Decarbonized Future Power-Gas Systems Under Large-Scale Electrification of Building Heating in New England

Morgan Santoni-Colvin (msantoni@mit.edu), Dr. Rahman Khorramfar (khorram@mit.edu), Dr. Dharik Mallapragada (dharik@mit.edu), Prof. Les Norford (lnorford@mit.edu), Dr. Audun Botterud (audunb@mit.edu), Prof. Saurabh Amin (amins@mit.edu)

Background and Rationale

The electrification of building heating is needed to reduce on-site emissions in New England's residential sector

- Air-source heat pumps (ASHPs) are likely to be the primary technology used



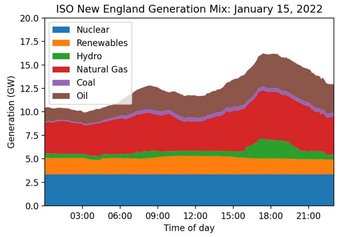
Leon Neal /Getty Images

New England's electricity mix is currently fossil-fuel-intensive

- 54% of 2021 generation was fossil-fueled[1]

Future supply-side impacts of demand changes from deep electrification are not well-understood

- Electrification is likely to mutually change the roles of electric power and natural gas (NG) systems



Data from ISO NE

We couple a detailed <u>bottom-up model</u> of hourly building energy consumption in the residential sector with a <u>joint power-gas system model</u> to evaluate optimal planning decisions and costs under a mix of future scenarios.

Evaluated Scenarios for 2050

Weather & climate	Heat pump deployment	Emissions limits
Hourly weather patterns taken from six "extreme" historical years between 2000-2021[2] Use "morphing method"[3] on these years to reflect effects of climate change using predictions from **CESM2 model, SSP370** (high emissions)[4]	**Medium electrification** based on the Massachusetts Clean Energy & Climate Plan ("ME")	80% below 1990 levels
	High electrification based on the Massachusetts Clean Energy & Climate Plan ("HE")	
	High electrification + improvements to efficiency of building envelope ("HX")	95% below 1990 levels
	Reference scenario based on NREL Electrification Futures Study[5] ("RF")	

- Supply-side models include biogas as fossil natural gas substitute at ~4x the price

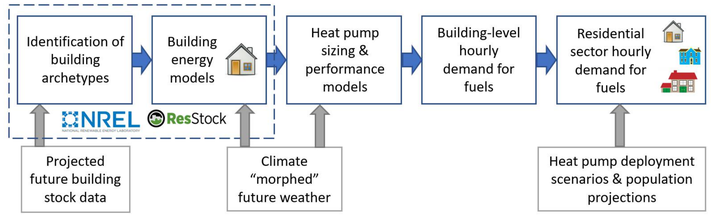
References and Acknowledgments

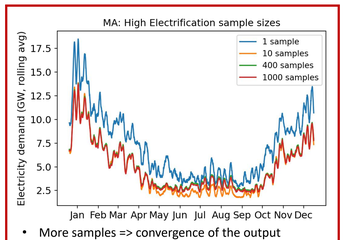
1. ISO New England. (n.d.). *Resource Mix*. https://www.iso-ne.com/about/key-stats/resource-mix
2. Weather data generously provided courtesy of OikoLab.
3. Belcher, S. E., Hacker, J. N., & Powell, D. S. (2005). Constructing design weather data for future climates. *Building services engineering research and technology*, *26*(1), 49-61.
4. Danabasoglu, G., et al. (2020). The Community Earth System Model Version 2 (CESM2). *Journal of Advances in Modeling Earth Systems*, *12*(2). https://doi.org/10.1029/2019ms001916
5. Mai et al. (2018). *Electric Technology Adoption and Energy Consumption* (10.7799/1461472) [Dataset]. National Renewable Energy Laboratory. https://data.nrel.gov/submissions/92

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Methodology for Demand Modeling

Bottom-up building energy model of residential sector

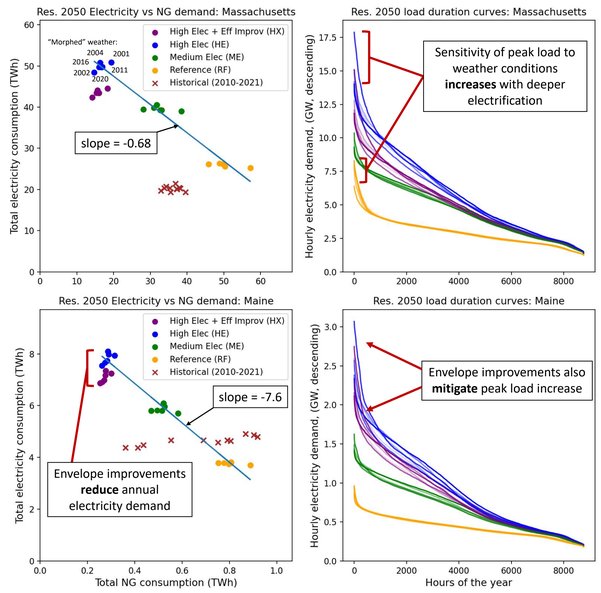




- More samples => convergence of the output
- Sufficiently large number of samples **faithfully represents the heterogeneity** of the physical housing stock and occupant behavior
- We select 400 samples per state

- **Highly detailed physical simulations** of building energy performance for a sample of archetypes that represent the stock
- Weighted sum of the archetype profiles gives state-level demand
- Two options for heat pump sizing:
  - 1. Meet winter load
  - 2. Meet smaller summer load, keep existing system for the coldest days
- Scenarios include differing mixes of both

Results for Demand Modeling



- All electrification scenarios (except RF) result in a shift from **summer-peaking** to **winter-peaking** electricity demand
- ISO-NE system peak load increases by 15 - 193% (2.3 - 23.4 GW) over reference peak load (12.1 - 15.7 GW)
- Rate of NG displacement with increasing electrification varies from state to state

Methodology for Supply Modeling

Joint power and natural gas (NG) system planning model

Minimize CAPEX and OPEX (Power + NG)

2050 Power/NG demand

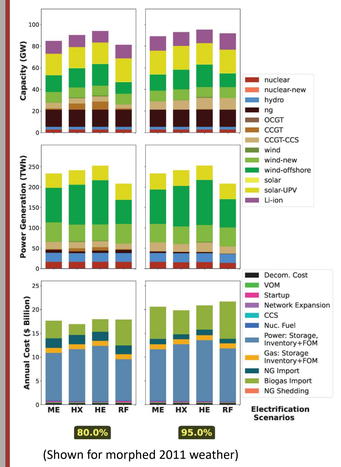
Power System (hourly, over 20 rep. days):
- **Investment** (new plants and transmission lines) and **operating constraints**
- **Policy**: RPS, resource availability
- Other: **CCS** with dedicated pipelines
- **Li-ion** batteries

NG System (daily, full year):
- **Investment** (new pipelines) and **operating constraints**
- Biogas (net-zero emissions)
- Other: **Storage/Vaporization/Liquefaction** facilities

Coupled by:
1. **NG consumption in power system**
2. **Economy-wide emissions limit**

Results for Supply-Side Impacts of Demand Scenarios

Capacity, generation, and cost impacts of electrification and emissions limit scenarios

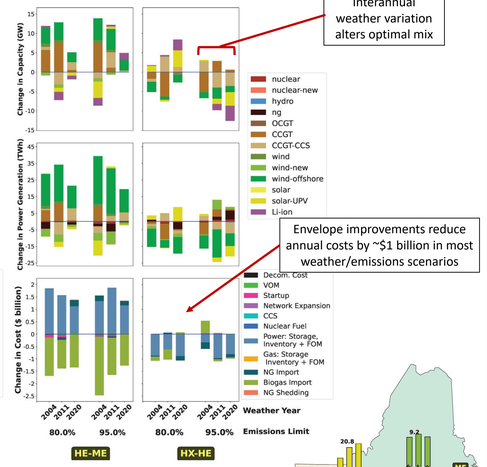


(Shown for morphed 2011 weather)

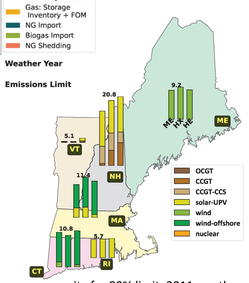
Difference plots between system outcomes for key electrification scenarios

Interannual weather variation alters optimal mix

Envelope improvements reduce annual costs by ~$1 billion in most weather/emissions scenarios



- High electrification coupled with envelope improvements results in the **lowest** bulk system cost
- More stringent emissions limit => more biogas needed
- More electrification => less biogas needed



Ex. New power capacity for 80% limit, 2011 weather

Conclusions and Future Work

- Residential heating electrification in New England will likely significantly increase total and peak electricity demand
- Aggressive electrification may **reduce power-gas bulk system costs** and biogas reliance
- Weather and climate-related uncertainty merit further research
- Planned application to other regions (esp. Mid-Atlantic) may provide broader insights