Incorporating building load growth into long-term electricity load forecasts

Sean Murphy

U.S. Department of Energy
Energy Innovator Fellows Informational Webinar
February 20, 2025

This work was funded by the U.S. Department of Energy Building Technologies Office under Contract No. DE-AC02-05CH11231.

Poll: Have you ever used or analyzed a load forecast?

- Yes
- No

Contents

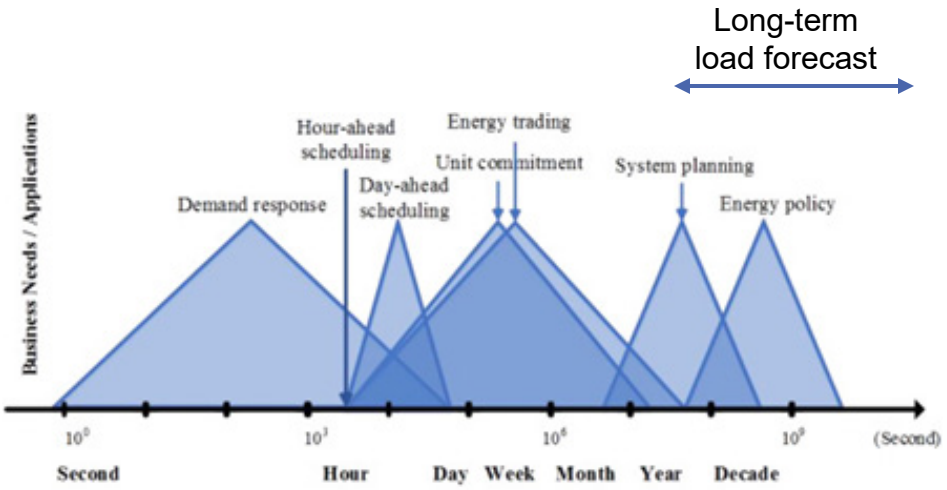
- Introduction
- Framework overview
- Defining use cases
- Establishing scope
- Selecting base year load
- Choosing scenarios
- Technology selection and adoption
- Estimating changes in load
- Applying results of load forecast
- Key takeaways

Introduction

- Utilities develop long-term electricity load forecasts (5–20 years) to inform:
  - Generation planning
  - Transmission system planning
  - Distribution system planning
  - Financial planning

- A common approach is to estimate:
  - *Gross* peak demand via a regression of historical load, economic data, and weather data
  - *Net* peak demand by accounting for the impacts of distributed energy resources and adoption of new loads on gross peak demand (see slide 38)

- Utilities are incorporating state and local policy goals into forecasts and exploring the impact of building electrification.



Source: T. Hong and S. Fan, "Probabilistic Electric Load Forecasting: A Tutorial Review," International Journal of Forecasting 32 (3): 914–938, July–September 2016

Introduction (cont.)

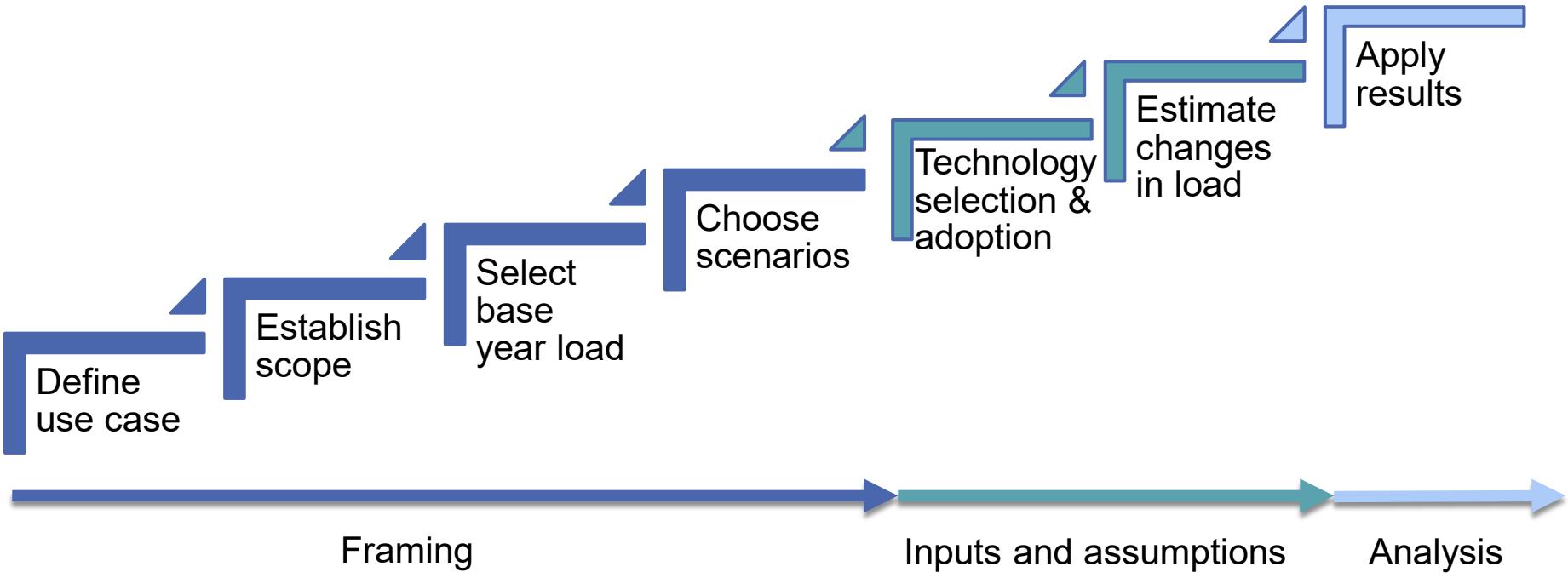
- Berkeley Lab developed a framework* for developing a long-term electricity load forecast that accounts for adoption of building electrification technologies.

- Each step in the framework provides:
  - Guiding questions and considerations for users
  - Examples from two municipal utilities, Sacramento Municipal Utility District (SMUD) in California and Fort Collins Utilities in Colorado, for all relevant steps

- The framework does not represent the only way to develop load forecasts that account for impacts of building electrification.
  - It reflects lessons learned from application of the framework for the two utilities.
  - The framework focuses on how to incorporate publicly available building end-use load profiles into load forecasts.

*Murphy, S., M. Pigman, N. Mims Frick (2024), *Guidance on incorporating building and transportation electrification into long-term load forecasts*

Framework for incorporating new building end-use loads into long-term forecasts



Framework steps and examples

Defining use case

- **What planning decisions inform the forecast?**
  - Generation
  - Transmission
  - Distribution
  - Financial

- The use case will inform the forecast's scope, scenarios, and how to apply the results.

Defining use case: example

- Fort Collins Utilities wanted to understand the impact of building electrification on its **distribution system**. In particular:
  - Whether upgrades to existing feeders may be necessary to accommodate building electrification
  - The impact of increasing the efficiency of building electrification technologies

- SMUD was focused on the **systemwide** peak demand impacts of policy-driven building electrification to inform integrated resource planning and energy efficiency program design.
  - SMUD also was interested in the impact of extreme cold weather and high-efficiency electrification technologies on electrification demand.

Establish scope

- **What physical part of the power system, customer segments, and time frame will the forecast cover?**

- Align physical scope with the use case
  - Individual or multiple feeders may be relevant for distribution system planning.
  - Generation and power purchasing may require systemwide planning.

- Select customer segments and/or rate classes that are:
  - Relevant to the use case
  - Within the physical scope

- Select a time frame that aligns with one or more of the following:
  - Statutory requirements
  - Utility planning processes
  - Policies and goals
  - Period within which significant adoption of new electrified end uses may occur

*See slides 5 and 6

Establish scope: example

- Forecast scopes for Fort Collins Utilities and SMUD were based on the utilities' use cases and timelines set by their internal planning and policy goals.

Scope	SMUD	Fort Collins Utilities
Part of power system	SMUD service territory	15 high-growth distribution system feeders
Customer segments	Residential and commercial	Residential
Time frame	2025–2045 2045 aligned with end date for compliance with Sacramento and California policy goals and objectives	2025–2040 2040 aligned with change in timing of peak demand from summer to winter

Selecting base year load

- The base year load for the forecast is the load shape of the utility's system, or component of interest (e.g., feeder or substation), to which building electrification load is added.

- **What year (or time period) serves as a foundation for the forecast?**
  - Econometric model: Projects historical relationship between load and weather and economic indicators, among other variables (e.g., electricity prices) into the future
  - Single year: Reflects variation in load specific to weather, economics, and events in a single year
  - Multiyear: Smooths out impact of weather, economics, and events that characterize annual load shapes

- **What data are needed to characterize the base year load**?
  - 15-minute or hourly gross or net interval metering data
  - Rooftop PV generation data for the customer segments in scope of the forecast over the baseline period
    - The level of aggregation (e.g., individual feeder or whole system) depends on use-case and scope.

Selecting base year load: examples

- Hourly metered 2018 load was the base year load for analysis for both utilities.
  - While not the most recent year of metering data available, the 2018 data aligned with the weather year of the end-use profiles used in the forecast (see slide 20).
  - Since many buildings and uses are temperature-sensitive, it is important for metering data to reflect the same weather that serve as the basis for end-use load profiles.
- SMUD – Aggregated system-wide 2018 metered net load for residential and commercial customer classes
  - Calculated gross load by adding systemwide 2018 rooftop solar generation to net load
- Fort Collins Utilities – Aggregated 2018 net load for each of the 15 selected feeders
  - Created a gross load shape for the base year for each feeder by adding back feeder-specific 2018 rooftop solar generation profiles estimated from reported installed system capacity

Choosing scenarios

- **Are there policies that affect building electrification?**
  - Policies can inform which technologies (e.g., efficiency level) are adopted and the rate of adoption.
  - Expected market changes also can affect which technologies are adopted and the rate of adoption.

- Relate scenarios to prevailing policies and expected market changes and explore variation in key parameters of building electrification load:
  - Technology adoption levels
  - Technology efficiency
  - Rate design
  - Weather (e.g., historical weather, future weather, or planning conditions)

- Establish a baseline scenario to compare alternative scenarios against.

- Make it easier to interpret increasingly complex forecasts as the number of scenarios increases.
  - Limit the number of scenarios
  - Assign probabilities to forecasts and aggregate outputs into a single probabilistic forecast*

*Probabilistic forecasting uses a range and probability distribution for each of the driving variables to quantify uncertainty for each scenario.

Choosing scenarios: examples

- SMUD and Fort Collins Utilities scenarios:
  - Accounted for impacts of state and local policies
  - Addressed uncertainty in weather and technology adoption
  - Considered multiple levels of efficiency for building electrification technologies

SMUD

- Three scenarios differing in efficiency level of installed building technologies:
  - *Baseline efficiency*: lower end of efficiency in current market offerings
  - *High efficiency*: high end of efficiency in current market offerings plus envelope upgrades
  - *Minimum efficiency heat pump*: simulated minimum efficiency operation of heat pumps for space and water heating during a winter cold snap

Fort Collins Utilities

- Two scenarios differing in efficiency level of installed building technologies:
  - *Baseline efficiency*: lower end of efficiency in current market offerings
  - *High efficiency*: high end of efficiency in current market offerings plus envelope upgrades
- Each scenario explored *three levels of building technology adoption* (low, medium, and high).

Building electrification technology selection

- **What building electrification technologies are included in the forecast?**
  - Decide whether the forecast considers full and/or partial electrification of space heating.
    - No electric resistance element is necessary if buildings retain existing fossil heating system as a backup to heat pumps for space conditioning.
  - Select technologies:
    - Applicable to customer segments selected as part of forecast scope
    - Consistent with forecasted policy and market changes
    - Appropriate for retrofits in the types of buildings in the scope of the forecast (e.g., ducted versus ductless heat pump)

- **What level(s) of building technology efficiency can the forecast consider?**
  - Set lower and upper bounds on efficiency based on:
    - Building codes
      - Current codes establish minimum efficiency levels.
      - Anticipated or known code revisions can inform future minimum efficiency levels.
    - Energy efficiency programs
      - Technologies included in energy efficiency programs or certified by trade organizations (e.g., Consortium for Energy Efficiency) can inform high efficiency levels.

Building electrification technology selection: examples

- Included residential technologies that electrify space heating, water heating, cooking, and clothes drying
- Selected baseline and high-efficiency technologies available in ResStock, the tool used for generating building electrification load shapes (see slide 20)

End use	Baseline efficiency	High efficiency
Space conditioning	Single speed heat pump (SEER 15, 9 HSPF)* with backup electric resistance	Variable speed heat pump (SEER 24, 13 HSPF or SEER 29.5, 14 HSPF based on presence of ducts in the baseline) with backup electric resistance Envelope upgrades: Attic insulation (R-49 if initially <=R-30) Air sealing (30% reduction in ACH50 if initially >=15 ACH50) Duct sealing and insulation (10% leakage, R-8) Wall insulation (R-13 drill and fill)
Water heating	Heat pump water heater (3.35–3.45 UEF)	Heat pump water heater (3.35–3.45 UEF)
Cooking	Resistance	Induction
Clothes drying	Resistance	Heat pump

*SEER – seasonal energy efficiency rating; HSPF – heating seasonal performance factor; UEF – uniform energy factor

Electrification technology adoption

- **What is the existing stock of building electrification technologies in the geographic scope of the forecast?**
  - Determine the number of buildings that have technologies of interest in the base year of the forecast by:
    - Leveraging existing studies in the region (e.g., CA , MA) or conducting a similar effort
    - Reviewing publicly available datasets on U.S. housing stock
- **What are the drivers of technology adoption?**
  - Identify statutes and regulations, including building codes, that could impact adoption rates.
  - Consumer preferences and economics of electrification also affect adoption.
- **How does building technology adoption change over time?**
  - Determine the adoption rates implied or required by relevant policies by:
    - Conducting market research
    - Leveraging publicly available forecasts for technology adoption
  - Apply model of technology adoption to forecast period
    - Stock-turnover models relate adoption to replacement of existing equipment.
    - Bass diffusion models capture consumer uptake by early and late adopters.
- **How does adoption vary geographically?**
  - Advanced practice estimates likelihood of adoption of technologies by premise or at higher-level geographic area (e.g., zip code) based on the relationship between historical adoption data and socioeconomic and demographic indicators.
  - Standard practice assumes an even geographic distribution of technology adoption.

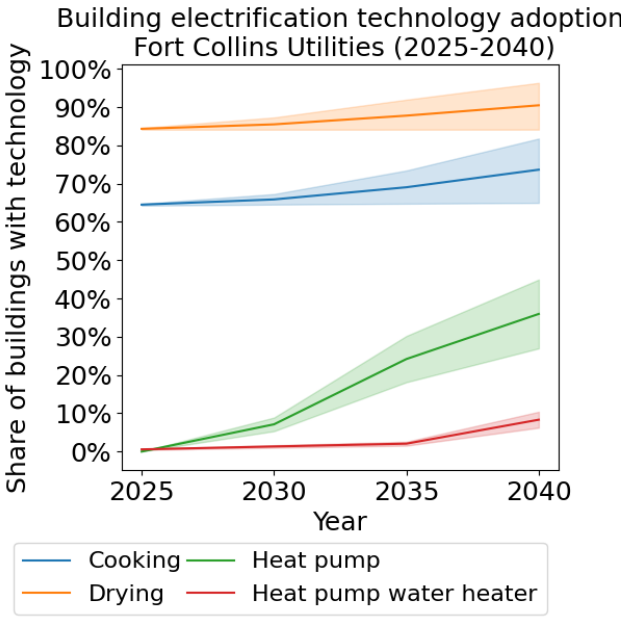
Building electrification technology adoption: example

SMUD

- Set building electrification technology adoption rates over the forecast period to comply with SMUD policy goals:
  - 100% electrification of space and water heating and 78% electrification of cooking and clothes drying by 2045
  - 100% all-electric new construction after 2030
- Increased building technology adoption levels linearly over the study period from a baseline established by the most recent California Residential Appliance Saturation Survey

Fort Collins Utilities

- Developed low, medium, and high adoption trajectories based on:
  - Studies commissioned by Fort Collins Utilities, its wholesale power provider (Platte River Power Authority) and the National Renewable Energy Laboratory's Electrification Futures Study



Estimating building electrification load

- **How much load does building electrification add to the forecast?**

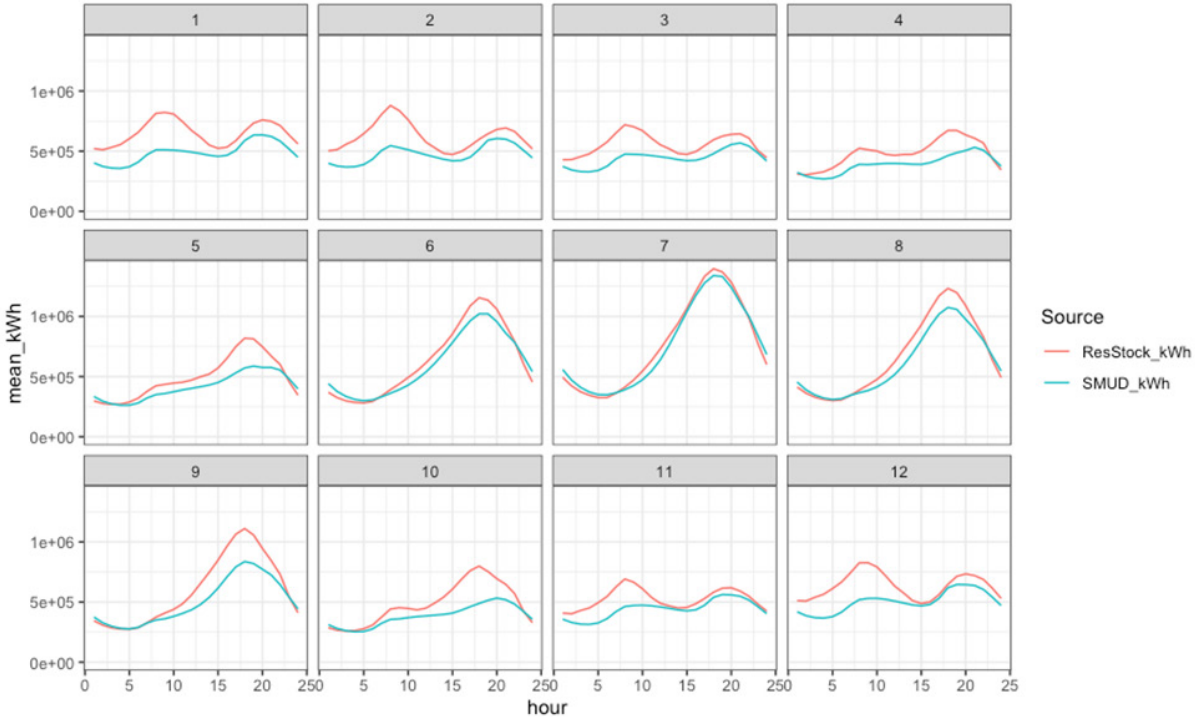
- Identify end-use load profiles for selected customer segments, electrification technologies, and scenarios:
  - ResStock and ComStock statistically represent the U.S. building stock:
    - As it was in the base year (2018),
    - "What if" scenarios with alternative efficiency and electrification packages.
  - Submetering of electrification technologies can provide empirical load shapes.

- Validate modeled end-use load profiles against metered data
  - Aggregate end-use load profiles by customer segment (and segments of building stock if applicable) for the part of the power system in scope (e.g., individual feeder or whole system).
  - If end-use load profiles are specific to an individual year (e.g., 2018), use metered data from the same year.
  - Compare total energy (MWh), peak demand (MW), and timing of peak demand between end-use load profiles and metered data.

- Scale technology-specific load shapes or changes in load according to assumed levels of technology adoption in each year of the forecast period (see slide 22).

- Account for new construction load (see slides 36-37).

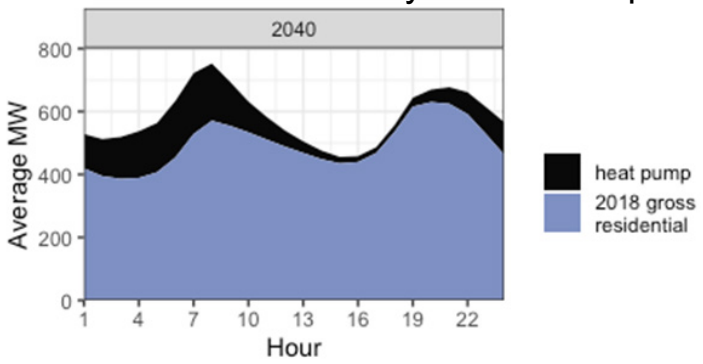
Validating building electrification load: example



- Validating modeled end-use load profiles against metered data is important for understanding whether load profiles are skewed in any way.
- This figure compares metered SMUD and ResStock mean load profiles by month.
  - Metered and modeled data have similar summer profiles and peaks, but the ResStock end-use load profiles have much higher winter morning peaks.

Scaling building electrification load shapes: example

- Estimating incremental load from building electrification
  - Calculate *hourly percent changes in load* between ResStock load profiles for the *existing* building stock and a building stock with *100% adoption of electrification technologies.*
    - Performed this calculation for each electrification technology in both the baseline and high-efficiency scenarios for full electrification
  - Estimate the incremental hourly load from 100% electrification adoption by multiplying the hourly percent changes in load (from ResStock load profiles) by the metered base year load profile.
  - Scale incremental load from 100% electrification adoption by the expected level of adoption in each year of the forecast for each electrification technology.
    - For example, since an estimated 76% of buildings with gas furnaces in SMUD's territory adopt heat pumps by 2040, incremental load was scaled from 100% to 76% electrification.
  - Add the adoption-scaled electrification load shape to the base year load shape.
    - The black area in the graph represents incremental load from heat pump space heating in February 2040. The blue area is the base year load shape.



Applying forecast results

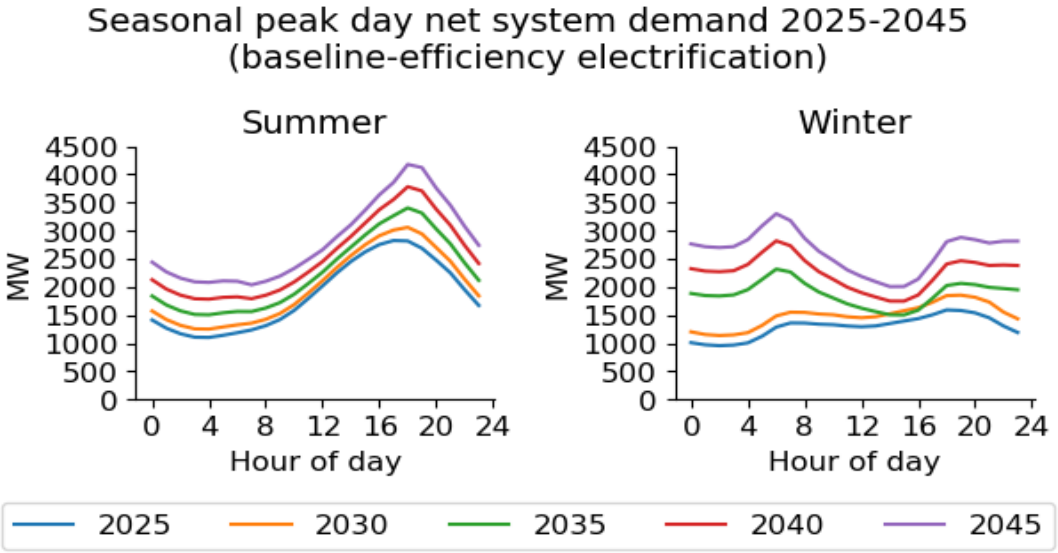
Apply forecast results: overview

- Following is a selection of results for SMUD and Fort Collins Utilities.
- These are examples of analyses that building electrification hourly forecasts enable, not a comprehensive list.

Analysis	Impact
Seasonal peak day load	Shows how the magnitude and timing of seasonal peak demand changes over time
Peak demand drivers	Identifies which electrification technologies increase peak demand the most
Feeder thermal overload	Assesses the impact of sustained high load from electrification on feeders
Efficiency impacts	Quantifies how much increasing the efficiency of electrification retrofits can reduce peak demand relative to baseline efficiency electrification
Extreme weather	Estimates cold snap impacts on winter morning demand by simulating minimum-efficiency heat pump operation

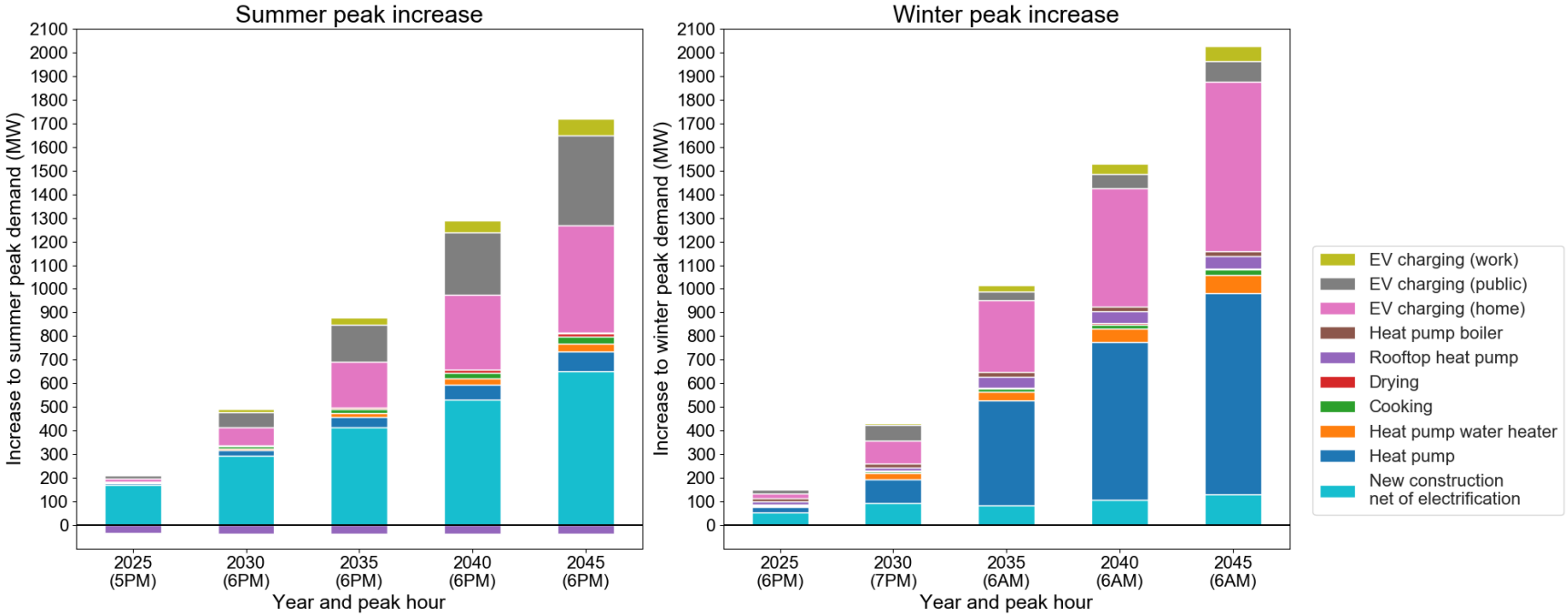
Applying forecast results: seasonal peak day load

- In each year of the SMUD forecast and for each scenario, we identified the summer and winter days that included the hour with the highest demand in each season. We used these load shapes for these days to understand:
  - Changes in magnitude of peaks in each season
  - Changes in the time of day of peaks in each season
- Baseline efficiency forecast for SMUD
  - Winter peak increases are larger than summer peak increases, though the system remains summer-peaking at the end of the forecast period.
  - The summer peak occurs later in the evening with each time step, and winter peaks move to the morning in 2035.



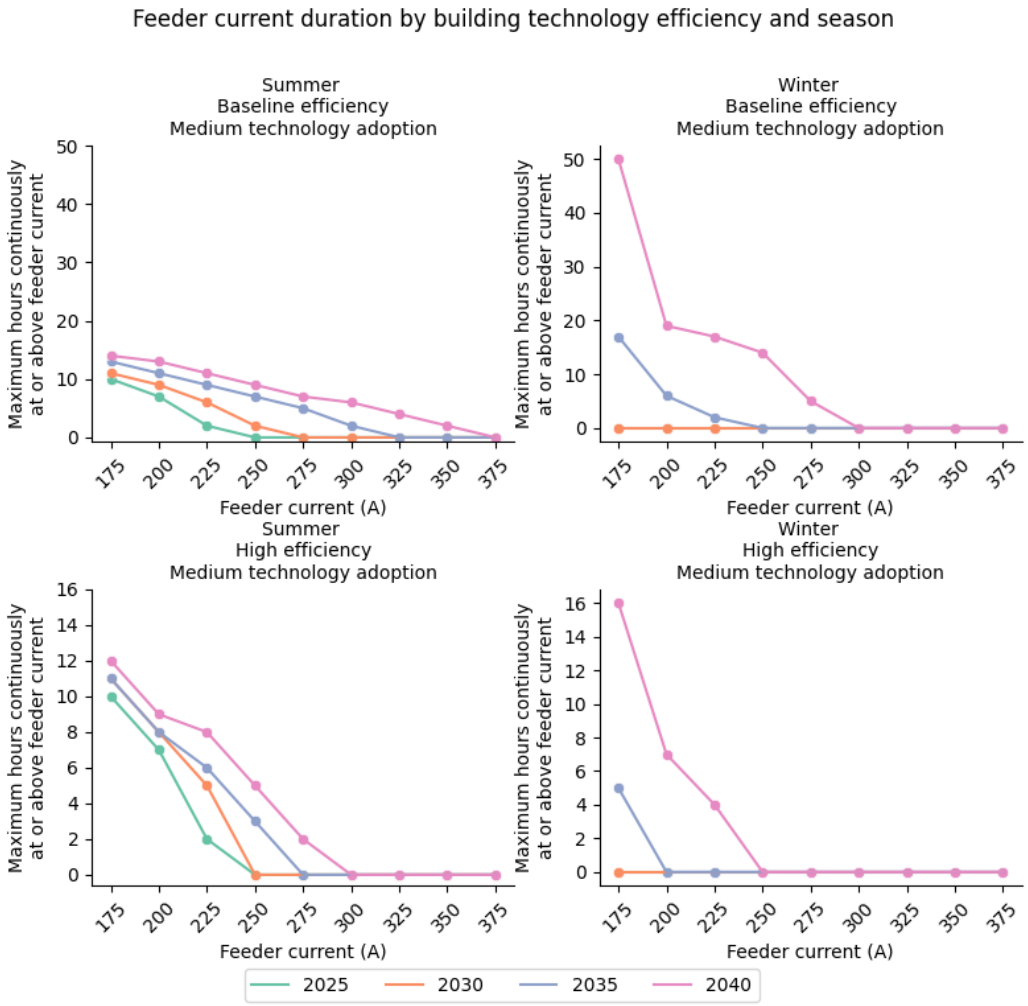
Apply forecast results: peak demand drivers

- Technology-specific forecasts provide estimates of each technology's contributions to peak demand.
- The figure shows the quantity of gross peak load increases by electrification technology on SMUD's system.
- For SMUD's system, heat pumps account for 42% of the cumulative increase in winter peak demand.



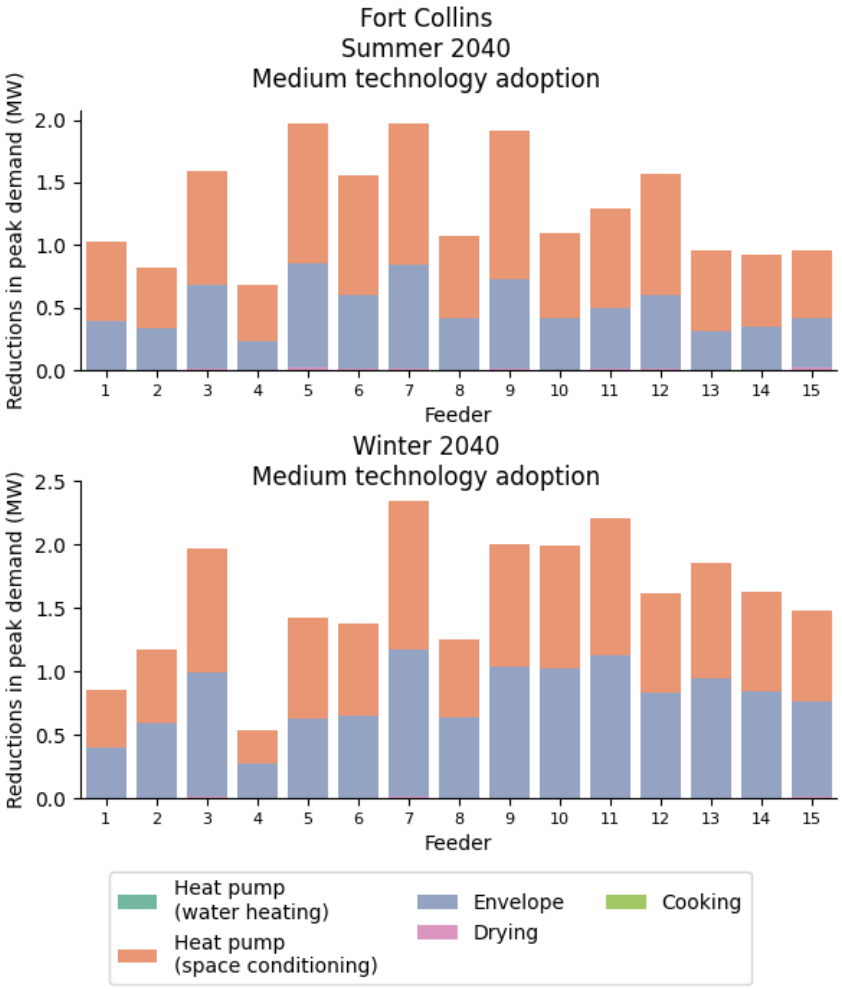
Apply forecast results: feeder thermal overloads

- Thermal overloads can occur when feeder current remains at high levels for extended periods of time.
- For Fort Collins Utilities, we determined the maximum number of hours that feeder current would remain at or above threshold levels for the 15 feeders studied—in summer and winter, for both the baseline and high efficiency forecasts.
- Checked whether durations exceeded design threshold values for the feeders.
- No violations were found.



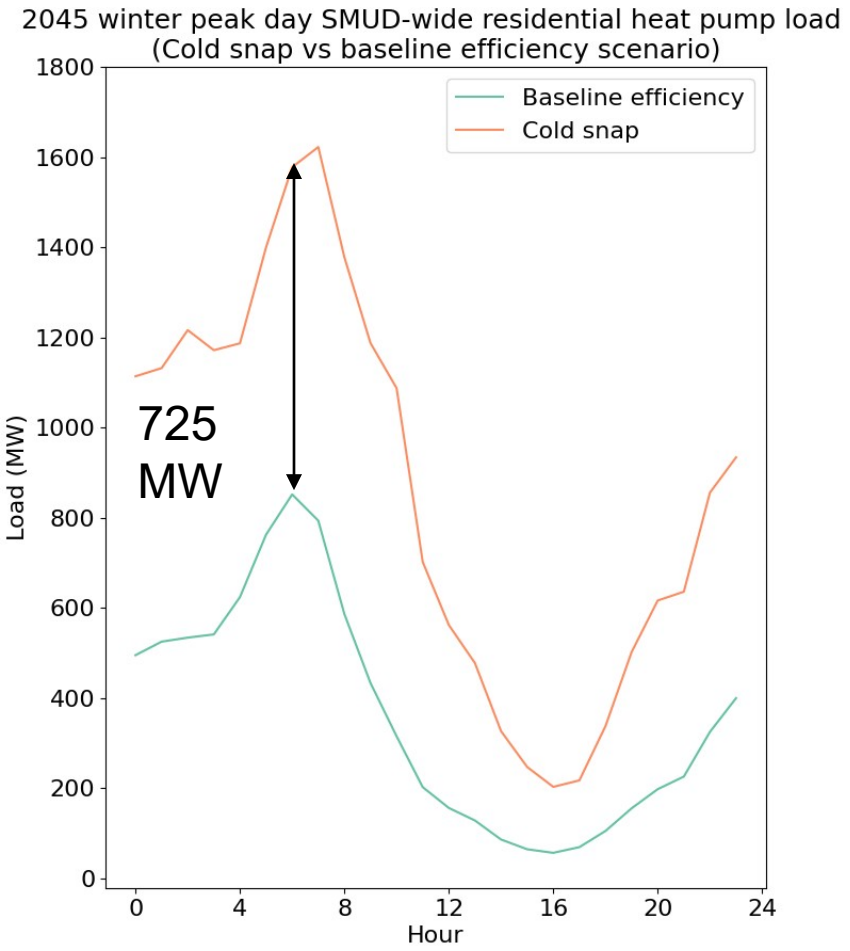
Apply forecast results: efficiency impacts

- Comparing scenarios that differ in the efficiency of building electrification technologies can show how energy efficiency can mitigate increases in peak demand.
- The impact of high efficiency electrification for Fort Collins Utilities for the 15 studied feeders was assessed by calculating the difference in demand between baseline and high efficiency scenarios for each electrification technology.
- The figure shows the impact of energy efficiency in the hour of the baseline scenario seasonal peaks.
- High efficiency heat pumps and envelope upgrades had the largest impact on peak demand.



Apply forecast results: extreme weather

- To consider the impact of extreme cold weather on electric space heating demand in SMUD's territory, a simulation assumed that heat pumps operated at minimum efficiency on the coldest day in the weather year of load profiles (2018).
  - Minimum efficiency corresponds to a coefficient of performance (COP) of 1 (the efficiency of electric resistance heat).
  - COP is the ratio of *heating delivered* by a heat pump to *energy used* by a heat pump.
  - This approach simulates electric resistance heat meeting every building's heating demand.
- Under these conservative assumptions, 2045 SMUD residential heat pump load increases 85% (725 MW) during the 6AM winter peak relative to the baseline efficiency scenario. Winter peak demand exceeds summer peak demand by 4% (170 MW).



Key takeaways

- Long-term electricity load forecasts can inform multiple types of utility planning practices.
- Forecast scenarios can explore uncertainty in building electrification technology adoption and efficiency level.
- Utilities can use publicly available end-use load profiles to account for the impacts of building electrification in long-term load forecasts.
- Utilities can apply forecasts to address planning questions related to building electrification, including the identification of peak demand drivers, feeder thermal overload risk, and the peak demand impacts of extreme weather.

Resources

- Load forecasting practices
  - Load Forecasting for Modern Distribution Systems
  - Electricity Load Forecasting: A Systematic Review
  - 2023 Energy Systems Integration Group Long-term Load Forecasting Workshop
  - Best Practices in Electricity Load Modeling and Forecasting for Long-Term Power System Planning
  - Developing Forecasts: Basics and Best Practices
- Data inputs for load forecasts
  - ResStock and ComStock for building end use load profiles
  - EVI-Pro Lite for EV charging load shapes
  - System Advisor Model for PV generation profiles
- Technology adoption projections
  - 2019 California Residential Appliance Saturation Study
  - Massachusetts Residential Baseline Study
  - Energy Information Administration Annual Energy Outlook 2023
  - Electrification Futures Study
  - Net-Zero America
  - Distributed Generation Market Demand Model

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Copyright Notice

This manuscript has been authored by an author at Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges, that the U.S. Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes

ENERGY MARKETS & POLICY

Contacts

Sean Murphy: smurphy@lbl.gov

For more information

Download publications from the Energy Markets & Policy Department: https://emp.lbl.gov/publications

Sign up for our email list: https://emp.lbl.gov/mailing-list

Follow the Energy Markets & Policy Department on Bluesky: @BerkeleyLabEMP.bsky.social

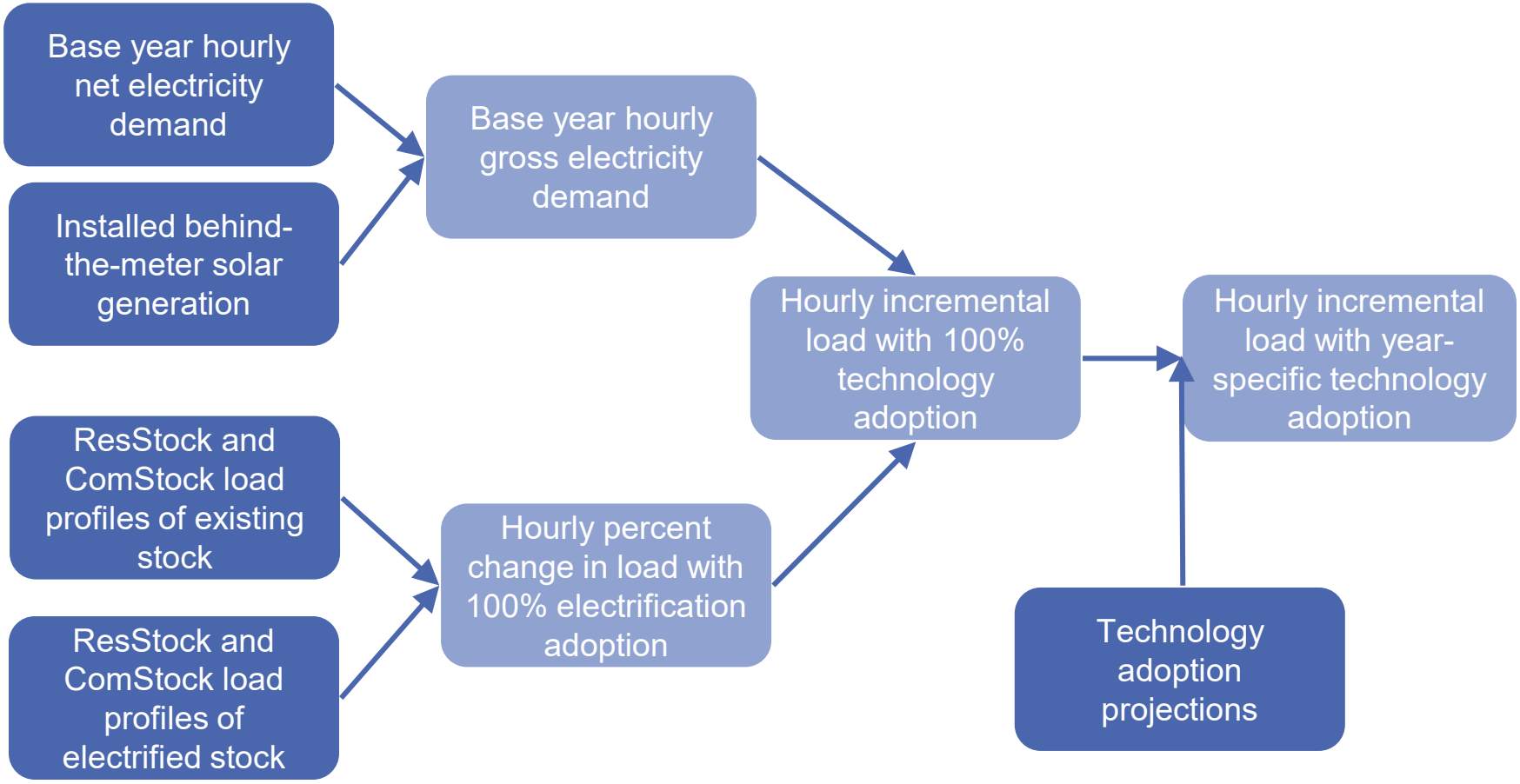
Acknowledgements

This work was funded by the U.S. Department of Energy Building Technologies Office, under Contract No. DE-AC02-05CH11231. We would like to thank Brian Walker and Cecilia Johnson-Hayman in the Building Technologies Office for their support of this work. We also thank Amrita Chakrbaborty (Sacramento Municipal Utility District) and Paul Zummo (American Public Power Association) for their review of this work.

The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Additional content

Building electrification load shape process



Dark boxes indicate inputs and light boxes indicate calculated outputs.

Estimating new construction load

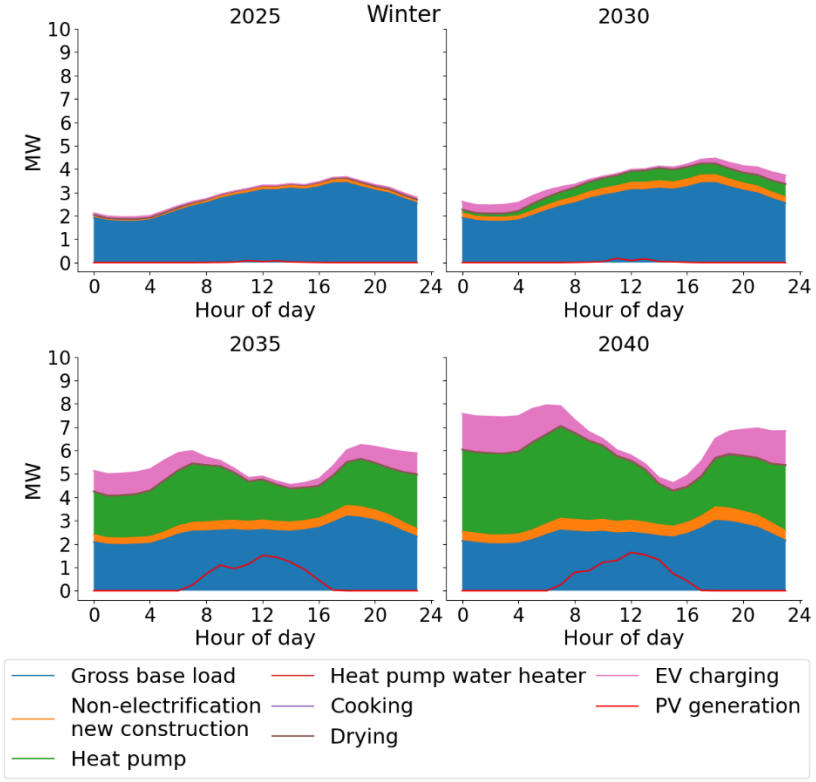
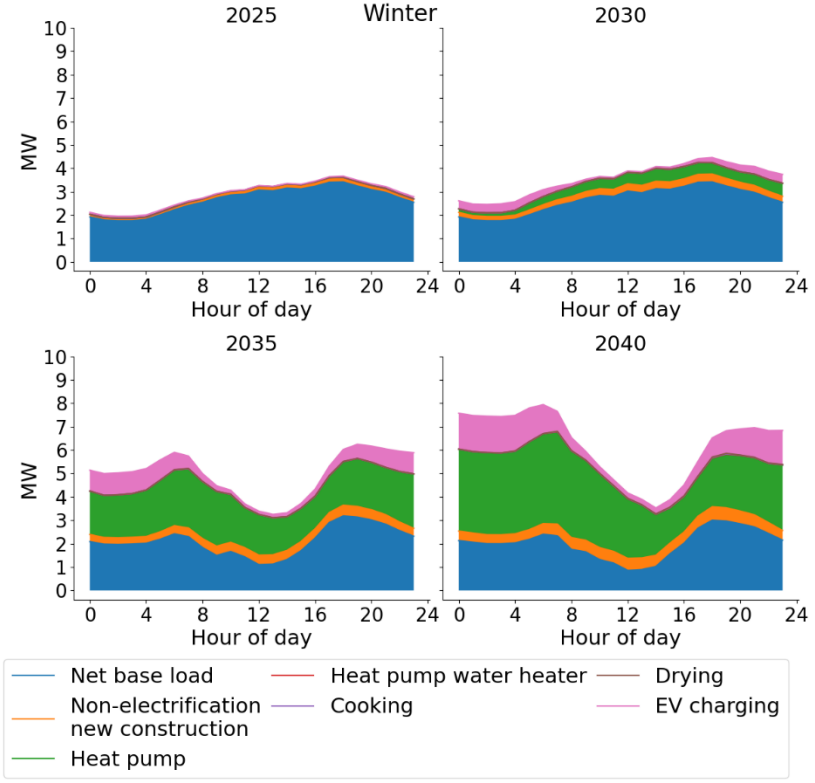
- **How does the forecast account for load from new construction?**
  - Estimate new construction load incremental to building electrification in existing buildings in two parts:
    - First, estimate incremental load from new construction *unrelated to electrification* by multiplying the metered base year load by the annual new construction rate.
      - This approach assumes that new and existing buildings have similar load shapes.
      - This approach only adds new construction load additional to that in the base year load.
    - Second, estimate the incremental load from new construction *due to electrification* by multiplying the incremental load from 100% electrification in existing buildings by:
      - The annual new construction rate and
      - The share of new construction that is converting to all-electric in a given year.
  - Calculate total new construction load by adding the load unrelated to electrification and the load due to electrification.

Estimating new construction load: example

- For SMUD, we estimated the impact of new construction for both residential and commercial buildings.
  - In residential buildings, we used the annual new construction rate (1.1%) and starting date for all-electric new construction (2030) that were used in the utility planning documents.
  - In commercial buildings, we assumed an annual new construction rate of 0.2%, based on EIA projections of commercial energy usage in the 2020 Commercial Building Energy Consumption Survey.

- We estimated the new construction load for residential and commercial buildings by multiplying the 2018 residential and commercial base year load profiles by the new construction rates for each building segment (1.1% and 0.2%).

- Then, we estimated the new construction load for 100% electrification of residential buildings starting in 2030.
  - We assumed that the share of new residential buildings that were fully electrified was the same as the share of existing buildings that adopted electrification technologies in a given year of the analysis.

Estimating net demand

- To calculate net demand, subtract the forecast of distributed solar generation from the gross load forecast.
  - The figure below illustrates this calculation. The net base year load (righthand figure in blue) is equal to the gross base year load (left hand figure in blue) minus the PV generation (left hand figure in red).