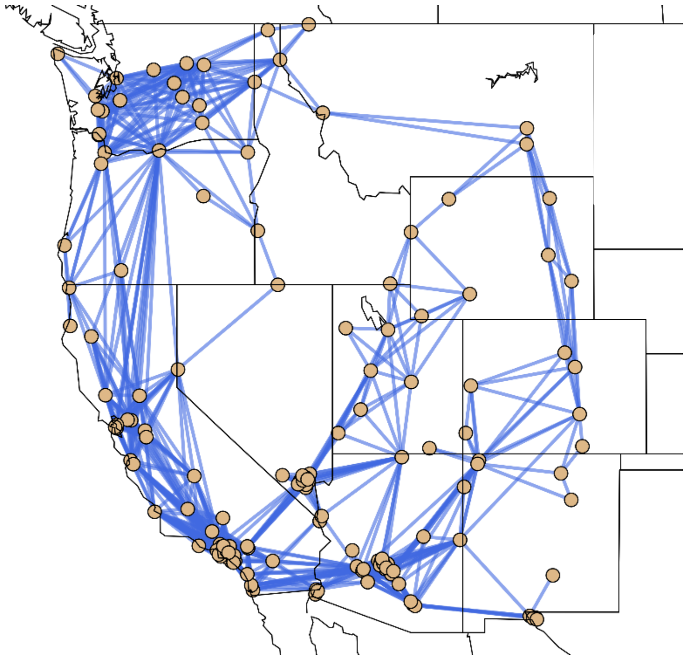
150 node network



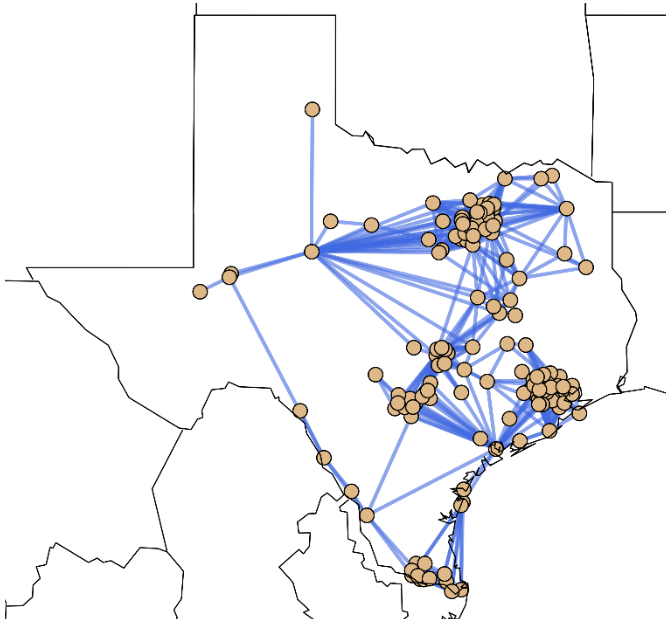
Network reduced, assets merged into smaller nodal set

The Grid Operations (GO) family of models

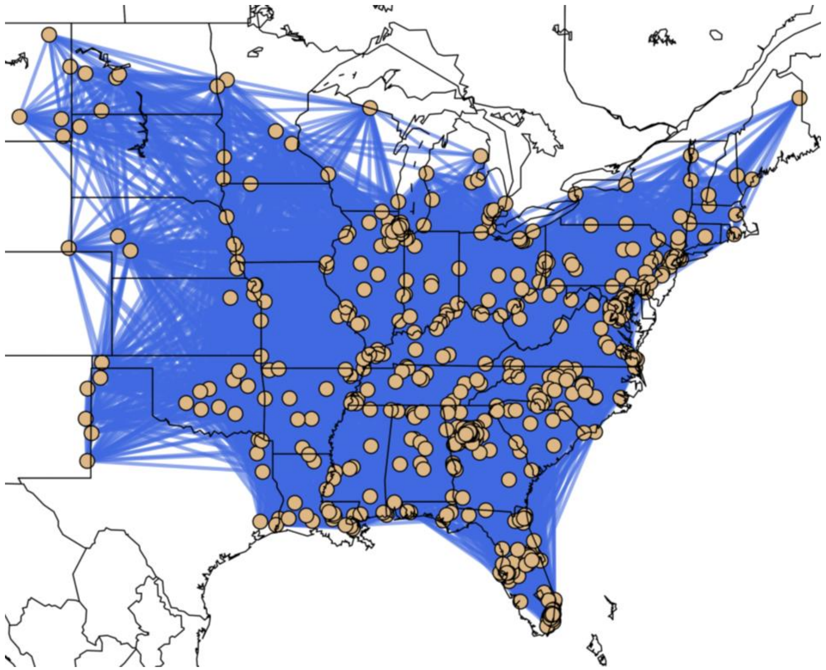
GO WEST



GO ERCOT



GO EAST



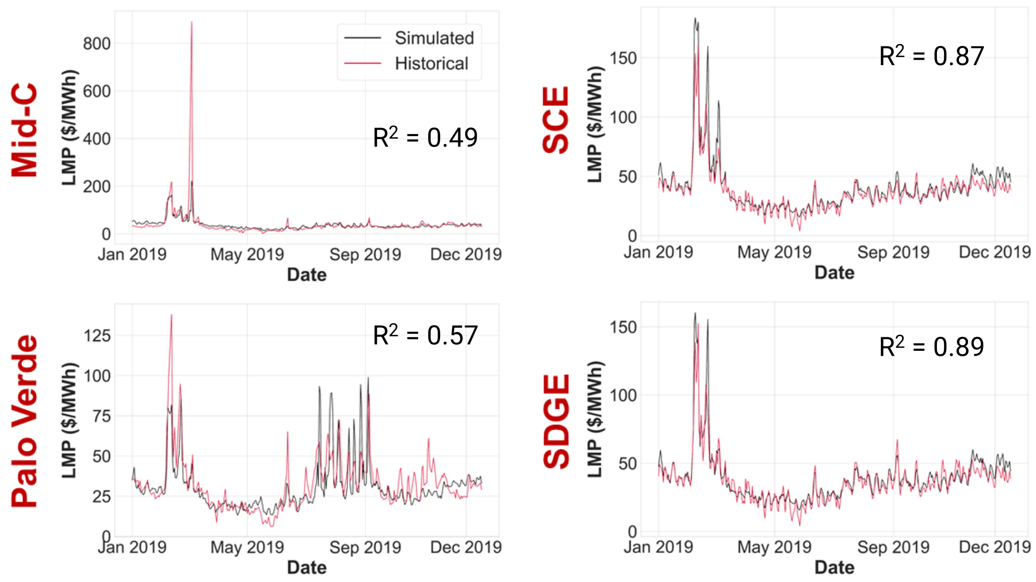
IM3

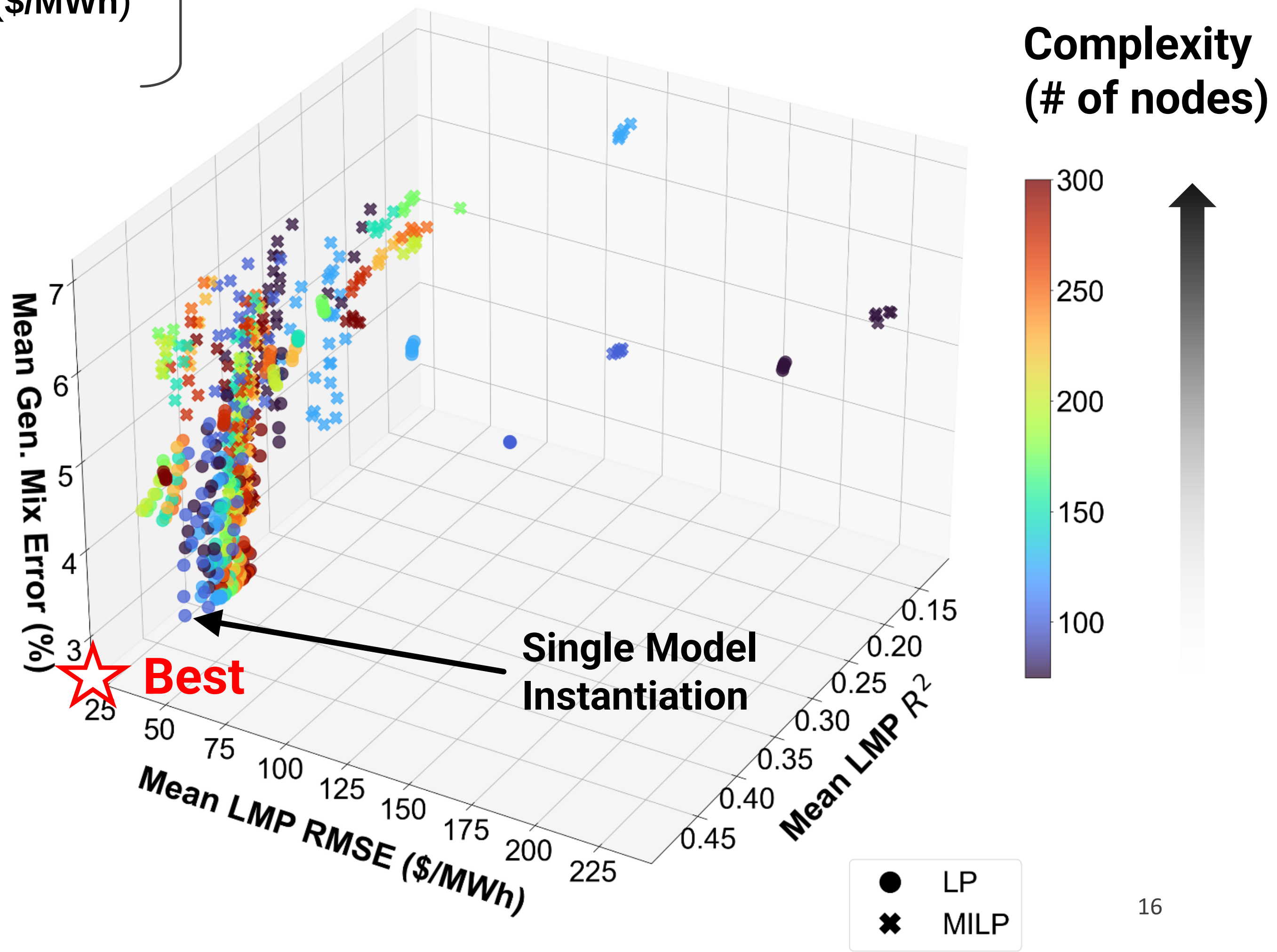
Parameter sweep:

- Network granularity (**# of nodes**)
- Mathematical formulation
- Transmission line scaling (**+MW**)
- Transmission exchange penalties (**$/MWh**)
- Scarcity price adders (**+$/MWh**)

100s – 1000s of model versions

Single Model Instantiation





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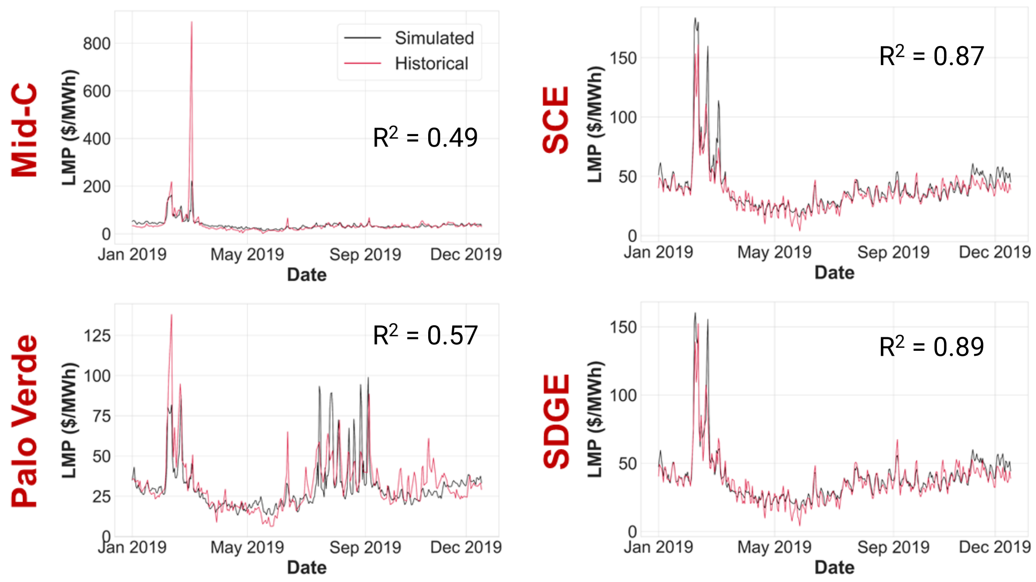
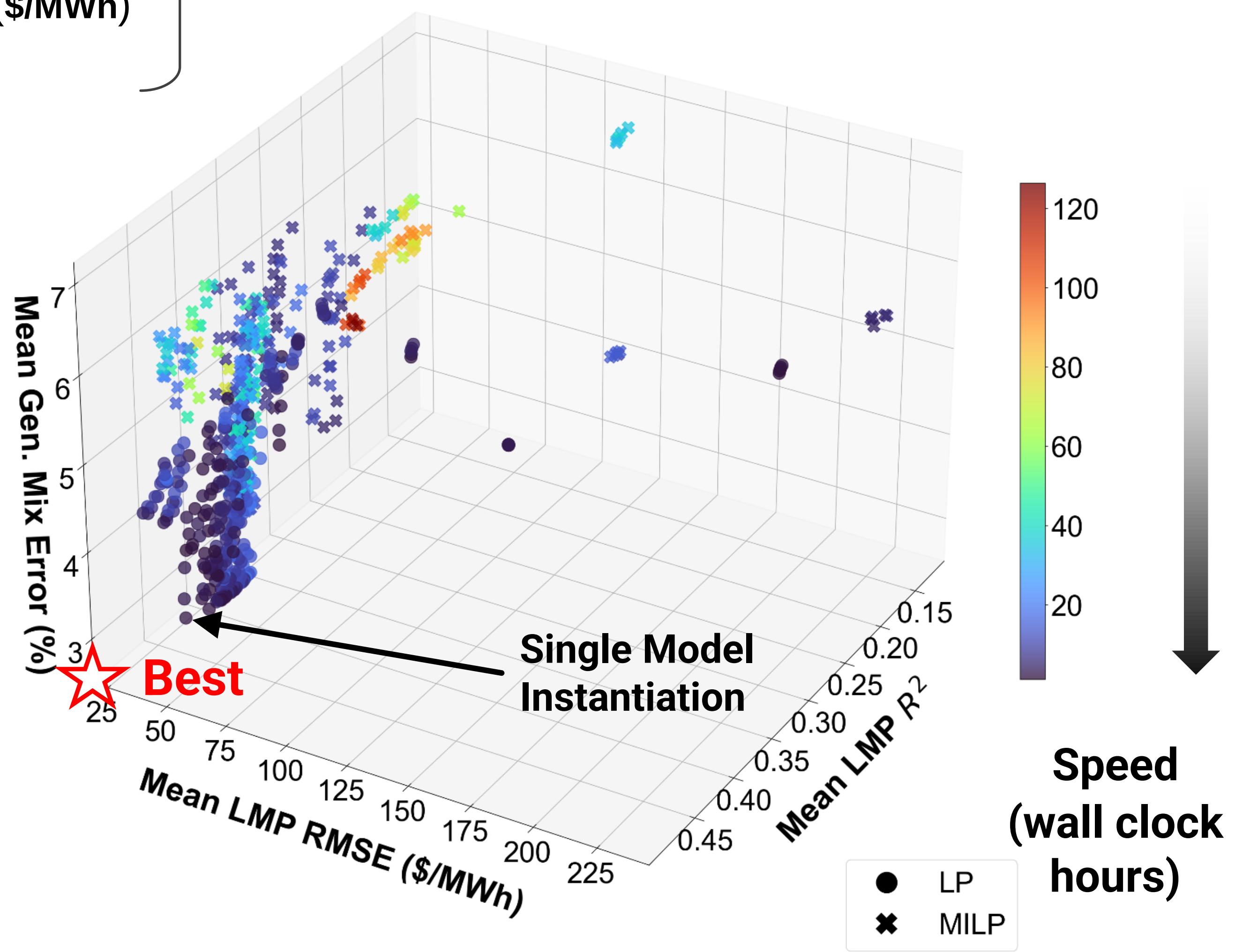
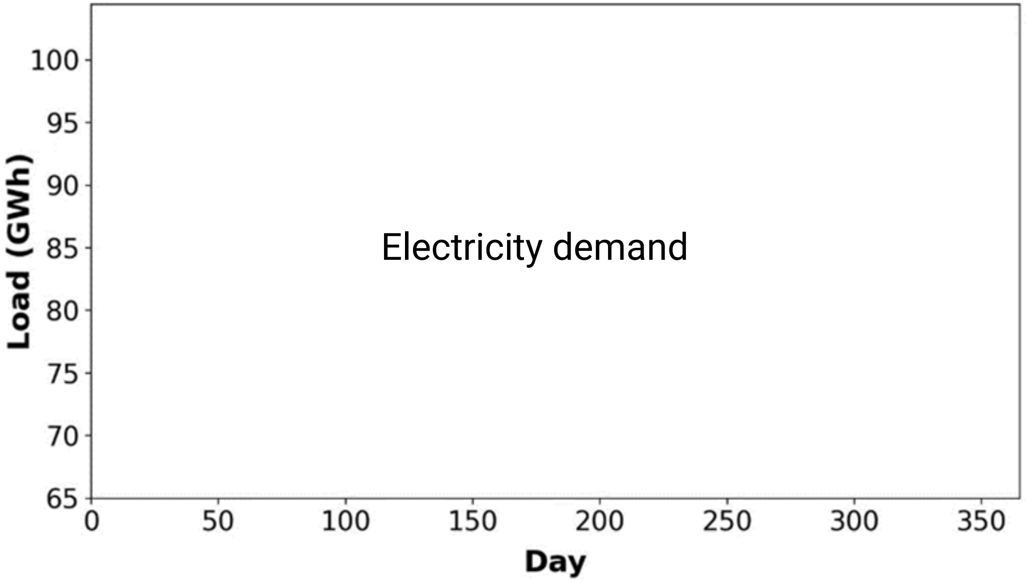
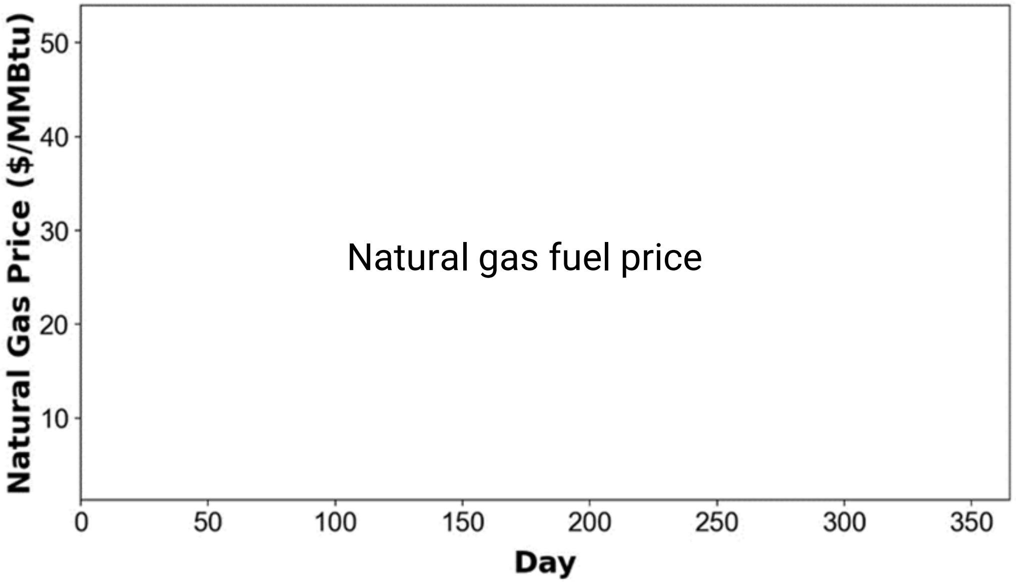


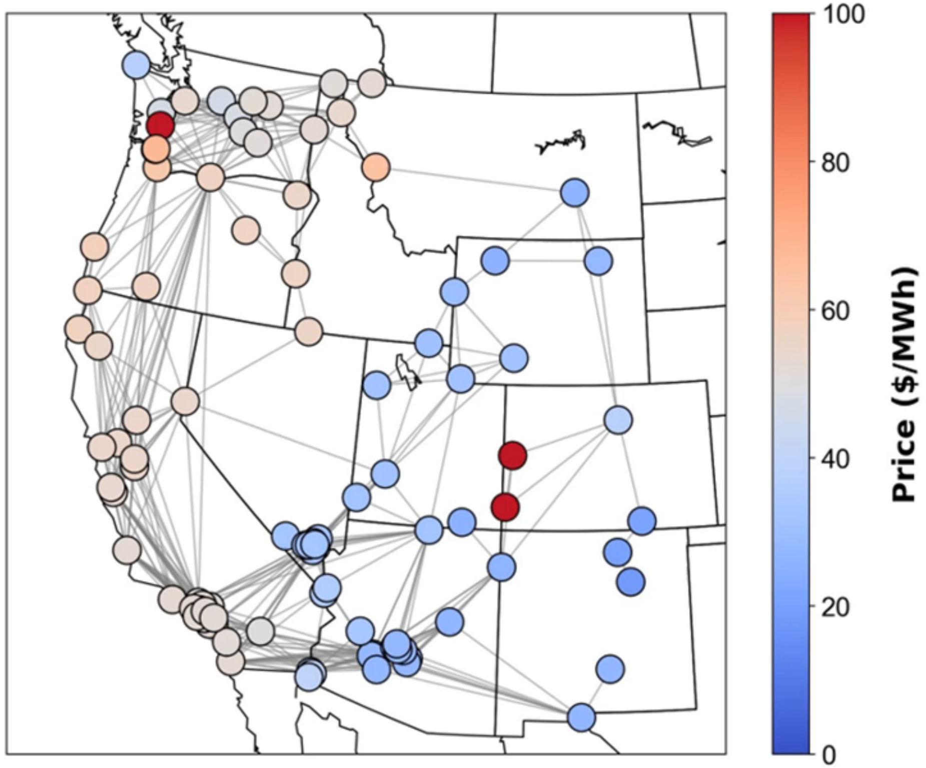


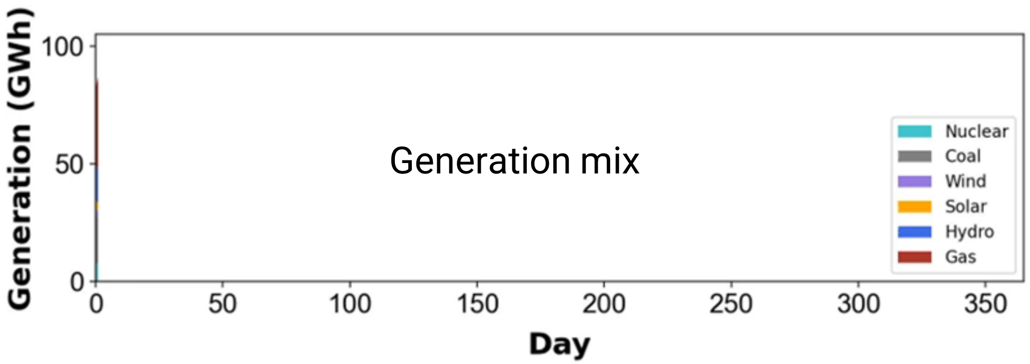
An example:

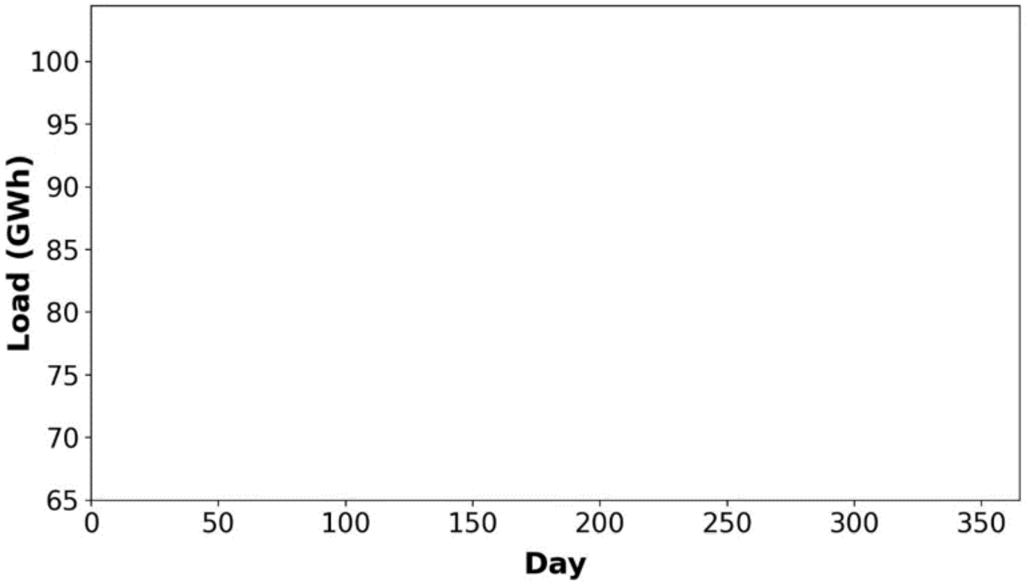
Recreating Western grid dynamics for 2019

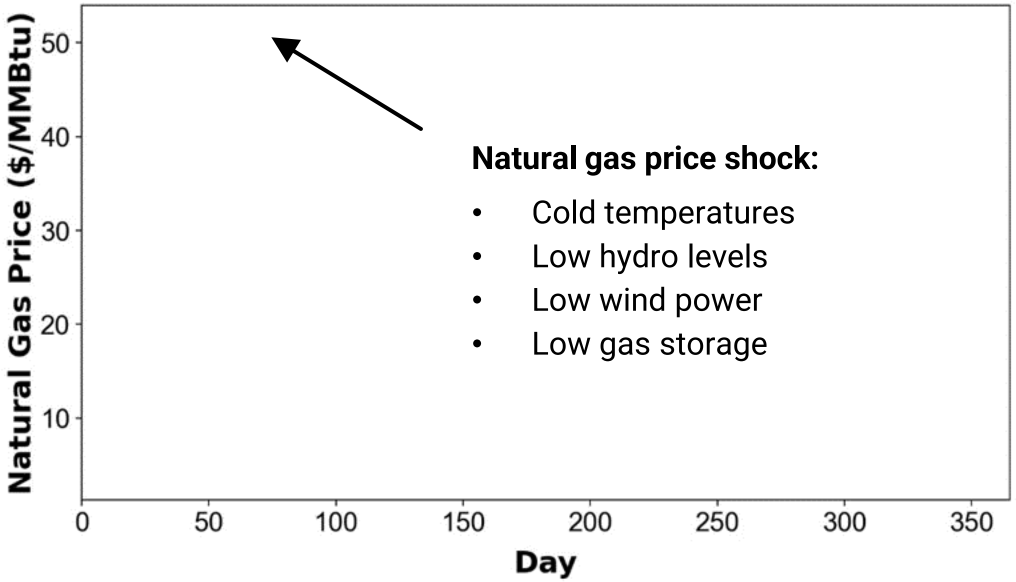

Electricity demand
Load (GWh)
100
95
90
85
80
75
70
65
0
50
100
150
200
250
300
350
Day

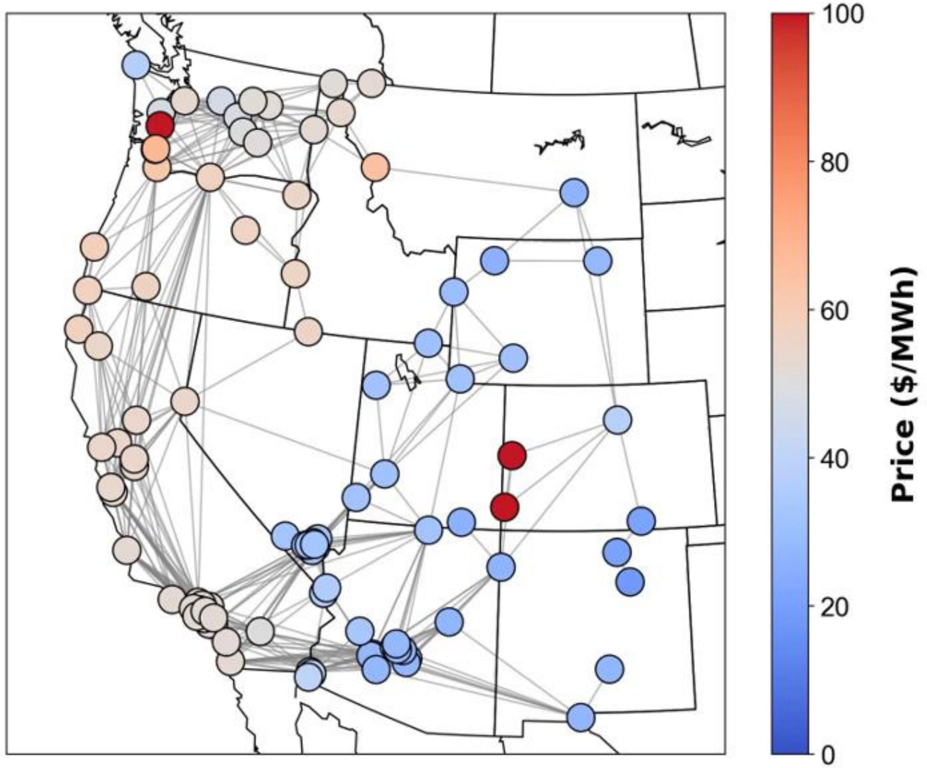

Natural gas fuel price
Natural Gas Price ($/MMBtu)
50
40
30
20
10
0
50
100
150
200
250
300
350
Day

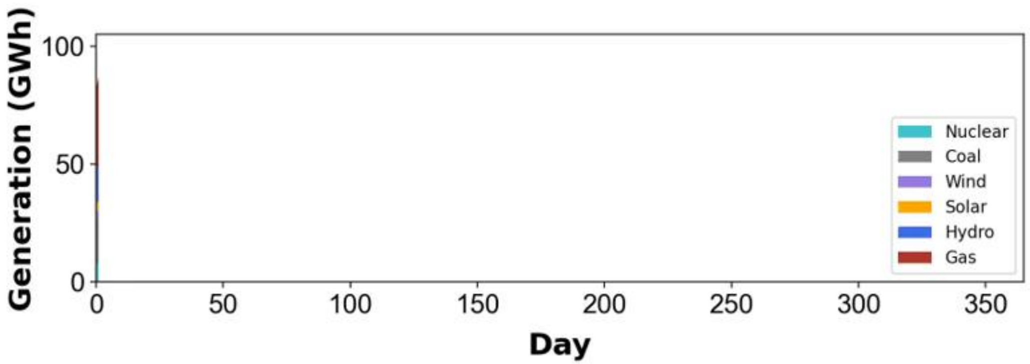

Price ($/MWh)
100
80
60
40
20
0

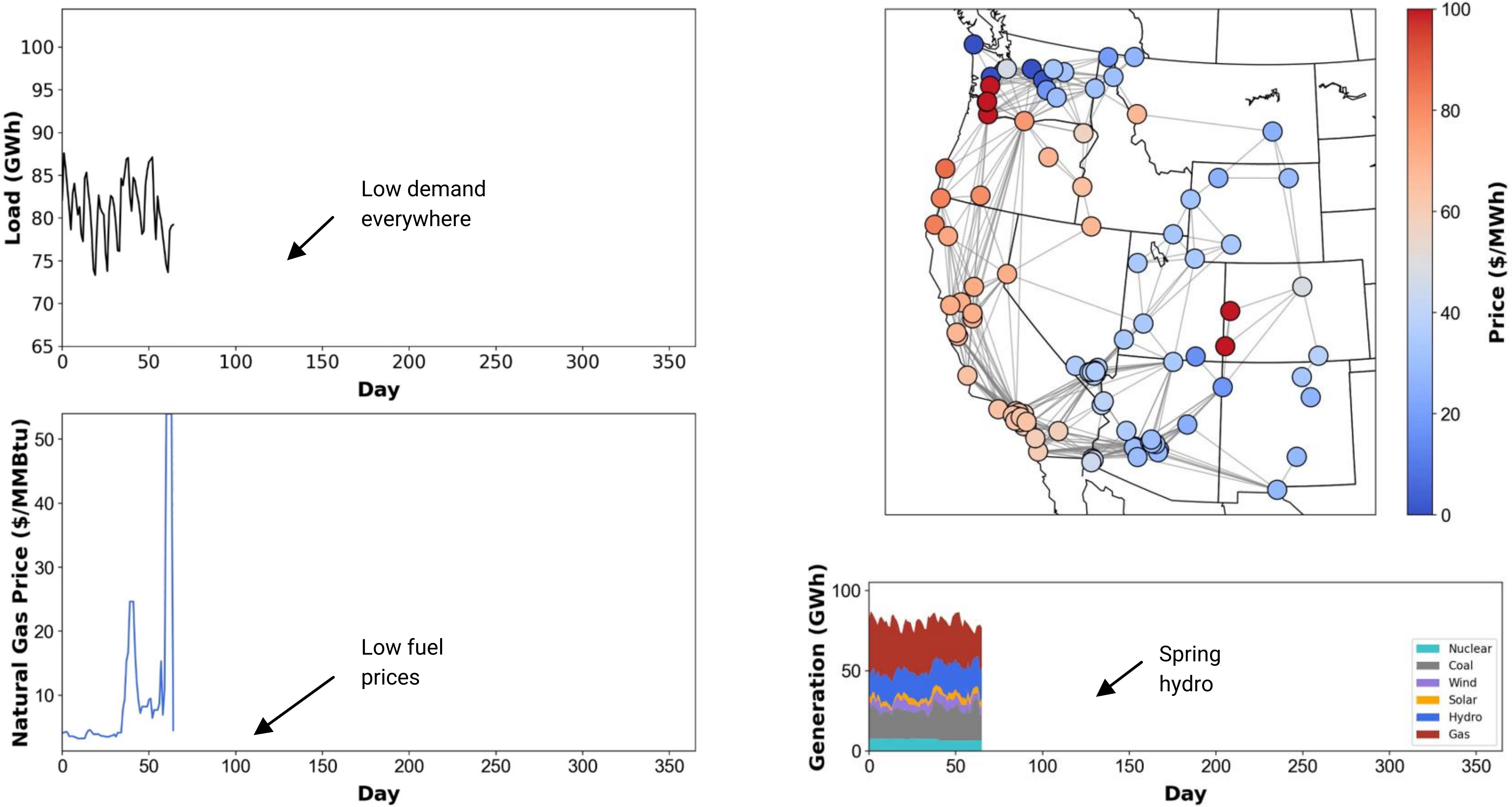

Generation mix
Generation (GWh)
100
50
0
0
50
100
150
200
250
300
350
Day
Nuclear
Coal
Wind
Solar
Hydro
Gas

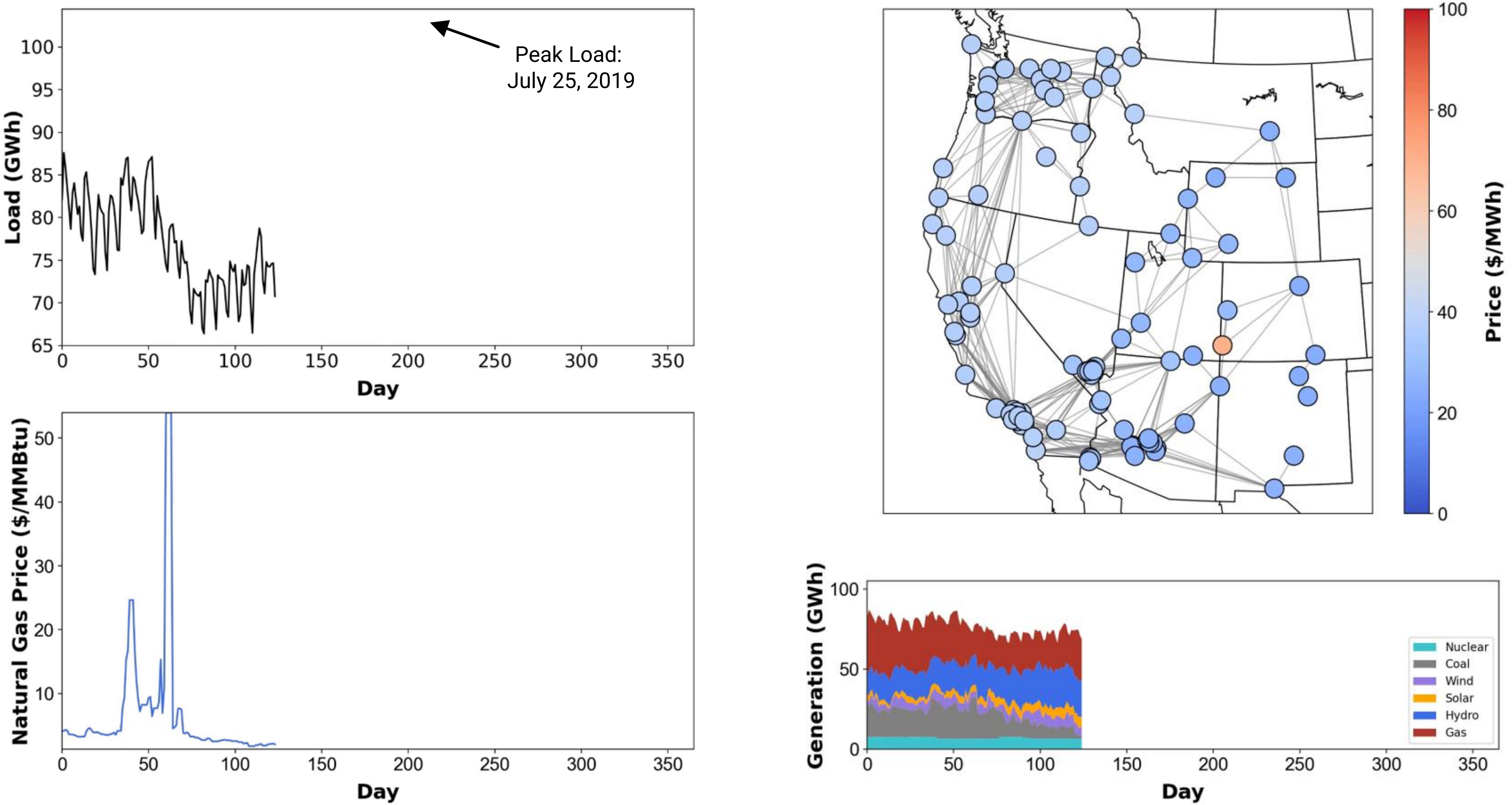

Load (GWh)
100
95
90
85
80
75
70
65
0
50
100
150
200
250
300
350
Day

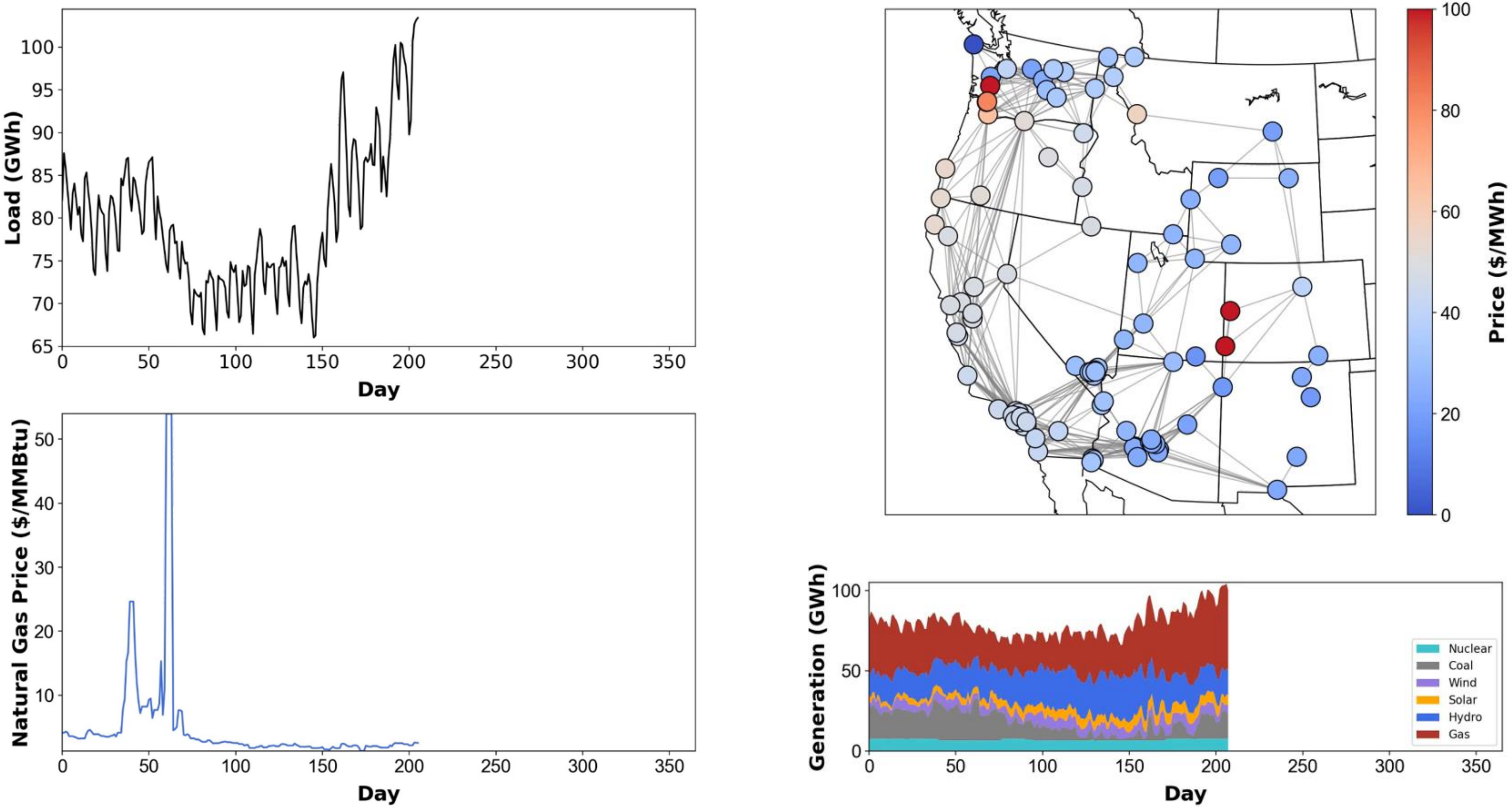

Natural Gas Price ($/MMBtu)
50
40
30
20
10
0
50
100
150
200
250
300
350
Day
Natural gas price shock:
• Cold temperatures
• Low hydro levels
• Low wind power
• Low gas storage


Price ($/MWh)
100
80
60
40
20
0


Generation (GWh)
100
50
0
0
50
100
150
200
250
300
350
Day
Nuclear
Coal
Wind
Solar
Hydro
Gas


Load (GWh)
100
95
90
85
80
75
70
65
0
50
100
150
200
250
300
350
Day
Low demand
everywhere
Natural Gas Price ($/MMBtu)
50
40
30
20
10
Low fuel
prices
Price ($/MWh)
100
80
60
40
20
0
Generation (GWh)
Spring
hydro
Nuclear
Coal
Wind
Solar
Hydro
Gas


Peak Load:
July 25, 2019
Load (GWh)
Day
Natural Gas Price ($/MMBtu)
Day
Price ($/MWh)
Generation (GWh)
Day
Nuclear
Coal
Wind
Solar
Hydro
Gas

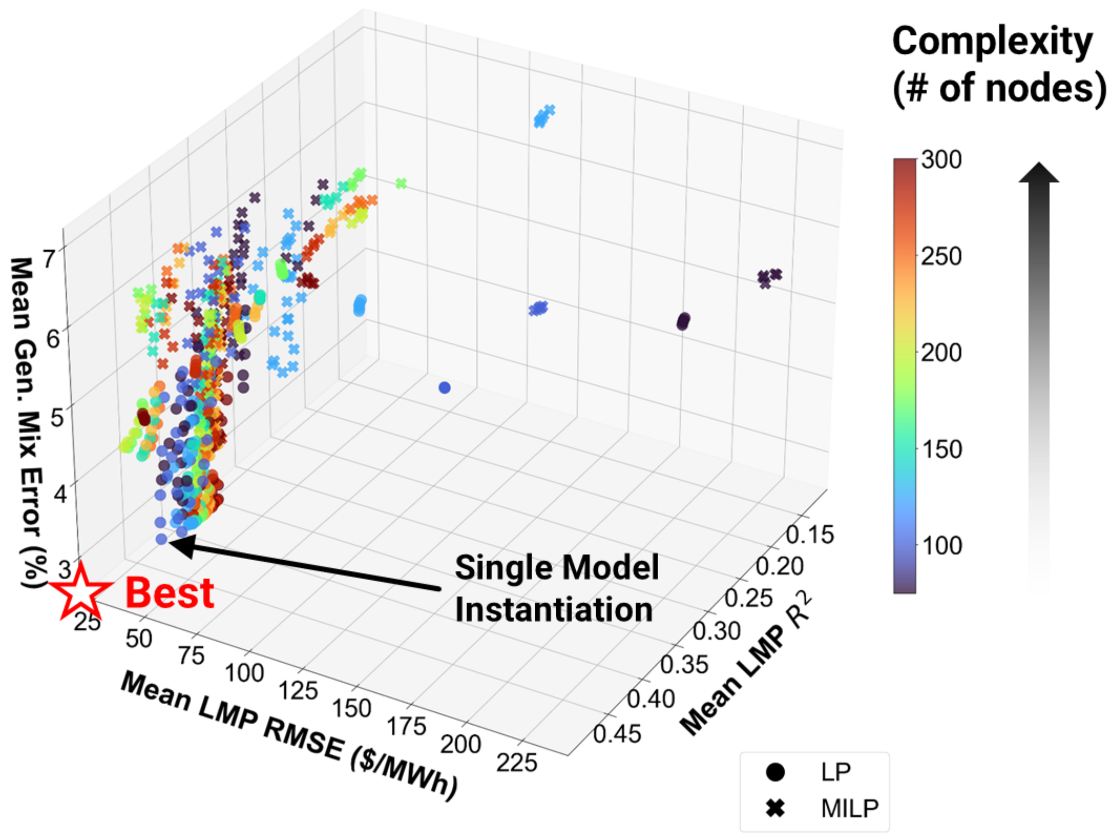


Load (GWh)
Day
Natural Gas Price ($/MMBtu)
Day
Price ($/MWh)
Generation (GWh)
Day
Nuclear
Coal
Wind
Solar
Hydro
Gas

EARLY PUBLISHED WORKS

Akdemir et al (2022) *Environmental Research: Energy*

- An in-depth tour of GO!



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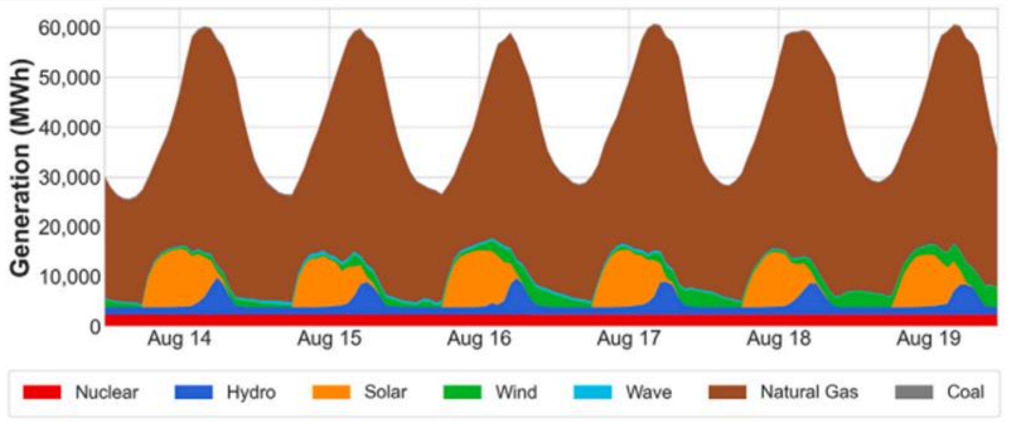

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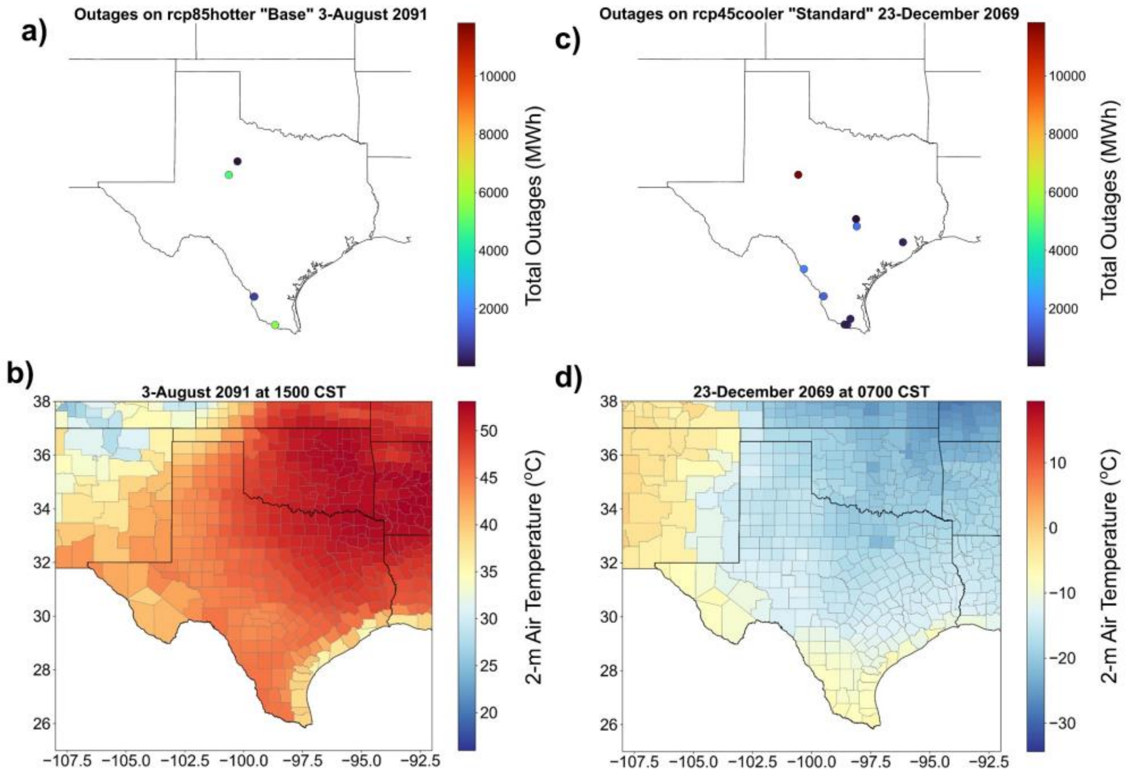
- Dualing effects of climate change and electric heat pump adoption on peak demand in ERCOT



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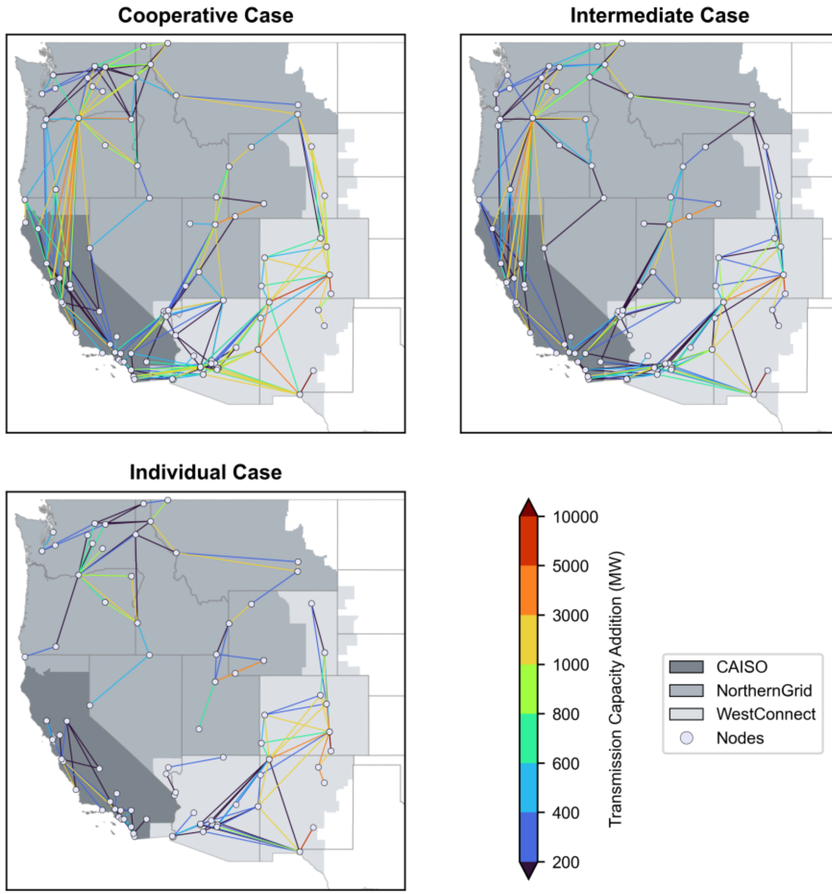
Akdemir et al (in review) *Applied Energy*

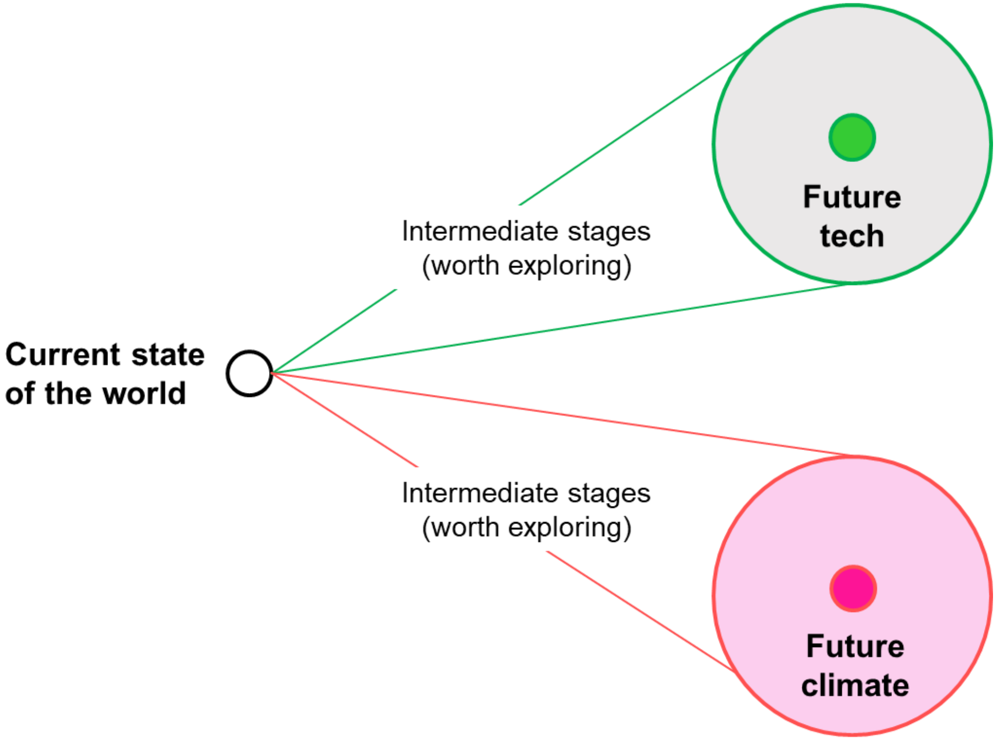
- Value of cooperating transmission planning under climate change

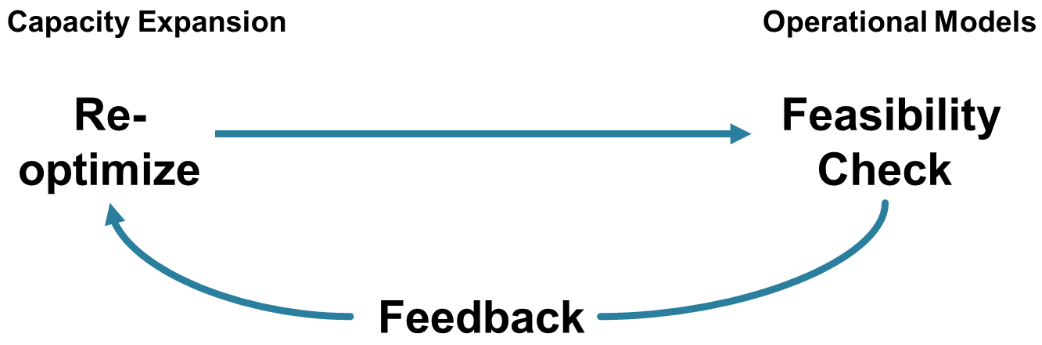


Poster Session F, Wed-050

GAPS, OPPORTUNITIES, AND ONGOING WORK

- **Faster, more detailed models** → better coverage of uncertainty, new model couplings

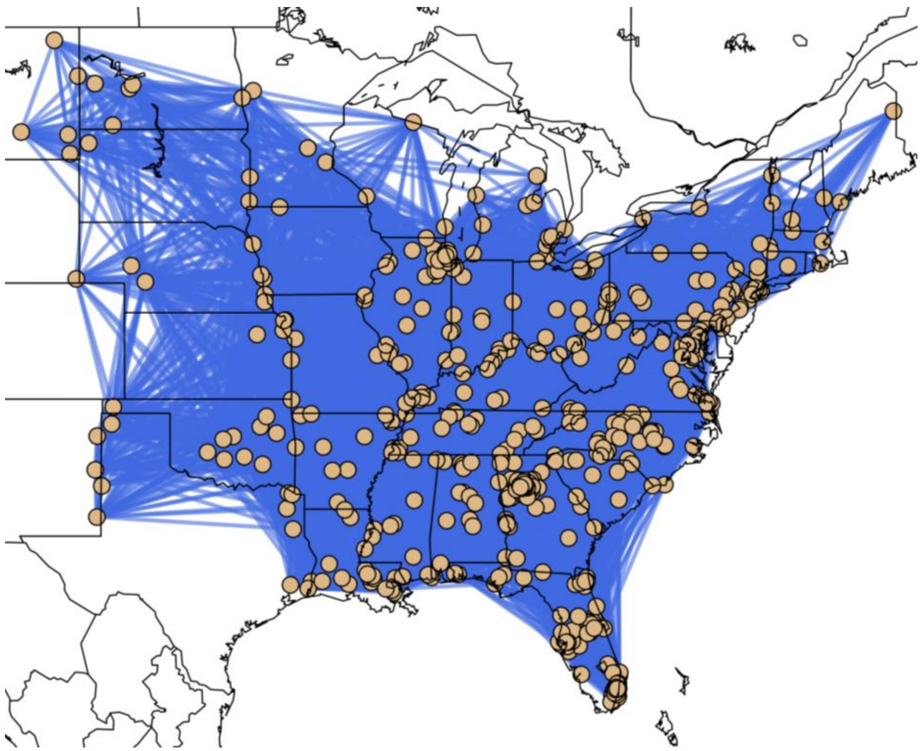




IM3

GAPS, OPPORTUNITIES, AND ONGOING WORK

- **Faster, more detailed models** → better coverage of uncertainty, new model couplings
- **Institutional and control boundaries**
  - **Assumption:** single centrally controlled system (globally cost minimizing)
  - **Reality:** 36 different balancing authorities; some are utilities, some are market operators
  - Limits on resource sharing, coordination, <u>especially</u> during periods of scarcity



IM3

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- **Faster, more detailed models** → better coverage of uncertainty, new model couplings
- **Institutional and control boundaries**
- **Natural gas:** two-way dependencies with the power grid, cascading failures during weather extremes (winter)
  - **<u>Much</u> more challenging data gaps**

GAPS, OPPORTUNITIES, AND ONGOING WORK

- **Faster, more detailed models** → better coverage of uncertainty, new model couplings
- **Institutional and control boundaries**
- **Natural gas:** two-way dependencies with the power grid, cascading failures during weather extremes (winter)
- **Physical security and public safety**
  - Electrification (more eggs in one basket)
  - Weather as “threat multiplier” during intentional attacks
  - Supply chain vulnerabilities