Evaluating the system-level demand impacts of heat electrification scenarios through bottom-up building energy models

Morgan Santoni-Colvin

MITEI Future Energy Systems Center Fall Workshop

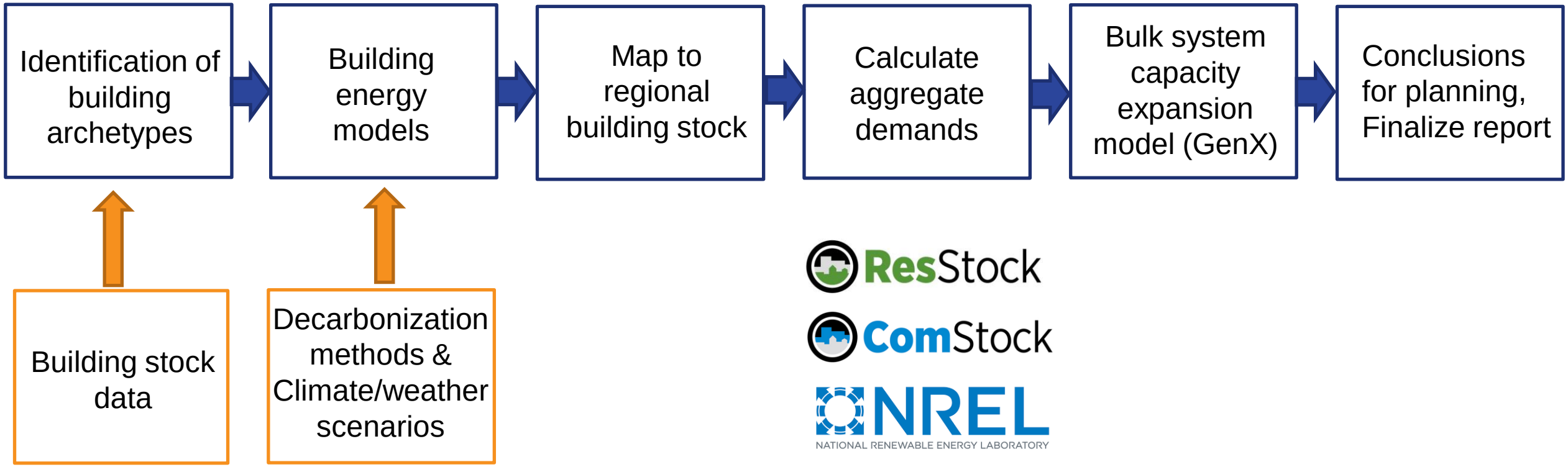
October 12, 2022

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Project Objectives

- Determine implications for bulk power system planning as a result of widespread heat pump deployment in the Northeast and Mid-Atlantic
- Analyze residential and commercial buildings
  - Capture the diversity of the building stock
- Investigate the grid-level aggregated impacts of different heating-related decarbonization methods made at the building level, particularly heat pumps

Methodology – Bottom-Up Modeling



Recent Project Progress

- Last update (May 2022)
  - Near-term residential heat pump deployment scenarios to 2030
  - Single weather scenario based on “typical weather year”
- This update (October 2022)
  - Long-term residential heat pump deployment scenarios for 2030 and 2050
  - Account for building stock turnover, climate change effects, and population growth
  - Two weather scenarios based on empirical weather data (2018 and 2012)
  - More detailed heat pump modeling & deployment logic

Building-Level Decarbonization Methods Currently of Interest in this Study

- Heat Pump:
  - Air-source heat pump (ASHP) optimized for cold-climate performance
    - HSPF 11 and up
- Sizing: What load to size the heat pump for?
  - Winter (peak heating)
  - Summer (peak cooling)
- Type of backup heat, if sizing for summer:
  - Pre-existing system
  - Electric resistance (COP of 1)
- Efficiency investments in building envelope

Climate/Weather Inputs: Rationale and Assumptions

- Weather data is key input to bottom-up building energy models
- Multi-decadal time horizon modeling should include effects of climate change on weather
- Our assumptions thus far:
  - IPCC CMIP6 SSP3-7.0 emissions scenario (medium-high)
  - Climate impact predictions come from CESM2 model
    - CESM2 is most prominent model that provides needed simulation variables (temperature, wind speed, irradiance, etc.)
  - Model climate change effects based on average conditions predicted by CESM2 for 5-year interval surrounding year of interest
  - **Climate ≠ Weather:** Use 2012 and 2018 empirical weather data as basis for underlying weather patterns

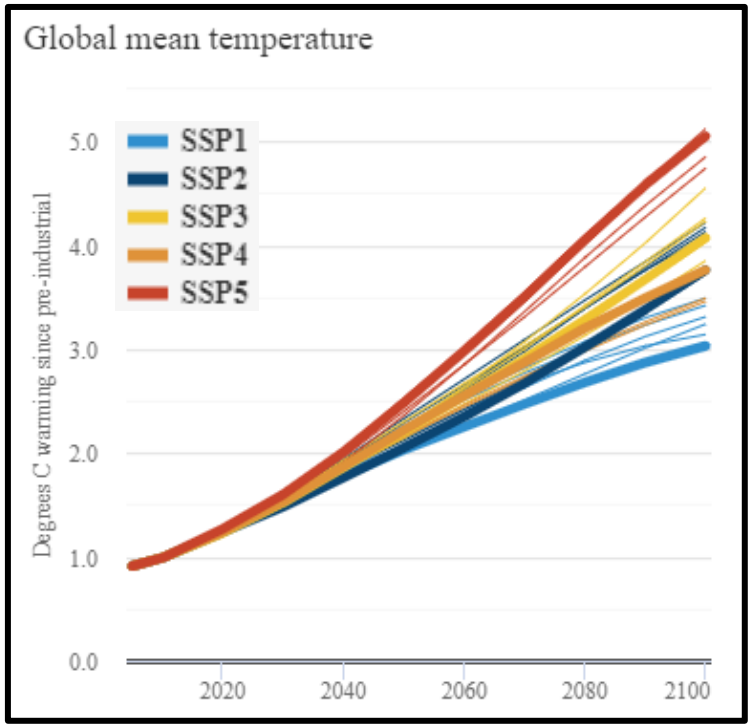
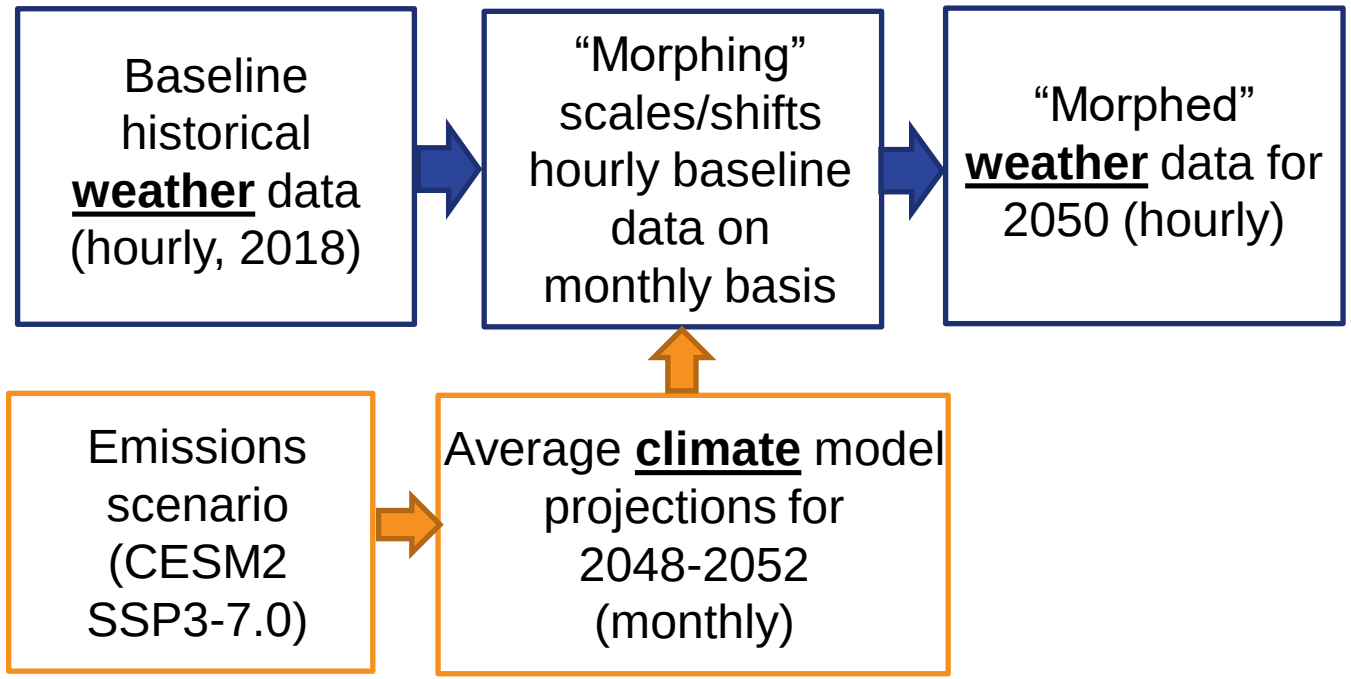
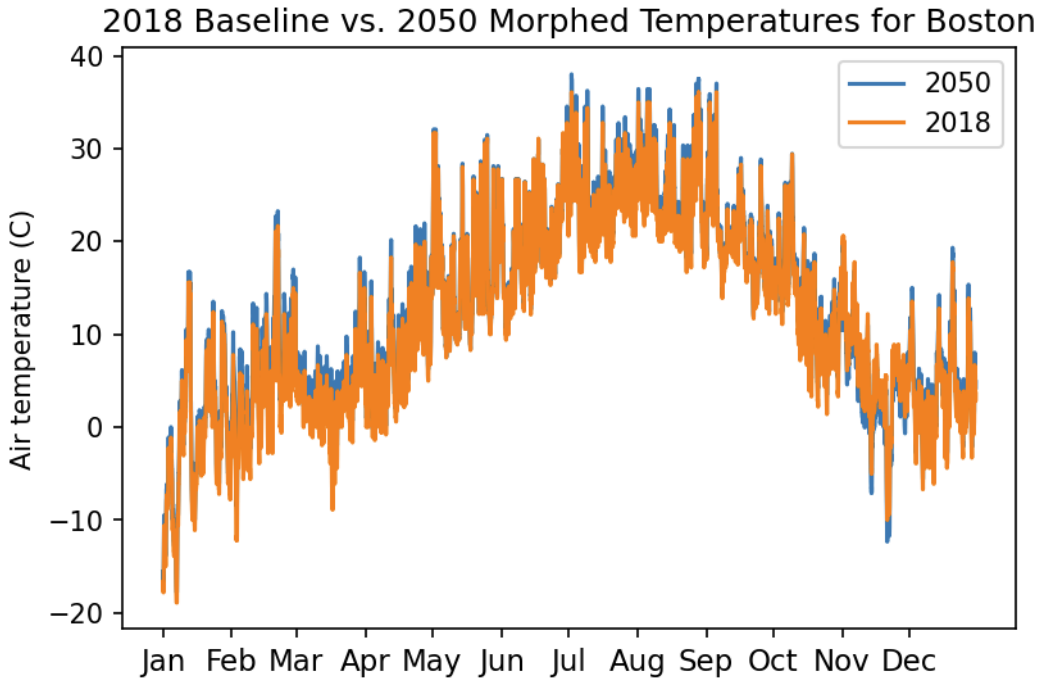


Image from https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

Example “Morphing” Method for Obtaining 2050 Weather Data Under Climate Change

- Climate model projections generally do not include all hourly variables needed for building simulations
- “Morphing” method is oft-used in the building model literature to estimate hourly variables from monthly predictions





Heat Pump Deployment Scenarios: Massachusetts

- Massachusetts Clean Energy & Climate Plan (CECP), June 2022:
  - Includes number of heat pump adoption scenarios; we use a subset
  - “High Electrification” scenario:
    - Rapid adoption of whole-home “winter-sized” heat pumps
  - “Hybrid” scenario:
    - Rapid adoption of electric heat pump systems with fossil-fuel backup
    - We assume hybrid heat pumps are sized for cooling -- “summer-sized”
- CECP scenarios also include rates of envelope upgrades
  - We assume homes that receive envelope upgrades get a low efficiency (“ECM2”) retrofit

1. https://www.mass.gov/doc/building-sector-technical-report/download

Heat Pump Deployment Scenario Parameters: Massachusetts

Scenario 1: Mass CECP “High Electrification”

Year	% of all homes given ASHP	% of all homes given Winter-sized ASHP	% of all homes given Summer-sized ASHP	% of all homes receiving envelope upgrades*
2030	26.3%	16.3%	10.0%	20.0%
2050	78.7%	63.0%	15.7%	55.1%

Scenario 2: Mass CECP “Hybrid”

2030	23.7%	3.1%	20.6%	20.0%
2050	58.1%	18.9%	39.2%	40.7%

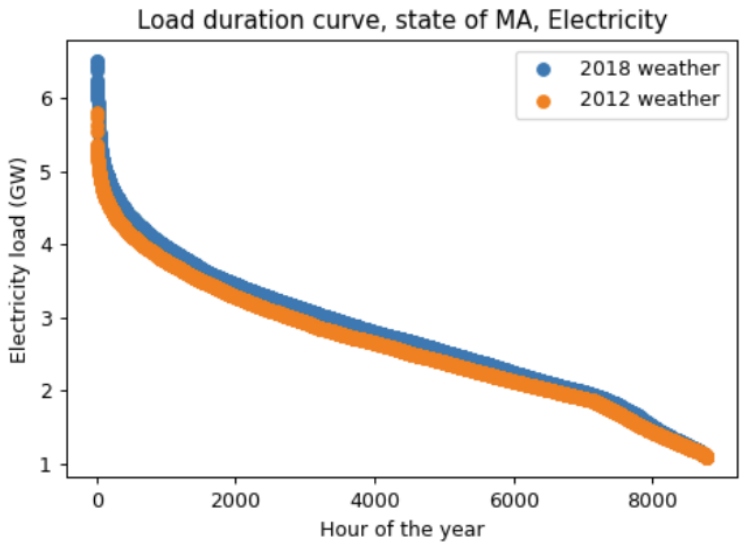
*Envelope upgrades are assumed to only go to homes that have also received a new heat pump installation

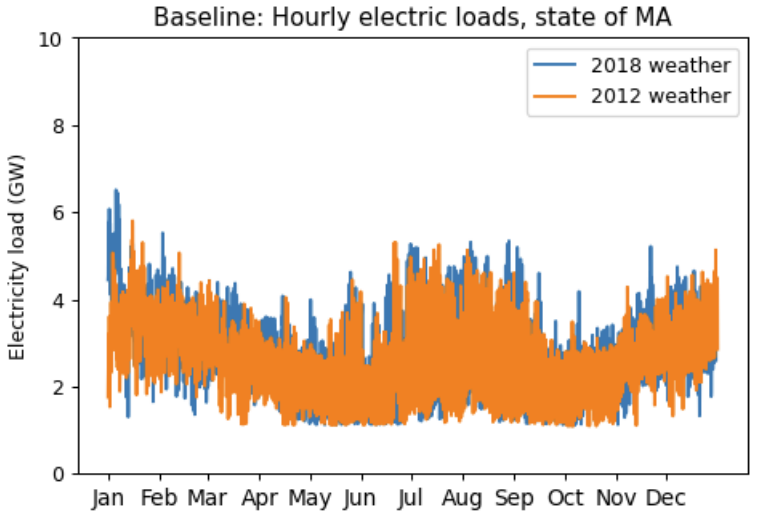
Role of Backup Heat in Summer-Sized Systems

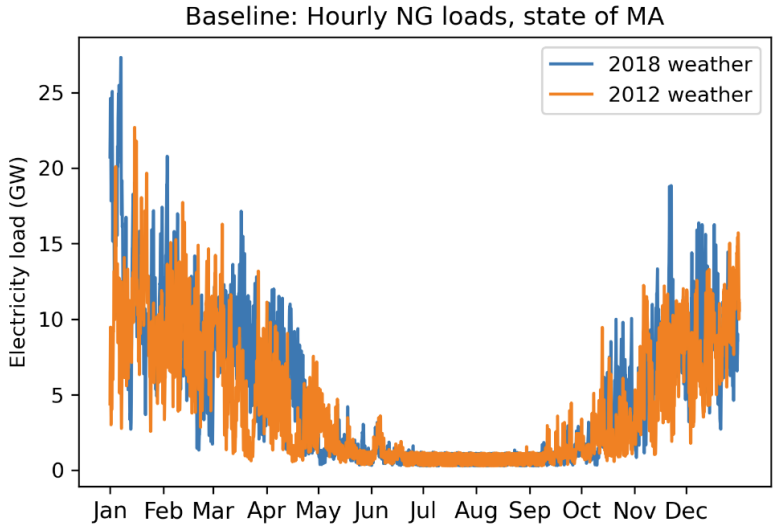
- We also seek to examine load effects from the eventual retirement of backup systems in summer-sized “hybrid” ASHPs. Two options for replacement:
  - A) Replace backup with similar system to pre-existing (same fuel / performance).
    - In MA, largely natural gas / fuel oil
  - B) Replace backup with electric resistance.
- Leads to four deployment scenarios:

Scenario #	CECP Scenario	New backup type upon retirement of old backup system
1a	High Electrification	Same as existing
1b	High Electrification	Electric resistance
2a	Hybrid	Same as existing
2b	Hybrid	Electric resistance

MA: Baseline (Present Day) Load Patterns



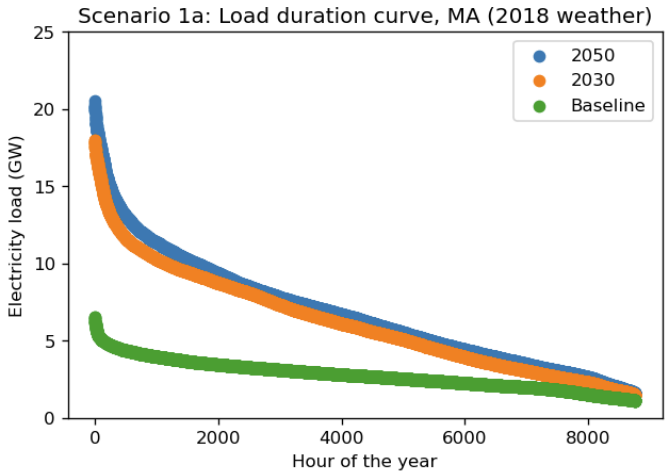


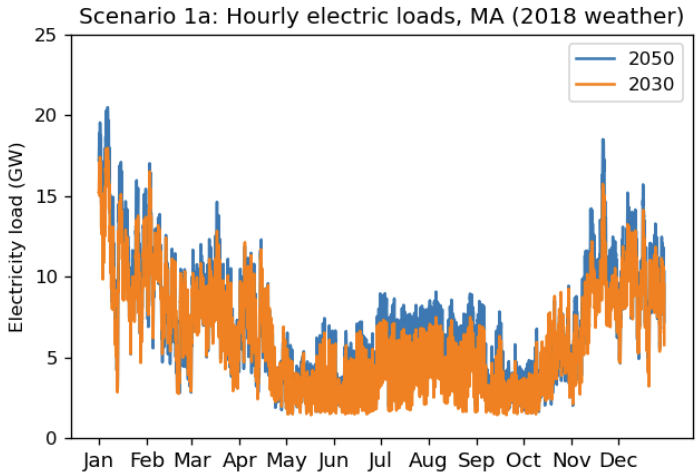


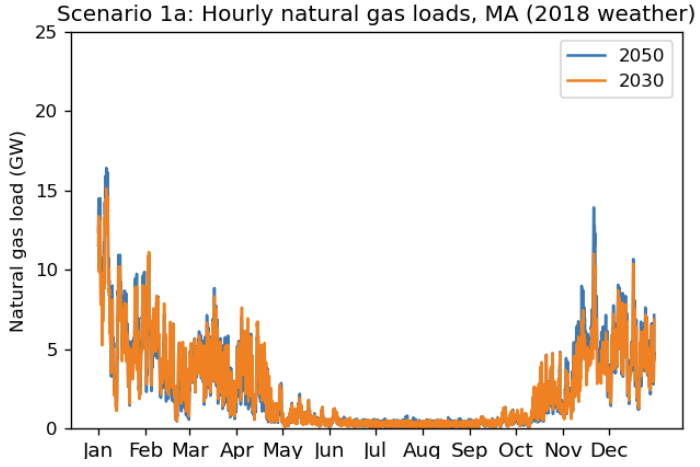
- ResStock currently indicates a winter-peaking residential sector under the modeled weather conditions
- Winter peak of 5.8 – 6.5 GW from the residential sector
- Heavy reliance on natural gas in heating season

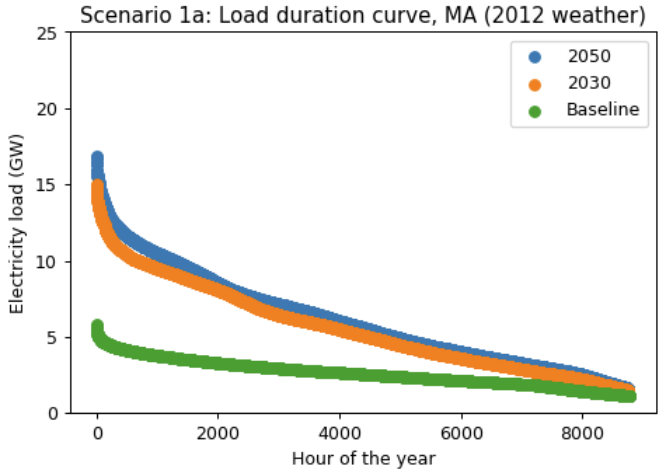
Scenario 1a: High Electrification, Existing Backup

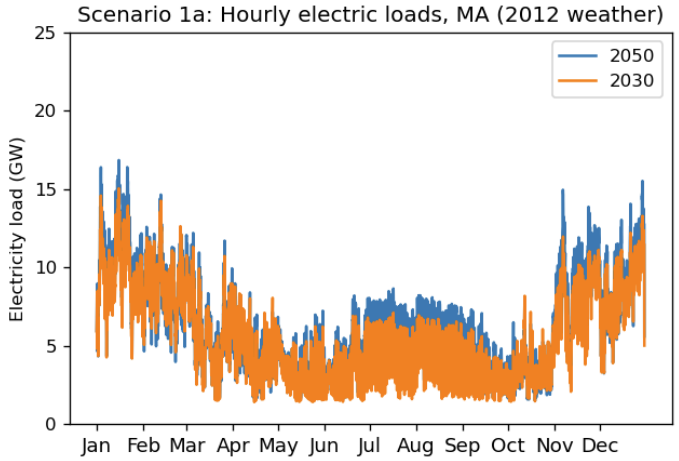
- Mostly winter-sized systems, some summer-sized “hybrid” systems
- Summer-sized “Hybrid” systems maintain same backup fuel type through 2050

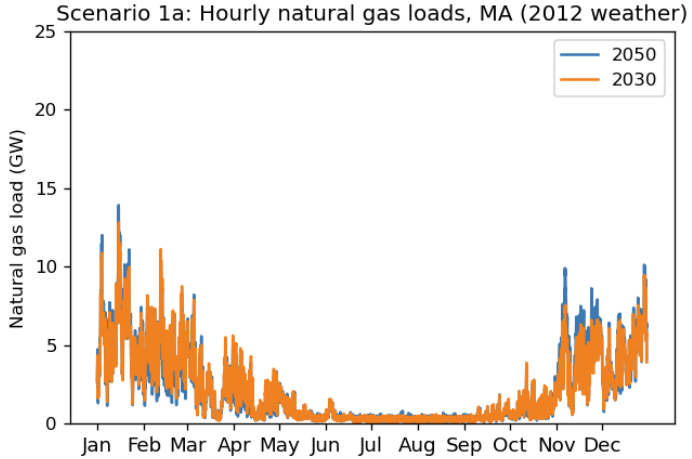




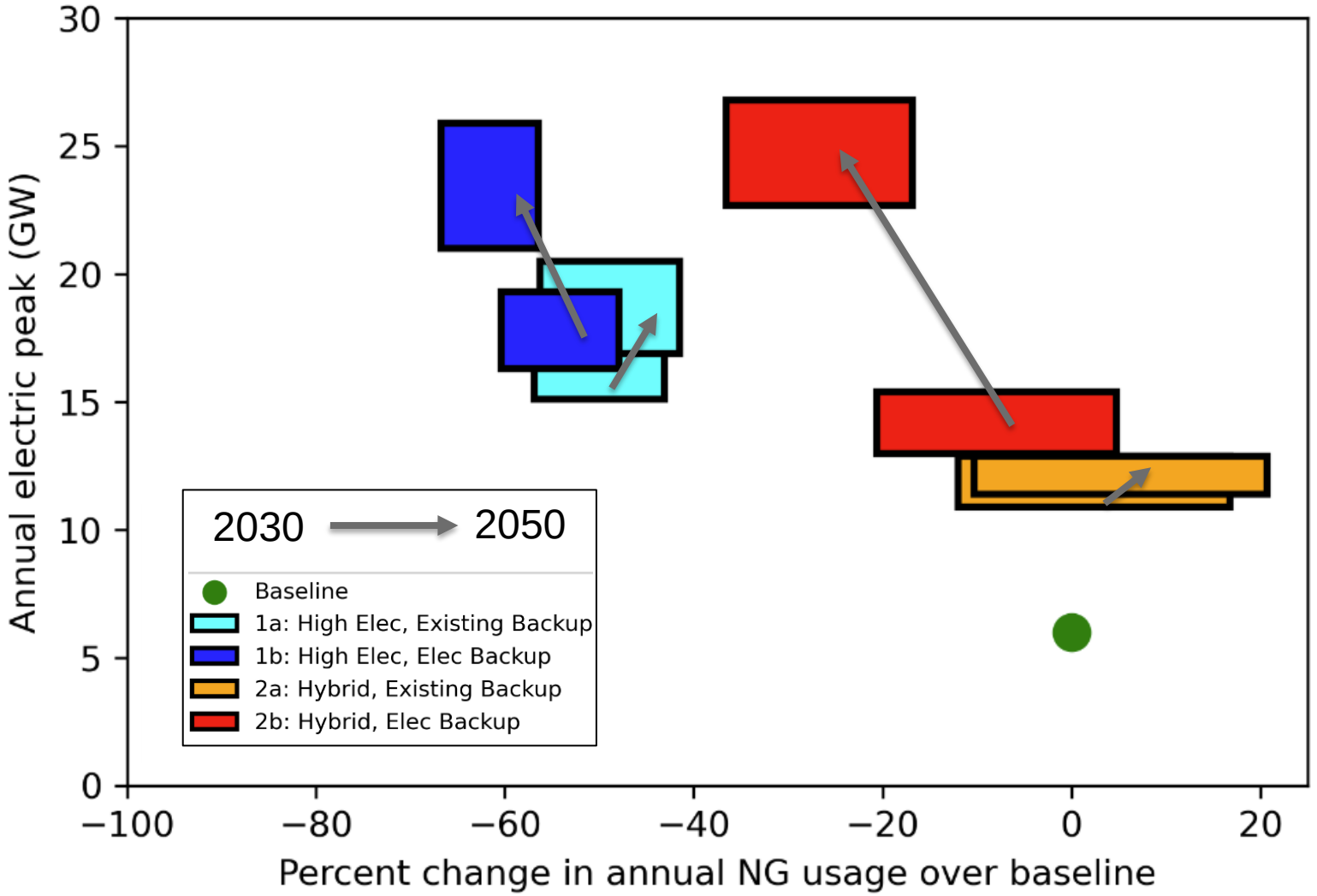








Graphical Summary of Preliminary Results for Residential Sector, MA



- Uncertainty (proportional to box dimensions) is due to weather
- Both “high electrification” scenarios lead to rapid peak increase, but large reduction in natural gas usage
- Magnitude of peak increase / NG reduction for “hybrid” scenarios depends significantly on what kind of backup heat is deployed

Recap: Sources of Uncertainty

- Sources of uncertainty covered: Weather
  - Interannual weather variation in historical / ”baseline” weather data
    - More baseline years would be informative
- Sources of uncertainty not currently covered: Climate
  - Interannual variation in climate model data (currently average period around year of interest)
  - Differences in potential emissions pathways
  - Differences between individual climate models
  - Climate-change-induced effects on frequency & intensity of extreme weather events
- Also not covered: Heat pump tech advancement / efficiency increases over time

Conclusions

- Heat pump adoption in cold climates has significant impact on residential sector demand profiles at the regional level
  - Assumptions about ASHP deployment rate and nature of backup heat are critical to load shapes
  - Weather and climate-related uncertainty of demand warrant particular interest for further research

Future Work

- Remainder of Fall ’22:
  - Probe climate uncertainty question more deeply
    - Gather more baseline weather data (beyond 2012 & 2018)
    - What additional models (other than CESM2) provide the variables needed for forming basis of future weather data in building simulations?
    - What are impacts of different emission scenarios?
    - How might we capture changes in frequency of extreme events?
- Winter ‘22:
  - If determined feasible/fruitful, proceed with climate uncertainty modeling, OR move forward with modeling of commercial sector

Thank you

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Supplemental Information

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Electric Power Systems Fall Workshop

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MA Decarbonization Roadmap – Building Efficiency Criteria

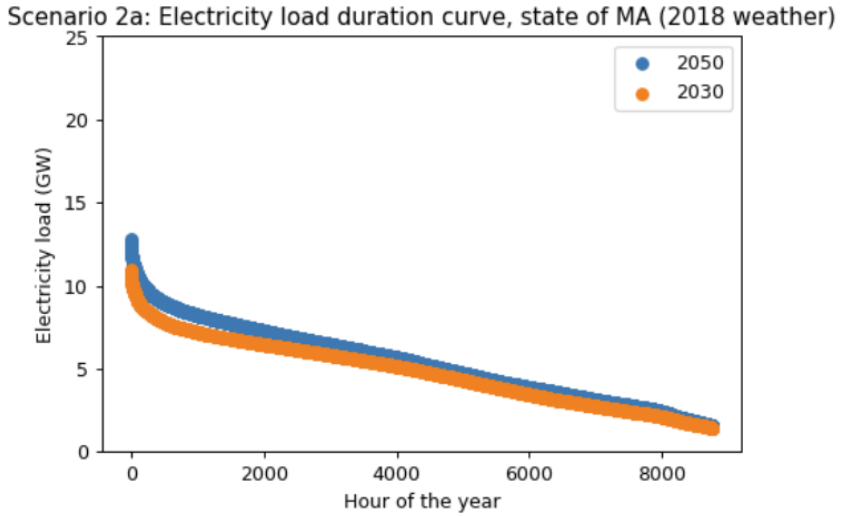
Single Family and Small Multifamily			
ECM 1 Electrification	ECM 2 Low Efficiency	ECM 3 Medium Efficiency	ECM 4 High Efficiency
	ECM 1 plus:	ECM 2 plus:	ECM 3 plus:
Systems			
Heat Pump Cooling SEER: 15	ECM 1	Heat Pump Cooling SEER: 20	Heat Pump Cooling SEER: ECM 3
Heat Pump Space Heating HSPF: 9		Heat Pump Space Heating HSPF: 10	Heat Pump Space Heating HSPF: ECM 3
Heat Pump DHW Heating UEF: 2.73		Heat Pump DHW Heating UEF: 3.2	Heat Pump DHW Heating UEF: 3.45
Envelope			
None	R-60 Roof/Attic	Window U-value: 0.25	R-30 Walls
	R-15 Walls	Window SHGC: 0.32	Window U-value: 0.21
	Airtightness to 0.4 CFM/sf at 0.3 in. wc.	Airtightness to 0.2 CFM/sf at 0.3 in. wc.	Window SHGC: 0.24
			Airtightness to 0.1 CFM/sf at 0.3 in. wc.
Controls			
Setbacks to 70°F and 75°F in heating and cooling, respectively	**Demand-Control Ventilation**	ECM 2	ECM 2
	70% Effective Energy Recovery		
Appliances			
Electric conversion	ECM 1	ECM 1	ECM 1

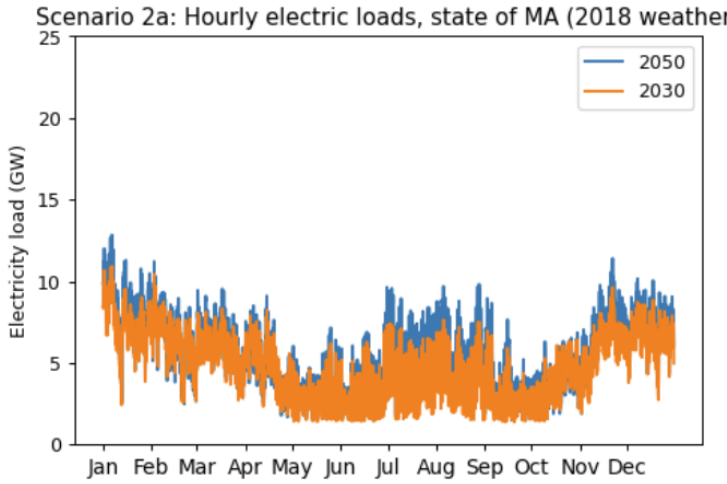
Summary of Preliminary Results for Residential Sector, MA

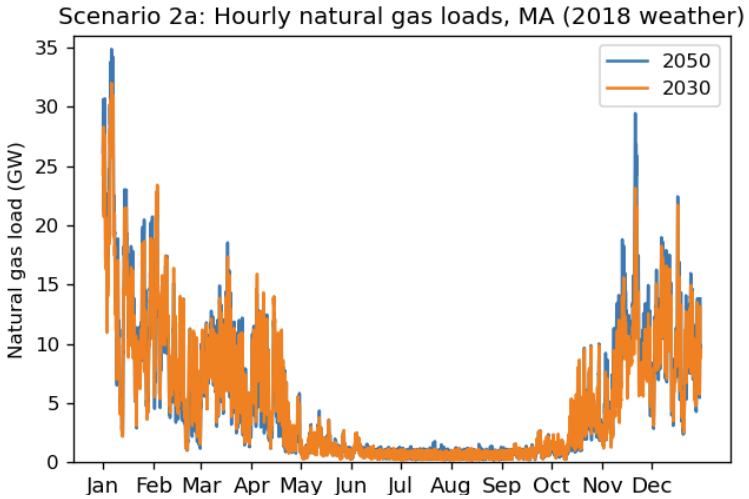
Scenario	Electric peak range (2030)	Change in annual NG usage (2030)	Electric peak range (2050)	Change in annual NG usage (2050)
1a: High Electrification, Existing Backup	15.1-17.9 GW (+131 to 209% above baseline)	-43.1% to -56.9%	16.9-20.5 GW (+159 to 253% above baseline)	-41.5 to -56.3%
1b: High Electrification, Electric Backup	16.3-19.7 GW (+150 to 240% above baseline)	-47.9% to -60.4%	21.0-25.9 GW (+221 to 346% above baseline)	-56.4% to -66.7%
2a: Hybrid, Existing Backup	10.9-12.9 GW (67 to 123% above baseline)	+16.8% to -12.0%	11.4-12.9 GW (75 to 121% above baseline)	+20.7% to -10.3%
2b: Hybrid, Electric Backup	13.0-15.4 GW (+99 to 166% above baseline)	+4.8% to -20.6%	22.7-26.8 GW (+248 to 361% above baseline)	-16.8% to -36.5%

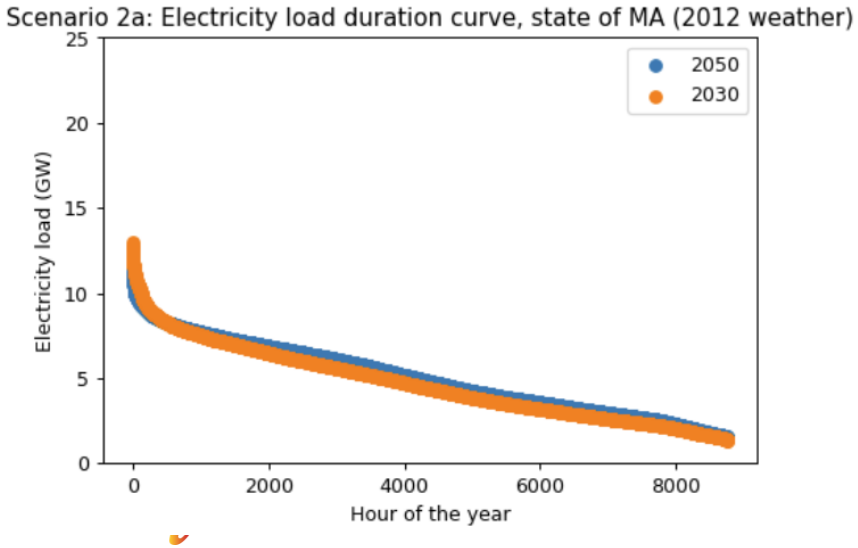
MA Scenario 2a: Hybrid, Existing Backup

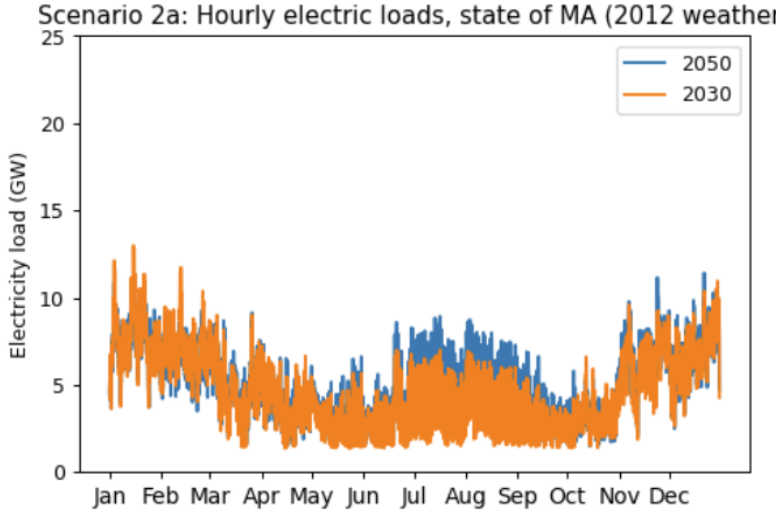
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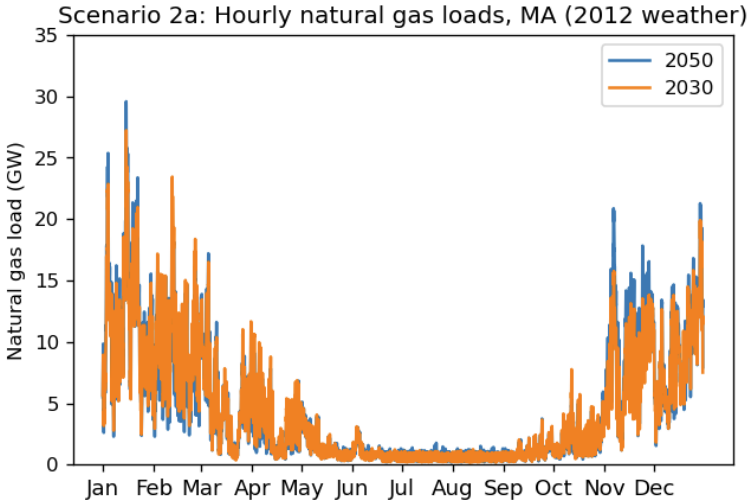






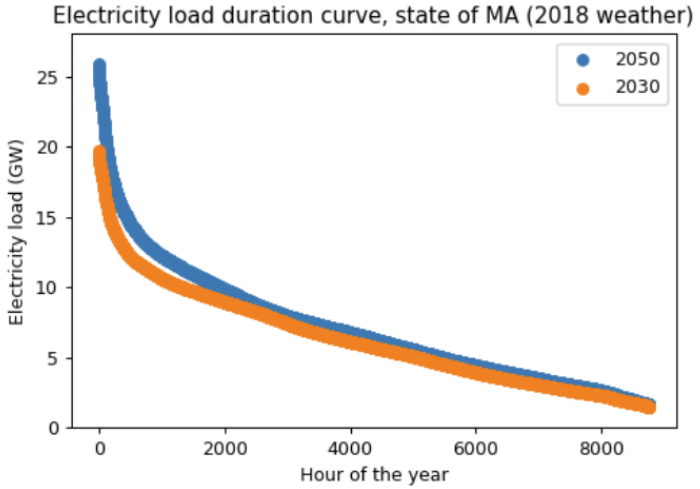


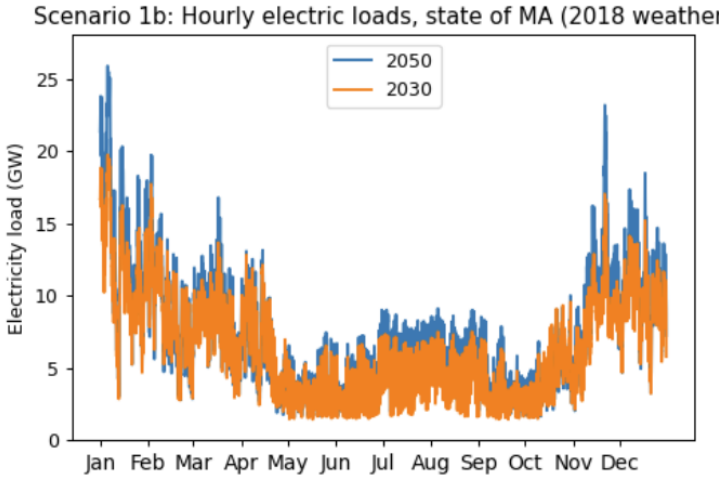


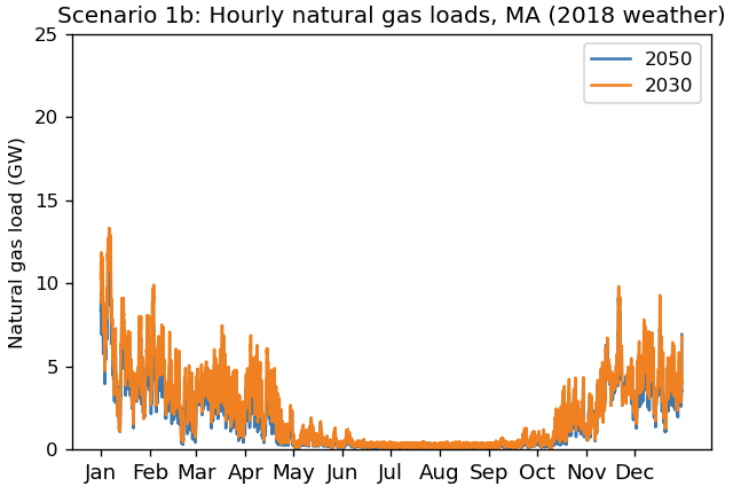


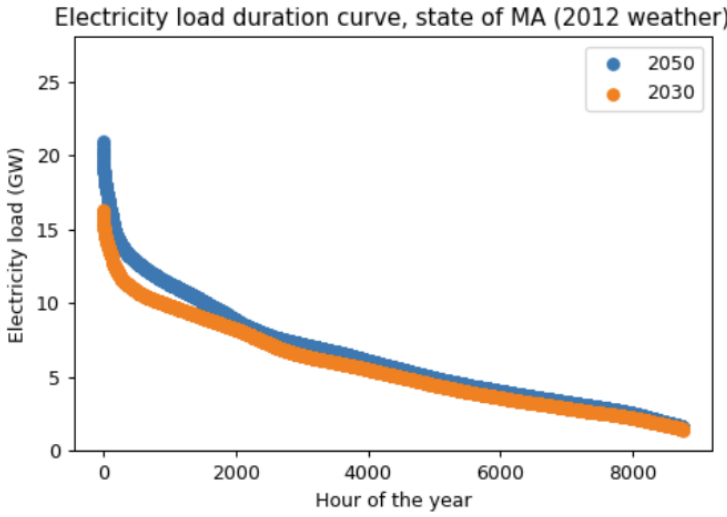
MA Scenario 1b: High Electrification, Electric Resistance Backup

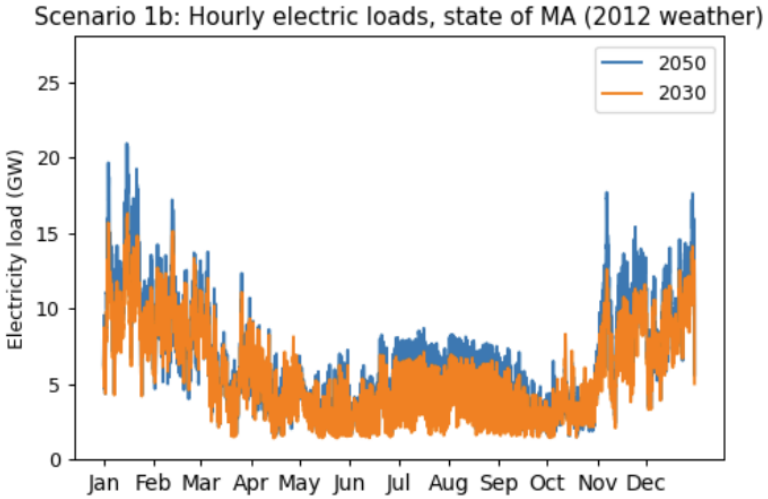
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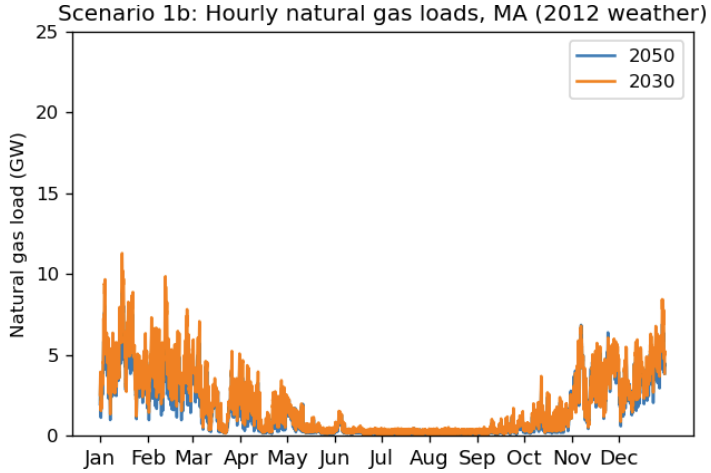












MA Scenario 2a: Hybrid, Electric Resistance Backup

- Mostly summer-sized “hybrid” systems, some winter-sized systems
- Summer-sized “Hybrid” systems gradually phase into 100% electric backup by 2050

