Leveraging NREL's ResStock & ComStock Dataset to Evaluate Building Stock Electrification

Preprint

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1 Energy and Environmental Economics (E3)
2 National Renewable Energy Laboratory

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Leveraging NREL's ResStock & ComStock Dataset to Evaluate Building Stock Electrification

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ABSTRACT

Residential and commercial buildings accounted for 40% of U.S. energy consumption in 2022 and represent a significant opportunity for decarbonization through energy efficiency and electrification, and for grid planning. Building stock energy modeling is a powerful tool that can evaluate what-if scenarios as utilities, municipalities, policymakers, building owners and others work towards equitable building decarbonization and climate goals. This presentation will highlight several high-impact use cases of the National Renewable Energy Laboratory (NREL)'s highly granular, bottom-up building stock energy modeling tools, ResStock and ComStock. These use cases cover a wide range of project scale, from neighborhood electrification analysis and municipality long-term energy planning, to state energy code development and national policy evaluation. This presentation will showcase specific real-world applications for which ResStock and ComStock have been utilized across the country, including California codes and standards cost-effectiveness analysis, New York City affordable housing electrification cost gap analysis, and California targeted electrification and gas decommissioning analysis. For each use case, this presentation will illustrate how ResStock and ComStock played a crucial role in accurately characterizing regional building stocks, providing discrete and aggregated end-use load shapes, and calculating lifecycle consumption, emissions, and costs for a variety of building electrification strategies and scenarios. Finally, this presentation will demonstrate how the data provided by ResStock and ComStock can help unlock significant outcomes for these use cases, including but not limited to, customer bill impact, incentive and program design, and energy equity analyses.

Introduction

Residential and commercial buildings account for 40% of U.S. energy consumption and 35% of total carbon emissions, thus representing a significant opportunity for decarbonization through energy efficiency and electrification measures (Department of Energy 2023). A key step in developing decarbonization solutions for the buildings sector is modeling the energy consumption of distinct types of building archetypes. Building stock energy modeling is a powerful tool that can evaluate what-if scenarios as utilities, municipalities, policymakers, building owners, and others work towards equitable building decarbonization and climate goals. The release of the NREL's ResStock & ComStock datasets has enabled highly robust analyses for decarbonization research. Before the release there was limited data on aggregate building stock consumption, with particular gaps around the dynamics of diversified loads, and energy analysts often had to make simplifications for modeling.

The ResStock and ComStock datasets unlock significant outcomes, including the assessment of customer bill impacts, the optimization of incentive and program designs, and the analysis of energy equity considerations. By providing granular insights, the datasets empower policymakers, utilities, and businesses to target energy efficiency initiatives effectively. Use cases span a wide range of scales, from neighborhood electrification analyses to long-term energy planning at the municipal level. Furthermore, these datasets inform the development of state energy codes and facilitate evaluations of national energy policies, highlighting their applicability across different contexts and jurisdictions. This paper will present three case studies that exemplify these use cases: 1) New York City affordable housing electrification cost gap analysis, 2) California codes and standards cost-effectiveness analysis, and 3) California targeted electrification and gas decommissioning analysis.

ResStock & ComStock Datasets

The transition towards a 100% clean energy economy by 2050 necessitates a deep understanding of energy usage patterns and their implications for grid flexibility. End-Use Load Profiles (EULPs) play a pivotal role in this context, offering insights into when and how energy is utilized, thereby informing strategies for energy efficiency, demand response, and distributed energy resource management. However, publicly available EULPs have historically been limited in applicability due to aging data and incomplete geographic coverage. To overcome these constraints, the U.S. Department of Energy (DOE) initiated the End-Use Load Profiles for the U.S. Building Stock project (Wilson 2022). This endeavor resulted in the release of publicly accessible datasets that simulate EULPs for residential and commercial buildings throughout the contiguous United States. Developed by the National Renewable Energy Laboratory (NREL), the ResStock and ComStock models are fundamental components of this initiative. These models utilize a combination of sampling techniques from a diverse array of public and private data sources, OpenStudio® building simulations, and advanced supercomputing capabilities. ResStock and ComStock models have undergone rigorous validation against empirical data sources, including hourly whole-building electricity meter data and annual gas data, ensuring accuracy and reliability.

ResStock and ComStock can accurately characterize regional building stocks, providing discrete and aggregated end-use load shapes. The datasets detail building characteristics such as types, sizes, and age, alongside annual and sub-hourly energy use, utility costs, and emissions. Moreover, they include analyses of energy efficiency and electrification measures, highlighting their impact on energy consumption patterns. Interested parties can access the datasets via web visualization tools or data lake platforms, ensuring ease of use and integration into energy planning processes. For further details, visit resstock.nrel.gov (“ResStock - NREL,” n.d.) and comstock.nrel.gov (“ComStock - NREL,” n.d.).

A team of analysts at E3 have built a python-based tool, called BldStock, that is now used across the firm to interface with the ComStock and ResStock database. BldStock works on a segment level, set by defining a combination of filters on building characteristics included in the ResStock and ComStock dataset. It can provide solutions for energy demand by end use, representative individual site shapes for a segment, aggregate load shapes for all sites within a segment and building stock characterization.

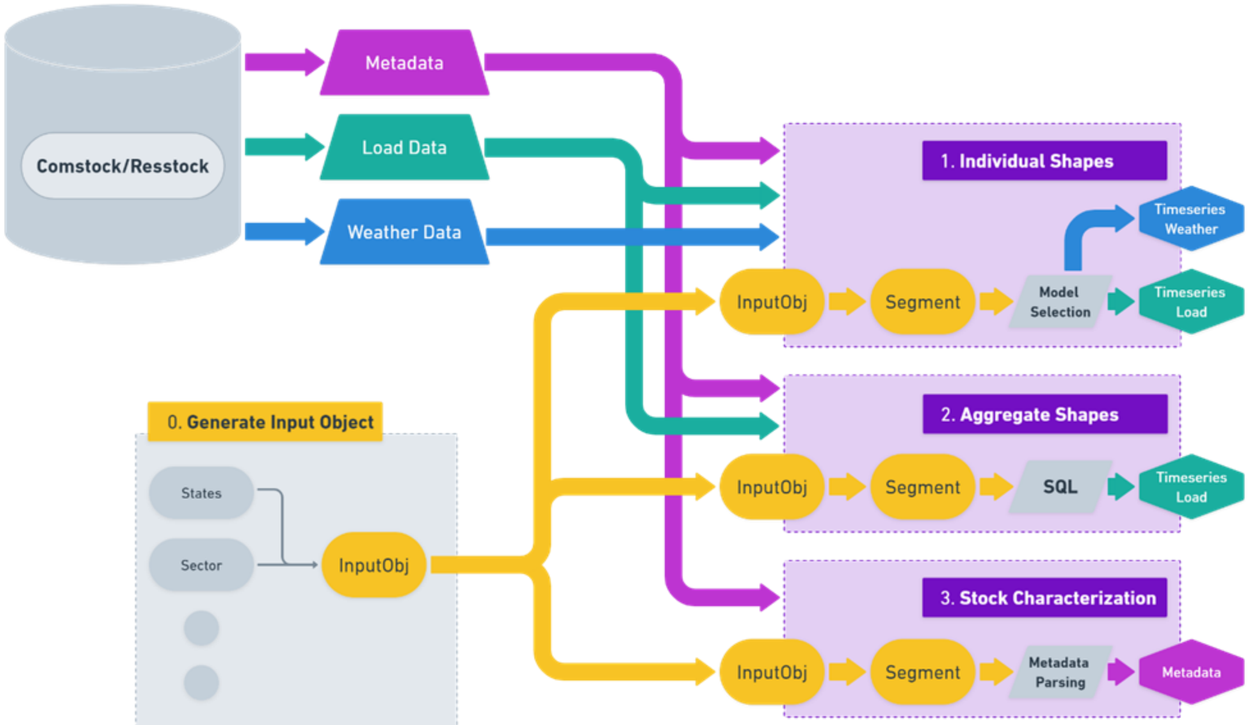

Figure 1. Detailed overview of BldStock workflow. *Source:* E3 2023.

Based on the building simulation data pulled using BldStock, E3 has also developed BldTech, a python-based tool used for estimating building energy use for different energy-consuming building appliances. The outputs from BldTech include hourly electric load profiles and gas consumption under typical design conditions, in addition to peak loads for system sizing.

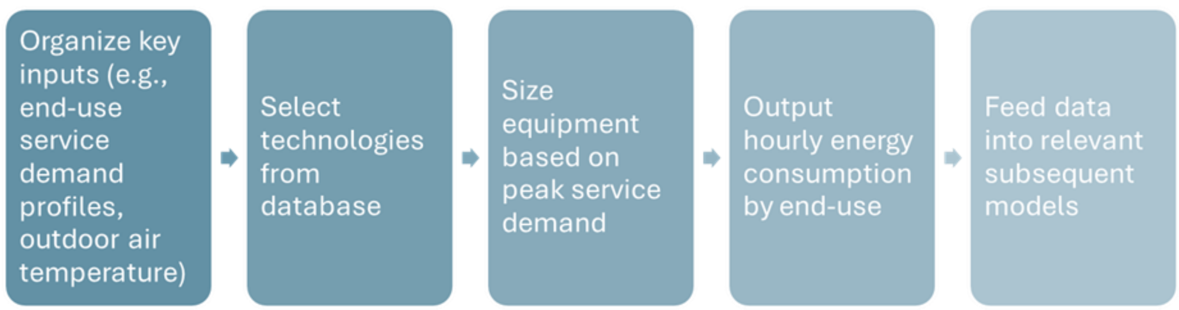

Figure 2. Overview of BldTech workflow. *Source:* E3 2023.

E3 is currently investigating the potential to incorporate a clustering strategy into BldStock, which would improve the current methodology that is deployed for selecting a subset of building prototypes. Instead of reducing the problem size and selecting a subset of buildings (N<50) as a representative sample of buildings from NREL's ResStock and ComStock databases, E3 plans to run a clustering algorithm to determine the representative clusters within a high-level building category (e.g., single-family homes), specific to each project. The goal of this approach is to select a set of buildings from a diverse set of clusters such that the model always receives a fully representative sample of buildings within the high-level group.

Case Study #1: NYC Affordable Housing Electrification

PowerUp NYC is New York City's first Long-Term Energy Plan (LTEP), mapping out the strategy for 29 clean energy initiatives across three broad topic areas: 1) the energy grid, 2) transportation, and 3) buildings (NYC Mayor's Office of Climate and Environmental Justice 2023). The LTEP's proposed initiatives within the buildings sector include advocating for progressive energy rate structures, pursuing increased utility bill assistance, and expanding technical assistance for electrification – all with a focus on centering equity, affordability, and health in the transition to clean energy. These initiatives were formulated as a result of an analysis on the funding gap to electrify the NYC rent-stabilized unsubsidized building stock and the energy bill impacts of electrification on these tenants (NYC Mayor's Office of Climate and Environmental Justice 2023).

Rent-stabilized building units make up 44% of all rental units in New York City yet, prior to PowerUp NYC, this segment of the building stock had not been thoroughly evaluated in building electrification studies (US Census Bureau 2021). Residents living in affordable housing, such as rent-stabilized units, often face unique and additional barriers to energy efficiency and electrification retrofits compared to their market-rate counterparts. For one, most rent-stabilized buildings in NYC were built between 1947 and 1974; older homes are associated with more inefficient building envelopes, leading to greater levels of energy lost and thus higher heating bills for those customers (NYC Mayor's Office of Climate and Environmental Justice 2023). Additionally, these older NYC housing units often have several health and safety issues – such as structural problems, asbestos, or lead – that must be addressed prior to completing an energy retrofit. Abating these health and safety concerns requires additional time and labor, and therefore leads to higher costs associated with energy efficiency and electrification upgrades. Owners of rent-stabilized housing units are not incentivized to pursue these important energy upgrades as they are not able to increase rent to recover the costs of building electrification investments, nor do they see the monthly energy savings if tenants are responsible for the utility bills. PowerUp NYC's building research was the first of its kind to consider these unique challenges in an analysis of the funding required to electrify the rent-stabilized unsubsidized housing stock in New York City and the associated tenant bill impacts.

Modeling Methodology

PowerUp NYC's study on affordable housing electrification is one example of how ResStock has been utilized to support cost-benefit analysis of building electrification. To complete this study, the NYC PowerUp's building research team first developed a collection of building typologies to represent the rent-stabilized unsubsidized building stock, segmented by jurisdiction, vintage, size, existing energy system, energy usage, and size. The project team then utilized the ResStock dataset to develop baseline load shapes for each building typology by end-use (including heating, cooling, cooking, and water heating). Based on the building typologies selected, the ResStock load shapes were filtered by building size, vintage, and energy use intensities.

Once the representative baseline load shapes were selected, the team then used data from Local Law 84 (LL84) and the Department of Housing Preservation and Development (HPD) to perform annual energy benchmarking. Using annual benchmark data to scale the hourly ResStock load shapes, the team was able to produce load shapes that reflected each housing typology. Next, all-electric load profiles were developed by coupling the baseline load profiles with heat pump capacity and efficiency curves. This project assumed heating, water heating, and cooking end-uses were electrified with cold climate air source heat pumps, heat pump water heaters, electric cooktops. The team used climate files with typical weather conditions to determine each hour's heat pump efficiency and capacity, which then provided the hourly energy consumption. The team modeled different electrification scenarios, with varying parameters such as full vs hybrid electrification and inclusion of shell upgrades.

Following the creation of the hourly energy consumption profiles and associated system sizes, E3 collected data on appliance costs, the estimated costs of addressing health and safety issues, and utility rates for electricity (including time-of-use, i.e., TOU), gas, fuel oil, and steam. The team also gathered a comprehensive list of available funding sources in NYC for efficiency and electrification upgrades, such as federal, state, and city incentives, loans, bill assistance programs, and tax credits.

Outcomes Unlocked by the Use of ResStock & ComStock

The load shapes generated using NREL's ResStock databases played a critical role in the PowerUp NYC analysis. The all-electric load profiles dictate the peak load for each building typology, and the peak load is used to determine the size of a heating and cooling system (e.g., a 2-ton ASHP vs. a 4-ton ASHP). System upfront costs are based directly upon the system size – i.e., larger systems incur a higher upfront cost – and upfront costs represent the most significant cost for a building owner to bear. Without additional intervention and funding assistance the large upfront costs of heating and cooling systems – like a cold-climate ASHP – pose a significant barrier for building owners to pursue electrification. What's more, the load profiles generated from the ResStock databases were crucial in calculating the bill impact for building owners or tenants. The load shapes identify which time of the day will experience the highest electricity demand and, since TOU rates charge higher electricity prices during peak periods, the timing of when the most energy is consumed can have a significant impact on utility bills. The availability of the ResStock database enabled the E3 analysis team to use the upfront and ongoing energy costs to calculate citywide funding gap for the entire NYC rent-stabilized building stock and the impact to customer utility bills.

Funding gap. The energy consumption profiles, upfront cost, energy rates, and funding source data were used to calculate the net-present valued incremental lifecycle costs to electrify each individual building typology, considering equipment costs, operations & maintenance (O&M) costs, health & safety upgrade costs, additional electric and avoided gas utility bills, and levels of available funding. The project team assumed that, for the citywide funding gap, all buildings were master-metered and that the building owners carried all costs and benefits. The funding gap was calculated by taking the total lifecycle costs to electrify, subtracting the cost of the counterfactual (i.e., baseline) costs, and then layering on the impacts of federal, state, and local funding. The total funding needs for each building typology was then scaled up for the entire NYC rent-stabilized unsubsidized building stock, considering the spending caps (i.e., budgets) of each of the funding sources applied.

Results show that the average funding gap for electrifying rent stabilized homes is about $32,000-$42,000 per apartment depending on whether the unit is fully electrified or pursues partial electrification (i.e., a smaller heat pump with backup such as gas or fuel oil). The citywide funding gap per apartment unit shown in Figure 3 represents the NPV total incremental lifecycle costs, including the anticipated prevalence of health & safety issues across the entire housing stock in NYC as well as the spending caps on existing funding programs. While pursuing partial electrification and pairing efficient electric equipment with a shell upgrade can reduce costs for building owners, without additional intervention from the city, the remaining gap per apartment is still too large for owners to be incentivized to pursue electrification.

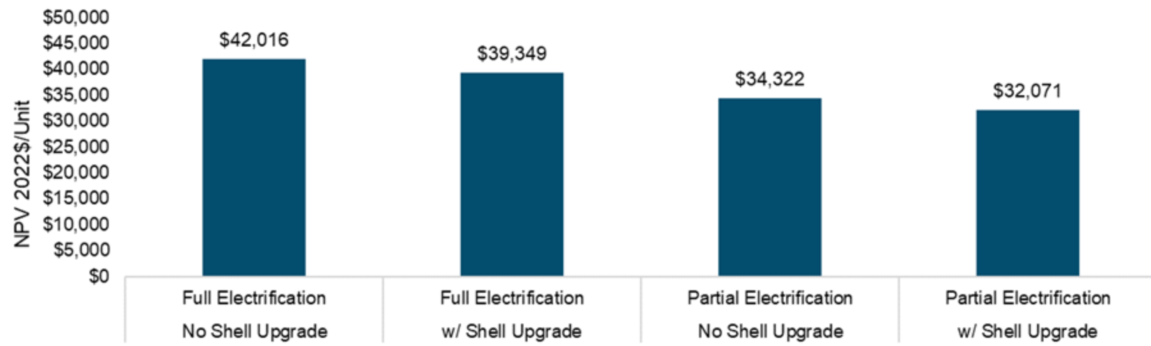

Figure 3. Citywide funding gap (NPV 2022$/apartment unit). Source: E3 2023.

Tenant energy bill impact. The citywide funding gap analysis identified the missing funding required to electrify rent-stabilized housing from the owner's perspective, but determining the impact on tenants is a much more complicated question. Today, the most common metering configuration in NYC apartments is central heating and hot water, meaning the owner pays for the heating bill (often gas) and the hot water, while the tenant pays for cooling (often a window AC unit) and electric plug loads. For the tenant energy bill analysis, the team used the collected cost data and energy consumption profiles to calculate tenant energy bills for each building typology, considering the incurred costs before and after electrification upgrades[1]. The team assumed that that all buildings have central heating and hot water in the counterfactual scenario, and the estimated future utility bills were calculated as the levelized net-present value bills over the lifetime of the equipment. Because of the large variance among metering in buildings and uncertainty around future metering configuration post-electrification in New York City, the team conducted a sensitivity analysis that considered different metering configurations to determine the impact on tenant and owner bills depending on who is responsible for which portion of the ongoing costs.

Modeling revealed that the impact of electrification on tenant energy bills comes down to who is paying for what costs after a home is electrified, as seen in Figure 4. If the responsibility of the heating and hot water bills shifts to tenants after electrification, their monthly energy bills skyrocket above the baseline amount. However, if the responsibility of heating and hot water bills remains with the owner, tenants actually see a significant reduction in energy bills, primarily driven by the reduction in air conditioning costs. Figure 4 incorporates the impact of existing bill assistance programs, but as seen by the significant increase in tenant energy bills if heating and hot water is not covered by the owner, current programs are not sufficient to offset the increase in electricity costs from electrification.

[1] For full methodological details, refer to the PowerUp Building Electrification Research & Findings Memo: https://climate.cityofnewyork.us/wp-content/uploads/2023/09/230914_PowerUp_ResearchandFindings-Memo_Building-Electrification.pdf.

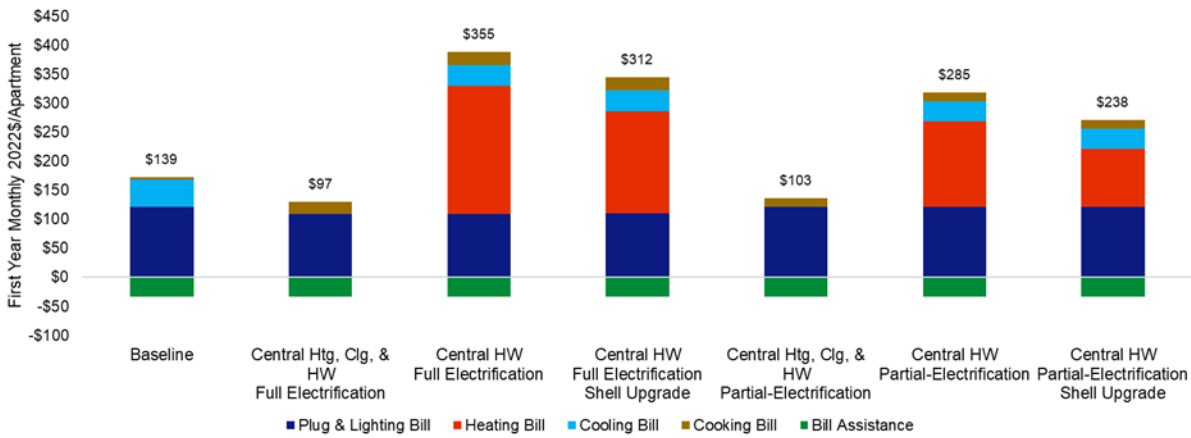

Figure 4. First year tenant energy bills (pre-war multifamily residential <7 stories with existing gas equipment). *Source:* E3 2023.

The use of ResStock and ComStock in the PowerUp NYC gap enabled the E3 research team to analyze the missing funding gap for an important and under-researched subsector of the New York City building stock: rent-stabilized unsubsidized housing. The owners and tenants of these buildings face specific and unique challenges to building electrification and energy efficiency retrofits, including barriers that have been historically hard to measure – such as the additional cost of abating health & safety issues and unclear metering configurations. By leveraging the NREL ResStock database and system performance indicators, E3 was able to explore the upfront cost and energy bill impacts from building electrification and efficiency for common building typologies given their varying system size requirements and specific energy consumption profiles. The analysis identifies which building types face the largest barriers to electrification and how local policy can be developed to mitigate these hurdles for rent-stabilized buildings.

Case Study #2: California Codes & Standards Cost-Effectiveness Analysis

Overview of California Energy Code and Performance Metrics

The state of California continues to lead the nation in advancing building code innovation, transitioning to clean-energy buildings amid concerns over deteriorating air quality, rising gas prices, and safety concerns from gas usage. With over 60 cities and counties contemplating measures to endorse all-electric new construction, California is leading the way in promoting sustainable building practices (Kushen 2023). By implementing stringent energy conservation standards since the 1970s, California continues to set the guide for building designers and clean-energy leaders to guide the state through a transition from gas-powered to clean-energy buildings.

In the state of California, the law requires that all changes to the statewide building energy code (Title 24 Part 6) be cost-effective (Office of Energy Efficiency & Renewable Energy, n.d.). Since the 2005 code cycle, a metric, previously known as Time Dependent Valuation (TDV) factors, now known as Long-Term System Cost (LSC) factors, has been used to evaluate the cost-effectiveness of new measures proposed for the energy code. This metric captures the lifecycle net present value of long-term marginal costs to the statewide energy system. Because the timing of energy usage is as critical as the amount of energy consumed, these factors are generated hourly throughout a typical year and developed for each of California's various climate zones. For the 2025 code cycle, the updated standards will be proposed for adoption in 2024 with an effective date of January 1, 2026 (California Energy Commission current-date).

In addition to being used to perform cost-effectiveness analysis of proposed measures to the code, for building design teams that choose the “performance” compliance pathway, LSC factors are also used as a performance metric to evaluate code compliance of new building construction. This pathway requires design teams to model their proposed building design and run a whole-building energy simulation, to compare the LSC performance against a minimally code-compliant baseline building.

Moreover, source energy factors are developed each code cycle, providing a secondary performance metric that is a more direct measure of environmental benefits of proposed building designs. One of the key inputs used to help the California Energy Commission (CEC) develop hourly LSC factors and source energy factors is a long-term electric load forecast, which includes incremental load impacts of building electrification.

Weather-Specific Load and Generation Profiles

One of the key components in developing the hourly building electrification load shapes for the 2025 code cycle was building simulation data from NREL’s ResStock and ComStock database. Prior to the 2025 code cycle, there was no publicly available reliable data source for aggregate building end-use load shapes. Therefore, the project team previously ran individual building simulations using the code compliance software, CBECC-Res and CBECC-Com, and manually aggregated the load across building types and climate zones. However, this methodology was not able to accurately capture the diversity that would take place across a building stock.

With newfound access to ResStock and ComStock, aggregated load profiles were generated for the single-family residential sector, multifamily residential sector, and the commercial sector within each of California’s 16 climate zones, split out by end-use. All-electric building load profiles were then developed using the baseline load profiles coupled with all-electric appliance efficiency and capacity curves, similar to the methodology described in the prior case study. These profiles were then scaled using an annual consumption forecast from a selected demand scenario. The selected demand scenario is intended to represent a realistic future scenario aligned with existing and anticipated future policy, characterized by different strategies aimed at achieving economy-wide decarbonization. The selected demand scenario sets several inputs assumptions used in this analysis, including electric vehicle load, decarbonized gas, renewable generation procurement, and most importantly, building electricity end use consumption for each year, including the effects of increased energy efficiency and electrification. For the 2025 code cycle, the CEC chose a demand scenario from the CEC Demand Scenarios Project named the “High Electrification Policy Compliance” scenario (California Energy Commission 2022b). This demand scenario is aligned with current policy and includes relatively high economywide electrification.

One interesting challenge in developing the hourly performance metrics for Title 24 Part 6 is that the metrics must align with a custom weather year that is generated for California codes & standards, known as the CTZ25 weather year. However, ResStock and ComStock only provide load shapes associated with weather files for a TMY3 and AMY2018 weather year. To convert ResStock and ComStock data to the CTZ25 building electrification load shapes, the project team deployed a novel methodology. The project team developed weather regression models, using a Random Forest (RF) regression approach, trained to predict weather specific end use load shapes for the CTZ25 weather for all California counties. For more details on the development of the electricity and gas consumption forecast, as well as LSC hourly results, please refer to the "Final Staff Workshop on Energy Accounting for the 2025 Building Energy Efficiency Standards" held by CEC (California Energy Commission 2022a).

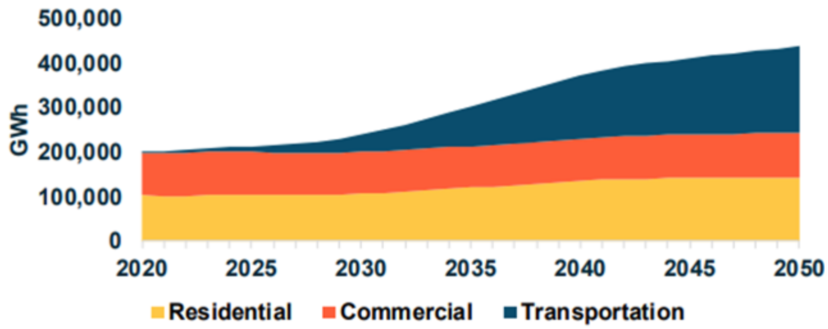

Figure 5. Electricity Consumption Forecast. *Source:* E3 2022.

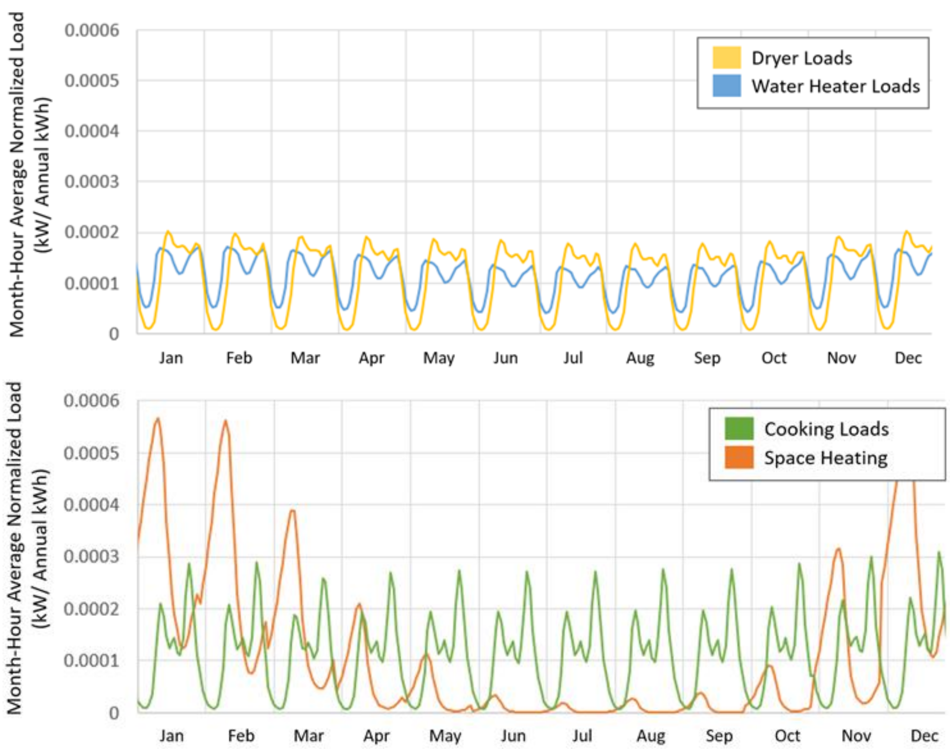

Figure 6. Month-hour average of building electrification load shapes. *Source:* E3 2022.

Outcomes Unlocked by ResStock/ComStock

For the 2025 code cycle, a proposal was put forth to establish prescriptive code requirements that would require heat pumps for residential space heating and water heating in all 16 California climate zones. This proposal aims to set the baseline building design, that all new residential construction designs across the state are evaluated against, to all-electric, thereby pushing the industry forward. Utilizing the LSC factors, the project team demonstrated that all-electric residential space heating and water heating is cost-effective in every climate zone across California. The LSC factors played a crucial role in establishing the cost-effectiveness of this proposed measure, partially due to the detailed load forecast built using the ResStock/ComStock database. It is important to emphasize that for the LSC factors developed for the 2025 code cycle, the utilization of the ResStock/ComStock database was pivotal in determining aggregate load shapes and weather files by county, significantly influencing the code's requirements.

Case Study #3: Bay Area Targeted Electrification

Building electrification is slated to play an integral role in the decarbonization of California's energy system, but widespread implementation will put significant strain on the "funding and cost recovery mechanisms" of the natural gas distribution system (Energy and Environmental Economics 2023). Customers that remain on the gas system and do not electrify will likely face drastically increased gas rates, since the fixed costs of the system will be distributed across fewer customers (Energy and Environmental Economics 2023). A managed transition for electrification will help mitigate additional costs and rate hikes for customers, but there are open questions on how states and municipalities should implement it. As such, Energy and Environmental Economics (E3), Ava Community Energy[2], Grid Works, and Environmental/Justice Solutions conducted a technical analysis for the California Energy Commission (CEC) on how targeted electrification can be paired with strategic gas decommissioning to ensure savings on the gas system while prioritizing local community needs (Energy and Environmental Economics 2023).

Targeted electrification and gas decommissioning, also known as zonal electrification, refers to the complete phase-out of natural gas services to a specific neighborhood, combined with the electrification of all gas end-use devices, such as gas space and water heating equipment, gas cookstoves, and gas clothes dryers. By avoiding the capital costs of pipeline main replacement, targeted electrification can improve the economics of the transition away from the natural gas system. In this pilot study for the CEC, utility bill and building characteristic data were collected from 1,500 customers across eleven candidate sites in the Bay Area and were used to conduct a benefit-cost analysis for targeted electrification. The pilot sites represent a diverse mix of building characteristics (i.e., vintage and size) and socioeconomic status, as well as the presence of commercial customers. The table below shows the key site characteristics for each of the pilot candidate sites. To evaluate the cost-effectiveness of targeted electrification for these candidate sites, the modeling team considered five cost tests: a Participant Cost Test (PCT), Electric and Gas Ratepayer Impact Measures (Electric and Gas RIM), a Total Resource Cost Test (TRC), and a Societal Cost Test (SCT).

[2] Ava Community Energy is the Community Choice Aggregator, *i.e.*, non-profit electric retailer, in the East Bay region of the San Francisco Bay Area. Ava Community Energy was formerly known as East Bay Community Energy

Site	Length of Mains	# of Cust.	DAC	Multi-Family	CARE	Electric Space Heating	Electric Water Heating	AC Present	Pre-1980 Vintage	Non-Res Sq Ft
	Miles	#	Y/N	%	%	%	%	%	%	Sq Ft
A	0.2	39	Y	53%	20%	13%	17%	23%	100%	15,000
B	0.3	65	Y	69%	31%	33%	25%	16%	87%	0
C	0.4	69	Y	3%	63%	34%	13%	13%	99%	0
D	1.0	337	Y	60%	87%	26%	20%	28%	100%	0
E	0.3	80		28%	12%	7%	4%	14%	99%	48,000
F	0.6	106		26%	38%	24%	12%	27%	99%	20,000
G	1.2	288		60%	66%	28%	14%	38%	96%	56,000
H	0.5	90		48%	48%	27%	10%	25%	88%	0
I	1.1	187	Y	17%	21%	17%	4%	19%	2%	0
J	1.3	175		0%	18%	15%	8%	13%	24%	0
K	0.7	96		3%	31%	23%	7%	19%	0%	0

Figure 7. Key Site Characteristics for CEC targeted electrification pilot. Note: DAC means Disadvantaged Community, as designated by CalEnviroScreen. Source: E3 2023.

ResStock Implementation on Project

In the table above, the presence of electric space/water heating and AC in dwellings was not available in the primary dataset but was necessary to complete the cost-benefit analyses, in order to determine upfront capital costs of electrification. The team was able to capture these appliance shares using data from ResStock. A machine learning algorithm was developed to determine whether each customer in the dataset uses gas or electric space heating, gas, or electric water heating, and if they have AC. This process involved two steps:

- Model Training: A random forest model was employed to train the algorithm using 10,000 building simulations from the ResStock database. In order to match the available data, inputs such as monthly gas usage, monthly electric usage, and building typology were included for training. The desired outputs were the type of fuel for space and water heating (electric vs. gas) and the presence of AC (True/False). During the training phase, the algorithm learned the connections between the inputs and desired outputs. Despite the fact that ResStock includes other building characteristics that could improve estimation accuracy, only the inputs that were available and complete within the Ava Community Energy customer dataset were used.
- Model Outputs: The trained model utilized Ava Community Energy customer data to determine the fuel type for space heating, water heating, and the presence of AC for each customer.

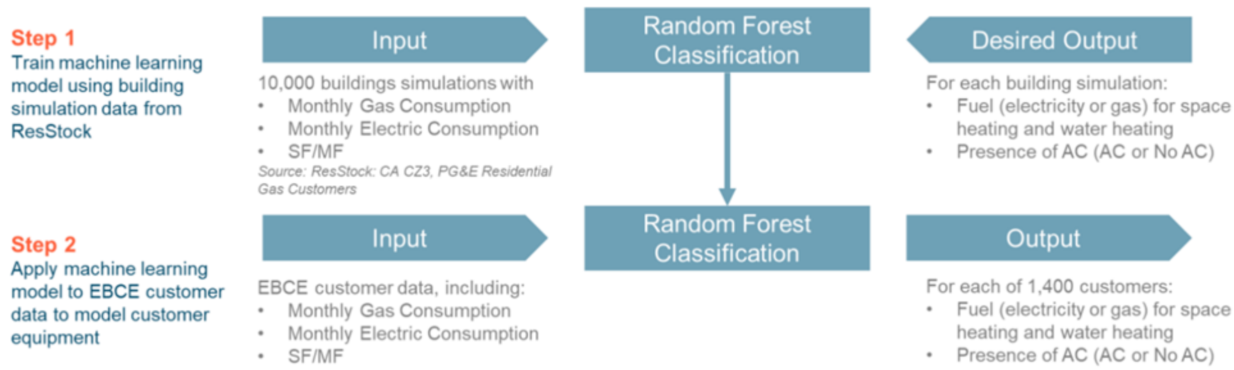

Figure 8. Machine Learning Model to Estimate Customer Equipment. *Source*: E3 2023.

Timing of New Electric Loads

Beyond modelling appliance shares, this analysis also used ResStock to estimate load profile-dependent cost components for various cost tests. Each of the cost tests relied on aggregating a set of discrete benefits and costs, several of which depend on the intra-day timing of electric loads. Since the timescale of the primary dataset was monthly, and not hourly, ResStock was used to help construct load curves for this purpose. The benefits and costs that relied on hourly load shapes include electric supply costs, utility gas and electric bills, GHG savings, and avoided methane leakage.

The bill impact modeling methodology assumed that, when advantageous, customers adopting electrification would opt for the E-ELEC tariff, a time-of-use rate featuring variable pricing according to the time of day and season. It was critical to model the level at which new electric loads would emerge during summer and winter seasons, as well as off-peak, part-peak, and peak hours. Simultaneously, electric supply costs from the Avoided Cost Calculator fluctuate hourly throughout the year, underscoring the significance of understanding the timing of these new loads to estimate electric supply costs.

To back these calculations, aggregated end-use load profiles from the residential building stock within coastal PG&E service territory were used. These profiles were obtained from building simulations within NREL’s ResStock library. The extracted load profiles were then utilized to derive the following information:

- Share of total building load specific to each end-use for different building configurations
- Share of electric and gas load across different seasons for different building configurations
- Breakdown of electric load occurring within off-peak, part-peak, and peak hours for different building configurations

This set of information was derived for space heating, water heating, cooking, clothes drying, cooling, and other building end-uses (“plug-loads”) for both mixed-fuel and all-electric buildings. Subsequently, this data served as the basis for calculating electric bills and emissions by end use.

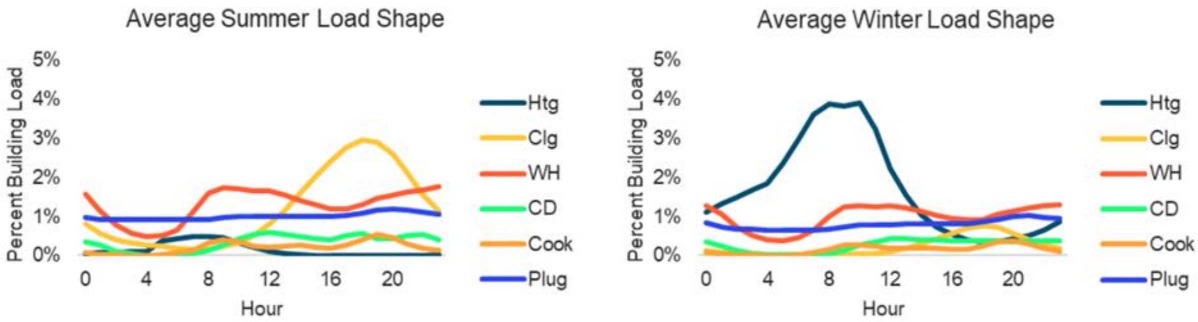

Figure 9. Seasonal End-Use Load Shapes. *Source*: E3 2023.

Load Impacts for All-Electric Systems

To assess the impact of electrification on electric load, the project team converted baseline gas consumption, by device, to electricity consumption, using assumptions for gas equipment efficiency and seasonal all-electric system efficiency. The efficiencies for both counterfactual and all-electric systems were derived from NREL's ResStock library, categorized by building type, vintage and system fuel type, as detailed in Table 1 and Table 2. Notably, the efficiency for residential electric counterfactual device for space heating is greater than 100%, reflecting a population of primarily electric resistance heating systems with a small proportion of heat pumps, as indicated by ResStock dataset. For the purpose of this model, electric counterfactual heating systems were modeled with the efficiencies listed in the table.

Table 1. Seasonal System Efficiencies for Heating Systems. *Source:* E3 2023.

		Heating				
			Single Family Residential		Multi-Family Residential	
Fuel	Season	Commercial	Pre-1980	Post-1980	Pre-1980	Post-1980
Gas Counterfactual	Annual	80%	80%	82%	80%	82%
Electric Counterfactual	Annual	100%	104%	109%	103%	106%
Electric Proposed	Summer	350%	353%			
Electric Proposed	Winter	325%	326%			

Table 2. Annual System Efficiencies for Water Heating, Clothes Drying and Cooking Systems. *Source:* E3 2023.

Fuel	Water Heater	Clothes Drying	Cooking Systems
Gas Counterfactual	66%	62%	40%
Electric Counterfactual	94%	71%	74%
Electric Proposed	300%	71%	84%

Outcomes Unlocked by ResStock

Targeted electrification and gas decommissioning was found to be cost-effective for the project's candidate sites, promising economic prospects extending to less dense regions within the service territory. The ResStock database provided essential data for training the random forest model with abundant building simulation results. The aggregated end-use load profiles sourced from the ResStock library played a crucial role in supporting these calculations. These load profiles enabled the determination of important metrics such as the share of total building load attributed to different end-uses, the distribution of electric and gas load across various seasons, and the breakdown of electric load across different time periods throughout the day.

Notably, about three-quarters of customers stand to benefit from bill savings resulting from electrification, underscoring the tangible and widespread impact of this transition. These bill savings are illustrated in the Figure below. Moreover, the savings estimated from avoided pipeline replacement present an opportunity to allocate resources toward supporting electrification projects.

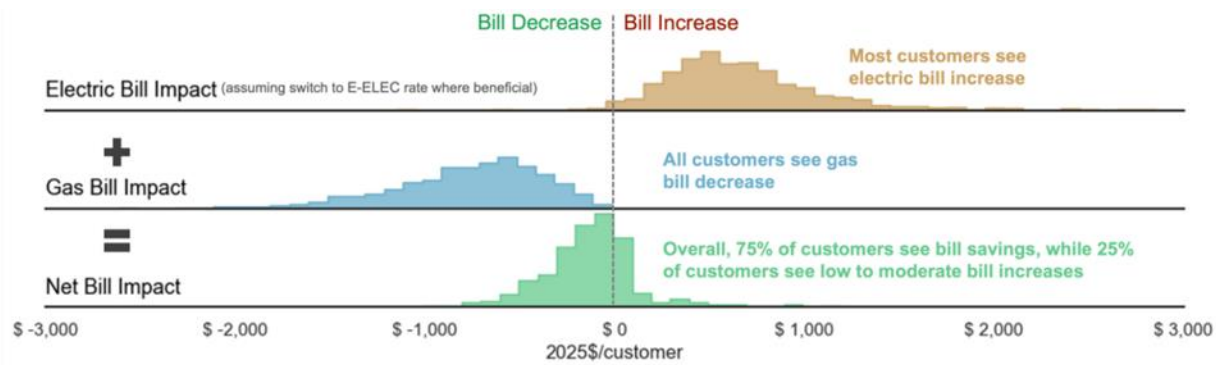

Figure 10. Distribution of First Year Bill Impact Among All Residential Customers in CEC Pilot Study. *Source:* E3 2023.

Conclusion

The development of an effective building decarbonization policy requires accurate energy consumption profiles for the residential and commercial building stock. Before ResStock and ComStock databases were made available, it was difficult for energy modelers to capture aggregate profiles for building stock consumption and the impact of diversified loads. The three case studies outlined in this paper highlight the ways in which ResStock and ComStock can be used to develop equitable incentive structures and climate-forward program design.

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