

System impacts of decarbonization pathways for space heating in cold climates

Project Brief

December 8, 2023

Morgan Santoni-Colvin, TPP student, MITEI
Jameson McBride, TPP student, MITEI
Tony Lee, TPP student, MITIE
Graham Turk, TPP student, MITEI
Nicolas Morell, Visiting student, MITEI
Rahman Khorramfar, Postdoctoral associate, MITEI
Pablo Duenas-Martinez, Research Scientist, MITEI
Tim Schittekatte, Research Scientist, MITEI
Saurabh Amin, Professor, Civil and Environmental Engineering
Leslie Norford, Professor, School of Architecture
Audun Botterud, Principal Research Scientist, LIDS
Dharik S. Mallapragada, Principal Research Scientist, MITEI

Motivation and objectives

Buildings account for 26% of global energy-related emissions.[1] Decarbonizing the building stock requires simultaneously electrifying building heating systems and deploying renewable electricity generation. This transition will require significant infrastructure investments and operational changes to ensure continued reliable and affordable energy service for ratepayers. The goal of this project is to evaluate the impacts of building decarbonization on electricity and natural gas networks, using the New England region as a case study.

Research and analysis performed

We addressed the following four research questions. Under each question, we summarize our approach:

1. How do building sector electricity and natural gas demand evolve under different decarbonization and weather scenarios?
We built a demand forecasting model starting with individual buildings and aggregating up to the entire New England region. Using projections of New England's future building stock and climate change-

[1] IEA. (2023). *CO2 Emissions in 2022*. IEA. https://www.iea.org/reports/co2-emissions-in-2022

driven future weather patterns, we generated annual hourly electricity and gas demand profiles from today until 2050 under six electrification policy scenarios.

2. What are the bulk system impacts associated with meeting new demand?
Using the profiles and scenarios from (1), we employed an integrated electricity-gas planning model to calculate the investments needed to reliably meet demand under a "least cost" framework. We studied the impact of weather variability and the availability of emerging technologies (e.g., carbon capture and long-duration energy storage) on the required bulk energy infrastructure outcomes for the region.

3. How can demand flexibility help reduce the need for electric distribution grid upgrades?
We used an optimization model to simulate price-responsive heating demand under several network tariff alternatives. We calculated the customer economics of heat pump adoption and the associated distribution level upgrades under various retail tariff designs.

Key results

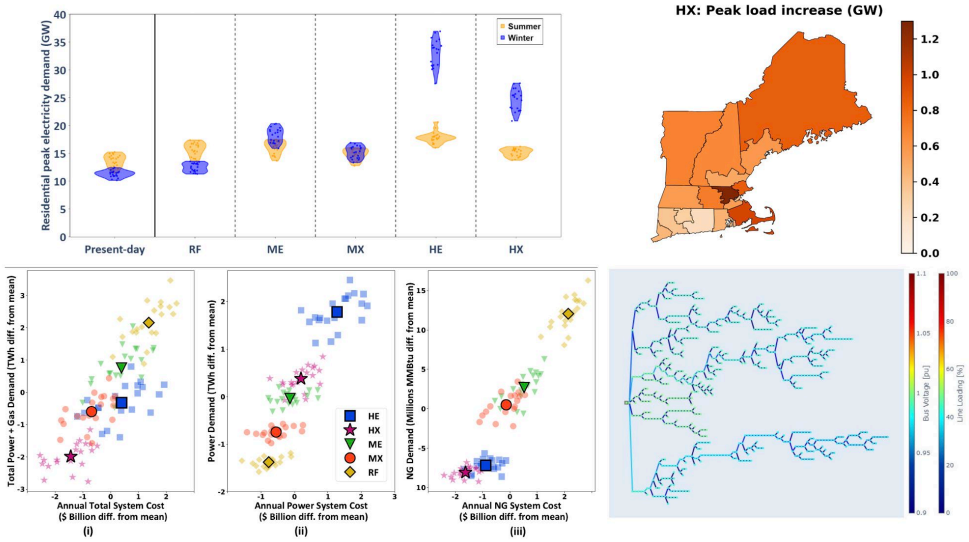
1. Under high heating electrification scenarios, we project a near doubling of regional electricity peak demand, exacerbated by extreme weather events and the lack of backup heating options.

2. We identify a few measures that can mitigate peak demand impacts of electrification and improve customer adoption economics to a varying degree: a) Retail rate design to incentivize time-shifting of demand and reduce network impacts, b) Building envelope improvements to reduce energy demand and c) Use of "hybrid" heat pumps with gas instead of electric resistance as the backup heating source, which reduces peak demand and lowers upfront capital costs for heat pumps.

3. Network investments will not be shared equally; rural, lower-income areas are projected to have higher upgrade requirements, posing a serious equity concern.

Contribution to decarbonization

As governments and utilities look to act upon decarbonization plans, this project highlights the changes needed to spur rapid electrification of heating while mitigating distributional outcomes. While New England has unique characteristics, in many ways it is a worst-case scenario: high existing electricity prices, limited renewable generation resources, and constrained gas supply. The key takeaways are broadly applicable to any geography where building decarbonization will rely heavily on electrification.



Clockwise from top left: (a) Summer and winter peak demands for the residential sector under different electrification scenarios; (b) Average residential peak load increases for scenario HX above present-day for 17 zones in New England; (c) Network topology and peak hour power flow for distribution grid model; (d) Total bulk power-gas system cost versus energy consumption under the 80% decarbonization scenario