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Homegrown energy: How household upgrades can meet 100 percent of data center demand growth

Technical Methodology

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Estimating peak demand reductions from heat pump upgrades, rooftop solar, and battery storage

1. Load modeling and peak reduction

Residential energy loads are calculated using the National Renewable Energy Laboratory (NREL)'s publicly available ResStock tool.[1] ResStock consists of 550,000 sampled residential buildings that statistically represent residential housing units in the United States. We model the upgrade scenarios described in the table below using EnergyPlus[2], simulating heat pump upgrades (heat pumps and heat pump water heaters, as described below) on each building model.

To determine the state-level residential peak demand for each upgrade scenario, we aggregate the relevant simulated hourly electric load profiles for every occupied single-family home. For example, to model a scenario where all electric resistance heating systems are replaced with heat pumps in the state, we combine the simulated heat pump upgrade profiles for all homes previously using electric resistance heat with the baseline load profiles from all other homes. This creates a new, representative state-level load profile for the scenario.

From this aggregate profile, we calculate the average load during the top 10 load hours in the summer (June-August) and winter (December-February). The greater of these two values is identified as the overall residential peak demand (measured in gigawatts) for the state under that scenario.

[1] https://resstock.nrel.gov/
[2] https://energyplus.net/

The peak reduction attributable to the upgrade is the difference between this scenario peak and the baseline peak where no homes have been upgraded.

2. Integrating rooftop solar

To model the peak reduction impact of rooftop solar, we first estimate the proportion of residential rooftops in each county that are suitable for solar, based on NREL data on the fraction of small buildings (<5,000 sqft) in each zip code with solar suitable rooftops.[3] Within each county, we randomly select a corresponding proportion of single-family occupied ResStock homes to receive solar installations.

We generate hourly solar production profiles for these homes using NREL's System Advisor Model PVWatts model.[4] This hourly generation is subtracted from each home's load profile to create a net load profile, which can be negative during times of excess generation, indicating the home is sending electricity back to the grid. The same process described in Section 1 is then applied to these net load profiles to calculate the new peak demand with solar.

3. Simulating battery dispatch

To compute the additional peak reduction potential of storage when paired with solar, we apply a peak shaving algorithm on the aggregate net state load profiles with solar for each scenario. We identify the seasonal peak days, the days containing the top 10 peak hours in winter and summer, for each state and scenario. For each peak day, we simulate a battery dispatch strategy aimed at maximizing residential peak reduction.

We identify the optimal hours of the day to charge and discharge the battery, shifting grid load away from peak times to overnight, within the constraints of the batteries' capacity and their ability to recharge without creating new peaks. This yields a new shaved peak, and the battery peak reduction for each day is then calculated as the difference between the original peak and this new shaved peak. We average these reductions across the top peak days per season. We then combine the prior reduction estimate resulting from solar generation alone, with the incremental storage reduction contributed by the battery. The total reduction from solar and storage adds this incremental storage reduction with the reduction already provided by solar generation alone.

[3] https://docs.nrel.gov/docs/fy16osti/65298.pdf
[4] https://sam.nrel.gov/photovoltaic.html

Caveats and limitations

Non-additivity of interventions: A critical feature of our methodology is that it captures the dynamic interaction between technologies. Because each intervention (e.g., heat pumps, solar, storage) changes the underlying load shape, their impacts on peak demand are not additive. This has two key implications: first, the peak reduction achieved from a combined deployment of heat pump upgrades, solar, and storage is not simply the sum of the reductions from each technology deployed alone; second, the best standalone heat pump upgrade may not yield the highest overall reduction when paired with solar and storage. For simplicity, we keep the estimate for the best heat pump upgrade constant for each state, both with and without solar and storage.

State residential peak vs. system peak: This method calculates the peak demand for the residential sector specifically, aggregated to the state level. The overall system-wide peak demand for a grid's independent system operator (e.g., ISO-NE, PJM) is managed at a regional level and may occur at a different time due to commercial and industrial load patterns. While the residential sector is often the primary driver of system-wide peak demand, this is not always the case. Therefore, these results should be interpreted specifically as the change to the residential component of peak demand, which is a major, but not sole, contributor to the total system peak. Still, our research demonstrates the potential for residential upgrades to meaningfully create capacity in a way that would be beneficial to the overall grid.

Assumptions on storage dispatch: The peak-shaving algorithm is applied to a state-aggregated load profile. This approach simulates a perfectly coordinated fleet of behind-the-meter batteries acting to minimize the state's total residential peak demand and represents the maximum technical potential for peak reduction. It is important to note that this analysis focuses on technical potential and does not assess the techno-economic feasibility or real-world adoption challenges required to achieve this ideal dispatch.

Assumption on rooftop solar photovoltaic (PV) sizing: The methodology for sizing rooftop PV systems assumes that all households with suitable roofs receive a 5 kW PV system, regardless of roof area or electric load, and that the panels are placed at a 20 degree tilt on a south-facing section of roof. All other assumptions about the system specifications are the standard specifications for NREL's PVWatts module[5].

[5] https://docs.nrel.gov/docs/fy14osti/62641.pdf

Model specifications for simulated heat pump, rooftop solar, and storage upgrades

Upgrade	Technical specification	Model
Heat pump	Replacement of a household's existing heating and cooling system with an air-source heat pump with performance characteristics similar to a centrally-ducted heat pump with Seasonal Energy Efficiency Ratio 2 ("SEER2") 17.1, 8.5 Heating Seasonal Performance Factor 2 ("HSPF2"), or a ductless mini split heat pump with SEER2 17.1, 9.4 HSPF2, depending on existing ductwork. The modeled heat pump uses electric resistance backup, is sized using the Home Energy Rating System ("HERS") methodology, and does not have a setpoint setback.	EnergyPlus
Heat pump water heater	Replacement of a household's existing water heater and installation of a heat pump water heater with Uniform Energy Factor (UEF) 3.35-3.45.	EnergyPlus
Rooftop solar	South-facing 5 kW DC system.	SAM's PVWatts module
Battery storage	Tesla Powerwall 3, with 13.5 kWh of capacity, and 5.8 kW DC bank power.	Peak shaving algorithm, described above

Estimating energy bill savings, emissions savings, and health impacts of electrification upgrades

We calculate annual energy savings by taking the annual energy consumption of ResStock homes and calculating the change in energy usage when the upgrade is applied.

To translate methane gas and electric energy consumption to dollar amounts, we use revenues and sales volumes reported by utilities to the U.S. Energy Information Administration (EIA)[6][7] and subtract out the fixed charges collected from various sources to calculate an average county volumetric charge, which we then apply to each building model's estimated consumption. For propane and fuel oil consumption, we use historical energy prices from the EIA for each state.

To translate energy consumption to greenhouse gas emissions, we use state-specific emissions factors from NREL's Cambium tool, projecting the annual emissions from an electricity grid where 95 percent of electricity comes from carbon-free sources by 2050.

To translate energy consumption to health impacts, we first calculate pollutant emissions factors for each fuel using data from the EPA's National Emissions Inventory, the American Community Survey, EIA, and Cambium, using the same electricity grid assumptions as above. We use the open-source air pollution transport model Intervention Model for Air Pollution[8] and effect sizes from the academic literature to convert these pollutant impacts to premature mortality impacts. To assign an economic valuation to the incidence of premature mortality, we multiply the premature mortality estimate by a value of statistical life (VSL) figure of $11.5 million in 2024 dollars.

Estimating the capacity costs of heat pumps, solar, storage, and natural gas power plants

To estimate the cost of a heat pump, we use large datasets of heat pump installations from programs in Massachusetts and California. We train a model to predict heat pump total installed costs based on the home's size, heat pump efficiency and size, the presence of ducts, any electric panel upgrades, installation date and location. We then use the trained model to predict heat

[6] Form EIA-86, "Annual Electric Power Industry Report"
[7] Form EIA-176, "Annual Report of Natural and Supplemental Gas Supply and Disposition"
[8] https://inmap.run/

pump costs for each single-family occupied home in ResStock. The average predicted price of a heat pump is around $18,500.

To estimate the cost of rooftop solar, we calculate the average national cost per household using the average cost of $2.53/W from EnergySage[9] and the specification of a 5-kW panel from our technical assumptions. We assume an average lifetime of 30 years.

To estimate the cost of a residential battery, we use average costs from EnergySage of about $13,300 for a Tesla Powerwall 3.[10] We assume an average lifetime of 15 years.

To calculate the cost per year of capacity ($/kW-year) for heat pump upgrades, we first multiply the average predicted cost of a heat pump by the number of households that heat with electric resistance in the states where that is the most effective solution. We assume that the initial capital expense is 50 percent of this total, based on the cost-sharing arrangement described in the report. We repeat this cost at year 15, the average lifetime of a heat pump. We then levelize the capacity these heat pumps provide and the capital costs over a 30 year period using an 8.99 percent discount rate.

To calculate the cost per year of capacity for rooftop solar and storage, we multiply the average cost of the solar and battery storage by the number of single-family households they are provided to. Battery storage is provided to all single-family households, and solar is supplied only to those with suitable roofs, as described above. We then apply a 40 percent cost compression through improved permitting and customer acquisition costs. We include 50 percent of the total cost as the cost paid by the hyperscaler. This is the initial capital outlay. We repeat the cost of storage at year 15, the average lifetime of residential batteries. We levelize the cost per kW-year using a 8.99 percent discount rate over 30 years, with the total capacity provided by the solar and storage over 30 years.

To calculate the capacity costs of a gas turbine power plant, we use a $2,500/kW initial cost, based on recent reporting.[11,12] We use a 15 percent capacity factor,[13] natural gas prices from the EIA,[14] and average fixed operating and maintenance costs of $18/kW[15] to estimate the costs over 30 years. We levelize these capacity costs using the same 8.99 percent discount rate.

[9] https://www.energysage.com/local-data/solar-panel-cost/
[10] https://www.energysage.com/energy-storage/how-much-do-batteries-cost/
[11] https://rmi.org/gas-turbine-supply-constraints-threaten-grid-reliability-more-affordable-near-term-solutions-can-help/
[12] https://www.reuters.com/business/energy/rush-us-gas-plants-drives-up-costs-lead-times-2025-07-21/
[13] https://www.gao.gov/assets/gao-24-106145.pdf
[14] https://www.eia.gov/outlooks/aeo/excel/aeotab13.xlsx
[15] https://www.eia.gov/outlooks/aeo/assumptions/pdf/elec_cost_perf.pdf

Estimating the effective costs of electricity with rooftop solar and storage

To estimate the effective cost of electricity paid by households after installation of rooftop solar and battery storage, we use data from ResStock to estimate total electricity consumption for each household under baseline conditions. We then calculate net electricity consumption from the grid after the installation of solar and storage, by subtracting annual solar generation from the annual electricity energy consumption. This net consumption is then used to calculate a new cost of electricity for each household, using the EIA volumetric rates for electricity described above. We then calculate the cost of the solar and storage to the household after the market compression and the contribution from the hyperscaler, averaged over the lifetime of each of the systems. These two costs, the annual net cost of electricity and the average yearly cost of the systems, are added together. This new cost is used to calculate a national average effective cost of electricity for households. This method assumes that all solar generation for the year is used by the household or sold back to the utility at the full retail cost, up to the total consumption of the household, but that anything beyond that is lost. For some households, this is likely an overestimation of the total benefits of solar and storage, due to the variability in how states compensate for solar credits and the hourly generation and consumption profiles.

State-specific projected data center demand

We use proprietary data from Aterio[16] on existing and announced data center locations and demand. To estimate the projected new demand from data centers over the next five years, we calculate the aggregate capacity for data centers in each state that are announced, under construction or delayed with an activation date before 2030.

[16] https://www.aterio.io/insights/us-data-centers