IDENTIFYING INFRASTRUCTURE PRESSURE POINTS
IN A DECARBONIZED GRID ACROSS CLIMATIC-TECHNOLOGICAL SCENARIOS

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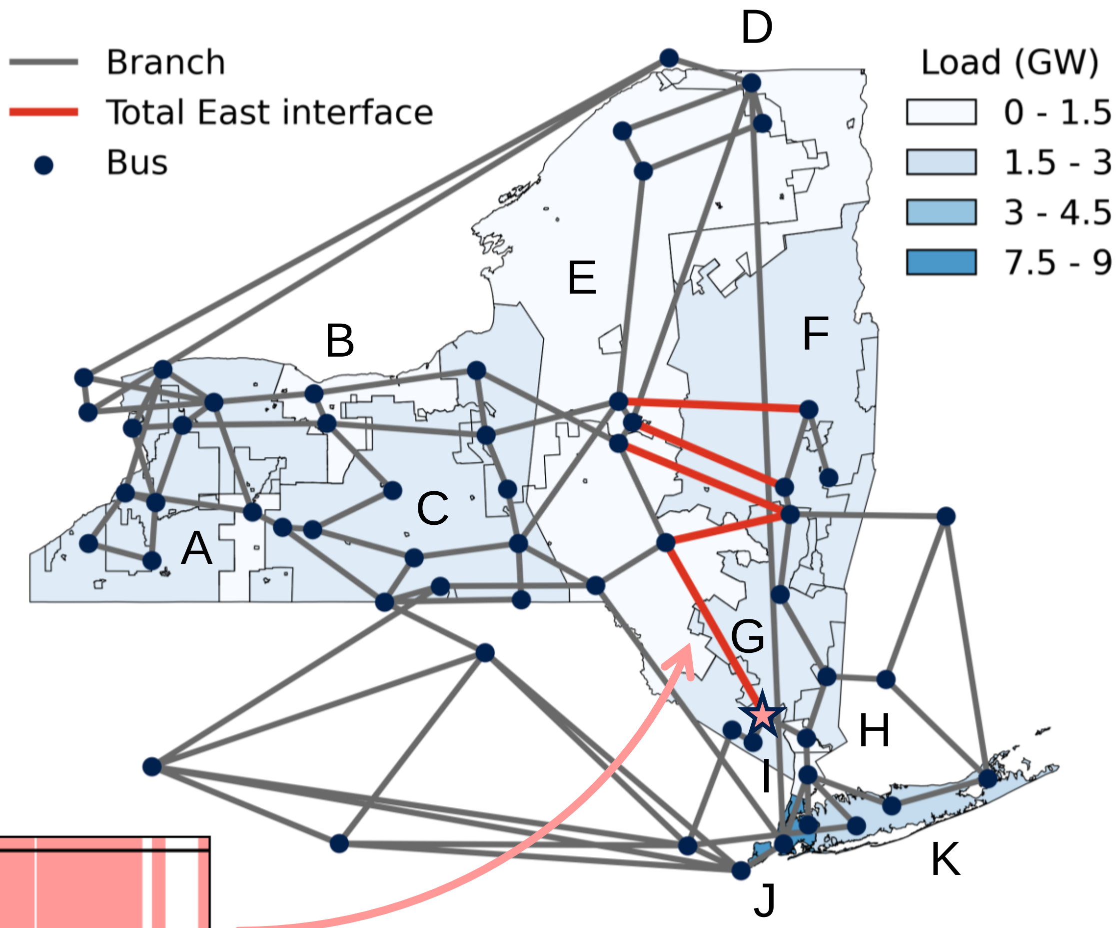
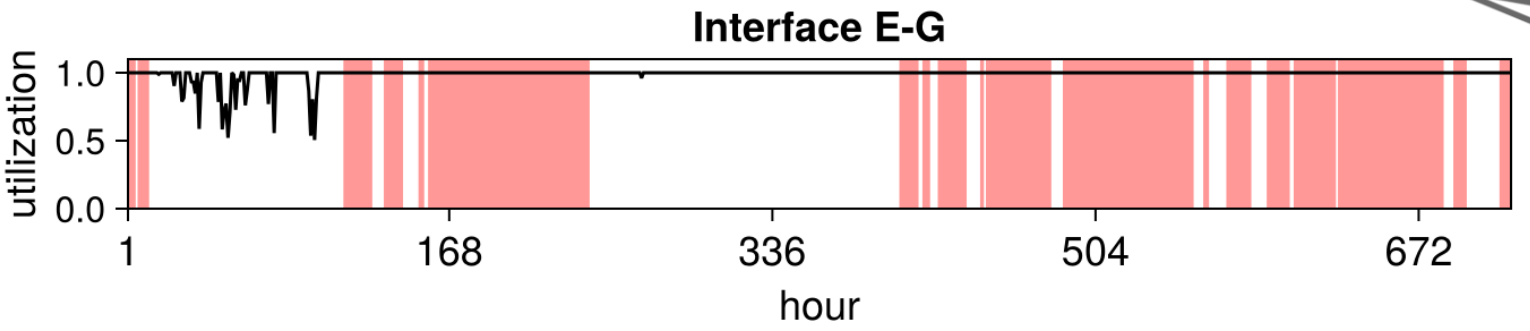
MOTIVATION & CHALLENGES

- As decarbonization efforts increasingly couple the energy system with weather and climate, identifying pieces of infrastructure determining reliability is critical.
- Complexity and interconnectedness of power grid mean “pressure points” may be disconnected from where failures occur, turning this into a question of network inference.
- Transfer entropy is a common tool for inferring connectivity in the brain, financial markets, gene regulatory networks, etc.

CASE STUDY: ZERO-CARBON NEW YORK STATE GRID

- Proposal includes expanded wind and solar capacity, electrification of transportation and heating sectors, and upgraded transmission lines.
- Spatially imbalanced renewable energy supply (upstate, A - E) and load (downstate, F - K) exacerbates transmission line congestion.

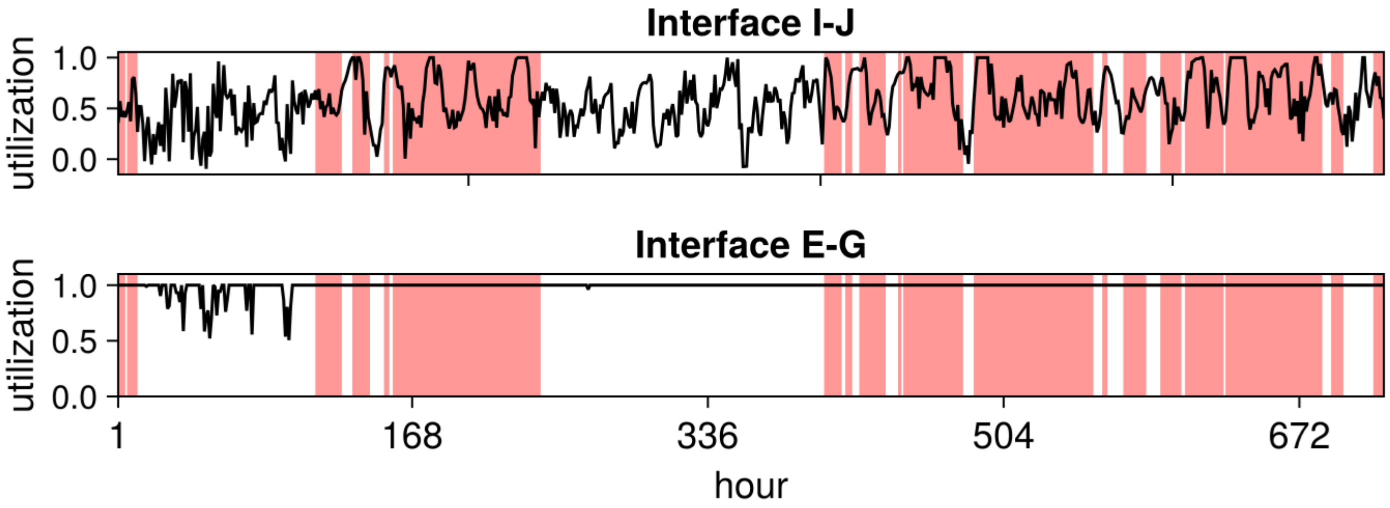




TRANSFER ENTROPY

- Wiener's principle of observational causality: process X "causes" process Y if knowing the history of X improves our prediction of the future of Y beyond what is predictable by the history of Y alone.
- Transfer entropy translates this into information theoretic terms:

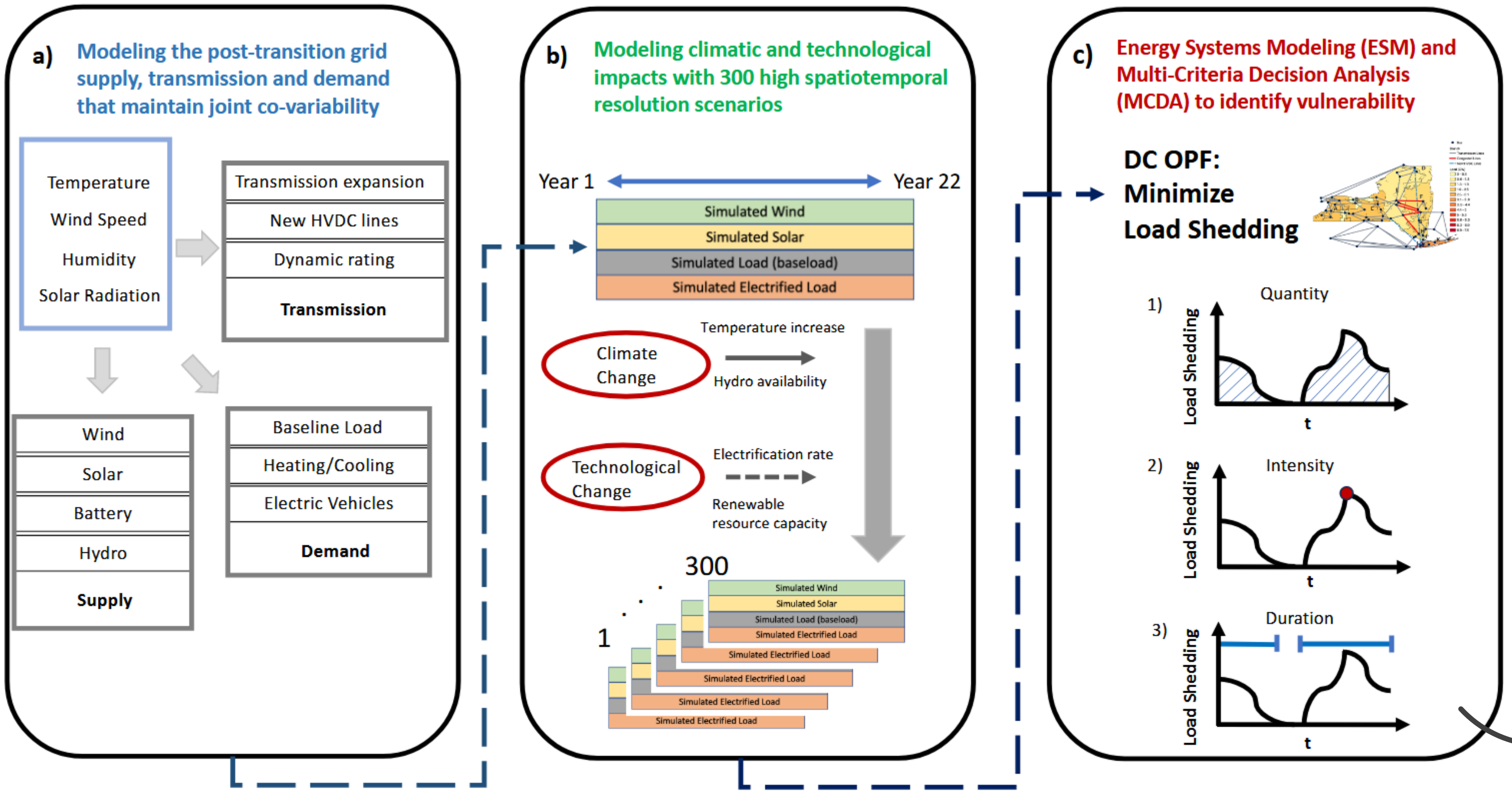
$$TE(X \to Y) = I(X^{-}, Y^{+} \mid Y^{-})$$



Here,
$TE(\text{IF flow} \to \text{load shedding}) > 0$

...but here,
$TE(\text{IF flow} \to \text{load shedding}) \approx 0.$

METHODS OVERVIEW

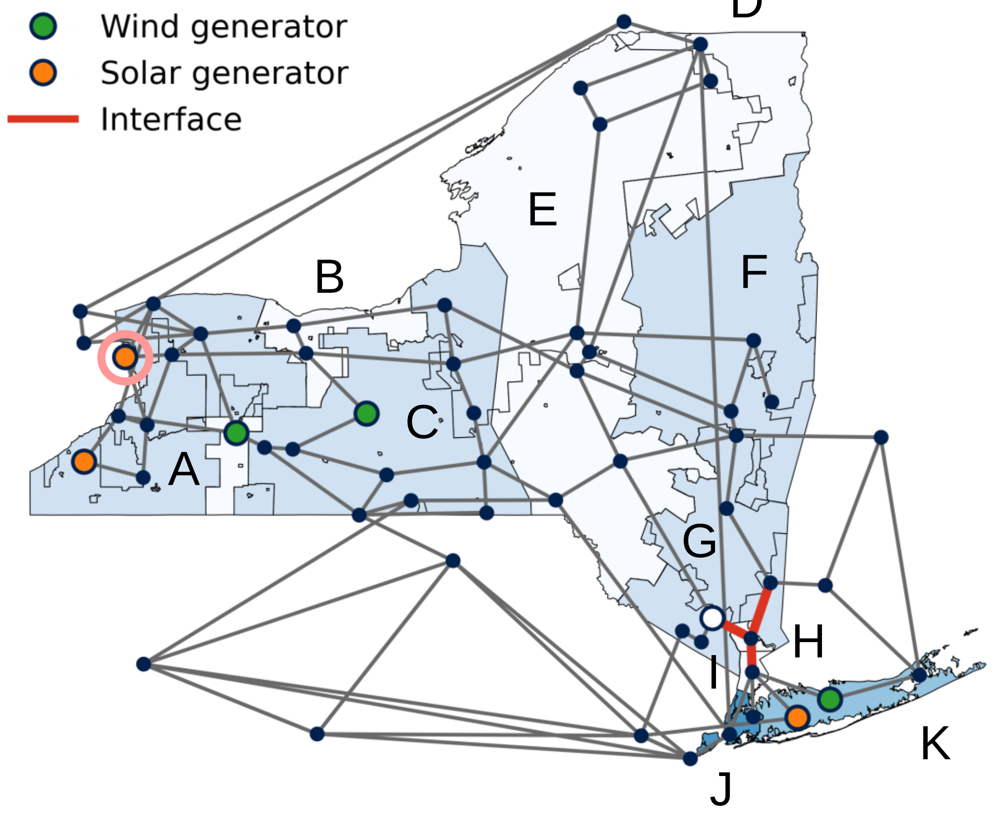


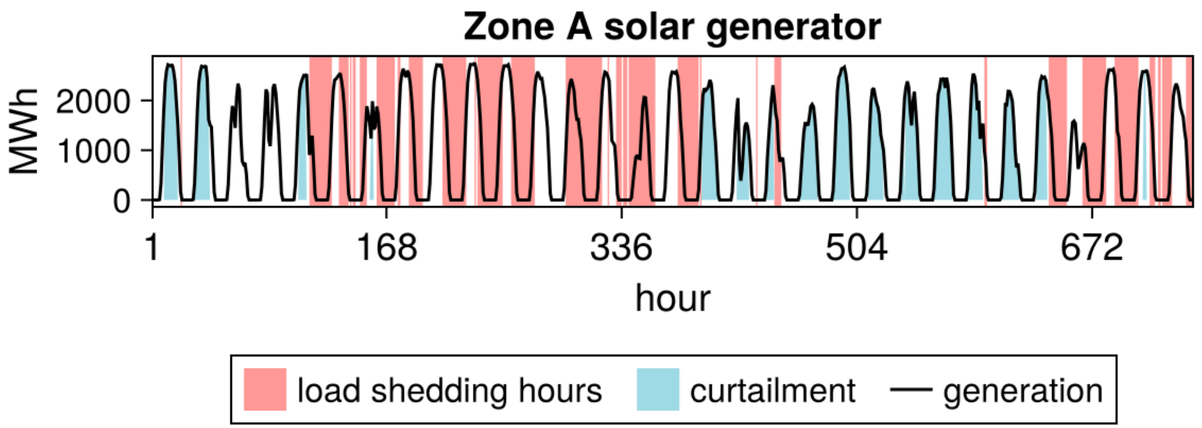
Pairwise transfer entropy analysis to identify infrastructure dynamics that are predictive of downstream load shedding

Source: Liu et al. (2023, preprint)

"BASELINE" SCENARIO

Moderate temperature increase, overbuilt wind & solar capacity, relatively low levels of load shedding





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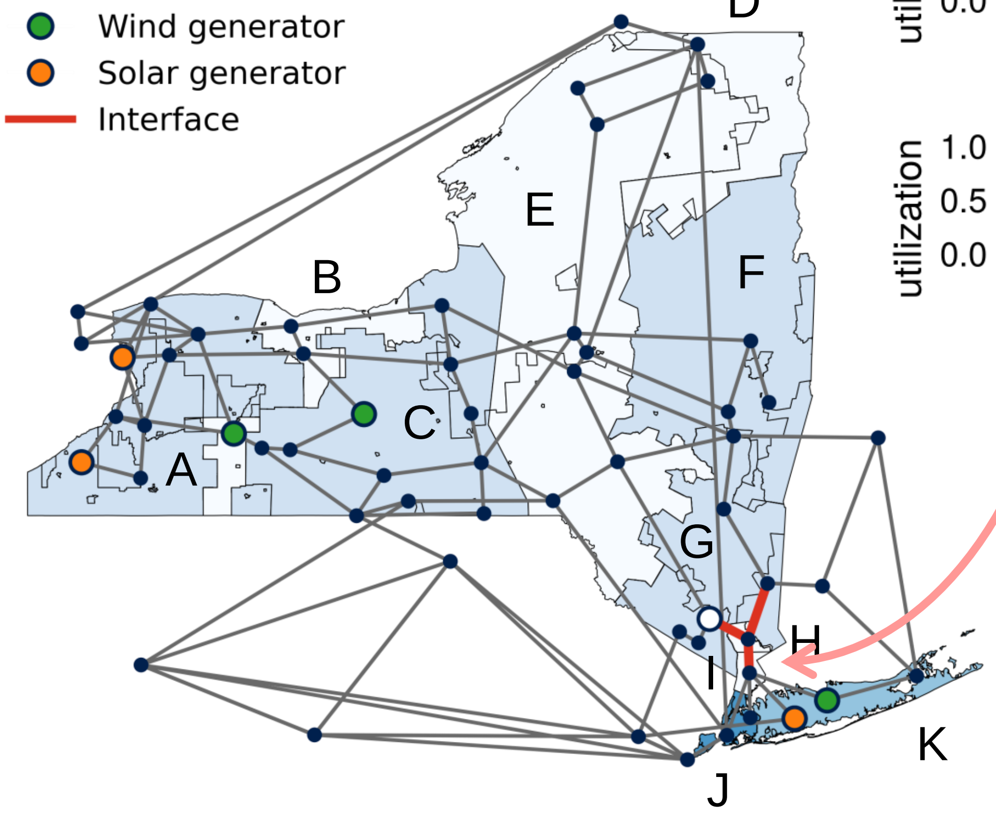
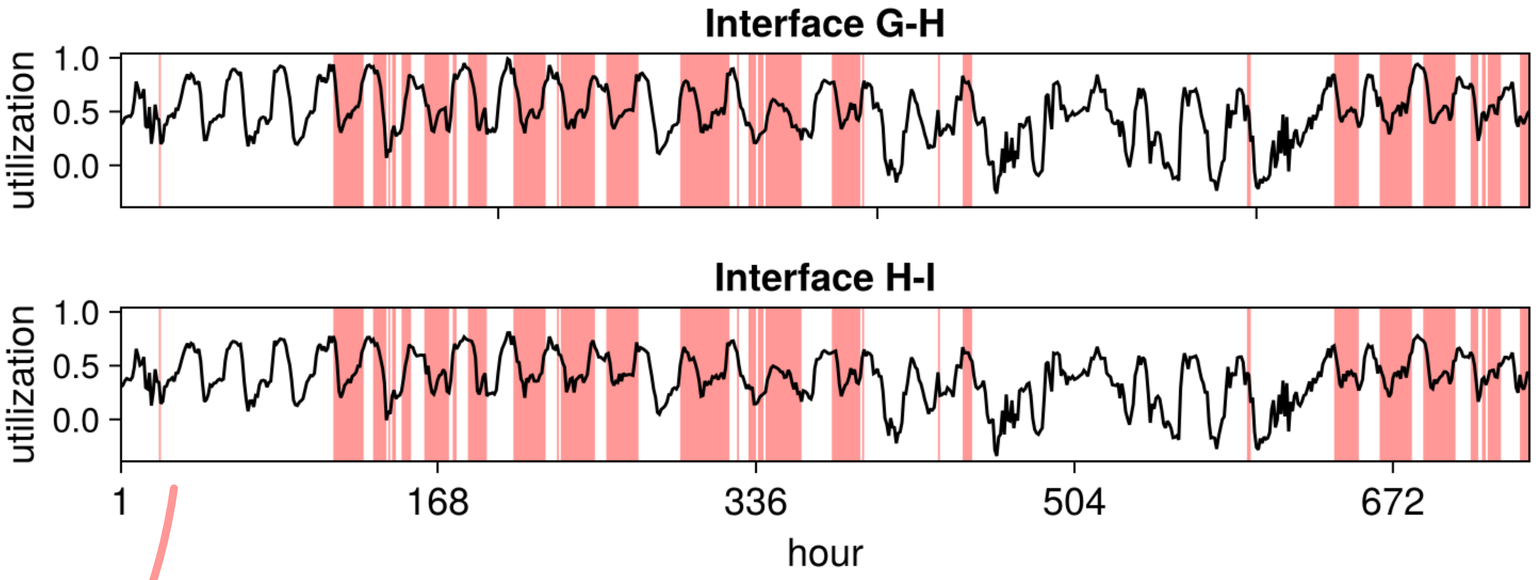
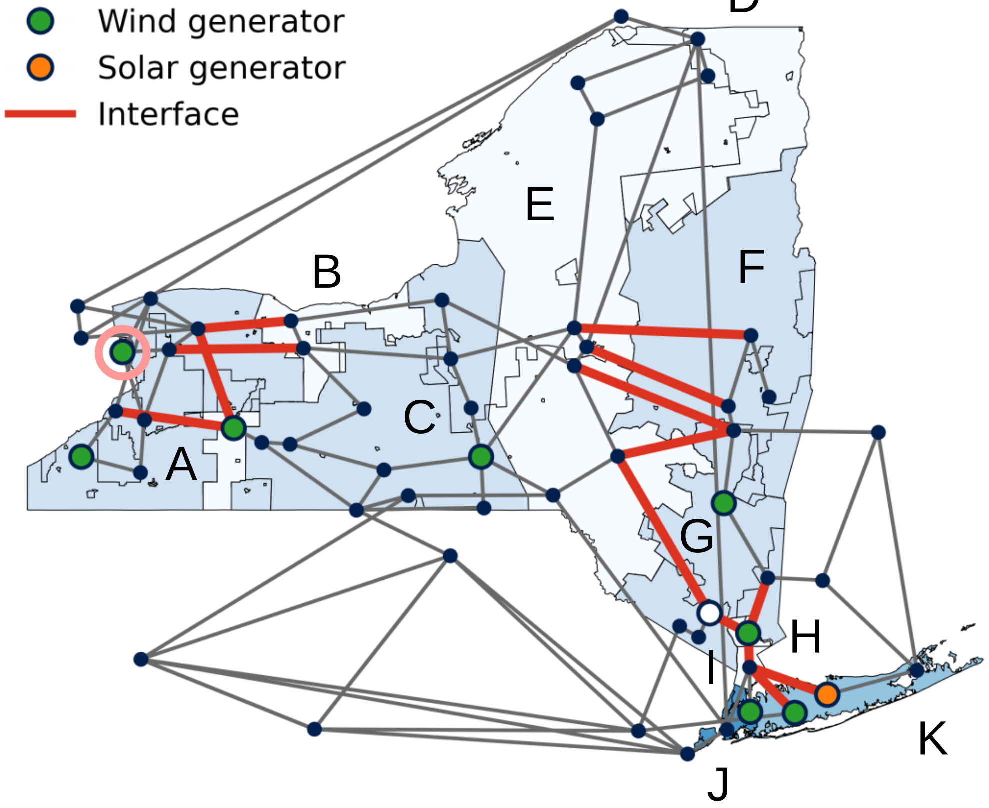


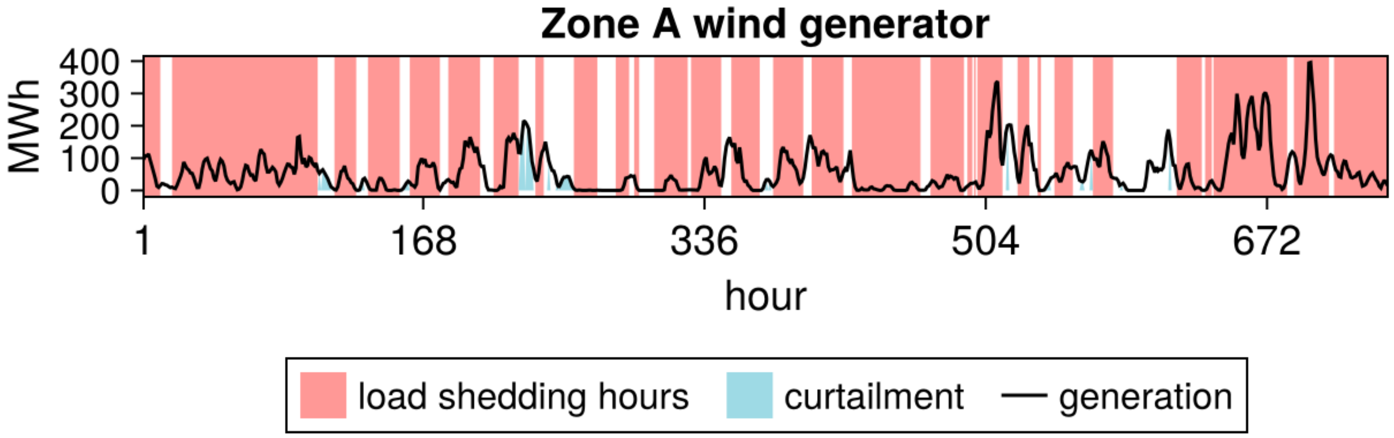


Takeaway: low wind and solar supply contribute to load shedding, but high levels of curtailment suggest long-duration batteries or hydrogen could increase reliability of system.

AN ALTERNATIVE SCENARIO

More extreme temperature increase, underbuilt wind capacity, relatively high levels of load shedding





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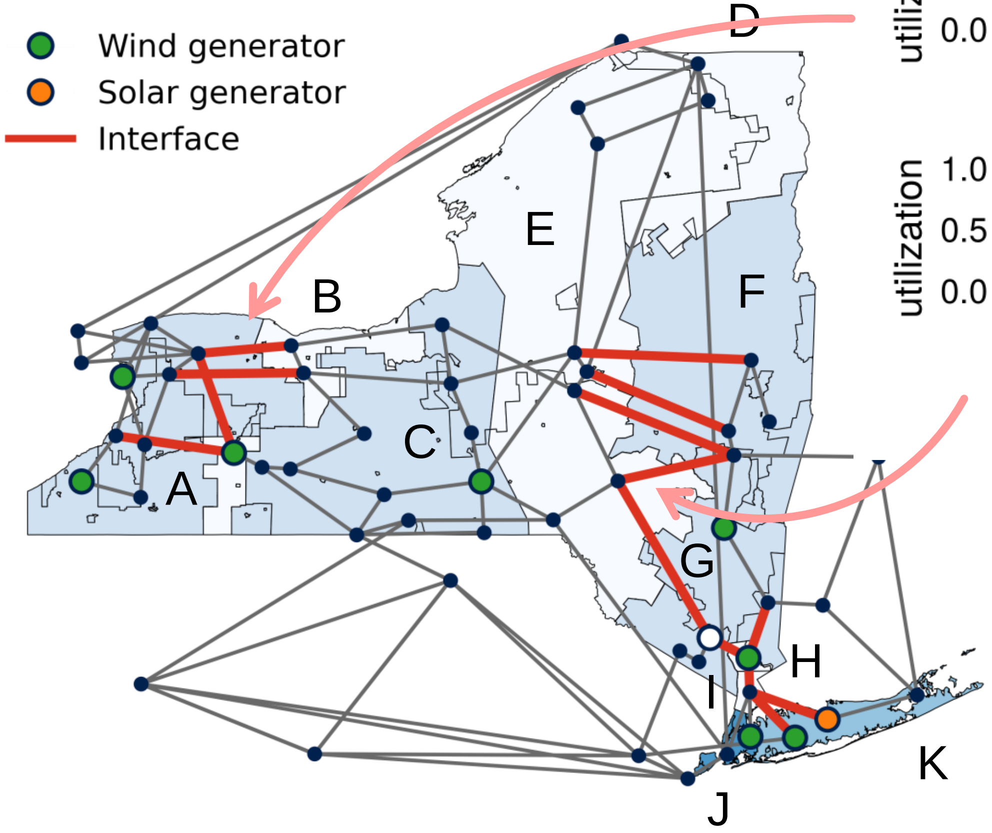
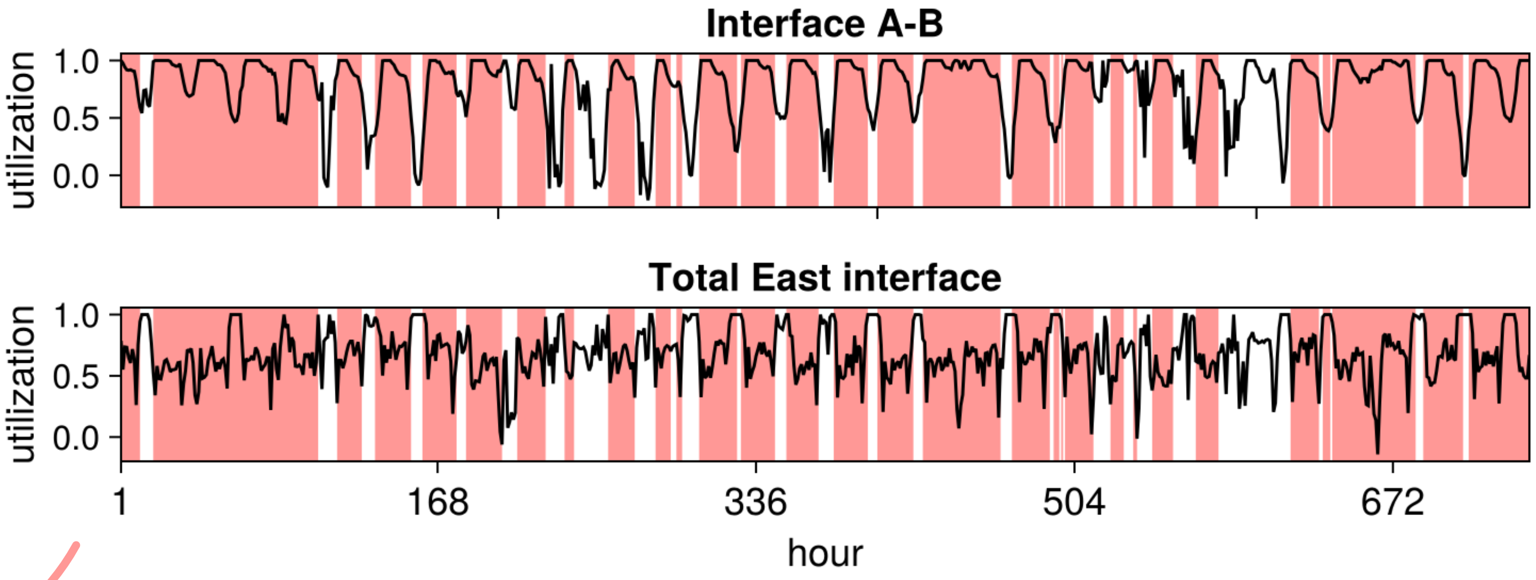
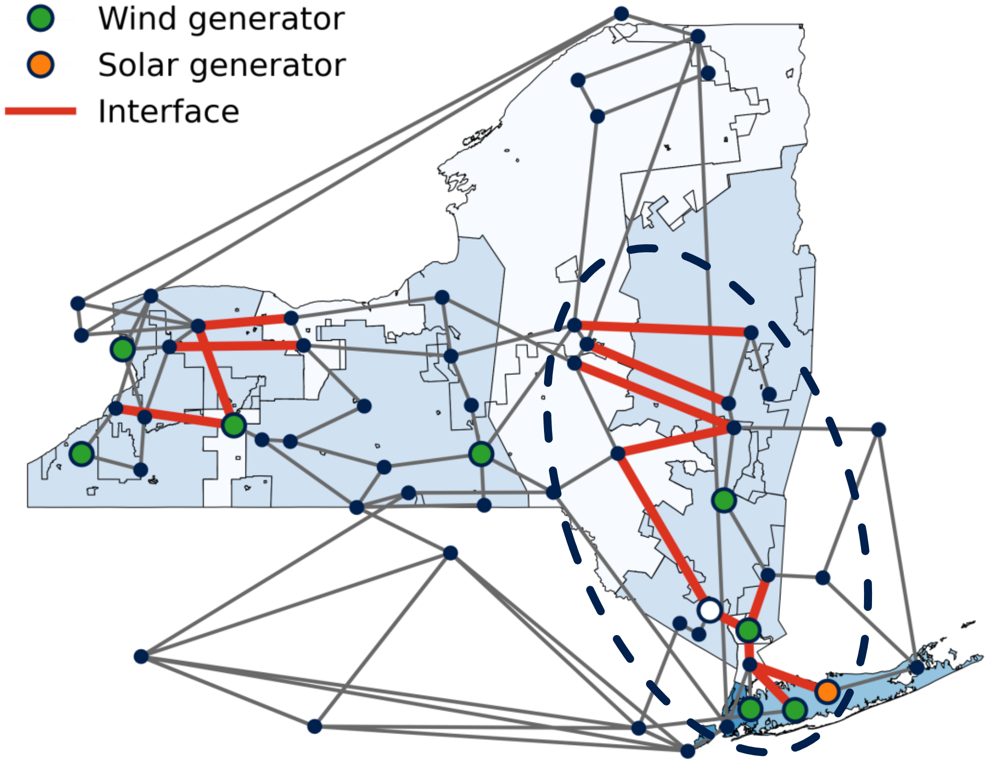




Takeaway: low wind and solar supply still a major factor in load shedding, but there are also periods of overwhelming demand.

CONCLUSIONS & NEXT STEPS

- Pairwise transfer entropy analysis helps uncover unexpected pressure points in the zero-carbon NYS grid.
- Scenario discovery could help map specific climatic or technological factors to the appearance of different pressure points.
- Overall, inference of the effective network remains computationally challenging using information theoretic tools.



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PCHES

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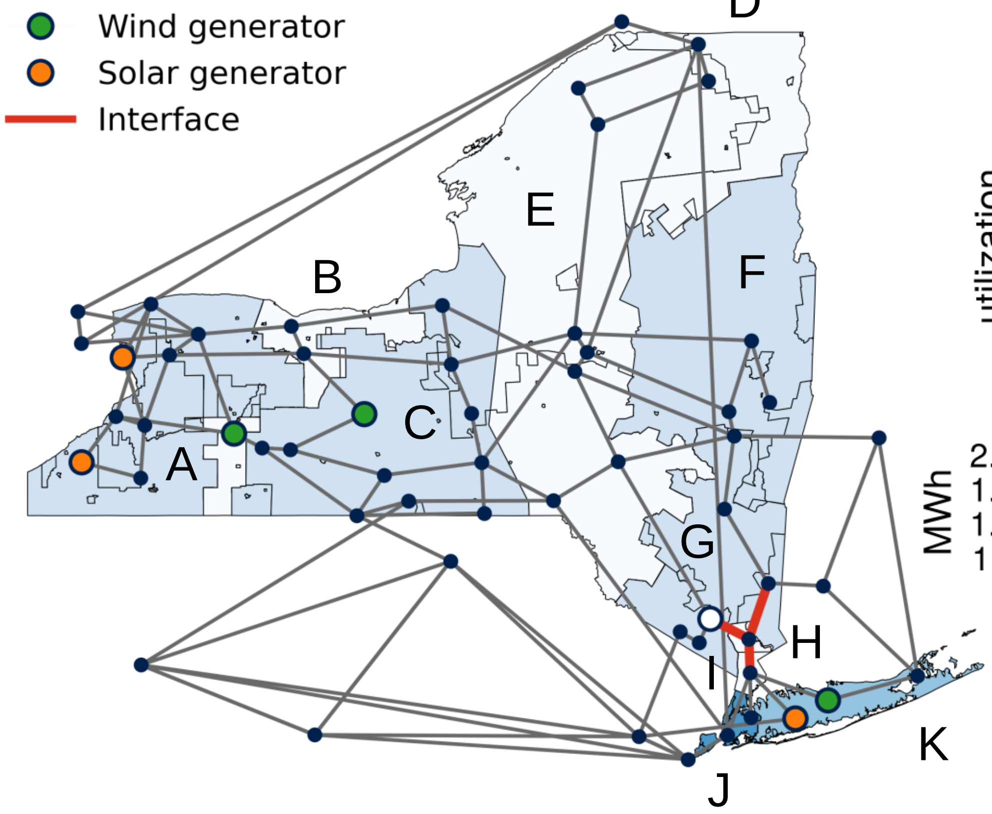

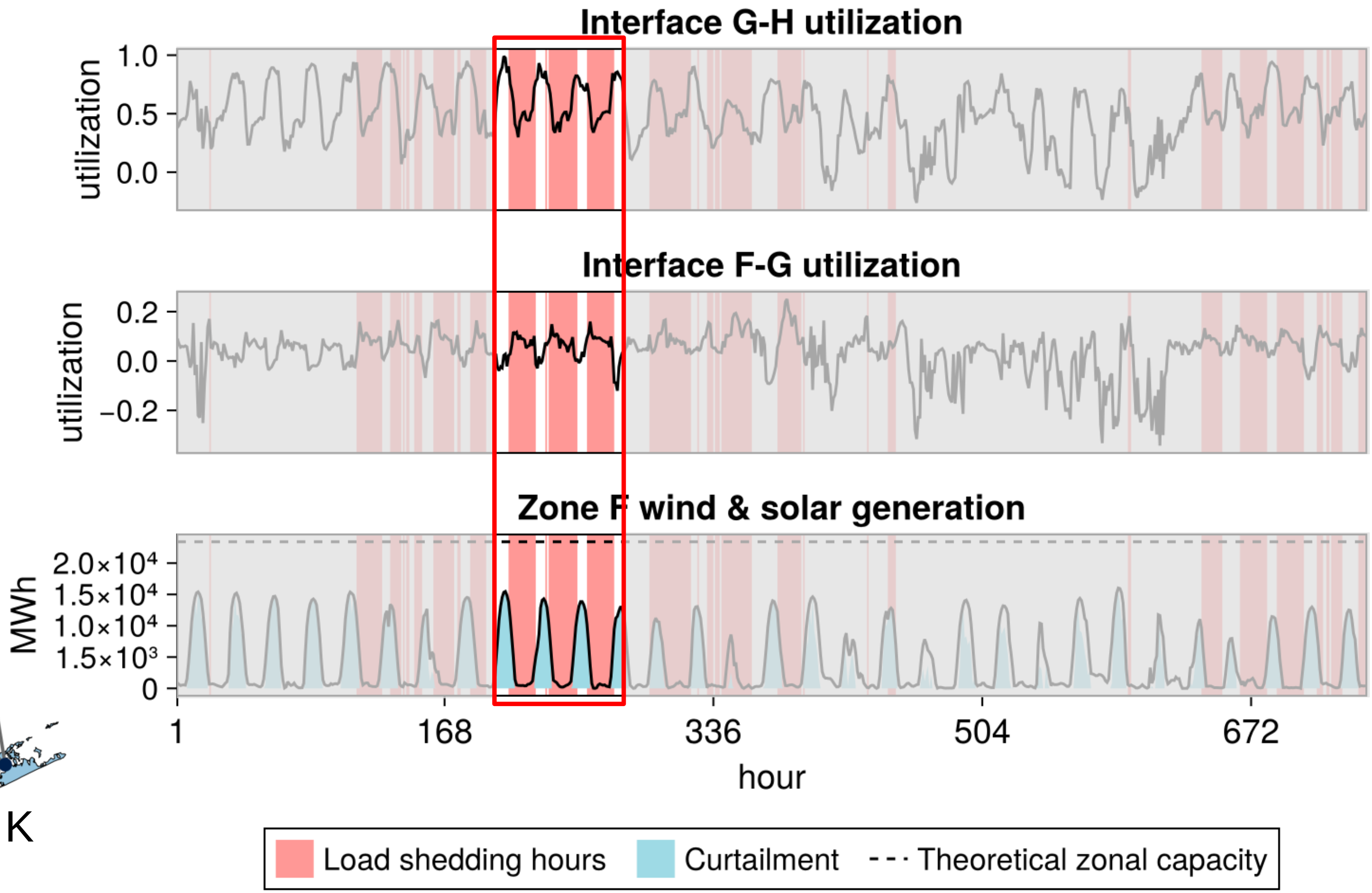

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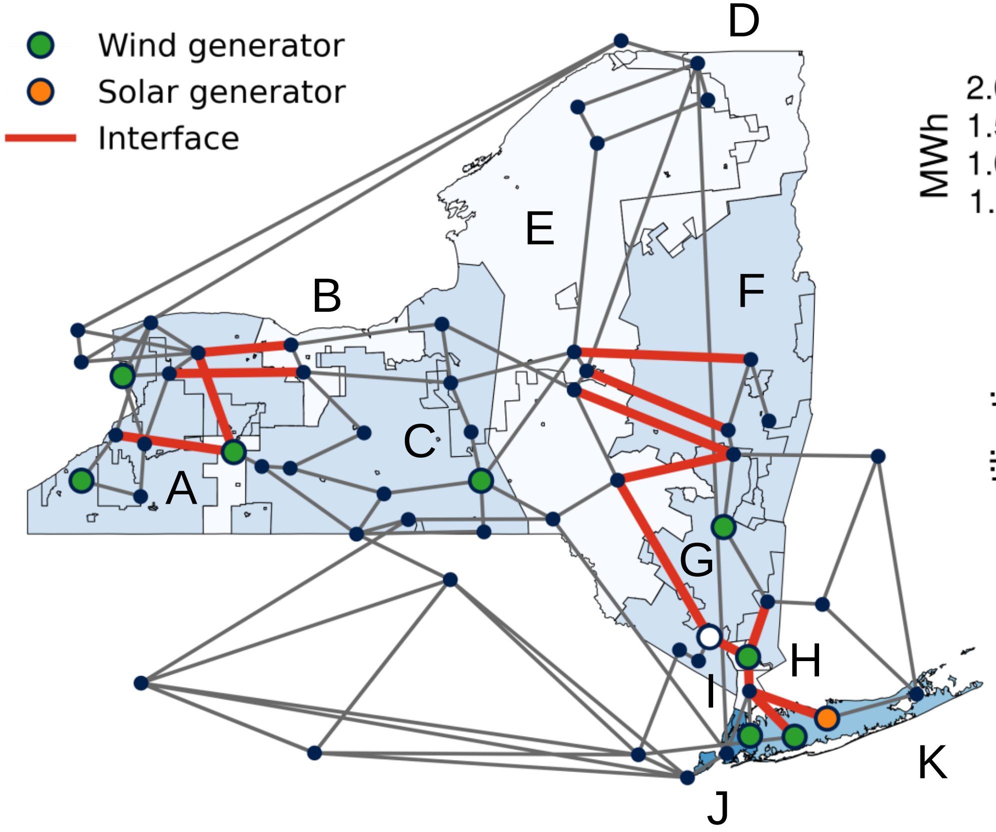

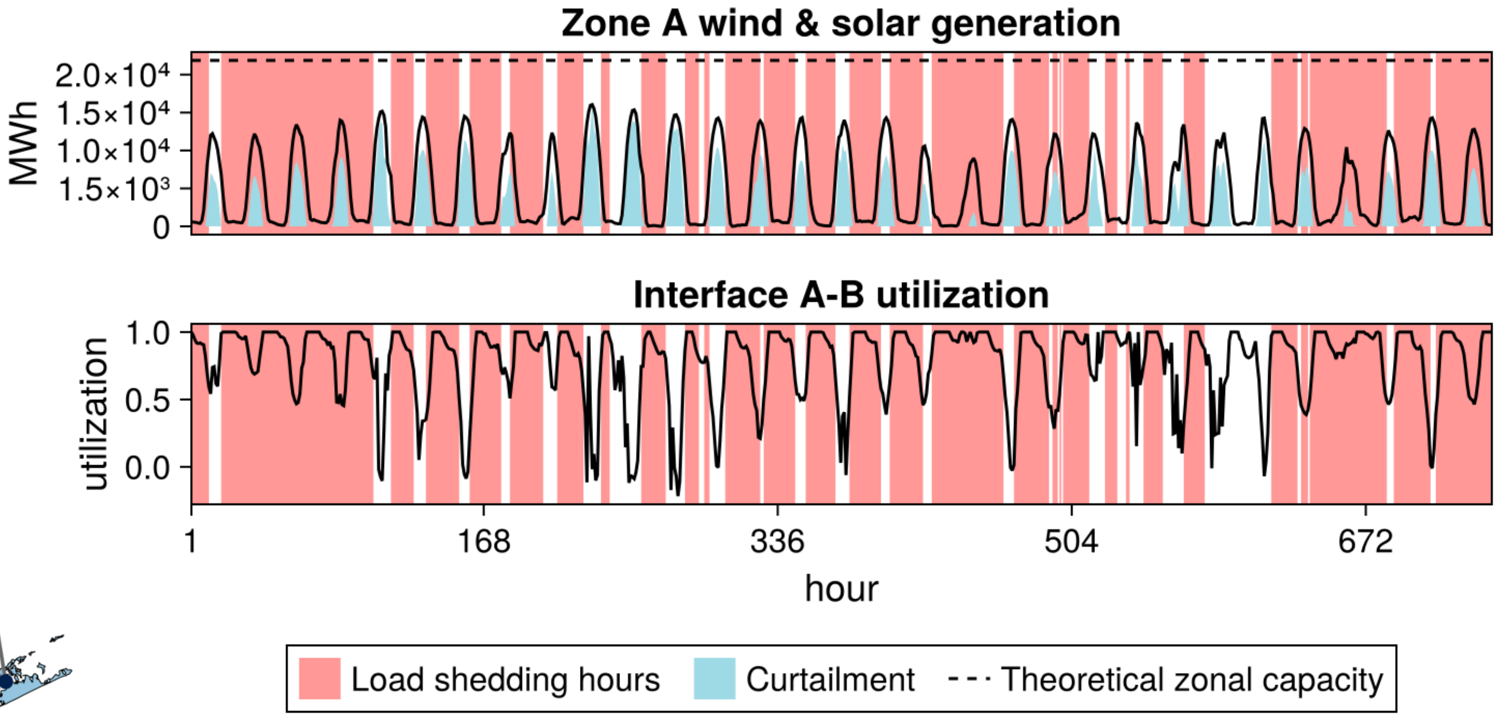

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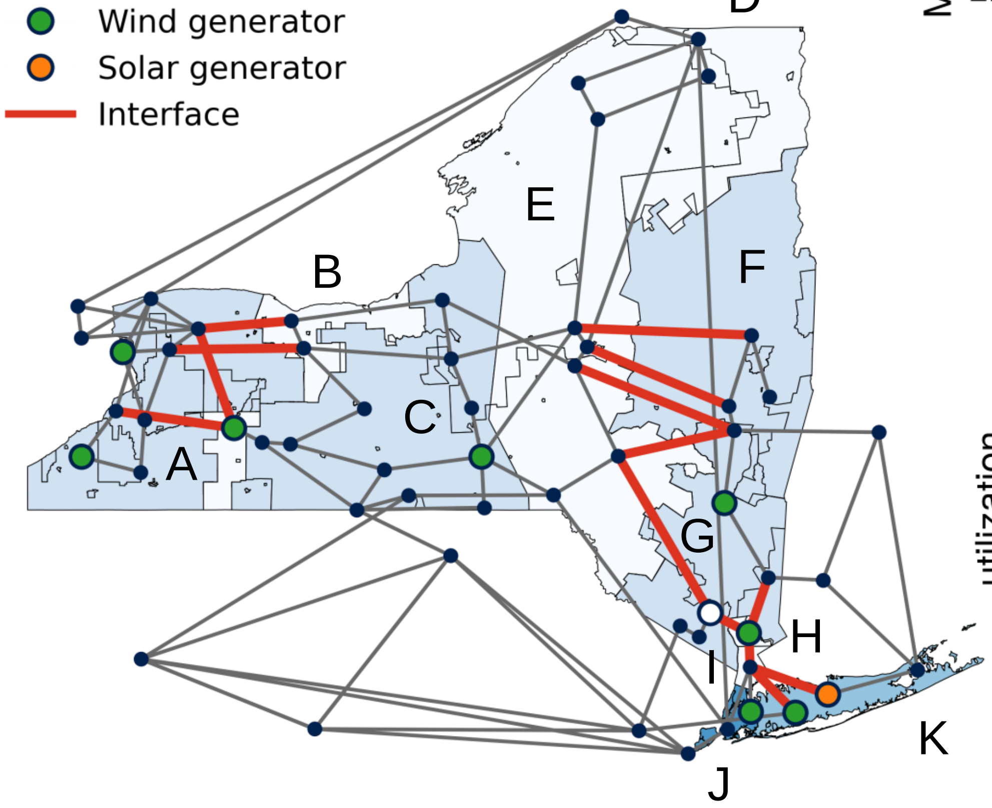

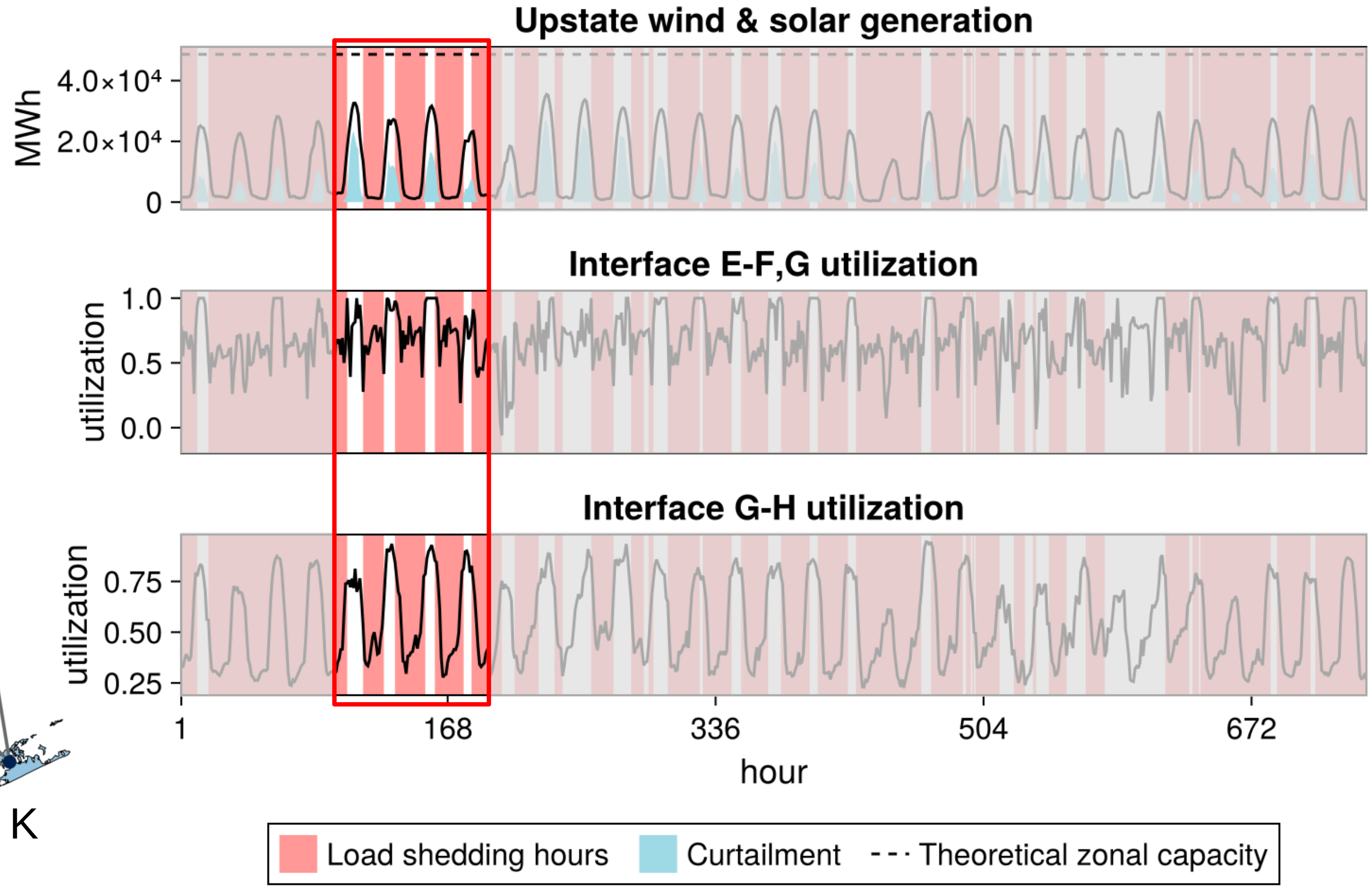

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