

Methodology

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1. Electric Grid Seasonal Headroom

We estimated the average summer and winter headroom in each state by determining the state's a) seasonal generation capacity and b) hourly demand.

a. Determine seasonal generation capacity

First, we used [EIA Form 860](#) for 2025 to determine the summer and winter statewide rated generation capacity (in MW), $C_{s,rated}$ and $C_{w,rated}$, for each generation resource type.

Second, we estimated the summer and winter derating value, d_s and d_w , by generation resource type by state.

Last, we multiplied the nameplate generation capacity, $C_{s,rated}$ and $C_{w,rated}$, by the seasonal derating, d_s and d_w , to estimate the summer and winter generation capacity available during peak demand events in each state, $C_{s,avail}$ and $C_{w,avail}$.

b. Determine seasonal peak demand

First, we purchased Evolved Energy Research's Annual Decarbonization Pathways (ADP) dataset. This included sector-specific hourly grid loads by state representing 2024 loads with weather data from 2018. We refer to this dataset as the "ADP dataset" and the summer (June through September) and winter (November through March) peak hourly demand as P_{adp-s} and P_{adp-w} respectively.

Second, we adjusted the ADP dataset to reflect the average observed ratio between summer and winter statewide peak demand from 2020 to 2024, P_{avg-s} and P_{avg-w} respectively, while maintaining the model's overall load magnitude. We used the following data sources for observed P_{avg-s} and P_{avg-w} :

- EIA's [Hourly Electric Grid Monitor \(Form 930\)](#) for balancing authority hourly demand data that represented all or nearly all of a state.
- EIA's [Annual Electric Power Industry Report \(Form 861\)](#) for utility-specific seasonal peak demand data from 2020 to 2024 for states not individually represented in Form 930. For large utilities missing from Form 861, we reviewed utility filings in relevant state dockets for exhibits with hourly seasonal peak information to identify seasonal peak demand.

$$P_{adj,s} = P_{avg,s} \times \frac{\text{avg}(P_{ADP,s}, P_{ADP,w})}{\text{avg}(P_{avg,s}, P_{avg,w})}$$

$$P_{adj,w} = P_{avg,w} \times \frac{\text{avg}(P_{ADP,s}, P_{ADP,w})}{\text{avg}(P_{avg,s}, P_{avg,w})}$$

We then adjusted each hour of the ADP dataset to reflect the P_{adj-s} and P_{adj-w} .

1) We calculated the adjustment factor for all summer and winter hours,

$$k_s = \frac{P_{adj-s}}{P_{ADP,s}}$$
$$k_w = \frac{P_{adj-w}}{P_{ADP,w}}$$

2) We adjusted the ADP hourly electricity demand for the residential sector, $L_{res,b}$, with the adjustment factor

- a) Multiplied $L_{res,b,t}$ by k_s for all summer hours and multiplied $L_{res,b,t}$ by k_w for all winter hours.
- b) Combined L_{res} with the other unchanged sectors in the ADP baseline to generate the adjusted baseline hourly electricity demand from all sectors, L_{all} .

Finally, we determined the summer and winter peak demand, $L_{all,peak-s}$ and $L_{all,peak-w}$, as the max value for L_{all} from June to September and November to April, respectively.

c. Determine seasonal headroom

We determined summer and winter headroom, H_s and H_w , as:

$$H_s = C_{s,avail} - L_{all,peak-s}$$

$$H_w = C_{w,avail} - L_{all,peak-w}$$

2. Heat Pump Deployment Impact on Seasonal Peak Demand

We estimated the maximum heat pump deployment that would not decrease the minimum annual headroom by a) defining the state type, b) determining the heat pump deployment strategy, c) determining the relative heating and cooling impact from heat pump upgrades in [ResStock 2024.2](#), d) adjusting the ADP dataset to reflect the heat pump upgrades and determine new seasonal peak demand, and e) optimizing the heat pump type that could be deployed in the maximum number of homes.

a. Define the state type and staged dataset

i. Climate

1. We defined each state as a cold-climate state if the majority of a state's population lives in IECC climate zone 4 or above, or else as a non-cold-climate state.

ii. Seasonal peak

1. We defined each state as a winter headroom state if

$$\frac{H_w}{C_{w,avail}} - \frac{H_s}{C_{s,avail}}$$

is greater than 10%, or else as a non-winter headroom state.

iii. Staged homes with cooling

1. We staged the analysis to first deploy heat pumps in homes with whole-home cooling (roughly 80% of US homes), then homes with part-home cooling (roughly 90% of US homes), and finally homes without cooling. This sequencing minimizes marginal summer peak demand increases from adding cooling to previously uncooled homes, allowing winter headroom to be utilized before any potential summer peak demand increases. While real-world deployment will not follow this order, this assumption is justified because any additional summer peak demand from installing a heat pump in a previously uncooled home would also occur if that home instead installed conventional air conditioning as the climate warms.

iv. Excluded states

1. We excluded Alaska and Hawaii since their data is not available in ResStock.

b. Determine the ResStock heat pump upgrade measure package

i. All-electric heat pump deployment strategy

1. We used [ResStock Measure Package 2](#) (high efficiency cold-climate air-to-air heat pump with electric back-up, 11 HSPF1, 20 SEER1) for cold-climate states.
2. We used [ResStock Measure Package 1](#) (EnergyStar air-to-air heat pump with electric back-up, 9.2 HSPF1, 16 SEER1) for non-cold-climate states.
- ii. Hybrid heat pump deployment strategy
 1. We used [ResStock Measure Package 4](#) (EnergyStar air-to-air heat pump with existing system as back-up, 9.2 HSPF1, 16 SEER1) for hybrid heat pumps deployment in all states. This package is limited to homes with existing primary heating fuel of natural gas, propane, or fuel oil, and those with a furnace, a non-ducted heating system with a room AC, or no cooling.

c. Calculate the ResStock package's relative heating and cooling impact

- i. We separated the ResStock state data into the following datasets to generate separate heat pump upgrade measure results for each dataset:
 - a. all homes
 - b. homes without cooling
 - c. homes without cooling and with electric resistance heat
 - d. homes without cooling and with fossil fuel heat
 - e. homes with cooling and with fossil fuel heat
 - f. homes with cooling and with electric resistance heat
- ii. For each hour, we defined the total cooling energy before deploying a strategy, $E_{clg-b,t}$, as the sum of the cooling energy in the baseline for all building ids.
- iii. For each hour, we calculated $E_{clg-m,t}$, as the sum of the cooling energy in the upgrade measure package for all the applicable building ids plus the sum of the cooling energy in the baseline for all non-applicable building ids.
- iv. Then we calculated the ratio between the total cooling energy after and before deploying the strategy,

$$k_{clg,t} = \frac{E_{clg-m,t}}{E_{clg-b,t}}$$
- v. We completed this same process for heating,

$$k_{htg,t} = \frac{E_{htg-m,t}}{E_{htg-b,t}}$$

d. Adjust the ADP residential demand to determine new seasonal peak demand

- i. In the ADP dataset, for each hour in L_{res} , we applied $k_{clg,t}$ and $k_{htg,t}$ to the cooling and heating components respectively, to approximate the changes in residential electricity demand resulting from heat pump adoption. The adjusted cooling and heating components were then added back to the unchanged components of L_{res} to obtain the adjusted residential load, $L_{res,adj}$.
- ii. In the ADP dataset, we added $L_{res,adj}$ to the other sector's unchanged components of L_{all} to obtain the adjusted total load, $L_{all,adj}$.
- iii. We determined the new seasonal peak demand in each state by finding the peak hour in the summer and winter months in $L_{all,adj}$.

e. Determine the all-electric and hybrid heat pump deployment mix

For the deployment scenario with a mix of all-electric and hybrid heat pumps, we maximized the number of homes that could install a heat pump without decreasing the minimum annual headroom, while giving preference to all-electric heat pumps.

The optimization followed three cases:

- i. Sufficient winter headroom: If deploying all-electric heat pumps in all homes would not decrease minimum headroom (e.g., in Arizona), all homes adopted all-electric heat pumps.
- ii. Limited winter headroom: If deploying all-electric heat pumps in all homes would decrease minimum headroom (e.g., in Illinois), but deploying hybrid heat pumps would not, we incrementally increased the share of all-electric heat pumps (and reduced the share of hybrid heat pumps) before decreasing minimum headroom. For example, in Illinois, 21% of homes could adopt an all-electric heat pump and 79% could adopt a hybrid heat pump without decreasing minimum headroom. This represents the maximum percentage of homes with an all-electric heat pump while still allowing all homes to install either an all-electric or hybrid heat pump.
- iii. Very limited or no winter headroom: If deploying hybrid heat pumps in all fossil fuel-heated homes would decrease minimum headroom, we limited all-electric heat pump deployment to homes with electric resistance heating (where heat pumps reduce winter peak demand), while fossil fuel-heated homes adopted hybrid heat pumps only until minimum headroom decreased.

3. Downward Pressure on Electric Rates

We estimated the downward pressure on residential volumetric electric rates from the two heat pump deployment scenarios (only in winter headroom states as defined in section 2) by calculating (a) current volumetric rates, (b) the incremental load to power the deployed heat pumps, (c) the incremental electricity supply costs from additional heat pump load, (d) the incremental distribution costs from the additional heat pump load, and (e) the new volumetric rate and rate reduction potential.

a. Calculate current volumetric rates

We first estimated the current statewide average residential volumetric electric rate

- i. We determined total statewide residential revenue by multiplying residential blended \$/kWh rates by residential sales, obtained from [EIA Form 861M](#).
- ii. We calculated the average residential monthly fixed charges for each state using Arcadia's [utility tariff database](#).
- iii. We multiplied the average residential monthly fixed charge by the number of residential customers, obtained from [EIA Form 861M](#), to estimate total statewide fixed charge revenue.
- iv. We then subtracted fixed-charge revenue from residential revenue to estimate statewide volumetric revenue.
- v. Finally, we divided volumetric revenue by residential electricity sales to estimate the statewide average residential volumetric electric rate (\$/kWh).

b. Calculate additional heat pump hourly electricity load

For each state, we calculated the additional hourly electricity demand (MWh) resulting from the modeled all-electric and hybrid heat pump deployment scenarios from step 2D above.

c. Calculate heat pump upgrade wholesale electric supply costs

We next estimated the incremental wholesale electricity costs associated with the additional electricity load from heat pump deployment in each state.

- i. We multiplied the additional hourly load by the corresponding state-average hourly locational marginal price (LMP) to estimate incremental electricity supply costs.
- ii. State-average hourly LMPs were based on average prices from 2023 to 2025 for each RTO or ISO sub-balancing authority, obtained from the [SPP Portal](#), [ISO NE](#), [ISO Express](#), and [LCG Energy Online](#). For vertically integrated utilities outside organized wholesale markets, we used representative wholesale energy prices from utilities within a given state as proxies for statewide LMPs. We obtained

this data from the [CAISO Historical OASIS Data Downloader](#) for Western Energy Imbalance Market (WEIM) participating states.

d. Calculate heat pump upgrade distribution costs

Because distribution system upgrade costs vary significantly across utilities and are not consistently available nationwide, we estimated state-specific distribution costs using a national baseline adjusted for local conditions.

- i. National average: We estimated a national average distribution capacity cost of \$40/kW-year based on the US Department of Energy [Better Buildings Energy Efficiency Cost-Effectiveness Tool](#) (generic transmission and distribution capacity costs) and two private distribution planning datasets from utilities in California and New York.
- ii. State-specific: We adjusted the national average using two state-specific factors:
 1. State-specific available residential headroom: We estimated the percentage of added winter peak from heat pump deployment that would trigger distribution upgrades corresponding to available residential (not total grid) winter headroom, based on distribution upgrades in three studies: i) Synapse’s [Assessment of Electric Grid Headroom for Accommodating Building Electrification memo](#) for New York, ii) Kevala and Grid Lab’s [California Load Management Standard Avoided Distribution Grid Upgrade Study](#), and iii) Jenn and Highleyman’s [Distribution grid impacts of electric vehicles: A California case study](#). While these were not specific to heat pump deployment’s impact on distribution system studies, that level of research is not publicly available, so these were the most relevant studies available, and we used these studies to estimate the table below. Current residential headroom is divided by two to factor in the average winter headroom between today and when headroom will be zero once summer and winter headroom are equal after heat pump deployment. The results are summarized in the following table:

Current statewide residential winter headroom divided by two	Percentage of added winter peak MW from heat pumps triggering distribution upgrades
0%–5%	30%
5%–10%	25%
10%–15%	20%
15%–20%	15%
20%–25%	10%

25%–30%	5%
30%–35%	3%
35%+	1%

2. State-specific distribution cost index multipliers are based on:

- a. Population density, using the [US Census Bureau](#) data (multiplier ranging from 0.8 to 1.6);
- b. Cost of living, using the Council for Community and Economic Research's [Cost of Living Index](#); and
- c. Grid infrastructure characteristics, based on desktop research evaluating factors such as underground distribution systems, grid hardening requirements, and average feeder lengths.

e. **Calculate new volumetric rate and rate reduction potential**

We estimated the new volumetric rate by adding the additional statewide supply and distribution costs to the current volumetric revenue (in the numerator from section *Calculate current volumetric rate*), and adding the additional electricity load to the current total electricity sales in the state (in the denominator from section *Calculate current volumetric rate*).

We calculated the residential rate reduction as: $1 - (\text{New volumetric rate} / \text{Current volumetric rate})$.

4. Greenhouse Gas Reductions

We estimated the greenhouse gas emissions (GHG) reductions associated with the grid-optimal heat pump deployment strategies by leveraging the NLR's [ResStock greenhouse gas emissions outputs](#). These leverage the NLR's Cambium database and long-run marginal emissions factors. For each state:

- a. Calculate GHG savings for the entire heat pump upgrade measure package across all applicable homes
 - i. We calculated the total GHGs of the applicable buildings in the baseline, GHG_b , by multiplying the output “out.emissions.all_fuels.lrmer_mid_case_15.co2e_kg” in ResStock’s metadata file by the ResStock weight 252.3.
 - ii. We calculated the total GHGs of the applicable buildings in each heat pump upgrade measure package, GHG_m , by multiplying the output “out.emissions.all_fuels.lrmer_mid_case_15.co2e_kg” in ResStock’s metadata file by the ResStock weight 252.3.
 - iii. We calculated the GHG reduction for the all-electric heat pump and hybrid heat pump upgrade measure packages, $GHG_{saving, all-elec}$ and $GHG_{saving, hybrid}$, by subtracting their respective GHG_b minus GHG_m .
- b. Calculate GHG savings for the peak-limited deployment of heat pumps
 - i. We determined the peak-limited GHG reduction for the all-electric heat pump only deployment, $GHG_{saving, peak-limit, all-elec}$, by multiplying $GHG_{saving, all-elec}$ by the percentage of all-electric homes that could upgrade to heat pumps without increasing peak demand.
 - ii. We determined the peak-limited GHG reduction for the mix of all-electric heat pumps and hybrid heat pump deployment, $GHG_{saving, peak-limit, mix}$, by multiplying $GHG_{saving, all-elec}$ and $GHG_{saving, hybrid}$ by the corresponding percentage of all-electric and hybrid homes that could upgrade to heat pumps without increasing peak demand when including the grid-optimal mix of all-electric and hybrid heat pumps.