ML-Assisted Optimal Planning for Decarbonized Energy Systems

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NSF Workshop on Cyber-enabled Infrastructure to Support Carbon-neutral Electricity and Mobility (Panel 2)

Civil and Environmental Engineering

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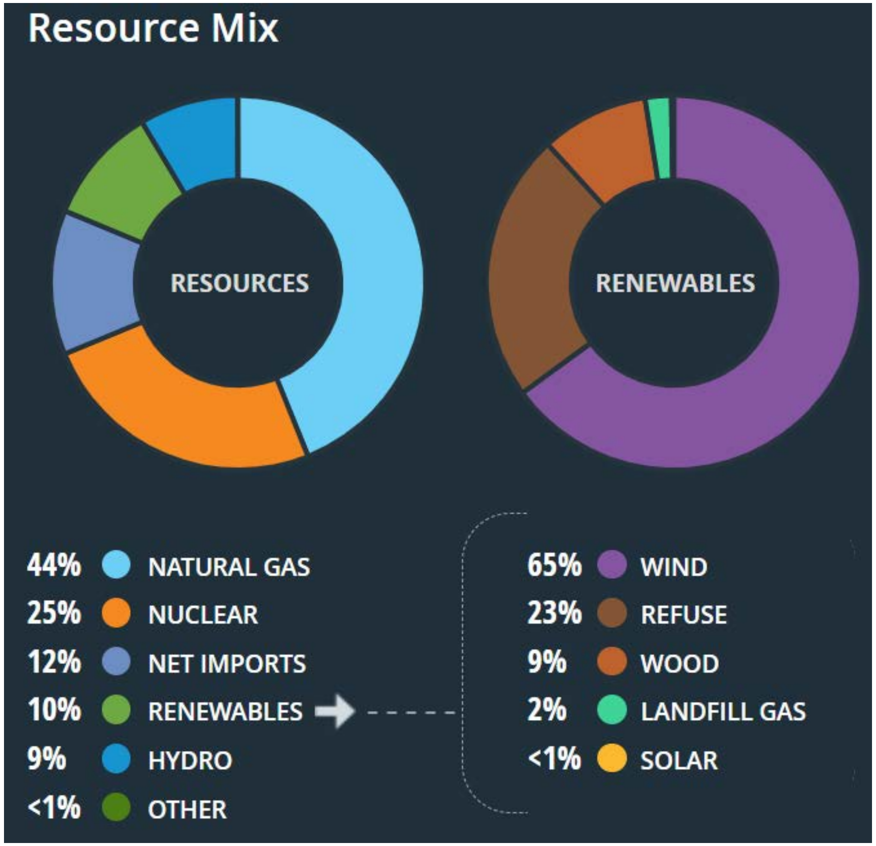
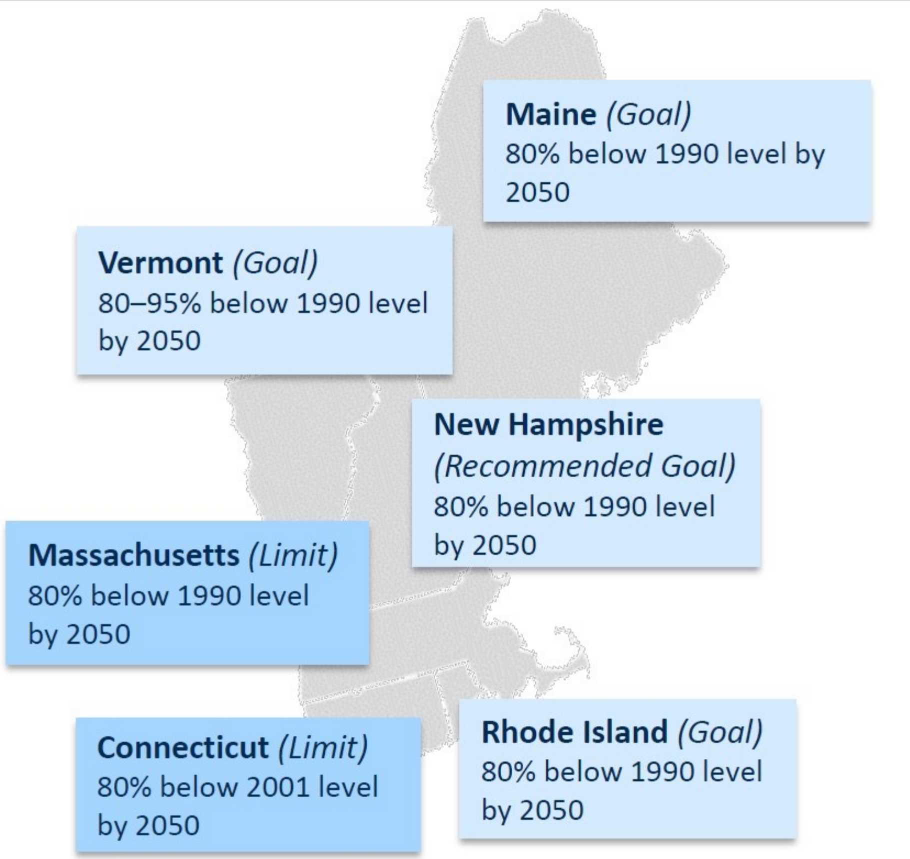
April 24, 2023

New England Energy System

Requires *coordinated* investment planning



ISO New England: Generation Mix, Oct. 27, 8pm



Source: Brattle Report, Achieving 80% GHG Reduction by 2050

- Significant reliance on NG power plants
- Variability of renewable energy generation
- Ambitious economy-wide decarbonization targets

Implications for Resilience

Poor coordination can lead to adverse impacts

WINTER STORM 2021

Texas largely relies on natural gas for power. It wasn't ready for the extreme cold.

Texas largely relies on natural gas — especially during times of high demand — to power the state. Experts say natural gas infrastructure, from pumping it out of the ground to the plants in city centers, was unprepared for the plunging temperatures brought by the winter storm.

BY ERIN DOUGLAS FEB. 16, 2021 5 PM CENTRAL

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Coordinated Investment Planning

Regional-scale multi-vector energy system for the New England

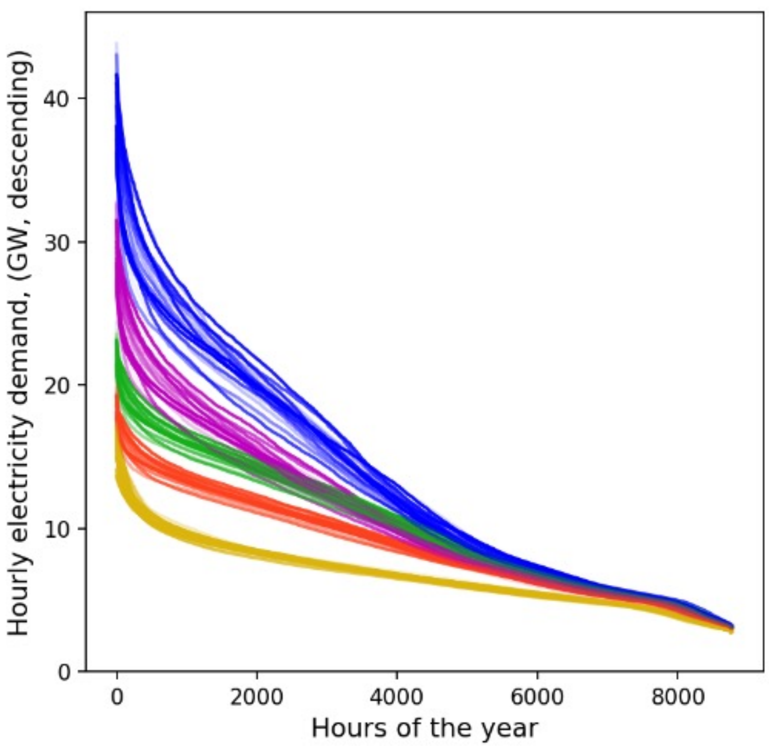
- Power and natural gas (NG) system: different spatial and temporal resolutions, investment and operational constraints
- Planning for various decarbonization targets & electrification scenarios
  - Evaluating adoption impacts, e.g. space-heating electrification
- Role of low-carbon fuels, long-duration storage, and carbon capture
- Resource allocation for network resilience under disruptions

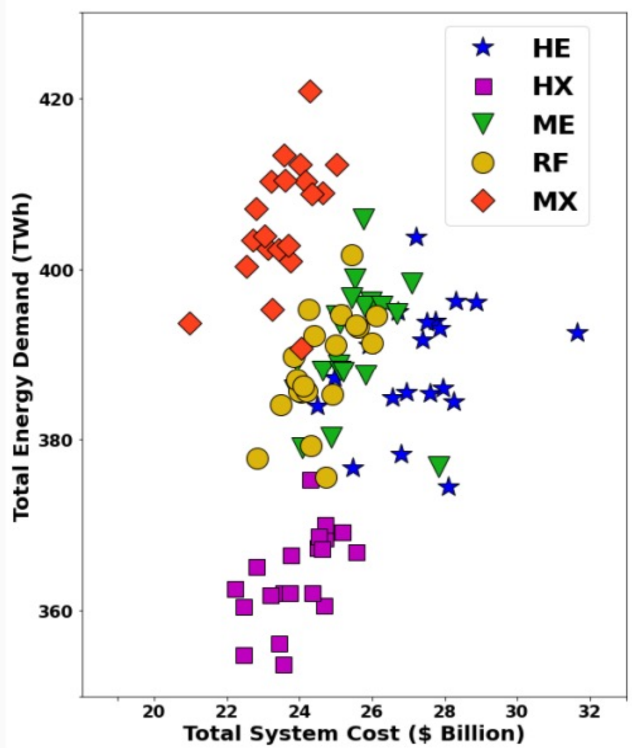
Coordinated Investment planning for Electric Power-Natural Gas Network

Large-scale Optimization
To minimize CAPX+OPEX
(MILPs, Stochastic, Multi-Stage)
+ Machine Learning Models
(spatio-temporal aggregation, predictive analytics)

Investment Planning under Uncertainty

Climate change + Inter-annual weather variations → demand-supply impacts





Planning outcomes (investment cost, generation mix, network capacity):

- must be robust to demand-supply fluctuations
- account for uncertain cost and adoption rates for emerging technologies
- Consider behavior shifts of consumers, esp. with mass adoption of EVs

Capacity Expansion Problem (CEP)

Challenges: Tractability and accounting for key uncertainties

minimize (CAPEX and OPEX for both power and NG systems)

subject to:

- investment and operational constraints for both systems
- renewable portfolio standard (RPS), resource availability, CCS
- coupling constraints: Power-NG interdependency, Emissions

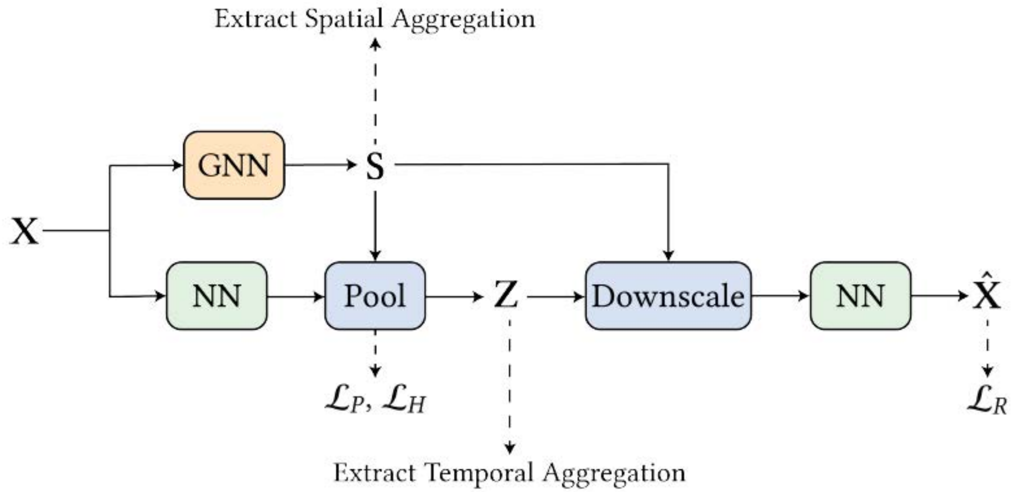
decisions:

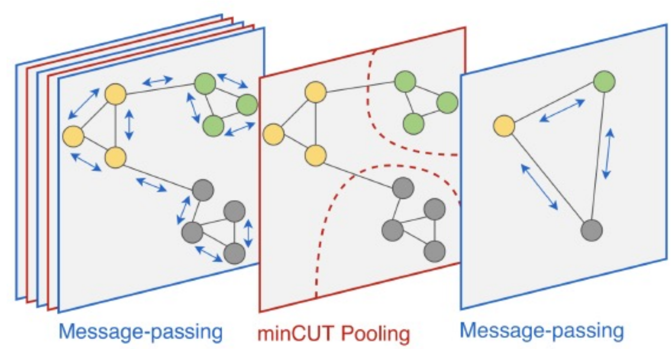
- Power system: Generation investment [I]/decommissioning [D], transmission expansion, and operational decisions (unit commitment, dispatch, storage)
- NG system: Pipelines [I/D], supply sources, pipe flows, storage

ML-Assisted Aggregation for CEPs

Tailored graph convolutional autoencoder + graph pooling with tailored "proxy" loss function → learn spatio-temporal aggregation

- automatically learn spatial and temporal aggregations of problem parameters (using power/NG loads, capacity factors)
- multi-objective loss function tradeoffs desirable characteristics:
  - relative influence of power vs. NG load in temporal aggregations,
  - spatial regularity vs. demand behavior similarity for spatial aggregations

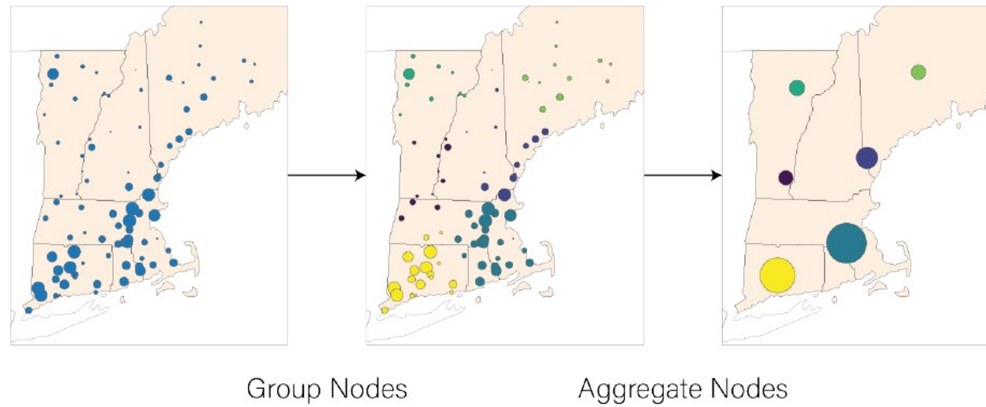




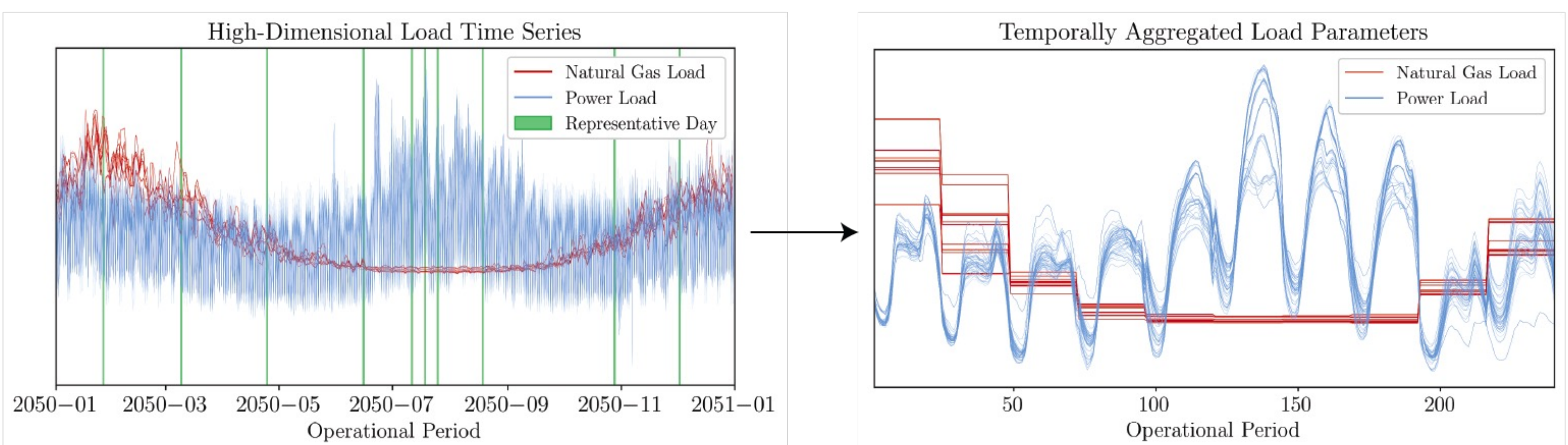
Brenner, Aron, Rahman Khorramfar, and Saurabh Amin. "Learning Spatio-Temporal Aggregations for Large-Scale Capacity Expansion Problems." *ICCPS* 2023

Spatiotemporal Aggregations for CEP

- Spatial aggregation [node clustering] → 10-40% better solutions than ad hoc methods

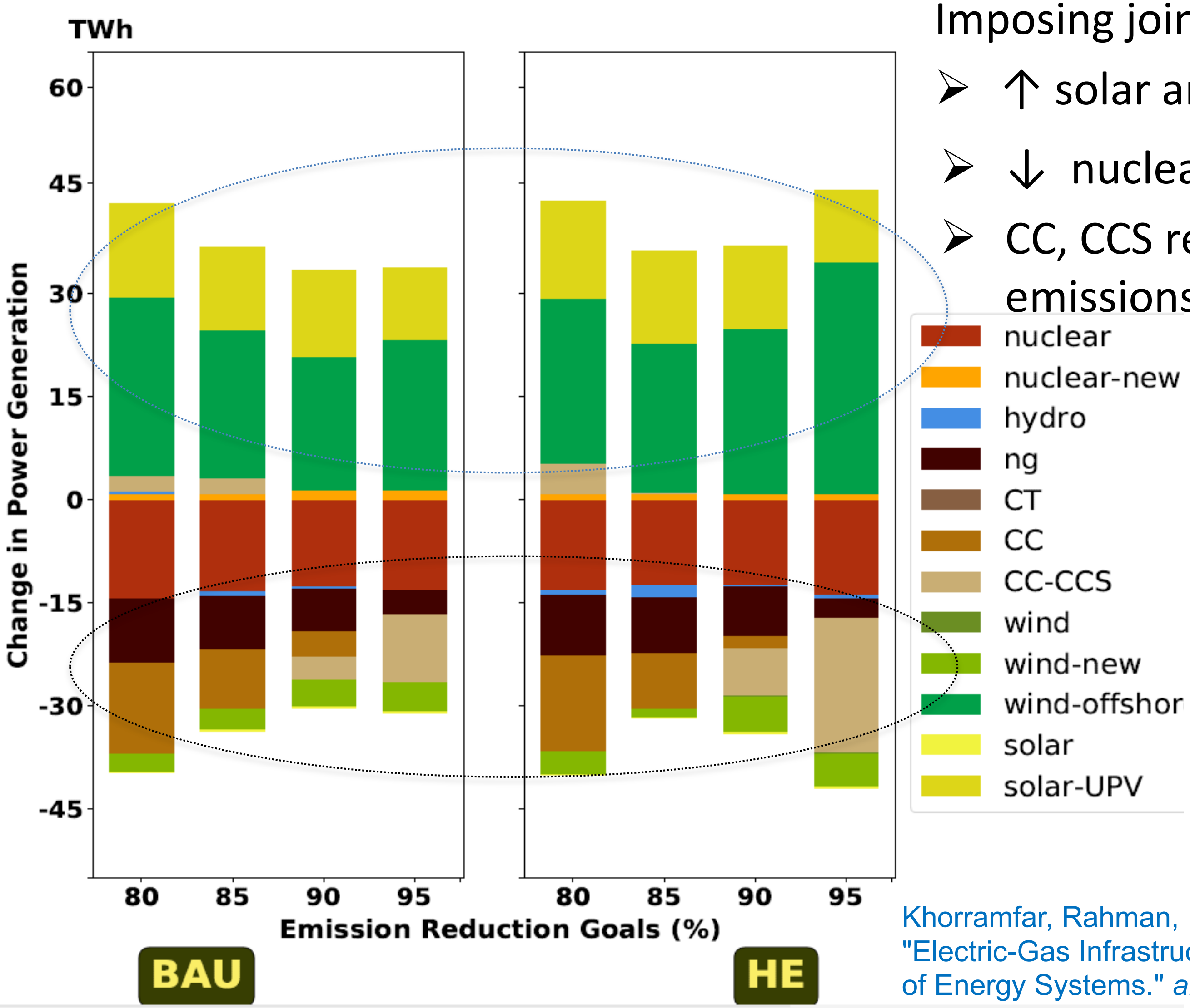


- Temporal aggregation [set of representative days] → 7-10% better solutions than standard methods (k-medoid and PCA)



Modeling Emissions Constraint

Joint emissions versus power system only

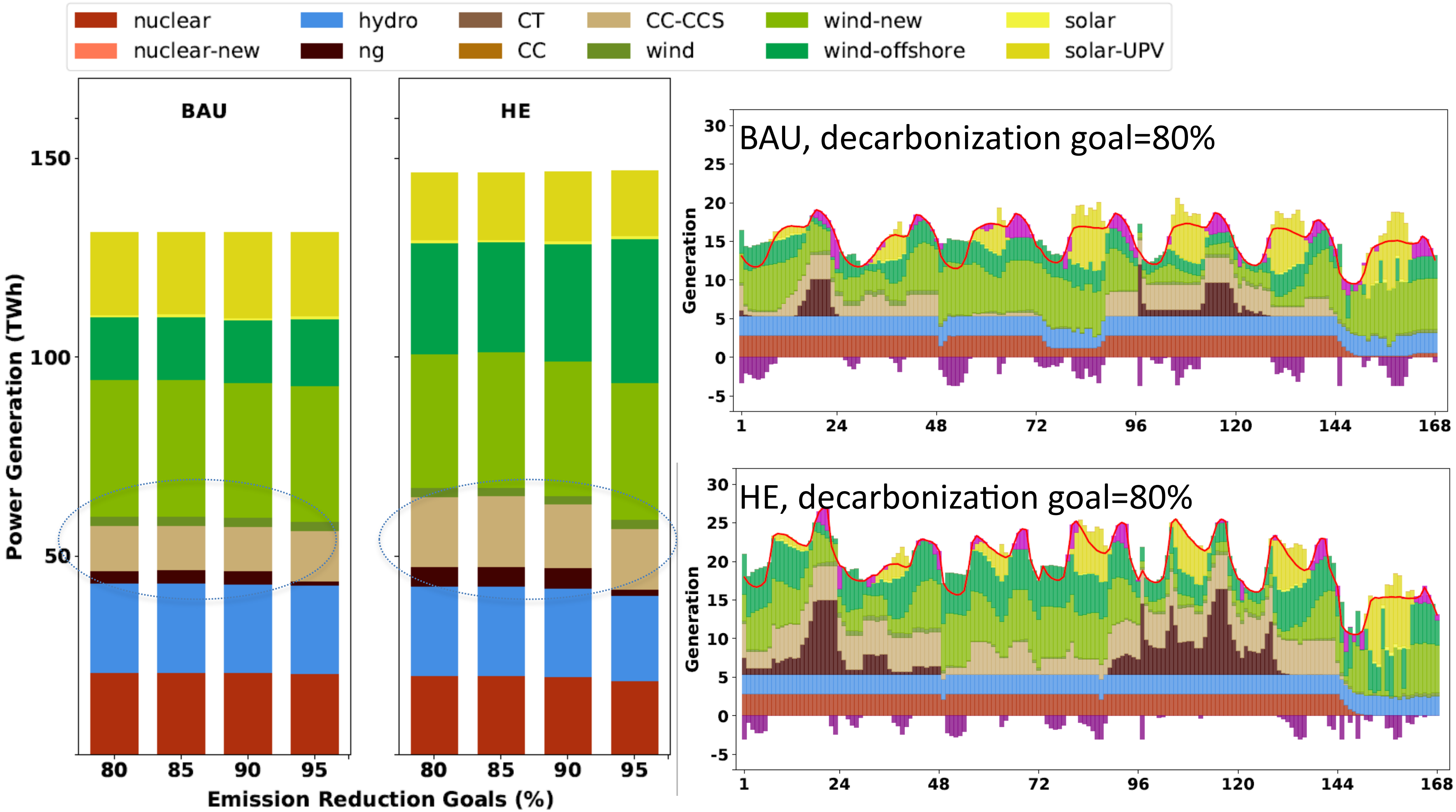


Imposing joint emissions constraint

- ↑ solar and off-shore wind
- ↓ nuclear and NG-fired plants
- CC, CCS relatively less attractive as emissions reduction goals ↗

Khorramfar, Rahman, Dharik Mallapragada, and Saurabh Amin. "Electric-Gas Infrastructure Planning for Deep Decarbonization of Energy Systems." *arXiv preprint arXiv:2212.13655* (2022).

Impact of Electrification



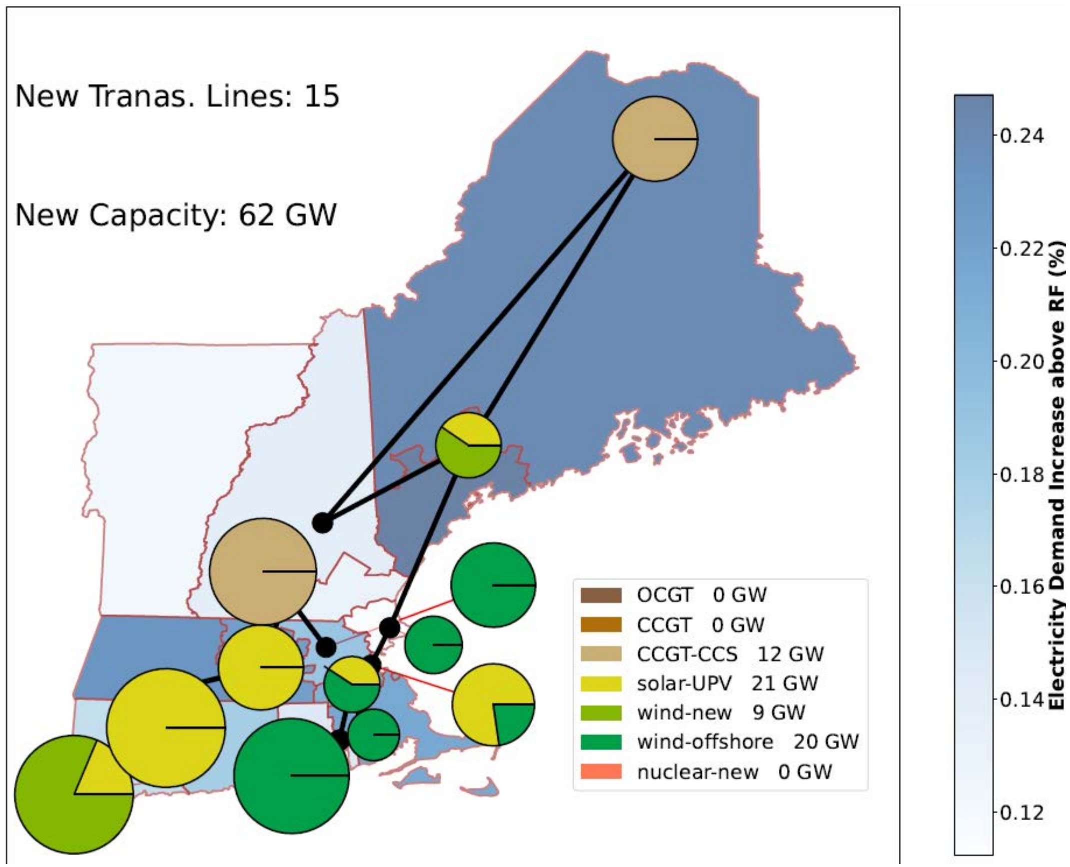
High electrification bumps up NG-based power production

Typical winter week: higher dispatch from gas-fired plants under electrification

Khorramfar, Rahman, Dharik Mallapragada, and Saurabh Amin. "Electric-Gas Infrastructure Planning for Deep Decarbonization of Energy Systems." *arXiv preprint arXiv:2212.13655* (2022).

Spatial Distribution of Investments

- Off-shore wind and solar are dominating in coastal regions
- No new capacity in west MA even with increased demand due to cheap power via new transmission lines
- Higher decarbonization target → more capacity (offshore wind, more CCGT-CCS, less CCGT) and transmission lines



Take-aways and Future Directions

- Joint planning of interdependent energy vectors
  - high-fidelity models of interdependent networks,
  - proper accounting for emissions and evaluation of outcomes
- To meet decarbonization goals, we need:
  - Robust when and where decisions for renewables: offshore wind, solar
  - Evaluation of gas-fueled power generation (esp. newer technologies) considering cost, reliability, and resource availability
  - Assess role of Renewable Natural Gas (RNG) and zero-emission biofuels

- **ML+OPT** for modeling climate change uncertainties
  - including inter-annual weather fluctuations $\Longrightarrow$ impact on supply/demand variations $\Longrightarrow$ energy planning outcomes
  - identify scenarios of interest to obtain robust planning decisions
  - tractable algorithms for regional-scale multi-vector energy models