Are distribution networks ready for electrification of heating? A tale of heat pumps, PV, tariffs and H_2

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A collaborative research within MITei



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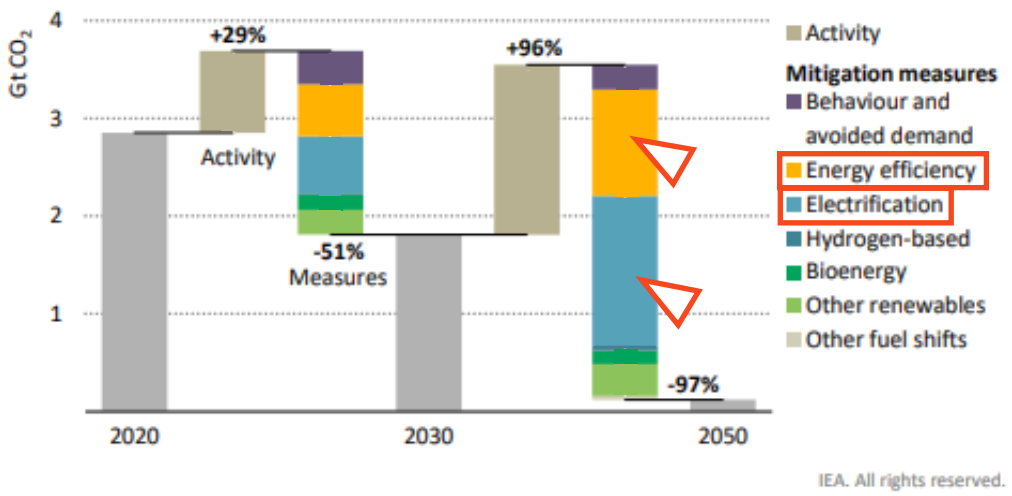
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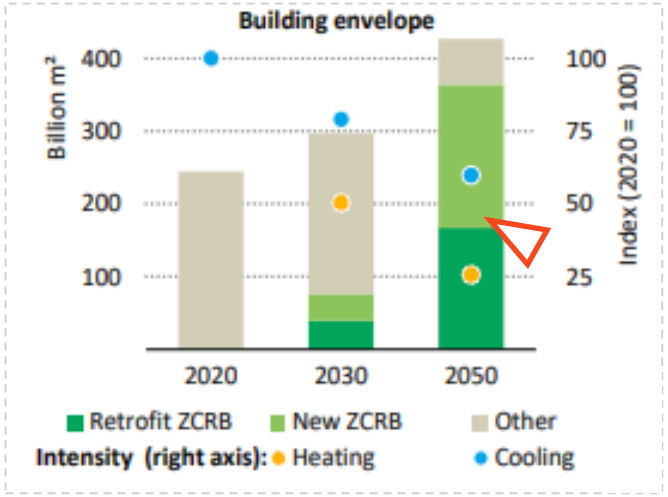


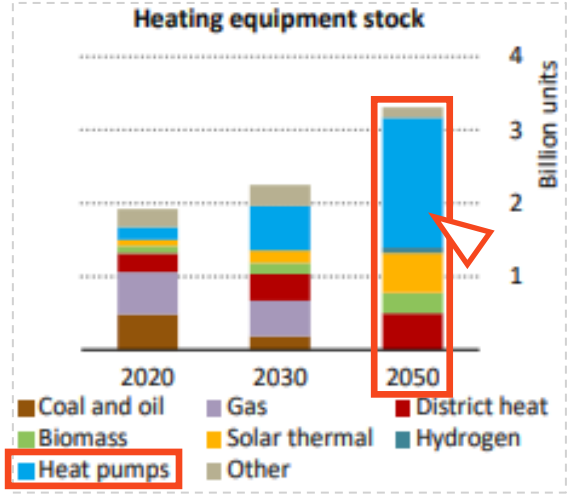
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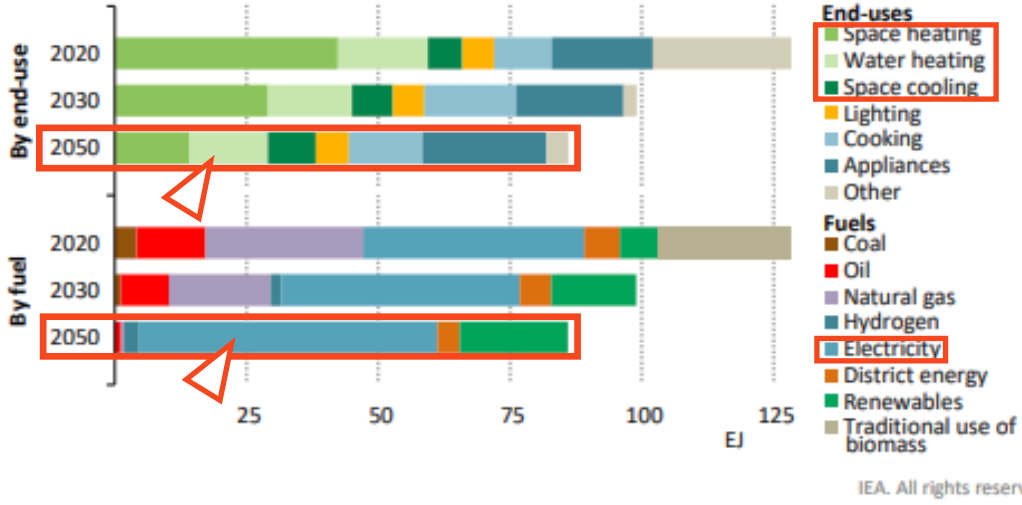
J. McBride, “Clean Heat at What Cost? Economic Optimization of Space Heating in Massachusetts”, MSc thesis
T. Lee, “Implications of Heating Electrification on Distribution Networks and Distributed Energy Resources”, MSc thesis
J. Dancker et al., “Can low-carbon gas reduce the impact of heat pumps and rooftop PV on distribution networks in Northeast U.S.?”
N. Morell et al., “Effect of flexible demand on network tariff design”

Buildings are representing about 10% of direct global CO2 emissions, almost 3 Gt









All thermal loads: space heating/cooling, water heating, even cooking; will be mostly covered by electricity

Source: International Energy Agency. Net Zero by 2050 - A Roadmap for the Global Energy Sector. May 2021

Buildings can actively contribute to CO_2 emissions reduction

Electrification of heating	Replace fossil-fuel based heating by electricity in all sectors: residential, commercial and industrial; eliminating distributed CO_2 emissions and enabling new flexible resources.
Demand response	Aggregate low-cost micro-actions (e.g., thermostats, lighting, load rescheduling), contributing to guaranteeing the reliability in times of scarcity in a renewable-based electricity system.
Energy efficiency	Implement measures that lower energy consumption, offer synergies with previous actions, reduce electricity bills, and mitigate new investments in the bulk power system.
Distributed generation	Adopt behind-the-meter generation equipment—PV panels, batteries, CHPs, and EVs—favored by reducing economies of scale, public subsidies or consumers' preferences.
Distributed hydrogen	Produce hydrogen locally through electrolysis using excess renewable generation and substituting remaining carbon-based uses.

Our aim is explaining the challenges and opportunities at distribution level

Planning

- What is the optimal equipment to be installed in a building to procure energy and benefit from providing energy services?

- Is a specific technology or action techno-economically viable? What is the viability gap? Does it depend on the climate or type of building?

- Will consumers adopt a specific technology after regulatory changes, tariff structures, or new business models?

- Will consumers change their energy (consumption/generation) pattern after new business models or tariff structures?

- How much value can offer/obtain the consumer to/from providing ancillary services, improving resiliency, or supporting decarbonization?

Operation

- What should be the expected operation of a specific technology under real conditions?

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Distributed Energy Consumption in Actively Responsive Buildings (DECARB) model



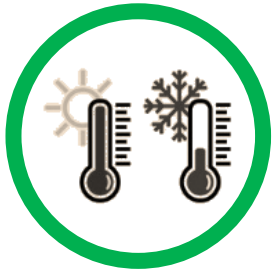
How much and when electricity is purchased or sold back



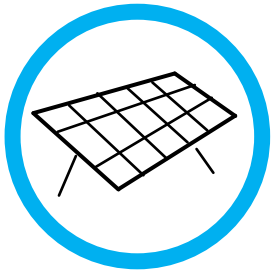
How much and when fuels are consumed



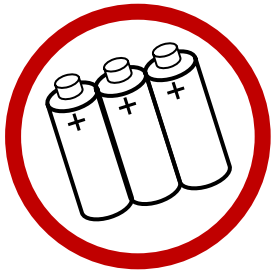
How much saved or increased CO_2 emissions



Control of indoor temperature and hot water production



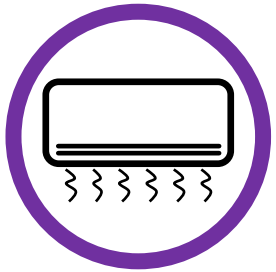
Capacity planning and injection of solar power



Capacity planning and cycling of electric batteries



Provision of heat and/or electricity by co- or tri-generation units



Provision of heating or cooling by HVAC units

4-D versatility to configure an extensive and granular range of realistic cases

Geographical

- Direct normal and diffuse horizontal irradiance
- Outdoor temperature
- Wind speed
- Morphology, materials, glazing, ventilation, occupancy
- Location: latitude, longitude, altitude, orientation, time zone

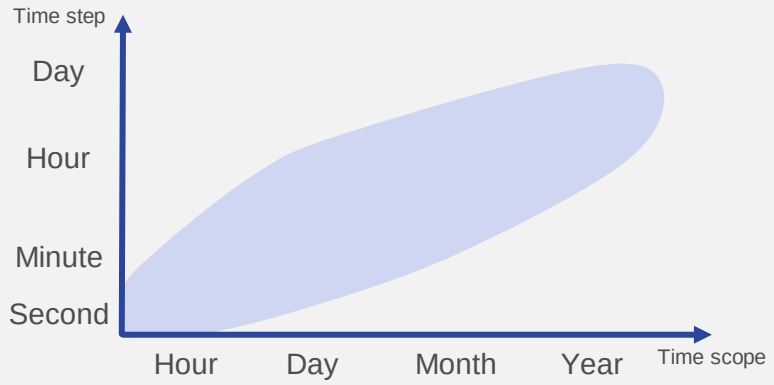
Technological

- Thermostat: smart control, setpoints
- CHP: fuel to electricity and heat (air/water)
- HVAC: electricity to heat or cold (air)
- Absorption chiller: fuel or heat to cold (air)
- Water heater: fuel or electricity to heat (water)
- PV panel: fixed or 1- or 2-axis
- Battery: Li-Ion
- Wind turbine

Economical

- Electricity: tariffs (flat, time-of-use, real-time, capacity peak pricing); purchases and sales
- Fuel: temporal granularity; gas, liquid or solid
- Costs: investment, interest rate, O&M, discomfort

Temporal



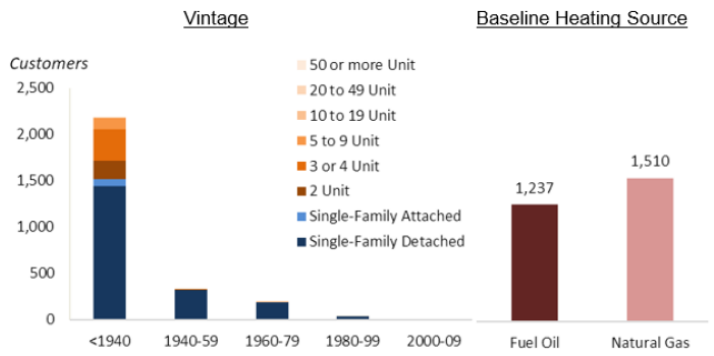
Study 1—Policy strategies for heating electrification in residential buildings

Estimation of installation costs from real data, in terms of size and efficiency, for an average-sized whole-home air-sourced heat pump without ductwork

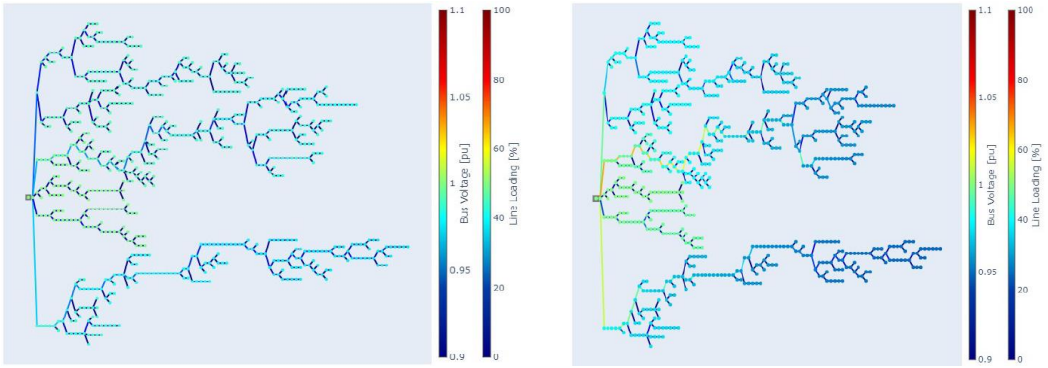
	10 HSPF	11 HSPF	12 HSPF
37,000 BTU	$19,020	$19,850	$20,680
46,500 BTU	$21,405	$22,376	$23,347
57,200 BTU	$24,092	$25,221	$26,351
70,000 BTU	$27,306	$28,625	$29,944

- The MA Decarbonization Roadmap concludes that **100,000** existing homes must install heat pumps **every year** until 2050.
- Only 3,300 in 2020, despite a **subsidy** of up to **$10,000** for installing whole-home air-sourced heat pumps.
- The current MA residential portfolio reflects a **dominance of natural gas**, with some inefficient electric and oil heating
- Under the current policy, even if free, oil heating systems are substituted majorly by **high-efficiency natural gas furnaces**: rate ratio between electricity ($0.22/kWh) and natural gas ($0.05/kWh), and cold outdoor temperatures.
- Only a **rebate on electricity rate** for heating favors heat pump adoption, to some extent.
- In terms of carbon emissions, 100% electrification may **reduce emissions up to 35%**, while ~50% rebate may result in about 25% reduction.

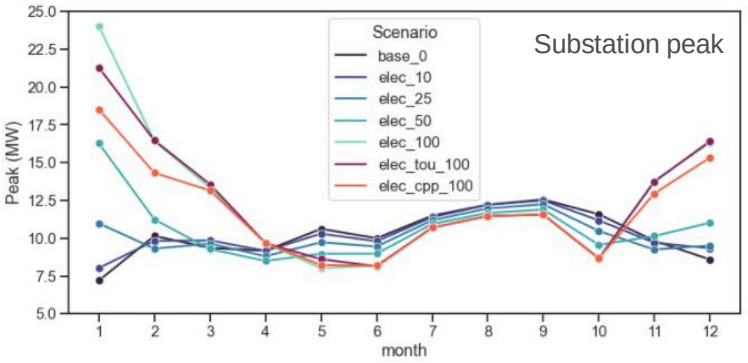
Study 2—Implications of tariffs and heating electrification on distribution networks



Scenario	Adoption Rate	HVAC Equipment	Electricity Tariff ($/kWh)
Base	0%	Existing furnace or boiler (natural gas / heating oil), existing electric air conditioner	Flat 0.22
Elec	10, 25, 50, 100%	Cold-climate air source heat pump (22 SEER, 11 HSPF) sized to fully meet heating needs.[12]	Time of Use 0.33 / 0.11
Elec TOU	100%		
Elec CPP	100%		Critical Peak 1.35 / 0.25 / 0.12



Substation
85% → 185%
Voltage
0.97 → 0.95
Thermal limit ✓



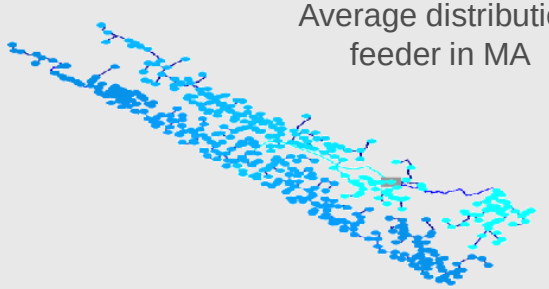
45% adoption creates stress in this feeder. Rate design can increase adoption to 50% (TOU) and 60% (CPP)

Study 3—Heat pumps, PV panels and H_2 blending in an average distribution feeder

Scenario	Rooftop solar	Heat pump
Low	No adoption	No adoption
Medium[a]	13%	19%
High	65%[b]	40%[c]

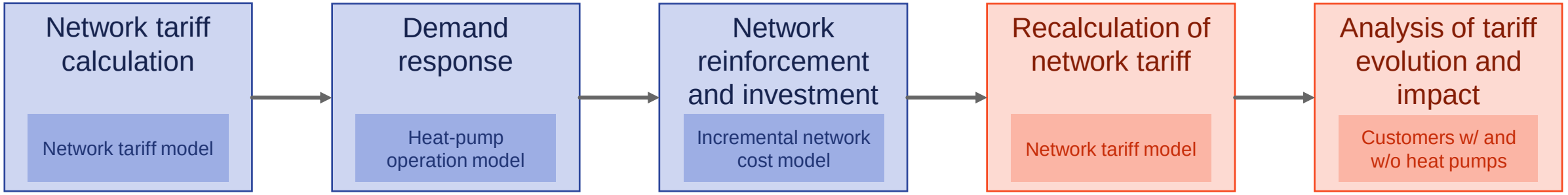
[a]Adoption rate by 2030
[b]Entire use of suitable area
[c] Adoption rate by 2050

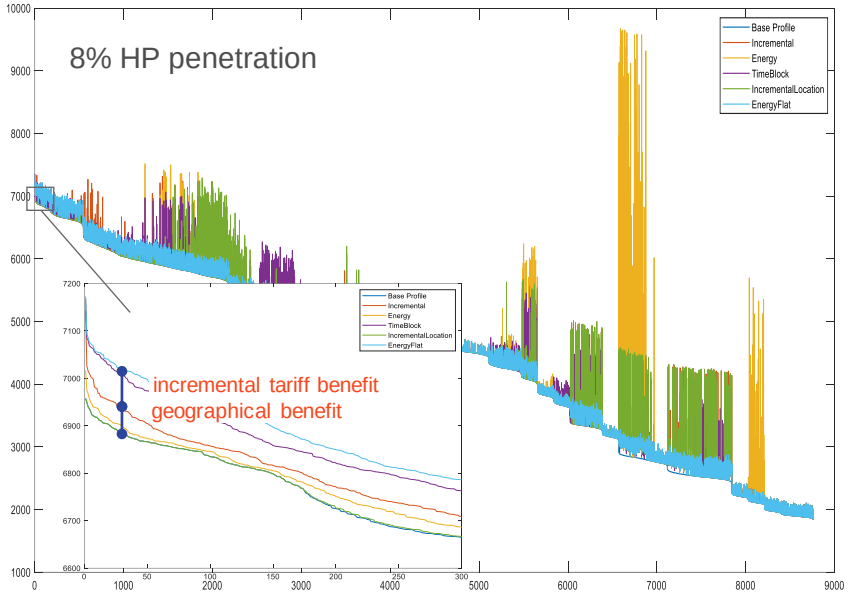
Average distribution feeder in MA



- **Many distribution feeders may be able to cope with expected levels** of residential heat pump and PV penetration, 40% and 65%, respectively, by 2050.
- **Congestions** appear at higher levels of **rooftop PV**.
- **Electrolyzers** can reduce PV impact from excess produced power but are **expensive** and exhibit **low utilization rates**.
- **Blending hydrogen** up to 20% **barely decreases CO_2 emissions** by 7% and would still require meaningful interventions.
- **Hydrogen for residential heating** reveals so far **uneconomical** and technically complex.

Study 4—Effect of flexible demand on network tariff design



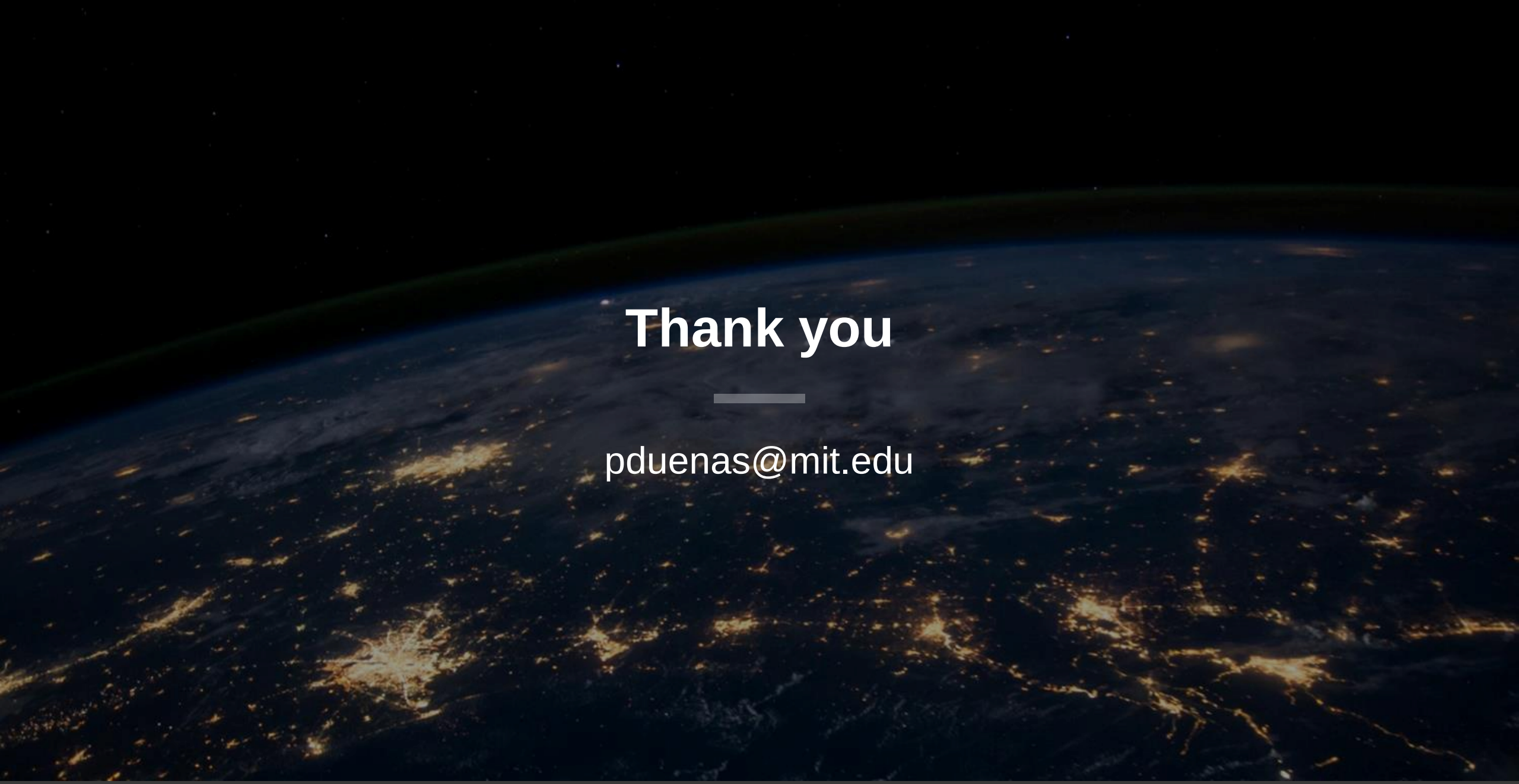


- Flat tariffs may work better than energy-based or incremental (pre-defined peak) tariffs.
- Peak pricing with massive response produce new peak times close to pre-peak hours to pre-cool or pre-heat.
- Besides consumers' preferences, a step-wise incremental tariff applied to peak hours would help consumers to distribute pre-cooling and pre-heating strategies.
- Spatial granularity down to transformers is necessary for the temporal granularity to send the correct signal to consumers.

Conclusions and future research

- Net zero scenarios demand decarbonization of (residential) buildings.
- Electrification of heating in Northeast US may require price interventions or mandates.
- Distribution networks in Northeast US may be able to accommodate realistic scenarios of heat pump adoption by residential consumers.
- Hydrogen, as of today, does not seem to become a sustainable solution for residential heating.
- Tariffs will need to design carefully and creatively to avoid cumulative effects on previous non-peak hours.

- Disseminate current studies through usual channels: journal papers, working papers, etc.
- Expand our analysis with diversified feeders, climate areas, and building types.
- Add electric vehicles as an additional load, as well as an additional resource for flexibility.
- Continue designing tariffs that better capture expected dynamics.



Thank you

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