

Future Energy Systems Center

April 26, 2023

Interim Project Update:
Electricity and natural gas infrastructure planning for deep decarbonization of energy systems

System impacts of decarbonization pathways for space heating in cold climates



Project Team

Principal Investigators



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Postdoctoral Associate

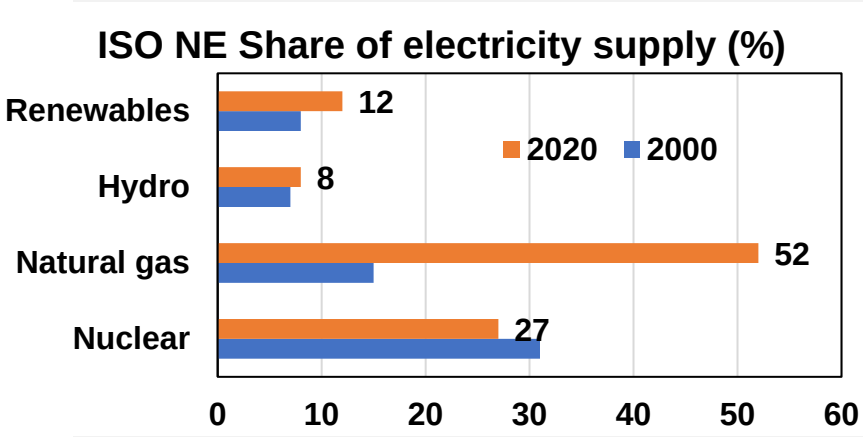


Rahman Khorramfar
MITEI and LIDS

Project motivation and objectives

Motivation

- Since 2005 to 2021, share of NG-based power generation in the electricity generation mix doubled to 38%[1] [EIA energy facts]
- Increasing VRE generation changing role of natural gas power generation on the grid
- Planning of electricity and NG infrastructure is becoming more coupled owing to the growing policy interest in electrification for achieving economy-wide decarbonization by mid-century




WINTER STORM 2021

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

BY ERIN DOUGLAS FEB. 16, 2021 5 PM CENTRAL

Objectives

1. Evaluate impact of joint power-gas planning on the infrastructure outcomes
2. Impact of inter-annual weather variation on supply and demand under different electrification and carbon constraints
3. Explore role for emerging supply (e.g. long-term storage) and demand-side technologies (e.g. envelope improvements)
4. What are the resiliency implications of alternative decarbonization pathways?

1. U.S Energy Information administration
2. Data sourced from https://www.iso-ne.com/static-assets/documents/2021/08/neppa_gvw_aug_2021_final.pdf

Joint Power-NG Expansion Model under Decarbonization Scenarios (JPoNG)

Minimize CAPEX and OPEX (Power + NG)

Residential demand Model + NREL EFS demand data for other sectors[1]

Power System (hourly, over >20 rep. days):
- **Investment** (new plants and transmission lines), **operational**
- **Policy**: RPS, resource availability, resource adequacy
- **Other**: CCS with dedicated pipelines
- Li-ion + **Long-duration** energy storage (**LDES**)

NG System (daily, full year):
- **Investment** (new pipelines), **operational**
- Biogas
- Other: **Storage/Vaporization/Liquefaction** facilities
- Strategic decommissioning of pipelines

Coupled by:
1. **Gas consumption in power system**
2. **Emission limit**

Key Model Parameters:
- Import gas price: **5.25$**/MMBtu
- Shedding cost: **10k$**/MWh-MMBtu
- WACC: **7.1%**
- Biogas cost: **20 $**/MMBtu

1. https://www.nrel.gov/docs/fy18osti/71500.pdf

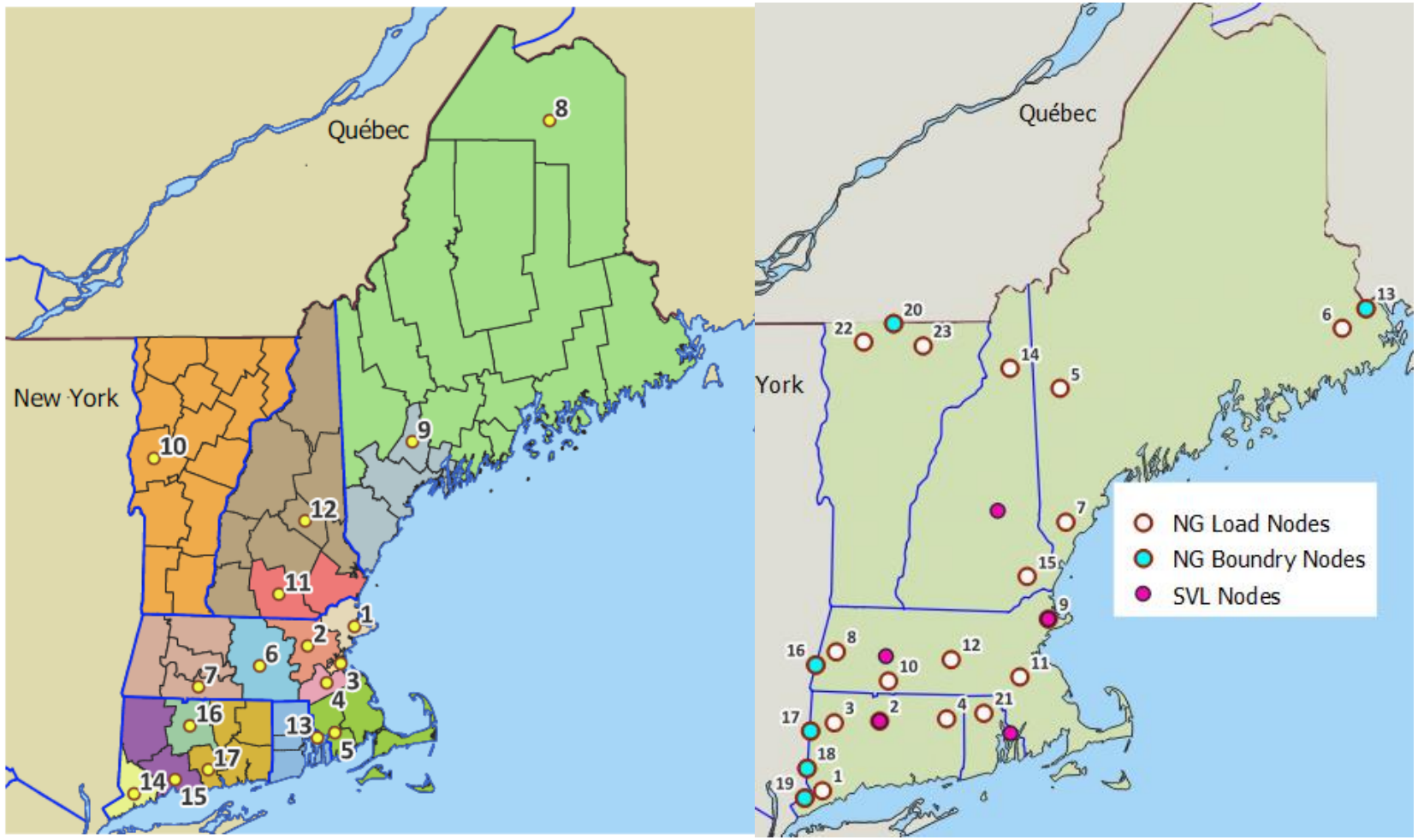
Preliminary results - do not disclose or distribute

Topology, Parameters, and Assumptions

References: Breakthrough Energy, EIA (energy information admin.), ISO-NE, etc.

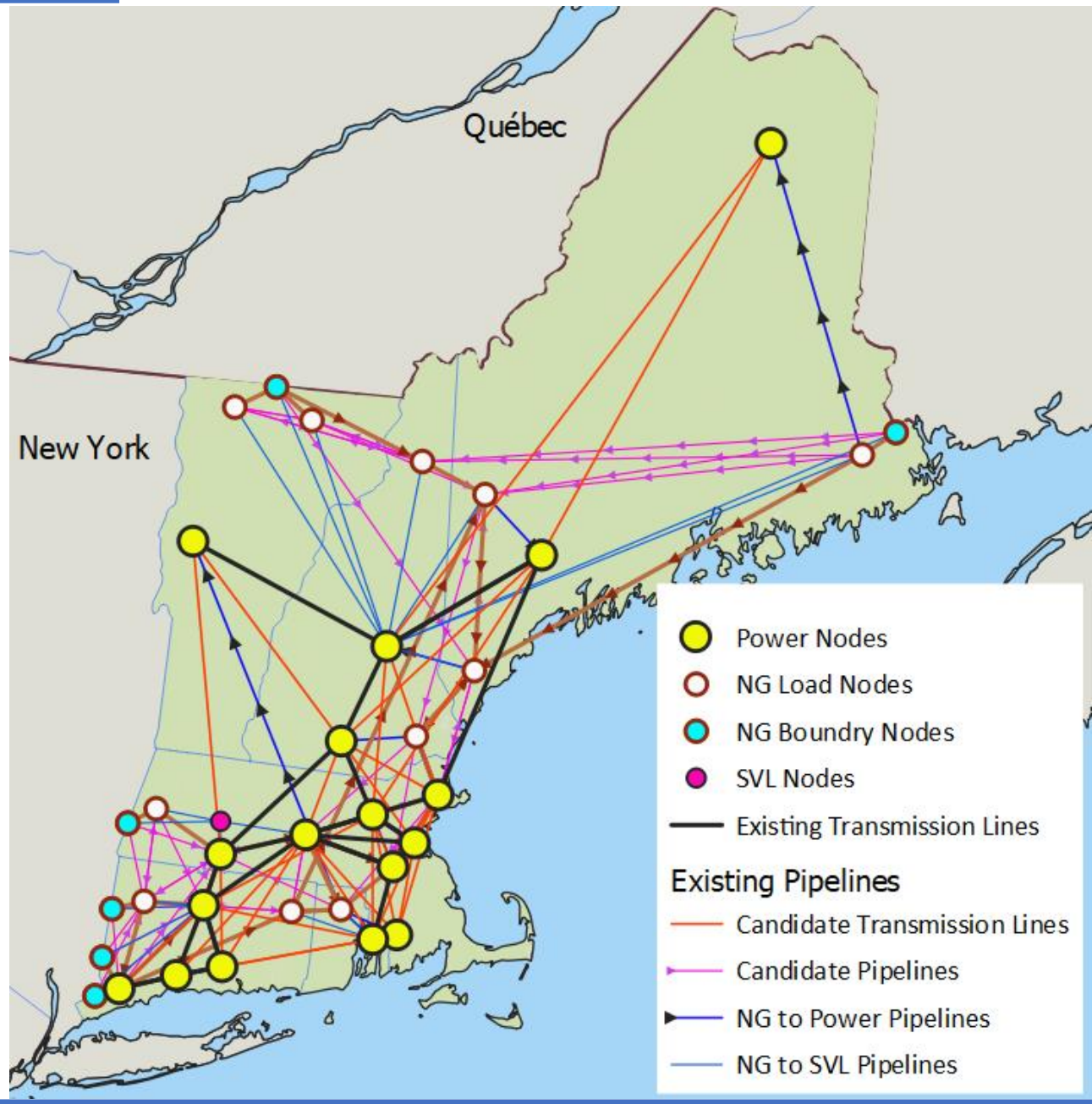
- Power system: 17 nodes each presenting multiple counties with at least 0.6 million population
- NG system: 23 nodes each representing intersection of inter-state pipelines

SVL: storage-vaporization-liquefaction facilities



Topology, Parameters, and Assumptions

- 30 existing, 34 candidate transmission lines
- 25 existing, 46 candidate pipelines
- Each power node is connected to the nearest NG node



Scenario design and Impact of different electrification levels and carbon emission constraints

Experiment design

Dimensions	Parameters
Decarbonization goals (vs. 1990 levels of emission from both systems)	**80-95%**
Electrification levels	**ME: Medium electrification** **MX: Medium elec. with efficiency** **HE: High electrification** **HX: High elec. with efficiency** **RF: Reference (least electrification)**
Inter-annual variations	**2003* vs. other weather years**
Temporal Resolution	**Power** System**: hourly,** **NG** System**: daily**
Spatial Resolution	**Power: 17** nodes, **NG: 23** nodes

Model investment decisions

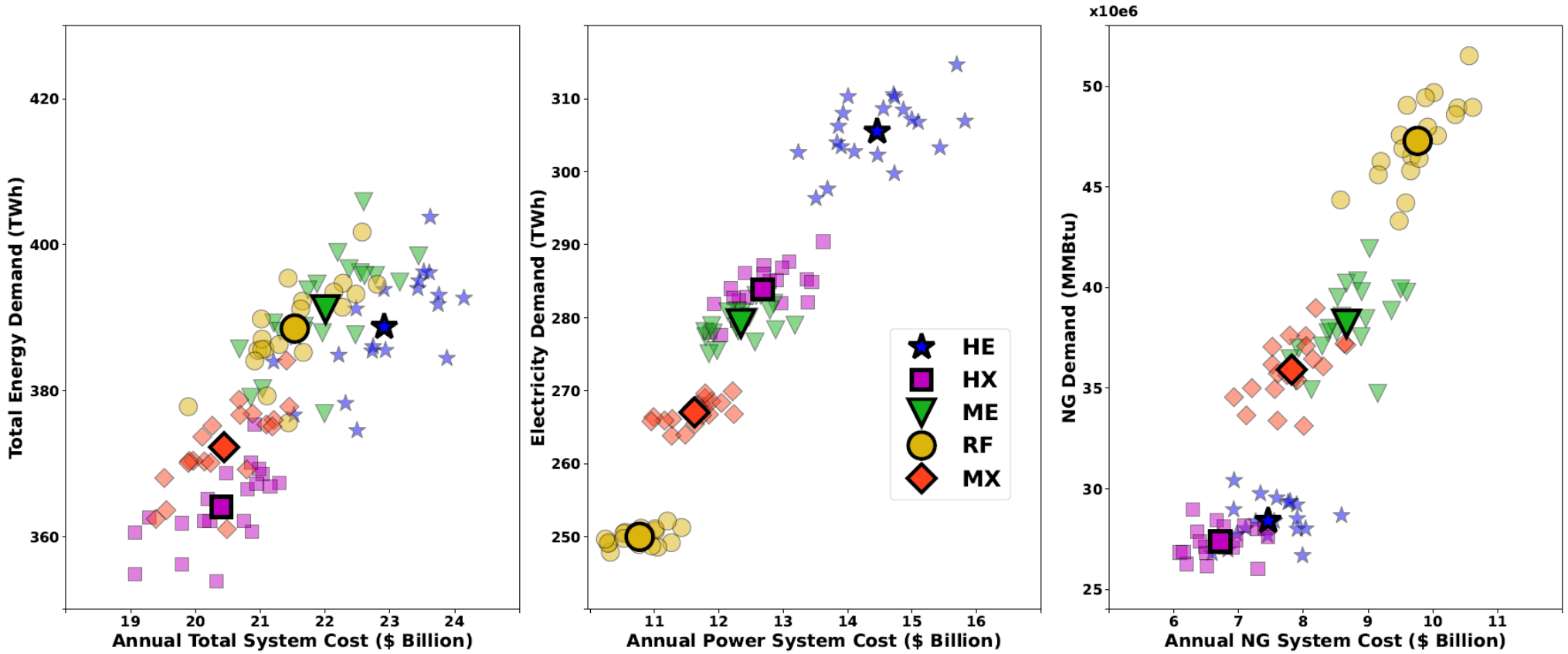
- VRE, gas power with and without CCS
- Li-ion storage, Long-duration storage (LDES)
- Biogas use for NG demand
- Network expansion, pipeline decommissioning

*2003 has the highest total energy demand, where total energy is non-power NG demand + final electricity demand

Impacts of Inter-annual variation (80% emissions reduction)

- Scenarios with medium to high electrification + efficiency improvements (HX, MX) tend to have lowest system costs on average across various weather years
- Energy efficiency improvements also reduces inter-annual variation system costs

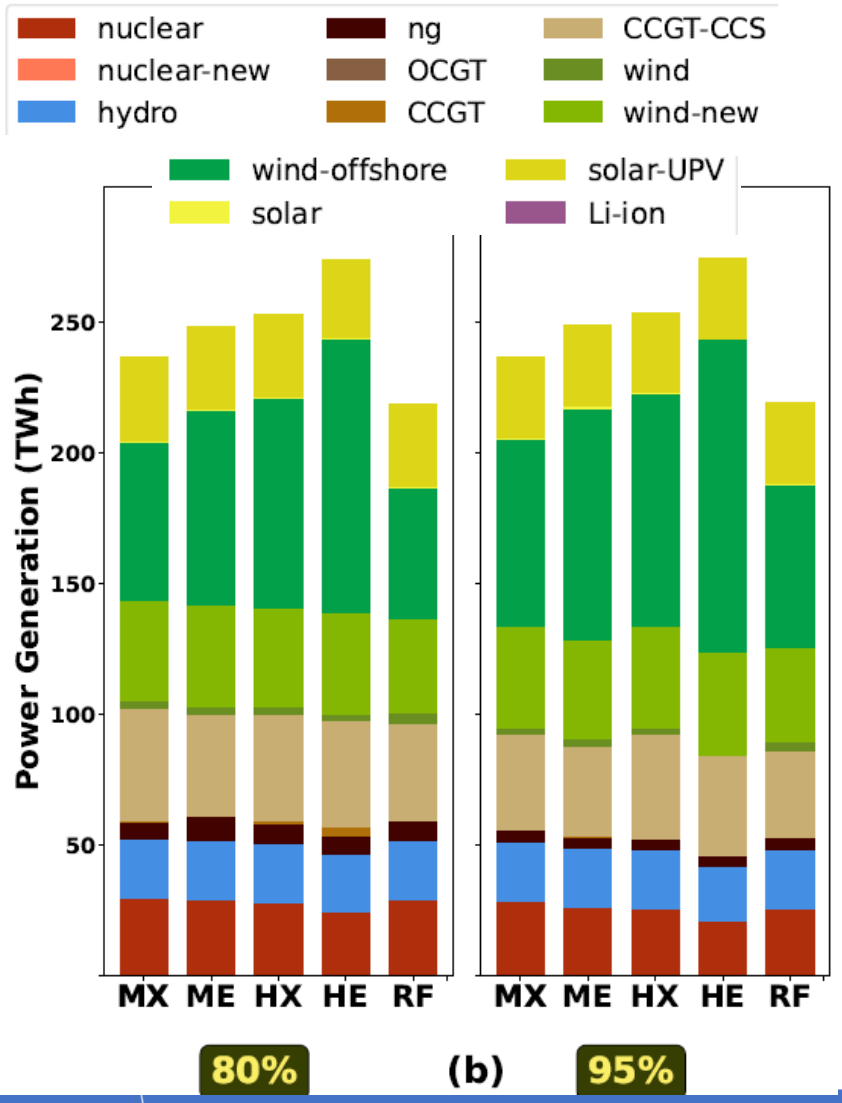
ME: Medium electrification
MX: Medium elec. with efficiency
HE: High electrification
HX: High elec. with efficiency
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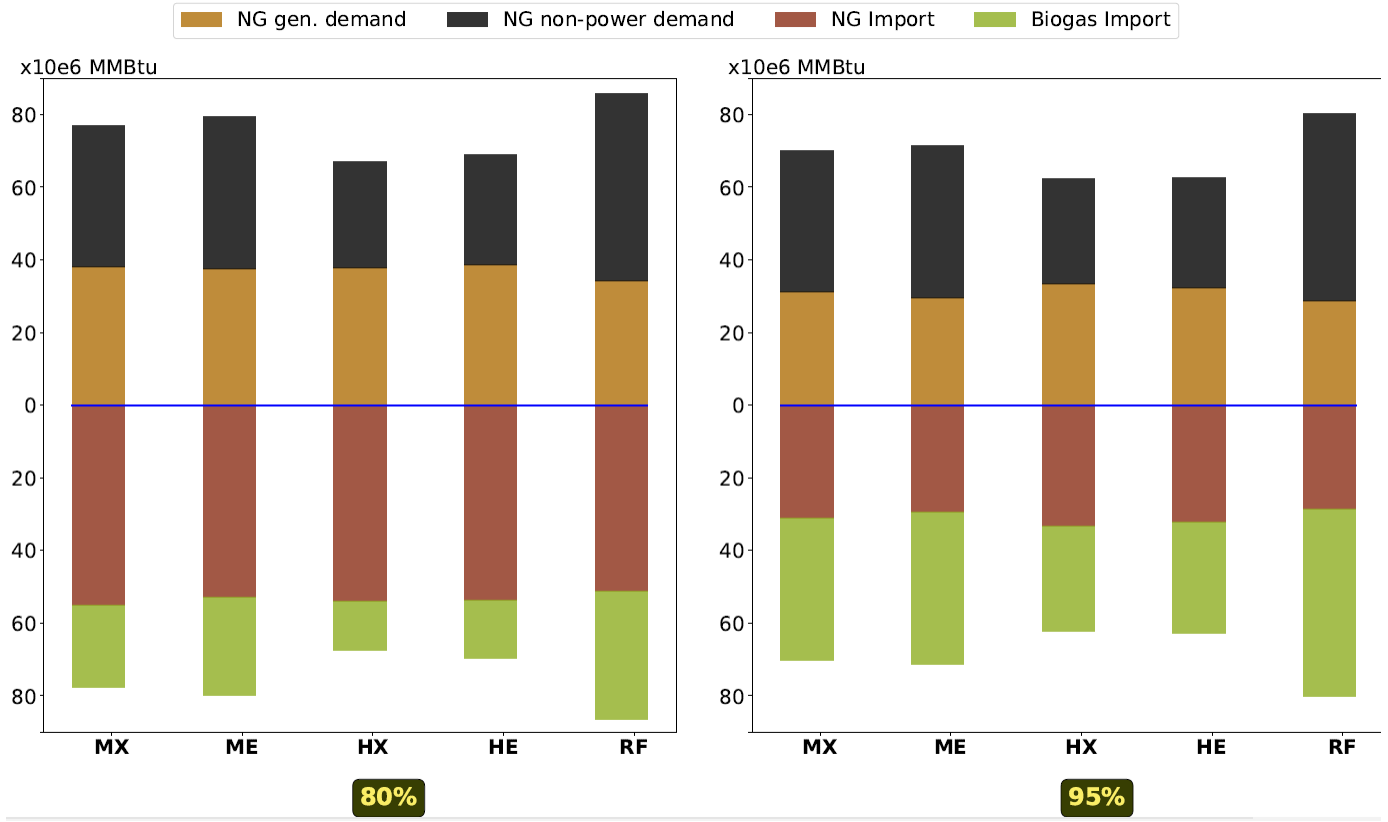


Total energy demand: non-power NG demand + final electricity demand

Supply-side Impacts of Electrification (2003 weather year)

- Most existing gas capacity retained due to capacity reserve margin
- Role for CCGT-CCS in all scenarios
- Higher decarbonization goal, more reliance on biogas
- Electrification reduce non-power NG load, but it can increase overall NG usage

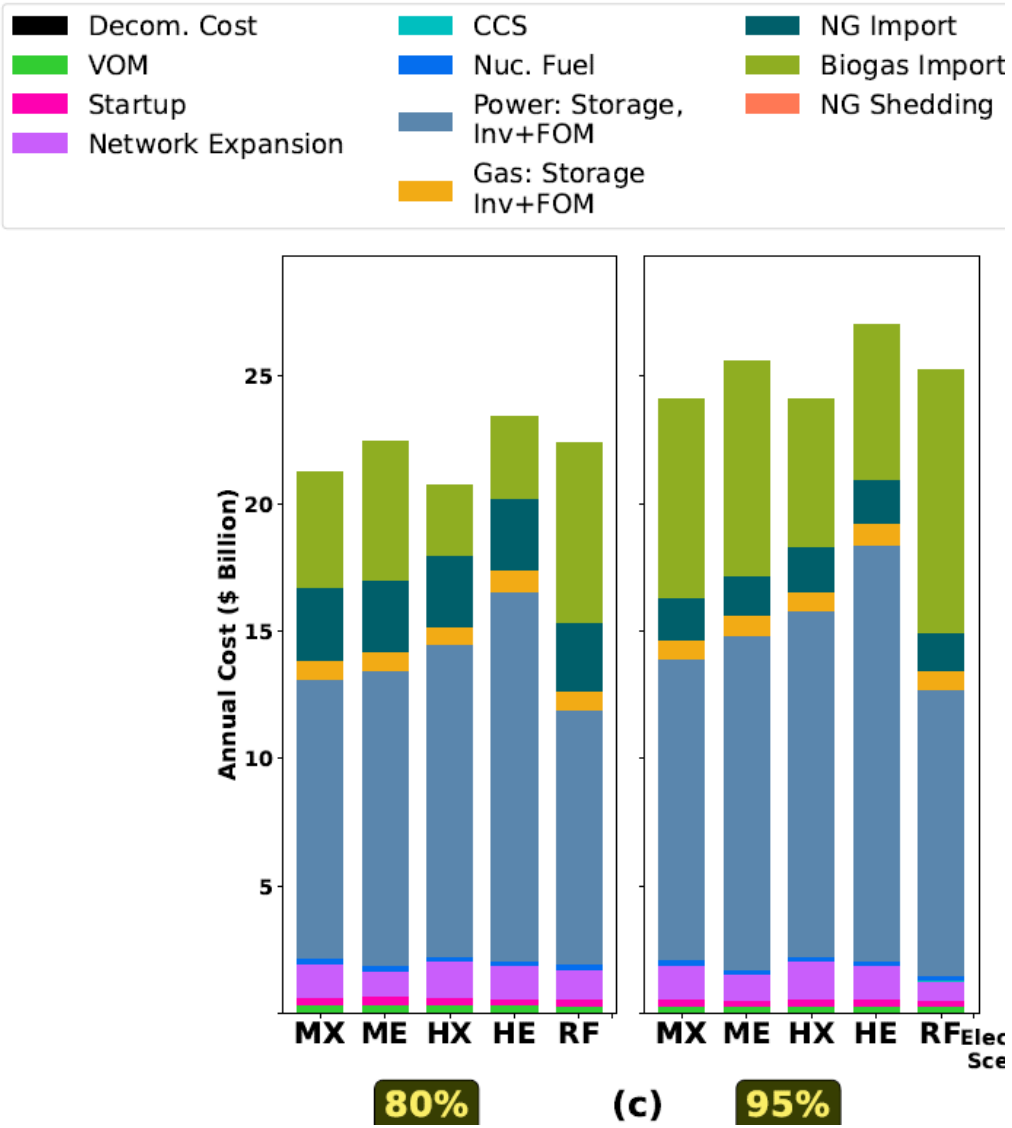




CCS = CO2 infrastructure costs; FOM = Fixed O&M costs

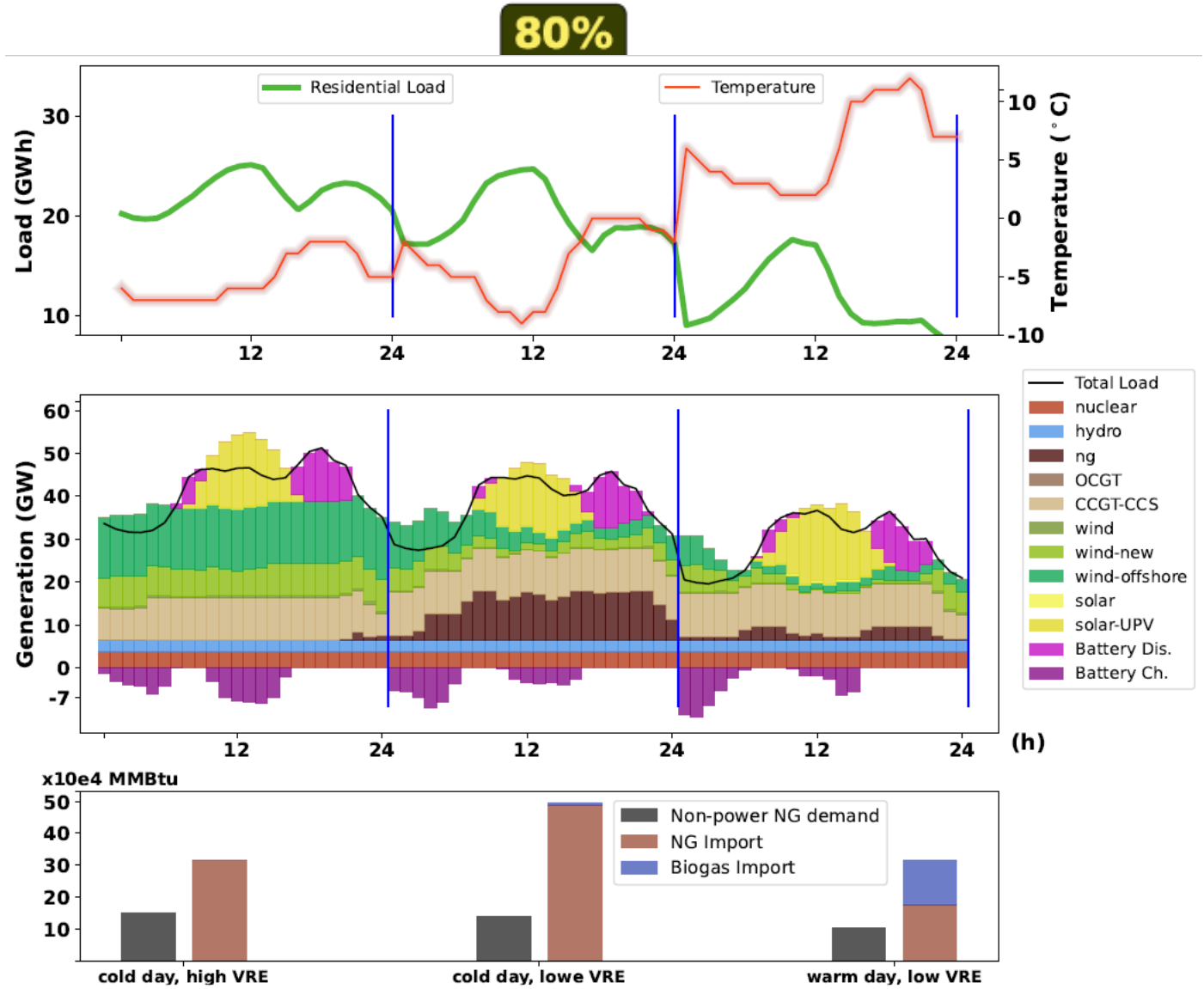
Supply-side Impacts of Electrification (2003 weather year)

- All scenarios involve transmission expansion (9 to 16 lines with total capacities 23-41 GW)
- Electrification with efficiency reduces cost of biogas imports and power sector investments such that HX cost less than MX
- No major investment in pipelines across any of the scenarios
- 30-40% decommissioning of the existing pipelines capacity



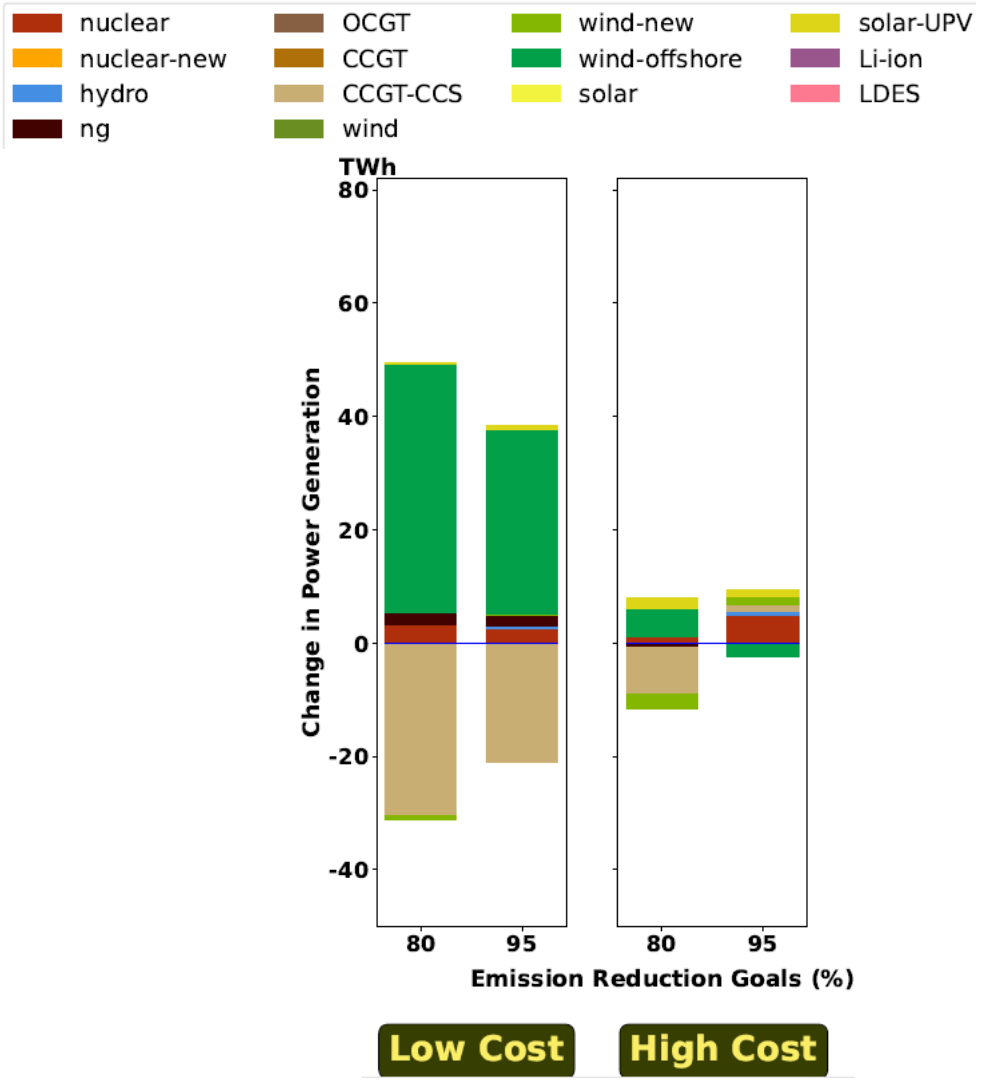
Typical Winter Days Operations (HX, 80% emissions reduction, 2003)

- Need for low-carbon firm resources (CCGT-CCS) for baseload
- CCS capacity factor 47% (overall high in other scenarios as well)
- Existing unabated gas used for peaking capacity on days with low VRE



Long-duration energy storage (LDES), HX, 80% emissions reduction, 2003

- Reduced NG in the power system reduces coupling between power-gas systems, and biogas utilization
- LDES increase reliance on offshore wind, and reduce the share of gas-fired generation
- LDES improves the capacity utilization of wind and solar generation



1. Low and high cost ranges for LDES based on cost estimates for metal-air batteries

Contributions and Takeaways

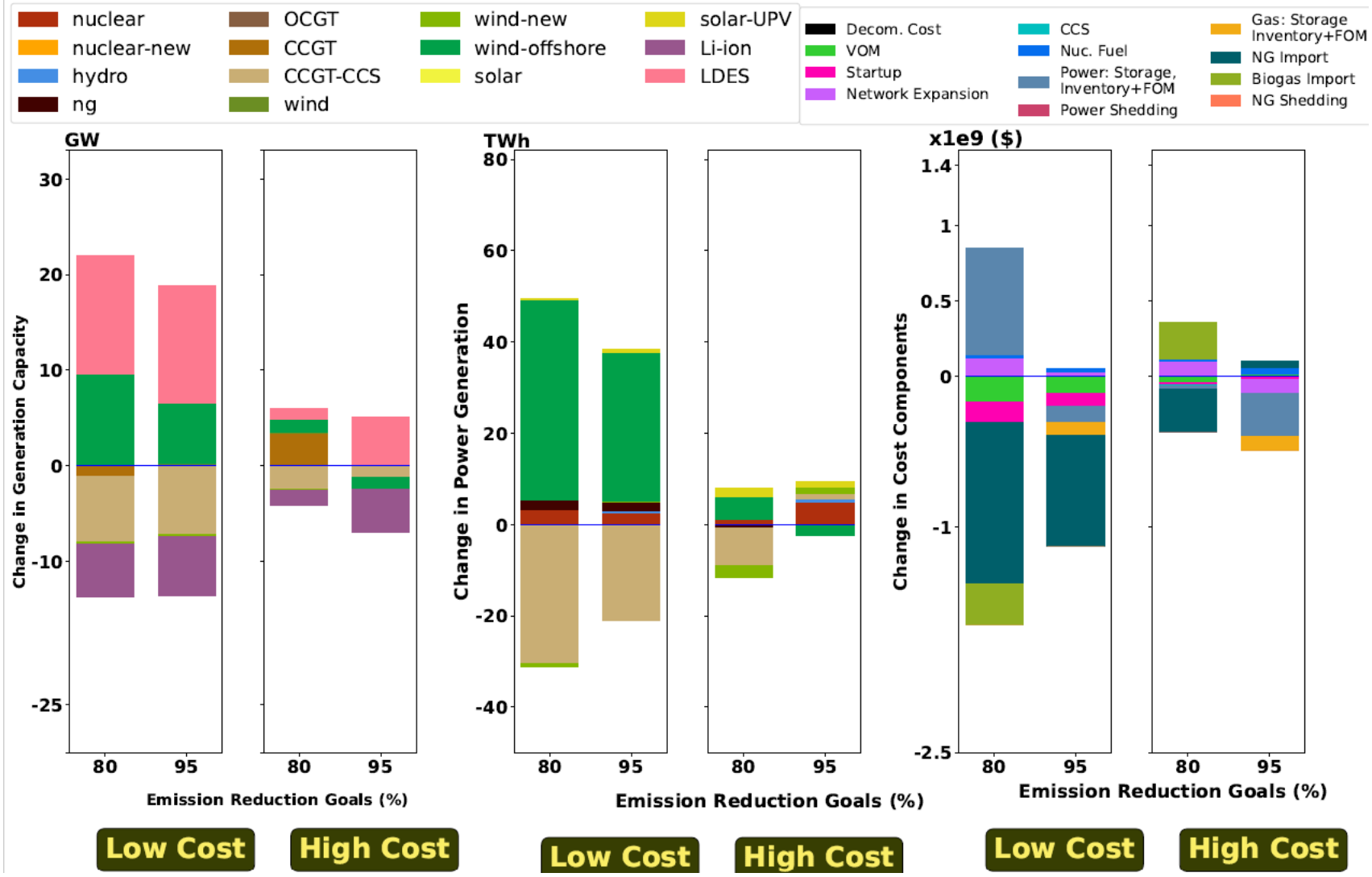
- Integrated energy systems modeling essential to identify bulk system impacts of alternative decarbonization pathways
- Electrification and grid decarbonization increases sensitivity of optimal infrastructure planning to inter-annual weather variation
- Energy efficiency improvements critical to reduce grid impacts of heating electrification and can contribute to mitigating impact of inter-annual weather variations
- High electrification, VRE expansion, transmission expansion and limited reliance on fuel-based generation (natural gas, or biogas) are parts of cost-effective energy system decarbonization pathways

Remaining project activities

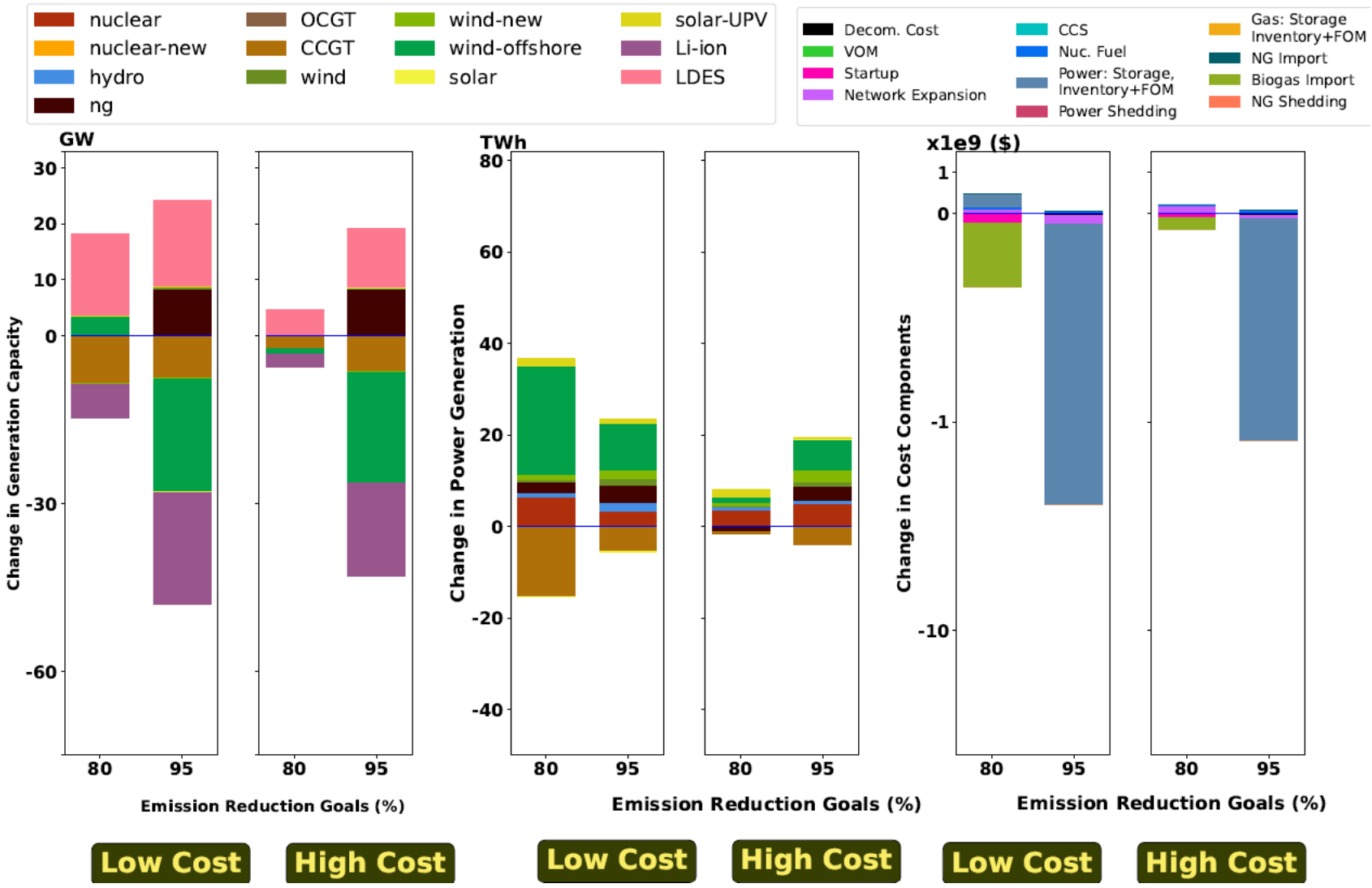
- **Incorporating Robustness** to inter-annual variations in supply and demand
- **Refining** the model, and incorporating more technologies and energy vectors
  - Incorporating imported hydro (e.g., from Canada)
- Exact solution methods

Q&A and Project Discussions

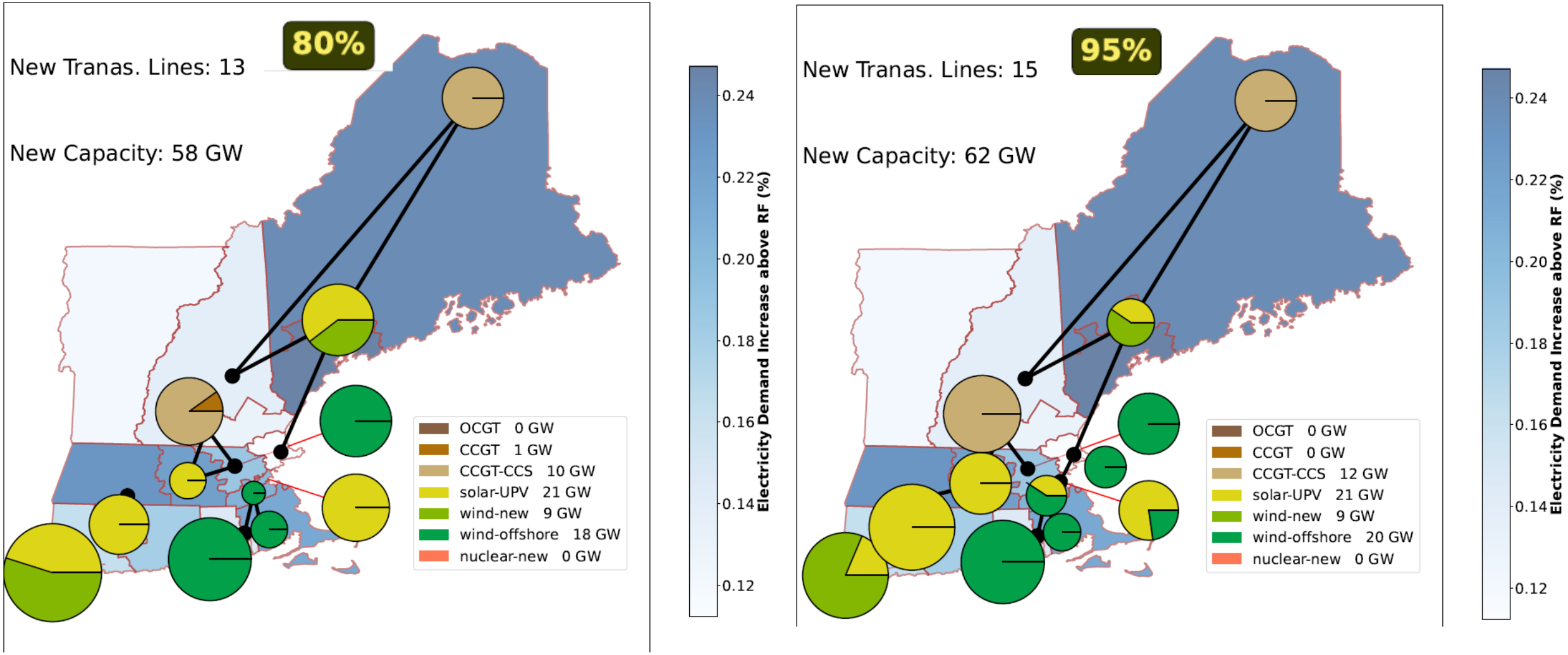
Backup Slides, HX, 2003, with CCS



Backup Slides, HX, 2003, no CCS



Backup Slides, spatial distribution of new investments,



Topology, Parameters, and Assumptions

67 counties
Population: 14.8 million

