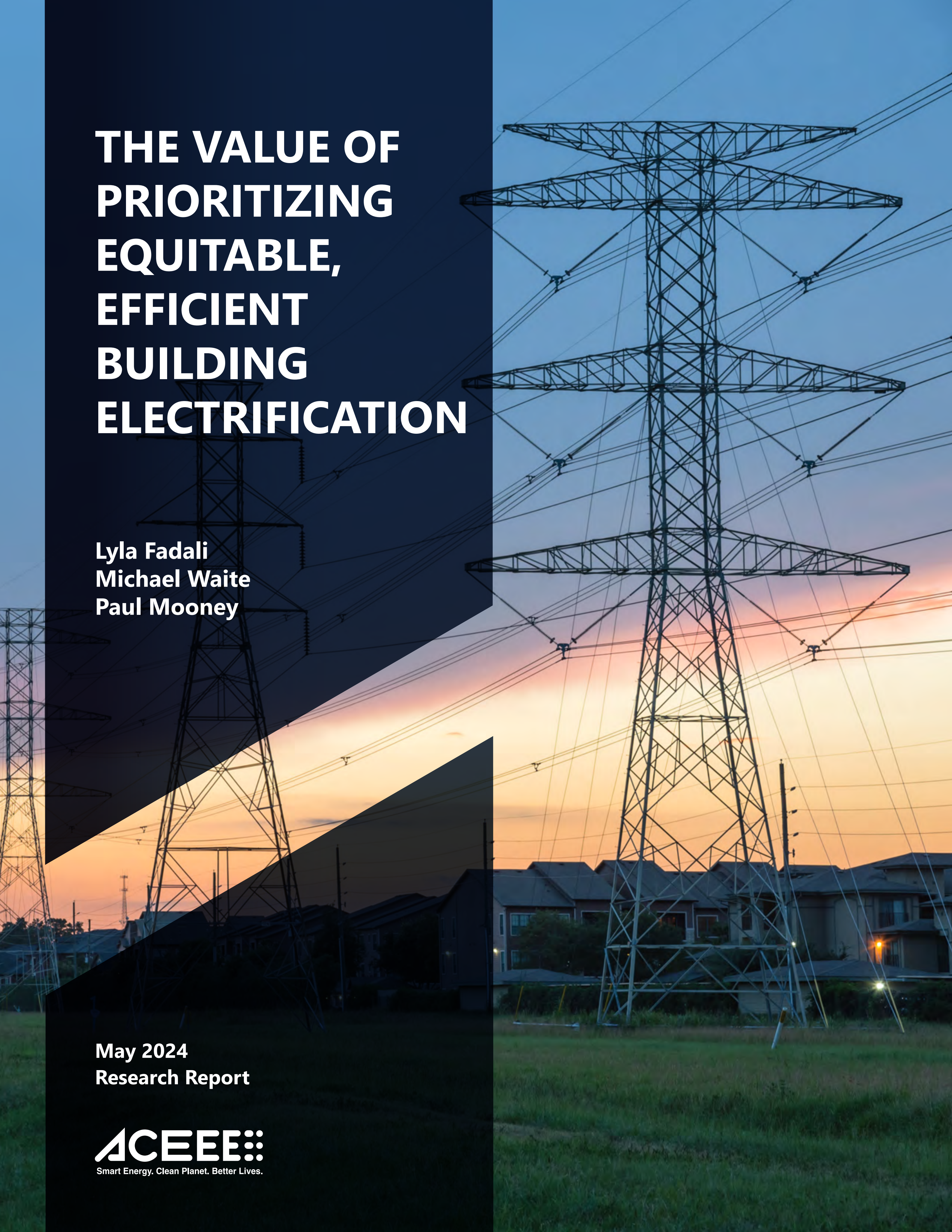

THE VALUE OF PRIORITIZING EQUITABLE, EFFICIENT BUILDING ELECTRIFICATION

Lyla Fadali
Michael Waite
Paul Mooney

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Research Report

ACEEE
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Contents

About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Abbreviated Glossary

Electrification: Typically, "electrification" refers to replacing fossil fuel equipment such as furnaces, boilers, and other equipment with electric heat pumps or other efficient appliances. However, electric resistance, an inefficient and often costly source of electric heat, is common among low- and moderate-income households, meaning that upgrading electric resistance equipment is an important consideration in this report. Thus, we use "efficient electrification" or simply "electrification" as a shorthand to refer to replacing both electric resistance and fossil fuel equipment with efficient electric equivalents.

Equitable electrification: Without support, low- and moderate-income households are likely to electrify after higher-income households because of various barriers, as discussed in the body of this report. By "equitable electrification," we mean that low- and moderate-income (LMI) households have the support they need to replace fossil fuel and electric resistance equipment with electric heat pumps and other efficient electric appliances at the same time that higher-income households are electrifying.

Executive Summary

KEY FINDINGS

- Prioritizing equitable building electrification—where low- and moderate-income (LMI) households have the support they need to replace fossil fuel and electric resistance equipment when higher-income homes are electrifying—ensures that historically disinvested communities will not be left behind in the energy transition.
- 75% residential electrification produces $96 billion in net cost savings (including both retrofit costs and energy cost savings compared to the status quo) over the 2024–2050 analysis period if LMI households are included but a net cost *increase* of $88 billion without equitable electrification.
- The societal benefits of electrification dwarf the costs in either scenario, but prioritizing equitable electrification maximizes societal benefits: $2 trillion over the analysis period compared to $1.8 trillion without equitable electrification.
- Prioritizing equitable electrification reduces LMI household energy burden—the percentage of income spent on energy: At a 50% electrification rate overall, the average energy burden for very low-income households drops from 9% to just over 6% but increases to 10.5% when these homes are excluded.
- At 75% residential electrification, LMI household utility bill savings total $120 billion if equitable electrification is prioritized. If not, LMI household energy costs could *increase* $64 billion.
- The benefits of electrifying LMI households are highest in the Midwest and Northeast; however, this is also where it is most expensive at the household level and most likely to require policies focused on supporting LMI household electrification.
- We recommend electrifying water heating first, as it is often the most cost-effective end use to electrify (based on equipment and energy costs alone).
- Electrifying space heating has the most significant societal benefit per household, but there are regional differences, with greater benefits from electrifying water heating in the South and West, on average.
- Combining an energy efficiency retrofit with electrification can lower household life-cycle costs in cold climates (above about 6,000 heating degree days).
- As gas prices for remaining customers will increase as others electrify, LMI households using gas are likely to require financial support to electrify in the near term to avoid increasing energy burdens.

Electrifying current fossil fuel appliances and equipment is the primary proven strategy to decarbonize space heating, water heating, and other common home energy needs as the grid becomes cleaner. Heat pumps and other efficient electric technologies can reduce energy costs for many households—including those currently using costly to operate electric resistance equipment—and are likely to be the least-cost approach to fully decarbonize most homes (Nadel and Fadali 2022). However, upfront retrofit costs have made efficiency upgrades more difficult for lower-income households, with research showing that disinvested areas are often underserved by utility programs designed to overcome these hurdles (Dewey 2023).

New programs and incentives stemming from the 2022 Inflation Reduction Act (IRA) will target lower-income households but are in their early stages; program administrators need guidance to prioritize outreach and investments. In practice, achieving equitable electrification will likely require a combination of targeted programs, policies, and public investments that prioritize LMI households' access to low-carbon technologies.

Quantifying the broad societal benefits of equitable electrification requires analyses to go beyond cost-effectiveness calculations that typically consider only energy costs and upfront investments. Policymakers can use the methodology and detailed model underlying this report to incorporate the positive health and societal economic impacts of electrification into cost-effectiveness analyses. This study should therefore be a resource to states and localities that are moving toward residential electrification but have so far not factored societal or health impacts into cost-benefit analyses.

This study systematically analyzes the costs and benefits to LMI households and to society at large of efficient electrification, including both installation and operation of residential space heating, water heating, and other equipment. We consider upgrading electric resistance equipment to electric heat pumps as well as replacing fossil fuel equipment. This analysis updates and builds off an earlier analysis of residential decarbonization (Nadel and Fadali 2022).[1] In addition, we quantify economic benefits of reducing climate-harming emissions and avoiding adverse health impacts stemming from related outdoor air pollution.[2] We present results for LMI households based on a range of characteristics, including income, region, current fuels, existing equipment, and home type; the underlying analysis includes many additional dimensions, including home size, annual energy usage, fuel expenditures, climate, and regional electricity grid emissions.

[1] One important difference between our study and Nadel and Fadali (2022) is that we assume that fossil fuels continue to be used, whereas Nadel and Fadali assume only the use of lower-carbon alternative fuels.

[2] Indoor air pollution also causes adverse health impacts, but we do not address these in this report.

While the analysis presented in this report shows the significant nationwide benefits of electrifying U.S. homes, we do not evaluate whether current policy or markets will produce such an outcome. Rather, we examine the impacts of prioritizing equitable electrification in high electrification scenarios, demonstrating quantitatively that failing to do so will increase the costs required to decarbonize homes across the United States while also missing cost-effective opportunities to reduce energy burdens in LMI households.

While the $4.5 billion in the IRA's High Efficiency, Electric Home Rebate Program marks an important down payment, we compute the total cost of installing efficient electric equipment in all LMI households to be about $625 billion. This is a seemingly large investment, but the societal benefits of electrifying 75% of all U.S. homes would be three times this number.

Electrification policy and programs should target space heating and water heating, and avoid an outsized focus on other appliances, like gas stoves and clothes dryers. That said, to advance broader electrification, programs could potentially approach electrification in phases and highlight the household cost savings of disconnecting from gas service altogether once heating retrofits are complete.

Programs should aim to fill the gap between the household costs and societal benefits of LMI household electrification, particularly in homes using natural gas. Programs converting natural gas systems to electric heat pumps may need new rate designs (Yim and Subramanian 2023), increased home heating assistance, and/or greater public investments in LMI gas-to-heat pump retrofits to reduce energy burdens in service of the broader societal benefits.

Effective planning and policy is needed now to address the challenge of natural gas conversions in LMI households, potentially including incorporating the value of such conversions into emerging clean heat standards. A price on carbon could also reflect the value of converting gas systems and assist in guiding policy and planning. Electrifying LMI households using gas must be prioritized now—and supported financially as needed to reduce energy burdens—so that households left on the gas system when gas prices spike are only those able to invest in cost-effective upgrades when they choose.

We also investigated a scenario that included both electrification and energy efficiency retrofits. This analysis did not change our overall findings at a national level. However, we did find that combining an energy efficiency retrofit with electrification can lower household life-cycle costs for electrification in cold climates (above approximately 6,000 heating degree days, or roughly the climate of Pittsburgh, Pennsylvania, and colder). This analysis is limited to household energy costs, and we do not quantify important benefits of envelope upgrades such as improved comfort or benefits to the electric grid, both of which could motivate envelope upgrades in more moderate climates (and provide additional motivation in cold climates).

The analytical findings of this report are complemented by input from community-based organizations (CBOs), who highlighted the importance of non-energy factors at both individual and community levels related to electrification and energy efficiency that are not easily quantified. Considering these factors will be important to ensuring benefits accrue to their communities. In reviewing our findings, ACEEE's Equity Working Group—a group of representatives from CBOs and others from LMI communities that ACEEE convenes to inform our research and policy work—noted the particular importance of coupling energy-efficient electrification with improving the resilience of energy systems in communities that have historically had less reliable services. It is therefore essential that electrification be part of an overall energy transition strategy that includes consideration of climate impacts, health impacts, and service reliability.

In multifamily buildings with existing central heating and hot-water systems, electrification can potentially shift utility costs from owners to renters, so tenant protections are also important. Some electrification programs require envelope upgrades before heat pumps can be installed, and while our analysis indicates this can have substantial benefits, it can present another financial barrier to an efficient electrification retrofit. Overall, the biggest challenge to LMI households is vastly inadequate funding.

The model and methodology underlying this report can be applied to specific states and to the full range of household characteristics in the underlying data set from the Energy Information Administration, such as householder race and measures of energy insecurity. Further developing the model into a technical assistance tool—and incorporating additional data sources, such as Census Bureau survey data and state and local databases—would provide policymakers and program administrators with actionable information for shaping programs that most effectively deploy limited resources. In addition to modeling efforts such as the one in this report, there is a need to systematically assess what policy and program approaches are successful in electrifying LMI households in the field when the traditional cost-benefit analysis does not work in their favor or when upfront costs are prohibitive.

This study shows that the benefits of the energy transition can be maximized by centering LMI households. Utility program designers and policymakers at all levels need support in realizing those benefits across all communities.

Introduction

Electrification is the primary proven strategy to decarbonize space heating, water heating and several other common home energy needs. Heat pumps and other efficient electric technologies can reduce energy costs for many households—including those currently using costly to operate electric resistance equipment—and are likely to be the least-cost approach to fully decarbonize most homes (Nadel and Fadali 2022; Nadel 2018). However, upfront retrofit costs have made energy conservation measures less accessible for lower-income households, with research showing that disinvested areas are often underserved by utility programs designed to overcome these hurdles (Dewey 2023).

New programs and incentives stemming from the 2022 Inflation Reduction Act (IRA) will target lower-income households but are in their early stages; program administrators need guidance to prioritize outreach and investments. Achieving equitable electrification outcomes means shifting what we value and prioritize: In practice, this will likely require some combination of targeted programs, policies, and public investments. This targeting requires benefit-cost analyses of electrification efforts to go beyond traditional cost-effectiveness calculations that typically consider only total upfront costs and subsequent energy costs. Instead, analyses must consider the full suite of societal costs and benefits.[3] Moreover, to realize these quantified benefits, policymakers and program designers must engage and partner with organizations and residents in impacted communities to ensure such investments are properly designed to lower barriers and ensure access to beneficial energy technologies (Dewey 2023).

This study carefully analyzes the upfront and energy costs of both current (fossil fuel or electric resistance) and efficient electric approaches to space heating, water heating, and other end uses. In addition, we quantify economic benefits of reducing climate-harming emissions and benefits of avoiding adverse health impacts stemming from related outdoor air pollution.[4] We examine the impacts of prioritizing equitable electrification, where low- and moderate-income (LMI) households receive the necessary support to replace fossil fuel and electric resistance equipment with electric heat pumps and other efficient electric appliances at the same time as higher-income households. We demonstrate quantitatively that failure to do so will increase the costs required to decarbonize homes across the United States while also missing cost-effective opportunities to reduce energy burdens in LMI households. We discuss the implications of these findings for policymaking and program administration.

[3] Some utilities—such as Avangrid in Connecticut, Massachusetts, and New York—are already including some of these factors in their cost tests that easily justify investments in low-income-targeted heat pump programs.

[4] Indoor air pollution also causes adverse health impacts, which we do not address in this report.

In this study, our goal is to show those designing utility programs, as well as policymakers at the state and local level, that the societal benefits of the energy transition can be maximized by centering LMI households. We make the quantitative economic case for such prioritization both regionally and across the United States as a whole by modeling the benefits of electrification retrofits in terms of energy costs, medical expenses, and the social cost of carbon (SCC). We also qualitatively present the contribution of such prioritization to societal climate and environmental justice goals. While the analysis presented in this report shows significant nationwide benefits of electrifying the homes of LMI households alongside higher-income households, we do not evaluate whether current policy or markets will produce such an outcome.

DEFINING LOW AND MODERATE INCOME (LMI)

In this report, we focus on low- and moderate-income (LMI) households.[5] Definitions of LMI vary across federal, state, and utility programs, but are usually tied to either the federal poverty level or area median income (AMI). For this study, we have followed the U.S. Department of Housing and Urban Development (HUD), defining LMI as under 120% of AMI adjusted for family size (higher limits for larger families). We calculate AMI as the area median income by state and urban type (rural, urban, or urban cluster) using American Community Survey microdata.[6]

According to the Census Bureau's Current Population Survey, the national median household income in 2020 was $69,113 (converted to 2020$ using the federal consumer price index) This varies by region, with households in the West and Northeast somewhat higher (both around $76,500) and in the South somewhat lower ($62,481) (Semega and Kollar 2022).

BARRIERS TO EFFICIENCY FOR LMI HOUSEHOLDS

LMI households face barriers to efficient electrification, including the need for upfront investments in equipment and required home upgrades or repairs, often higher energy costs in many areas, and split incentives where energy cost savings are possible (Drehobl, Ross, and Ayala 2020). Electrifying a household can provide deep savings in the long term, but generally takes a substantial upfront investment, which can be out of reach even with current incentives, particularly if those incentives take the form of a credit and require upfront capital.

LMI households are also more likely to rent, meaning they do not have control over the decision to retrofit (Bastian and Cohn 2022). This barrier is particularly acute if the tenants pay the energy bills, leading to a split incentives scenario wherein the landlord has little

[5] Equity may have aspects that go beyond income such as race, ethnicity, disability, and so on. We do not explicitly consider these factors in our report but note that they may be correlated with income.

[6] See Appendix A for the full formulation of our LMI definitions and determination of AMI.

motivation to pay for a retrofit whose financial benefit will accrue to the renters (Hynek, Levy, and Smith 2012). For buildings in which the owner pays the energy bills, a retrofit is more likely, though the building owner faces similar barriers and may not retrofit due to the high upfront cost and lack of information about programs and the benefits of efficiency (Hynek, Levy, and Smith 2012).

THE CASE FOR PRIORITIZING LMI HOUSEHOLDS

The difficulty in reaching LMI households underscores why energy efficiency programs need to target, and indeed should prioritize, low-income households. In all fields of energy use, substantial change requires making more difficult transitions; residential buildings are no exception and cannot be decarbonized while ignoring the challenges of electrifying LMI households (Serian et al. 2014; Vigen and Mazur-Stommen 2012). Due to the barriers to investment faced by LMI households, they are more likely to have inefficient equipment. As we describe in the discussion of LMI heating systems below, electric resistance heating, a much less efficient form of electrical heating than heat pumps, is concentrated in lower-income homes (see also Le, Huang, and Hewitt 2018; U.S. Department of Energy n.d.). In addition, LMI households are more likely to need repairs before taking on a retrofit project (Graham 2022). As time passes, the renovation needs of LMI homes will only grow, perpetuating pollution exposure and health-related hazards in these homes—and underscoring the value of timely public investments in these homes.

In addition to important benefits such as improved health and freeing income to meet essential needs like food and medicine, energy efficiency can have deep economic benefits for lower-income homeowners, who are more likely to experience high energy burdens (Drehobl, Ross, and Ayala 2020; Dewey 2023). A study of the long-term benefits of homeownership found that white families gained, on average, a greater share of wealth from home ownership than Black and Hispanic households. This disparity was due to the heightened rates of short sales and foreclosures for families of color due to a lack of liquid funds to pay monthly expenses (Kermani and Wong 2021). While a house allows many families to build generational wealth, this depends on families being able to keep their homes. For LMI homeowners, a persistent threat for foreclosure is monthly bills. Retrofits can directly address this issue when they lower these recurring costs.

While the IRA and IIJA provide substantial funding for energy retrofits in existing buildings, there are significant barriers to LMI families accessing these incentives. On the one hand, much of the IRA's incentives are in the form of tax credits, which require the household to purchase the equipment outright and then get the incentive at the end of tax season, meaning many LMI homeowners may be unable to benefit due to the liquidity constraints discussed above. Further, low-income households may not have a tax liability they can apply the credit toward. Taken together, this orients the IRA's most significantly funded electrification program toward higher-income homes.

On the other hand, the IRA's electrification incentives targeting LMI homes are in the form of rebate programs, which need to be set up on a state level—and not all states may accept the federal funding. These rebate programs could deliver funds to households immediately. However, in practice such programs' success at reaching the targeted households is highly dependent on states accepting the funds, effectively establishing the programs, and not creating bureaucratic barriers to accessing the rebates. The funding for these rebate programs is also limited and far less than the need, as we will show in this report, but there are no limits on the total funding for the tax credits. While the IRA makes important investments in electrification, the overall orientation toward higher-income households must be shifted to those homes most in need—which this report indicates provide the best return on investment.

THE LANDSCAPE OF LMI HOUSEHOLD HEATING AND HOT-WATER SYSTEMS AND FUELS

We use HUD's definitions for very low-, low-, and moderate-income households, as shown in table 1, along with the percentage of households in each group according to our calculations. Below, we consider how heating systems vary among these groups using microdata from the Energy Information Administration's Residential Energy Consumption Survey (RECS 2020) (U.S. Energy Information Administration 2020). RECS includes detailed data on building characteristics and energy use for a representative sample of homes across the United States, with weights provided by the Energy Information Administration (EIA).

Table 1. Percentage of households by income classification

Income group	Very low	Low	Moderate	Above
Definition	Less than 50% AMI	50–80% AMI	80–120% AMI	Over 120% AMI
Percentage of U.S. households	20%	15%	17%	47%[7]

For each income group, gas systems (mostly furnaces) are the most common type (see figure 1 and table B1 in Appendix B). In fact, the three most common systems are the same in each group: gas, electric resistance heaters, and electric heat pumps. In the lowest income group, however, electric resistance heaters are found more than twice as often as heat pumps and two-thirds as often as gas furnaces. In contrast, for the highest income group,

[7] By definition, half of households should have incomes below AMI and half should have incomes above. Most of the disparity here is likely explained by our using HUD's definition of AMI, in which the median household income is scaled according to the number of household members (see Appendix A). Households with fewer than four members are categorized according to an AMI adjusted to be lower than the overall AMI, and since most households have fewer than four members, our numbers appear to show a smaller number of LMI households. It is also worth noting that income data in RECS are binned, so all income-related categorizations in our analysis are approximate.

electric resistance heaters are less than a third as common as gas furnaces and are actually slightly less common than heat pumps. Across all income groups, gas furnaces are present more often and electric resistance is present less often as household incomes increases, while the proportion of electric heat pumps is nearly constant among income levels.[8]

Propane and oil are slightly more common in the highest income group and slightly less common in the lowest income group.

For all LMI households as a single group, central gas furnaces are the most common heating system, followed by electric resistance heaters. Electric heat pumps come in third, and fourth most common is gas boilers (excluding those households with no space heating at all). The full ranking is given in the appendix (table B2).

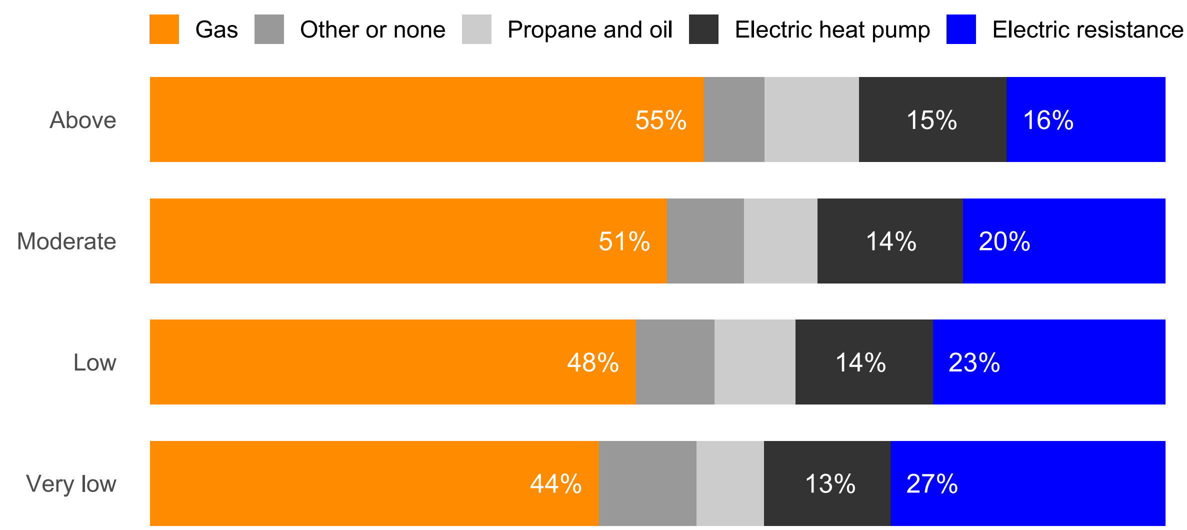

Figure 1. Proportions of heating systems in U.S. homes by income group. "Gas" includes central furnaces, boilers, and individual units; "electric resistance" includes electric central furnaces as well as built-in room units and portable electric heaters. "Other" includes electric boilers, wood or pellet stoves, and "other" responses in RECS.

Hot-water systems show less variation by income, but electric water heaters (presumably almost entirely electric resistance at this early stage of heat pump water heater adoption) are

[8] This is a relatively recent and promising development as the 2020 RECS data were the first to show a significant uptick in heat pump adoption in lower-income households. For more research on the consistency of electric heat pump adoption between income levels, see Davis (2023).

more common in LMI households, while gas is more common in the highest income group. Oil and propane show little variation across income groups. See figure 2.

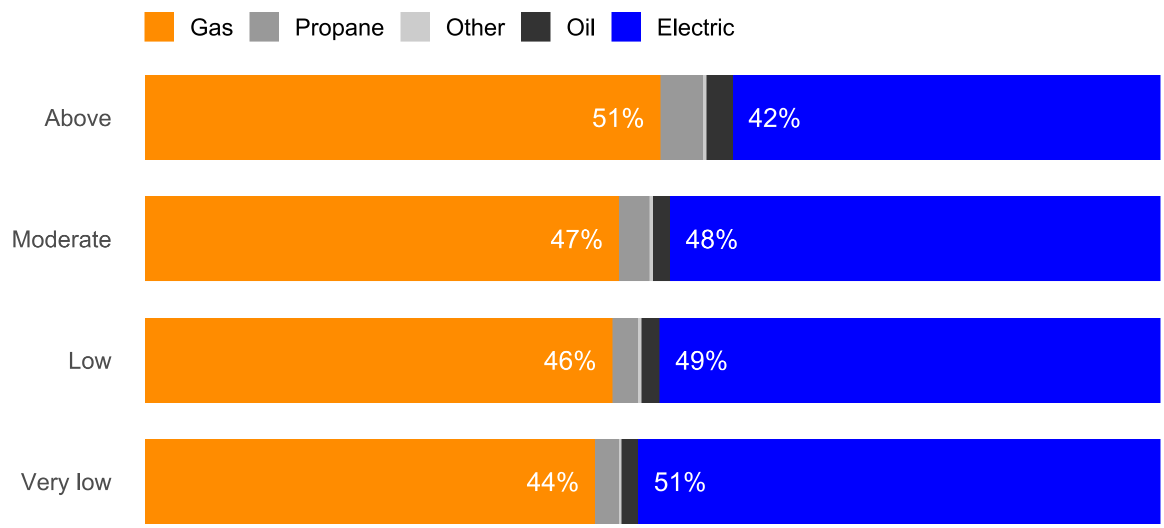

Figure 2. Proportions of water heating systems in U.S. homes by income group. RECS 2020 does not distinguish between electric resistance and electric heat pump water heaters, but we expect heat pump water heaters are a very small fraction of electric water heaters.

For the remainder of the section, we consider how heating systems are distributed in LMI households by building type, region, and owner/renter status. More detailed tables and discussion are available in Appendix B.

Building Type

Families in single-family detached homes are the largest group of LMI households, or about half of LMI households, according to our calculations (see table B2 in Appendix B). For these households, gas furnaces or boilers are by far the most common heating system, followed by electric heat pumps, as shown in figure 3. Single-family attached homes are somewhat similar. However, for homes in large multifamily buildings, electric resistance heaters are the most common system, and are present nearly twice as often as gas furnaces (see table B2).

In 2–4 unit buildings, electric resistance heaters are about as common as gas furnaces, but gas boilers are relatively more frequent (slightly ahead of electric heat pumps), making gas systems overall more common.

Unlike other building types, manufactured homes have electric heat pumps nearly as often as gas systems. Propane is more common for manufactured homes, likely a reflection of both being more common in rural areas. Electric resistance heaters are the most typical system for manufactured homes, including a larger proportion of portable electric heaters than in other building types.

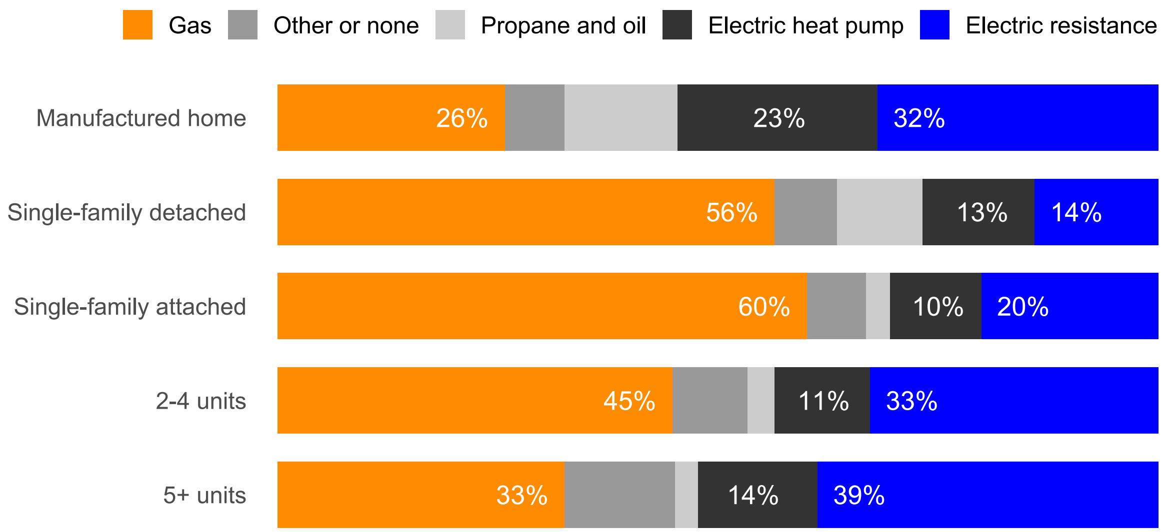

Figure 3. Proportions of heating systems in LMI homes by building type. ""Gas" includes central furnaces, boilers, and individual units; "electric resistance" includes electric central furnaces as well as built-in room units and portable electric heaters. "Other" includes electric boilers, wood or pellet stoves, and "other" responses in RECS.

Location and Climate

Next, we consider how heating systems vary among LMI households by Census divisions. A map of Census divisions and regions is in figure 4. Because of the highly differing climates in the Mountain division, EIA further divides this into Mountain South (Arizona, New Mexico, and Nevada) and Mountain North (Colorado, Idaho, Montana, Utah, and Wyoming).

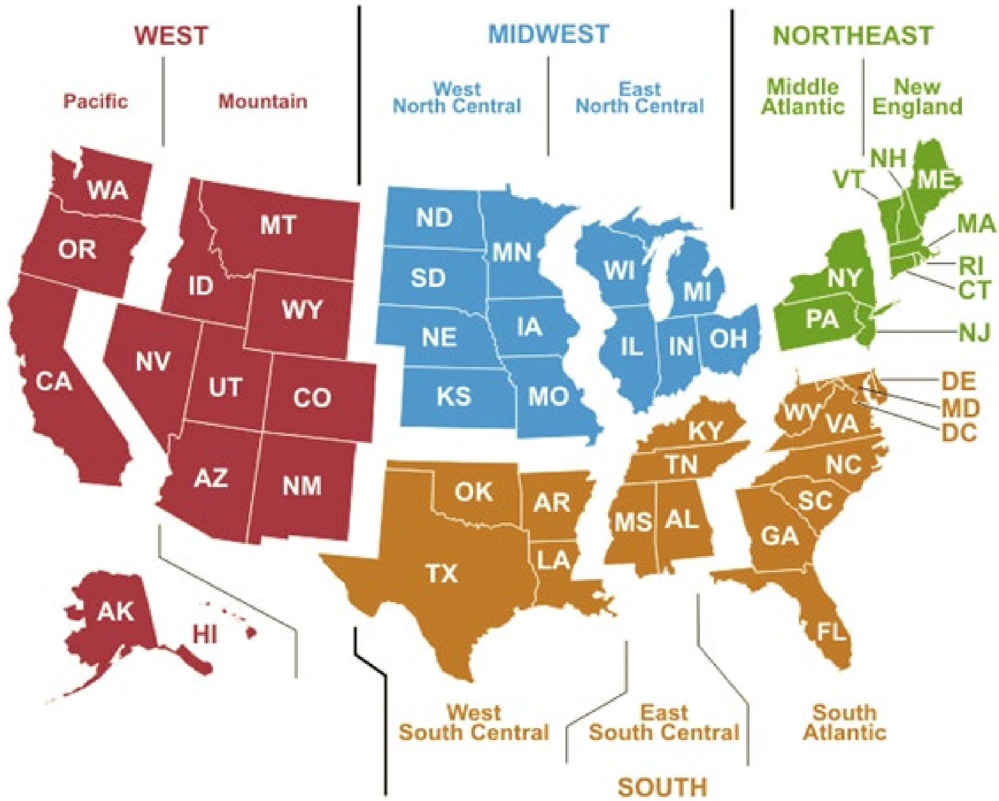

Figure 4. Census divions and regions. Source: U.S. Energy Information Administration 2018

For most Census divisions, gas furnaces are the most common system among LMI households and electric resistance is the second most common (see table B3 in Appendix B). However, the proportions vary, with larger amounts of gas in the northern part of the country (except New England) and more electric resistance heating in the south, as shown in figure 5. In the East South Central and South Atlantic divisions, electric heat pumps outnumber gas systems.

Oil systems (both furnaces and boilers) are present nearly as often as gas furnaces in New England, while they are virtually nonexistent in the West and South.

Gas boilers are a larger proportion of gas heating systems in the mid-Atlantic, significantly ahead of electric resistance and oil systems, the next most common types (see table B3).

Most of the households with no heating are found in milder climates in the South and West and were not investigated further in this study.

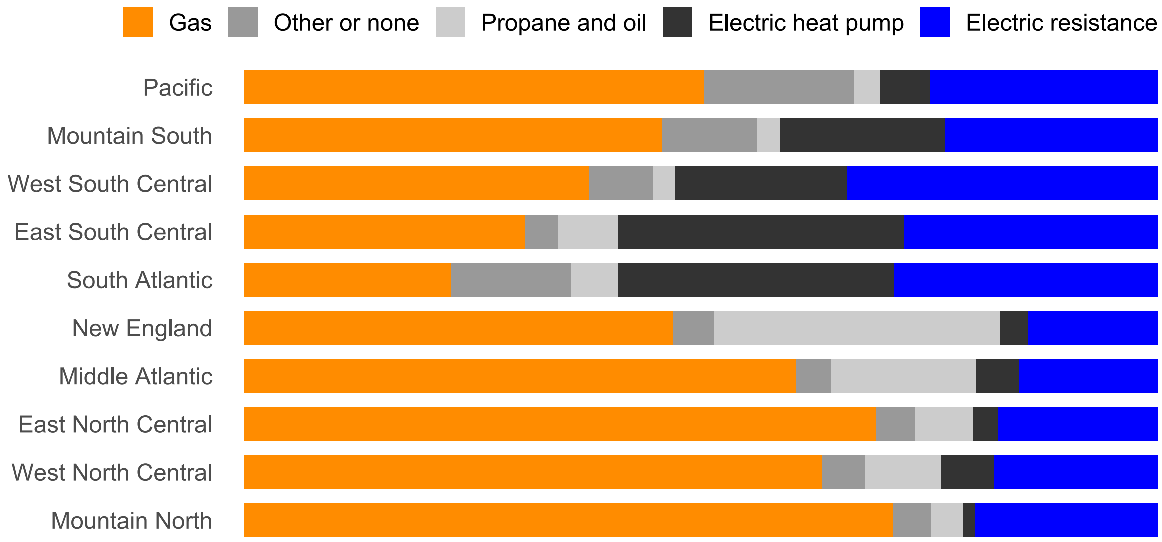

Figure 5. Proportions of heating systems in LMI homes by Census division. "Gas" includes central furnaces, boilers, and individual units; "electric resistance" includes electric central furnaces as well as built-in room units and portable electric heaters. "Other" includes electric boilers, wood or pellet stoves, and "other" responses in RECS.

Owner/Renter Status

About 55% of LMI households are homeowners and 43% are renters, according to our calculations, compared to 81% and 18% of non-LMI households, respectively.[9] Figure 6 shows that electric resistance heaters and gas systems are about equally common for renters, whereas for homeowners, gas systems are by far the most common, followed by electric heat pumps, with electric resistance heating a close third. The proportion of homes

[9] The remaining 2% of LMI households report occupying their homes without paying rent, neither renters nor owners. Per discussion with ACEEE's Equity Working Group, these households can present a particular challenge for electrification or efficiency programs.

using electric heat pumps is similar for both renters and owners, but gas systems are a much larger proportion for owners. (See appendix table B4 for additional detail.)

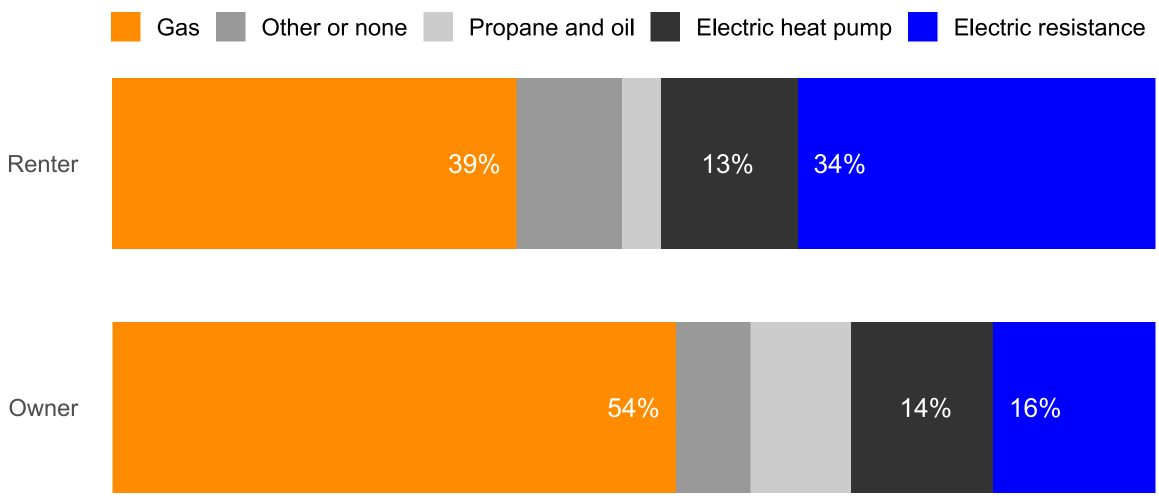

Figure 6. Proportions of heating systems in LMI homes by owner/renter status. "Gas" includes central furnaces, boilers, and individual units; "electric resistance" includes electric central furnaces as well as built-in room units and portable electric heaters. "Other" includes electric boilers, wood or pellet stoves, and "other" responses in RECS.

Analytical Methodology

We use EIA's RECS 2020 (U.S. Energy Information Administration 2020) to construct a detailed model of electrification costs and benefits, which updates and builds off of an earlier analysis of residential decarbonization (Nadel and Fadali 2022).[10] RECS includes detailed data on building characteristics and energy use for a representative sample of homes across the United States, with weights provided by EIA. While in this report we generally describe national results, the weighted sample of homes in each state is representative as well.[11]

For each home, we compute the equipment and operating costs of continuing to use the existing systems and replacing them with similar equipment. We compare those costs to that of electrifying the same end uses (space heating, water heating, dryers, and cooking

[10] One important difference between our study and Nadel and Fadali (2022) is that we assume that fossil fuels continue to be used, whereas Nadel and Fadali assume only the use of lower-carbon alternative fuels.

[11] The methodology and framework presented here—as well as many of the analytical results—could be applied to any state, though some local tuning of input data would likely be beneficial.

appliances) and purchasing electricity to serve those loads. Here we are focused on *efficient electrification* of equipment and thus refer broadly to *electrification* as including upgrading fossil fuel and electric resistance furnaces and water heaters with their heat pump equivalents, as well as upgrading clothes dryers to heat pump dryers and replacing fossil fuel cooking equipment with electric ranges in the *full electrification* scenarios.[12]

Replacement parameters for heating systems include the type of building (single family, 2–4 units, or 5+ units); cold climate heat pumps above 4,000 heating degree days (HDD, currently about the climate of Washington, DC and colder), and ducted or mini-split air-source heat pumps, based on existing systems for heating and cooling. For water heaters, we size replacements based on the size of existing equipment as given in RECS 2020 microdata. Detailed equipment assignments are described in Appendix A. For homes in locations with at least 6,000 HDD (currently about the climate of Pittsburgh, Pennsylvania) and existing fuel equipment, we also consider an option of electrification with dual fuel for back-up when temperatures are below 5°F. Additionally, we model dual-fuel central water heating systems with back-up below 20°F for apartments with at least 4,000 HDD where the existing water heater serves multiple units.[13]

Most of the roughly 18,500 survey responses in the published RECS microdata are included in the analysis, but not all are included for each end use. For example, for space heating we included approximately 15,000 homes, which is all homes except those that use wood or "other" as their primary heating fuel or that already have an electric heat pump as their main heating equipment. Unless otherwise noted, figures in this report focus on the subset of these households that are LMI.

For most analyses, we assume equipment is replaced in 2024 and operates until 2050. While the life expectancy of equipment is shorter than this period,[14] we wished to avoid speculating on the future performance and costs of equipment and thus ignore all replacement costs beyond those in 2024, both for costs of extending the status quo and

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[12] In a later section of the report, we include home efficiency retrofits. In cold climates, weatherization can be seen as an essential part of an overall efficient electrification retrofit and potentially a prerequisite for space heating electrification to reduce heat pump capacity needs and to ensure thermal comfort.

[13] The underlying data do not provide specific details on these systems configurations. We assumed shared central systems for apartment buildings would require split systems for domestic water heating. This represents a conservative estimate: Individual buildings without split systems would not see the same drop off in heat pump performance at low temperatures.

[14] We compute the remaining value of existing equipment in 2024 using lifetimes of 20 years for fossil fuel furnaces and boilers and 15 years for other equipment and include the remaining equipment value when computing the overall upfront cost of electrification.

costs of electrification: equipment costs are included only once. We do not include maintenance costs. Prices are in 2020$, with a 5% real discount rate.

The EIA's 2023 Annual Energy Outlook predicts variable residential electricity and fuel prices through 2050, but with relatively minor average changes (in real prices) and without the electrification expected with current policy and envisioned by this study (U.S. Energy Information Administration 2023a). As such, we consider no change in base energy prices in real terms, but developed our own approach (described as follows) to consider the impacts of electrification on electricity and natural gas prices. We assume that as electrification increases in colder climates, electricity prices rise to recover the costs of new capacity needed to meet winter peak demand. As in Nadel and Fadali (2022), we do not include an adjustment for growing electricity sales due to electrification, which could allow fixed costs to be spread over a wider base, reducing costs for individual customers. We further assume gas prices rise as the costs of maintaining the gas distribution network fall on fewer customers, increasing their costs (Nadel 2023). We consider prices for electricity and gas under four scenarios: 0%, 25%, 50%, and 75% electrification of all fossil fuels burned in homes nationally.[15] Zero percent electrification represents the 2020 level of electric equipment usage. These scenarios are not intended to represent specific times or rates of electrification, but to enable comparing electrification costs with different assumptions about the prices of electricity and gas.

Electricity pricing incorporates winter peak effects following Nadel and Fadali (2022) except that it is scaled by the percentage of fossil fuel electrification. For example, in Missoula, Montana, with 7,000 HDD, where Nadel and Fadali would increase the electricity price for an individual home by 30% (for 100% electrification), in our study, the electricity price is increased by 0%, 8%, 15%, and 23%, respectively, under 0%, 25%, 50%, and 75% electrification. There is no increase for homes below 4,000 HDD. For dual-fuel systems, we cap the price at the level for 6,000 heating degree days; for a home with a dual-fuel heating system in Missoula, this means the electricity price is increased by 0%, 6%, 12%, and 18%.

We assume that homes using gas have a fixed *customer cost* of $20 per month; 40% of the remaining cost is unaffected by electrification (analogous to *supply costs*), and the remaining 60% of the cost increases by $1/(1 - p)$, where p is the percentage of gas electrification (analogous to *delivery costs*).[16] [17] Prices for electricity and gas are illustrated in figure 7. As in

[15] Percentages are in terms of overall thermal energy across all homes (including non-LMI), fuels, and end uses.

[16] The exact breakdown of customer, supply, and delivery prices varies across the country and utility service territory. We were unable to discern a standardized model for these breakdowns and based the values here on a review of EIA data across the United States.

[17] Delivery costs will vary depending on how electrification proceeds and what gas infrastructure needs to be maintained. We attempted to account for this by using percentages of thermal energy as our benchmark of

Nadel and Fadali (2022), these multipliers are applied to the price of fuel and electricity for each home in RECS, calculated using annual consumption and expenditures for the individual home. Thermal energy required to heat the home in 2020 is normalized for the 30-year average, adjusted to 2020–2050 as described in the appendix.[18]

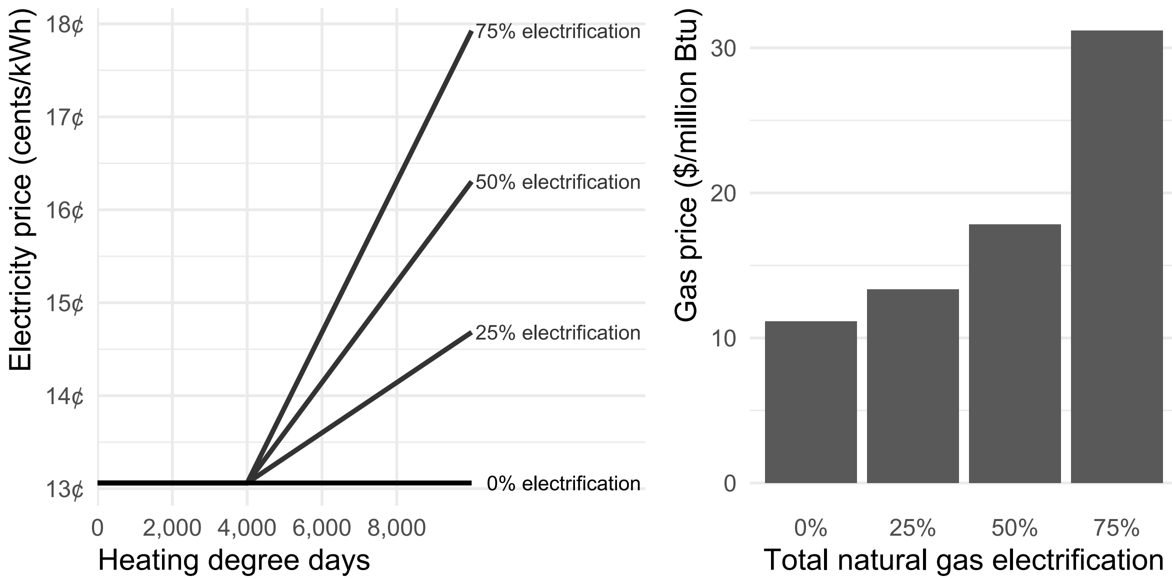

Figure 7. The graph on the left shows the national average electricity price (calculated from RECS 2020) with multipliers for winter peak pricing for a given number of heating degree days. The graph on the right shows the national average price for fossil gas assuming different levels of gas electrification. Note that while this figure shows multipliers applied to average national prices, in the analysis, multipliers are applied to prices for individual homes as calculated from consumption and expenditure data in RECS.

We consider life-cycle costs (i.e., equipment, installation, and operating costs) with and without externalities for the social cost of GHG emissions and health impacts. GHG emissions factors are based on publicly available sources from the National Renewable Energy Laboratory (NREL), the Environmental Protection Agency (EPA), and the National Energy Technology Laboratory (NETL) as described in the appendix. Health impacts are calculated for fuels and electricity by state using EPA's COBRA tool, which assigns a monetary value to events made more likely by outdoor air pollution, such as heart attacks, hospitalizations, and

electrification (rather than a percentage of homes), but a fixed level of natural gas electrification could still be distributed at a lower level across many homes (with higher maintenance costs for a more extensive gas network) or concentrated in a smaller number of homes (with lower maintenance costs).

[18] EIA provides HDD for each home in the public microdata (with random errors to protect the identity of respondents) for the period 1981–2010. We reduce HDD in our analysis to account for our changing climate: For example, Missoula, Montana, had 7,349 HDD for the period 1981–2010, but has 7,000 HDD after our adjustments. Unless otherwise indicated, HDD values in this report include these adjustments.

cases of asthma.[19] The social cost of GHGs estimates economic effects of climate change impacts on human health, property values and damages due to flooding and other extreme events, and changes in agricultural production. We base our social cost of GHG emissions on the EPA's draft report "Report on the Social Cost of Greenhouse Gases" (U.S. Environmental Protection Agency 2022).

Results

We applied our analytical methodology to the RECS dataset using the assumptions presented in detail in the appendix. Here we describe our principal results.

OVERVIEW

It is useful to look at a general trend before exploring detailed findings along different vectors in subsequent sections. Figure 8 shows national average life-cycle electrification costs per LMI household over the 27-year analysis period for six scenarios compared to preserving the status quo:

1. Electrifying space heating only
2. Electrifying space heating only with fuel back-up in cold climates (dual fuel)
3. Electrifying water heating only
4. Electrifying both space heating and water heating
5. Dual-fuel space heating and water heating
6. Full electrification

Note that absolute cost (as opposed to the difference in costs) increases for both preserving the status quo and electrification at higher levels of electrification—as described above, we assume the price of both electricity and gas will increase as electrification proceeds (the former because of costs to meet higher winter peak demand, and the latter because the costs of maintaining the gas network will fall on a smaller number of customers). Negative costs in the figure indicate net benefit over the analysis period (i.e., the energy savings more than pay for equipment upgrades). The overall trend is that the net costs of electrifying decrease and the savings increase at higher electrification rates. This is primarily because natural gas prices increase faster than electricity prices with more electrification.

[19] For more information, see the COBRA User Manual appendices (U.S. Environmental Protection Agency 2021).

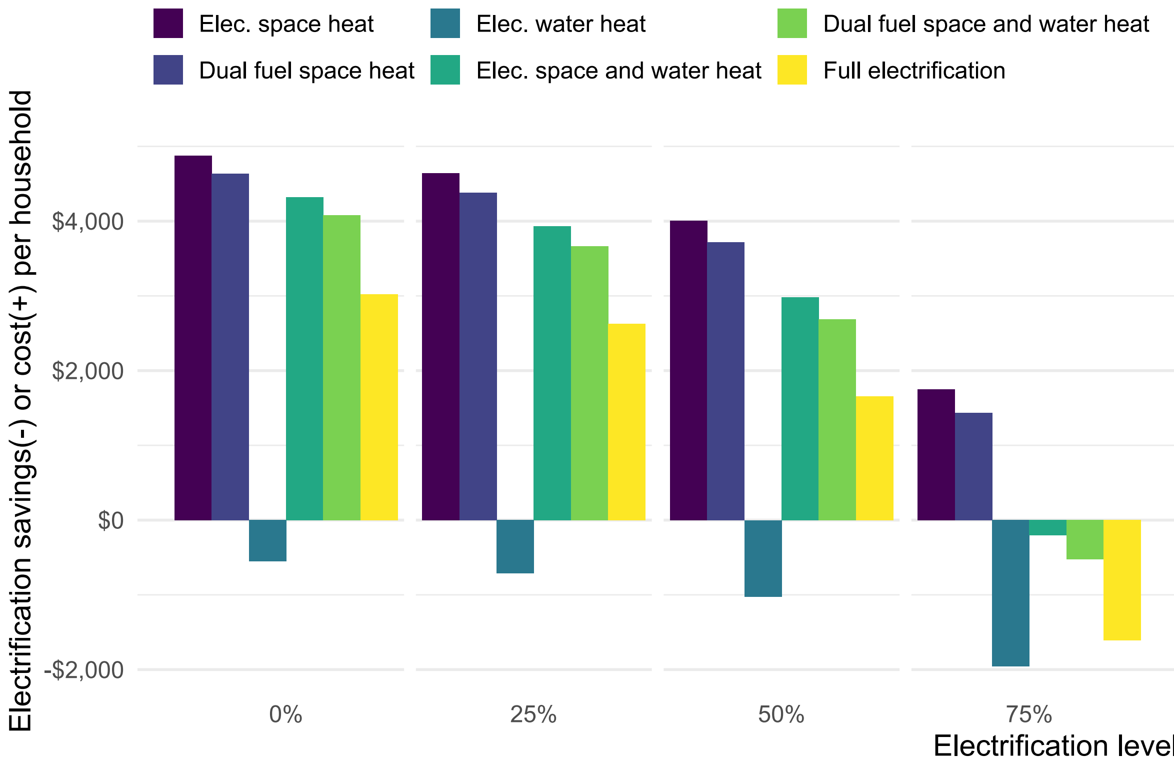

Figure 8. Average household life-cycle cost to electrify compared to status quo at different levels of electrification nationally. Zero percent electrification represents the 2020 level of electric equipment usage. Negative costs indicate a savings relative to the status quo. The lower cost of full electrification reflects elimination of monthly gas service charges.

Based on our assumptions, electrifying water heating reduces costs at any level of electrification. However, electrifying space heating as a standalone retrofit is expensive for LMI households, and even at 75% electrification costs over $1,500 more than maintaining existing heating systems on average. Dual-fuel systems reduce the costs for space heating, but not significantly. However, at 75% electrification, the benefits of efficient electric water heating and eliminating gas service fees more than make up for the cost of electric space heating. Also, it is worth noting that figure 8 shows national averages, and for many individual households, electrification may have lower life-cycle costs even using the base cost-benefit analysis with 2020 electricity and gas prices (0% electrification).

When we include health costs associated with burning fossil fuels (causing outdoor air pollution) and the social cost of GHG emissions (both on site and from generating electricity), the picture changes dramatically (figure 9). Electrifying space heating yields over $20,000–25,000 in benefits per household, while benefits increase about $9,000–10,000 for electrifying water heating. Some of the benefits (about $500 for water heating and a few thousand for space heating) are due to the reduced health costs of lower air pollution; most of the benefits come from avoided costs of climate change. Full electrification is the most beneficial option, reducing costs by about $10,000 relative to electrifying space heating alone.

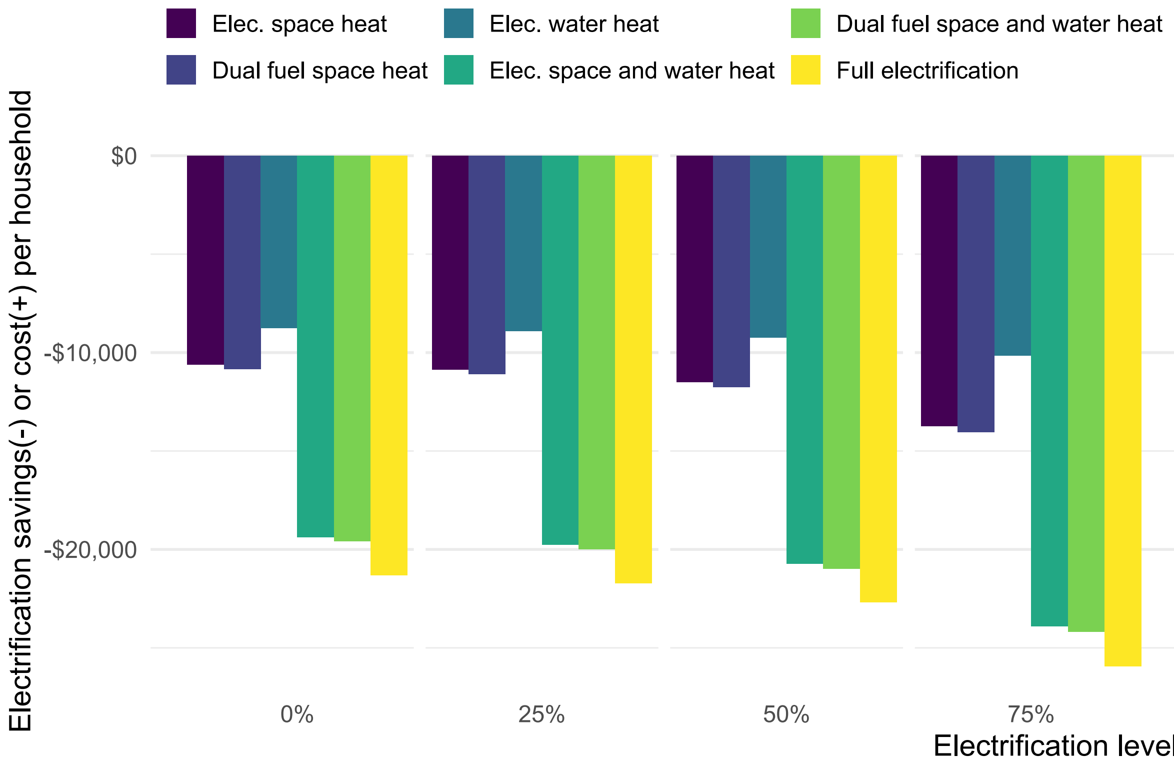

Figure 9. Average life-cycle cost to electrify compared to status quo at different levels of electrification nationally, including the social cost of carbon and health benefits. Zero percent electrification represents the 2020 level of electric equipment usage. Negative costs indicate a savings relative to the status quo.

The figures above do not differentiate among key drivers of the costs and benefits of electrification, such as current heating fuel and home type. In the following sections, we consider these results in more detail, first without externalities, then including the social cost of GHG emissions and health impacts.

REGIONAL DIFFERENCES

Life-cycle costs for electrification vary substantially by region, as shown in figure 10, although the Midwest, Northeast, and West are similar to the national average in the relative costs and benefits between scenarios. The Midwest region has substantially higher costs, due to the need for cold climate heat pumps, higher winter peak pricing, and fewer homes with existing air-conditioning units, increasing the need for electrical work. The South, opposite in all these characteristics, shows the least cost and most benefits at lower levels of electrification; this explains the significant uptake of heat pumps in this region currently without dedicated policy. The West, with a mix of climates and fuels, is in the middle.

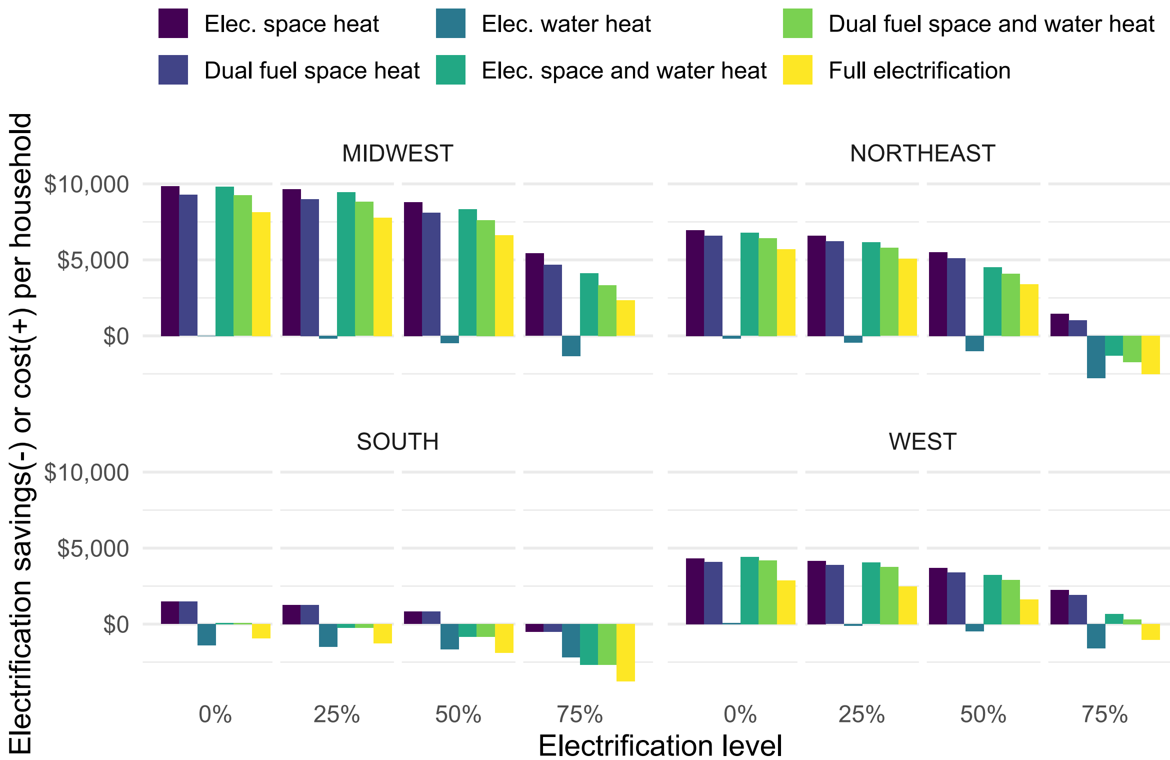

Figure 10. Average life-cycle cost to electrify compared to status quo by Census region. Zero percent electrification represents the 2020 level of electric equipment usage. Negative costs indicate a savings relative to the status quo. The lower cost of full electrification reflects elimination of monthly gas service charges.

Including externalities, benefits are highest in the Midwest and especially the Northeast (see figure 11). This is noteworthy since these regions also have the highest costs to electrify. The colder climate and higher fossil fuel combustion is a factor, as well as the greater prevalence of oil, which has worse health and climate impacts.

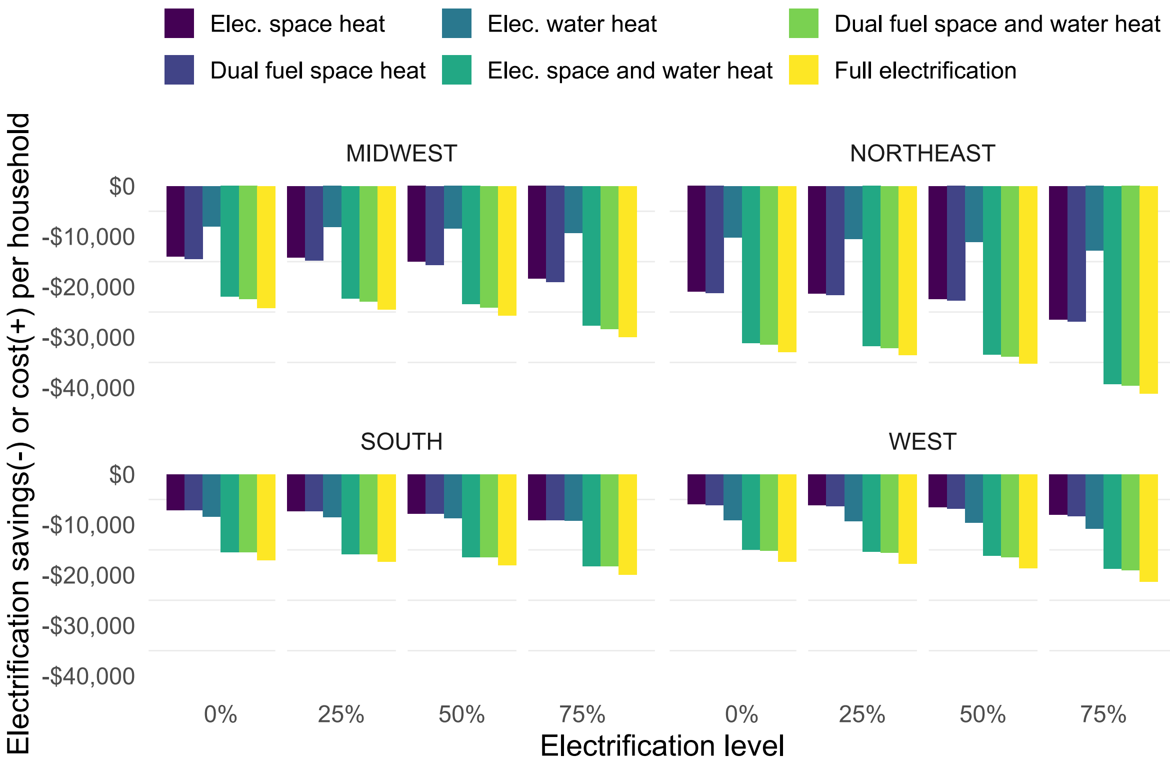

Figure 11. Average life-cycle cost to electrify compared to status quo by Census region including the social cost of GHG emissions and health impacts. Zero percent electrification represents the 2020 level of electric equipment usage. Negative costs indicate a savings relative to the status quo.

IMPACT OF HOME ENERGY EFFICIENCY RETROFITS

We modeled several energy efficiency retrofit packages for homes based on Less et al. (2021), with costs converted to 2020$. The most basic "weatherization" package includes R60 attic floor insulation, door weather stripping, "typical" envelope sealing and "typical" duct sealing for a total cost of $6,365 for homes in buildings with 1–4 units. The "home performance" package includes in addition: R25 foundation floor insulation, R13 "drill and fill" walls, and costs a total of $11,809 for 1–4 unit buildings. The heating energy savings for these packages are 29% and 42%, respectively. We also modeled a "deep" 69% energy-saving retrofit costing $55,138 for homes in 1–4 unit buildings, but this was substantially more expensive for almost every home and set of assumptions, so we do not discuss it further. [20]

[20] The deep retrofit package included R35 roof insulation, door weather stripping, R18 foundation wall insulation, "aggressive" envelope sealing, new ducts, a heat recovery ventilator, R13 "drill and fill" insulation, R16 exterior wall insulation, R21 gable wall insulation, and window replacements.

Based on costs for Nadel and Fadali (2022), we assume that retrofit costs for homes in 5+ unit buildings are half those for homes in 1–4 unit buildings; however, the small amount of fuel consumed in these buildings means that retrofits often do not make sense financially for individual households.

We find that energy efficiency retrofits reduce the life-cycle cost of electrifying space heating for homes in 1–4 unit buildings in colder climates, [21] above about 6,000–7,000 HDD, depending on price assumptions for electricity and gas (Pittsburgh, Pennsylvania, currently has roughly 6,000 HDD and Duluth, Minnesota, currently has about 7,000 HDD). Figure 12a shows a scatterplot of costs for homes in 1–4 unit buildings using the price assumptions for 50% electrification versus HDD for three electrification scenarios impacted by envelope improvements: dual-fuel space heating, electric space heating, and full electrification of all end uses. For clarity, we reprint the best-fit lines without data points in figure 12b.

We show equivalent figures to 12a for 0%, 25%, and 75% electrification assumptions in Appendix C.

In the scenarios shown in figure 12, electrification costs are lowest with no envelope improvements below about 7,000 HDD for dual-fuel systems and about 6,800 HDD for electric-only space heating or full electrification. The latter two reflect the same costs for space heating but are lower overall for full electrification because of the cost benefits of electrifying other end uses. In colder climates, envelope improvements reduce the cost of electrification for dual-fuel and fully electric systems alike.

It is important to note that figure 12 (and figures C1 through C4) reflect energy and equipment costs and benefits at a household level, and do not include other important benefits at an individual or societal level, such as comfortable living conditions or grid reliability.

[21] In addition to heating energy savings, we included modest cost savings for equipment size as detailed in the appendix (table A5 and the formula for cost below the table).

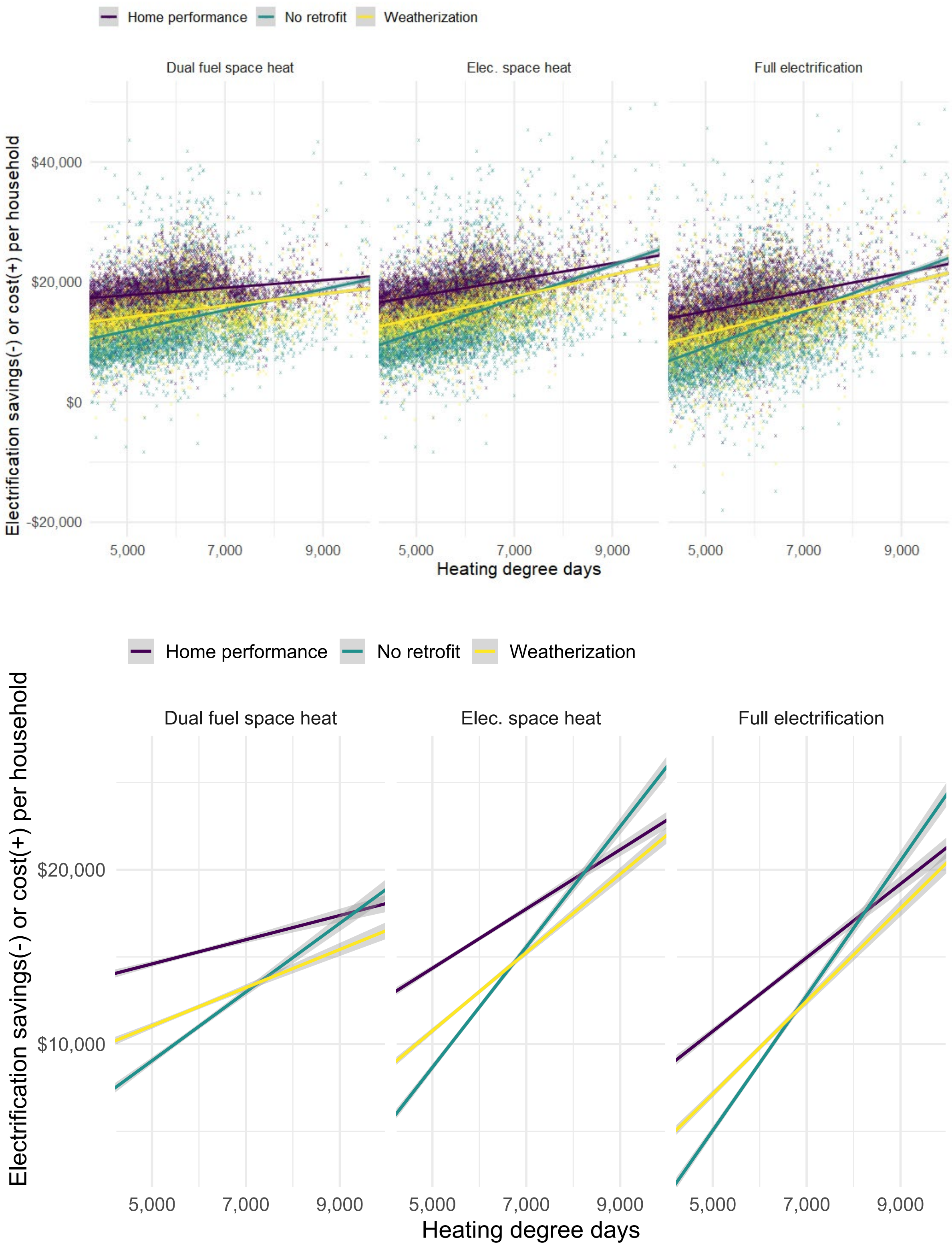

Figure 12. The figure shows life-cycle benefits or costs in the 50% electrification scenario for installing dual-fuel space heating, electric space heating, and full electrification with the "home performance" or "weatherization" retrofit packages, or no retrofit in homes in 1–4 unit buildings. Note this uses the

unweighted sample of homes from RECS microdata.[22] In the top image (12a), for a given color, each dot represents a different home (each home appears three times in each panel). The lines are best-fit lines. The bottom image (12b) shows the best fit lines without the underlying data.

COMPARING ELECTRIFICATION MEASURES IN LMI HOUSEHOLDS ACROSS BUILDING TYPE, END USE, AND FUEL

Table 2 shows the life-cycle costs of electrification in LMI homes (relative to cost of continuing to use their current system and fuel types) broken down by building type, fuel, and end use for energy cost scenarios with 0%, 25%, 50%, and 75% total fossil fuel electrification. For each row in table 2, the "electrification potential" percentage is calculated as the proportion of thermal energy that the electrification measure would convert to heat pumps or other efficient electric appliances in LMI households, out of the total thermal energy for all households, end uses, and energy sources, including electric resistance.[23] The "cumulative electrification potential" shows the sum of electrification potentials up to the end use, in the order given in the table (top to bottom). Electrification measures are given a rank in the table from most cost effective to least at 0% electrification, except "other" end uses (cooking and clothes drying), which assume space and water heating have been electrified first.

The table shows that electrifying oil and propane water heating is generally beneficial based on installation and operating costs alone. Since we assume no increase to fuel oil or propane prices with electrification, these end uses are only affected by the increased price of electricity; thus, higher levels of electrification have a less dramatic impact.

Electric resistance water heating is also beneficial to upgrade with any price assumptions, and electric resistance space heating becomes cost effective to upgrade in single-family homes at higher levels of electrification.

Gas system conversions generally result in higher household energy costs, but as electrification proceeds, it will become more economical for gas homes to electrify. Once a home electrifies gas water heating and space heating, the results indicate a significant financial benefit to disconnecting from the gas utility and thus avoiding gas service fees altogether. This benefit is shown as part of the "other" end uses measure, as we assume that the major end uses of space heating and water heating are converted to heat pumps first and households pay gas service fees until all end uses have been electrified.

[22] In addition, for the purposes of this analysis, we dropped about 100 homes as outliers with HDD>12,000 or standard residuals above 6 for the best-fit lines shown in figure 12. About 4,700 homes are shown.

[23] The total electrification potential includes that of non-LMI households. The electrification potential for LMI households is just under half the total.

Table 2. Base life cycle cost-benefit analysis for electrification measures by building type, fuel, and end use in LMI households

Building type	Existing heating/water heating fuel	End use to upgrade	Electrification potential	Cumulative potential (0%)	Rank (0%)	Cost per household (0%)	Rank (25%)	Cost per household (25%)	Rank (50%)	Cost per household (50%)	Rank (75%)	Cost per household (75%)
Single family	Oil/propane	Water heat	0.46%	0.46%	1	–$3,184	1	–$3,074	1	–$2,965	2	–$2,855
Single family	Elec. resistance	Water heat	3.68%	4.15%	2	–$2,626	2	–$2,718	2	–$2,809	1	–$2,901
2–4 units	Elec. resistance	Water heat	0.48%	4.63%	3	–$2,438	3	–$2,517	3	–$2,596	4	–$2,676
5+ units	Elec. resistance	Water heat	1.05%	5.67%	4	–$301	4	–$355	5	–$409	6	–$463
2+ units	Oil/propane	Water heat	0.14%	5.82%	5	–$268	5	–$113	7	$41	7	$196
Single family	Gas	Water heat	4.37%	10.19%	6	$510	6	$224	4	–$415	5	–$2,465
Single family	Elec. resistance	Space heat	2.23%	12.42%	7	$669	8	$525	8	$381	8	$238
Single family	Elec. resistance	Other	2.41%	14.83%	8	–$214	9	–$217	9	–$220	9	–$224
2–4 units	Gas	Water heat	0.79%	15.62%	9	$728	7	$418	6	–$316	3	–$2,747
Single family	Oil/propane	Space heat	3.60%	19.22%	10	$1,166	10	$1,800	10	$2,433	17	$3,067
Single family	Oil/propane	Other	0.79%	20.01%	11	–$181	11	–$181	11	–$181	18	–$182
2–4 units	Elec. resistance	Space heat	0.37%	20.39%	12	$3,201	12	$3,061	12	$2,921	15	$2,780
2–4 units	Elec. resistance	Other	0.25%	20.64%	13	–$121	13	–$123	13	–$124	16	–$130
5+ units	Gas	Water heat	1.25%	21.89%	14	$3,864	14	$3,697	14	$3,277	12	$1,844
2+ units	Oil/propane	Space heat	0.19%	22.08%	15	$4,724	17	$5,017	17	$5,310	23	$5,603

Building type	Existing heating/water heating fuel	End use to upgrade	Electrification potential	Cumulative potential (0%)	Rank (0%)	Cost per household (0%)	Rank (25%)	Cost per household (25%)	Rank (50%)	Cost per household (50%)	Rank (75%)	Cost per household (75%)
2+ units	Oil/propane	Other	0.04%	22.12%	16	–$16	18	–$22	18	–$37	24	–$87
5+ units	Elec. resistance	Space heat	0.60%	22.72%	17	$5,000	15	$4,924	15	$4,847	19	$4,771
5+ units	Elec. resistance	Other	0.59%	23.30%	18	–$74	16	–$74	16	–$75	20	–$76
5+ units	Gas	Space heat	1.22%	24.52%	19	$7,112	19	$6,978	19	$6,531	21	$4,827
5+ units	Gas	Other	0.46%	24.98%	20	–$1,063	20	–$1,068	20	–$1,079	22	–$1,114
2–4 units	Gas	Space heat	1.86%	26.84%	21	$8,810	21	$8,313	23	$6,931	13	$2,008
2–4 units	Gas	Other	0.32%	27.15%	22	–$1,107	22	–$1,113	24	–$1,135	14	–$1,217
Single family	Gas	Space heat	16.81%	43.97%	23	$9,003	23	$8,396	21	$6,817	10	$1,345
Single family	Gas	Other	4.04%	48.01%	24	–$2,792	24	–$2,810	22	–$2,860	11	–$3,035
All	Mixed	Other	0.06%	48.07%	25	–$1,384	25	–$1,394	25	–$1,419	25	–$1,506

Electrification measures (upgrading the existing system to an electric heat pump equivalent or other efficient electric appliances as appropriate) are shown ranked by order of cost effectiveness at 0% electrification compared to extending the status quo, except "other" end uses, which assume space and water heating have been electrified first. For 25%, 50%, and 75% electrification, upward changes in rank (that is, moving toward the highest rank of 1) are shown in blue bold text and downward changes in rank are shown in pink bold text. Colored text not in bold indicates a change from the original ranking but not the next-lowest level of electrification. Single-family gas water heaters go up in rank between 25% and 50% but decrease from 50% to 75%. In addition, we highlight the electrification measures with at least $1,000 in benefits per household in yellow. The fuel shown for "other" end uses is the space heating or water heating fuel in the home, not necessarily the fuel for cooking or clothes dryers. (Cases where the home uses fuel, e.g., gas, for either space or water heating and electric resistance heating for the other are grouped under the fuel. "Electric resistance" represents homes with electric resistance for both space and water heating, while the small number of homes with combinations of oil, propane, and/or natural gas for heating and hot water is grouped as "Mixed" fuel and placed at the bottom.)

Comparing Electrification Measures in Single-Family Homes

Figure 13 focuses on single-family homes and clarifies two of the underlying drivers of the dynamics in table 2: current heating fuel and overall electrification rate. Gas water heating is slightly cheaper than electric heat pump water heaters at low levels of electrification but becomes more expensive at 50% or 75% electrification. Electrifying gas space heating becomes more economical at higher rates of overall electrification as gas prices increase more than electricity prices. Disconnecting gas service altogether eliminates a fixed customer cost while also providing relief from rising gas prices, which is captured in the "other end uses" savings shown in figure 13.[24] Electric resistance water heating is beneficial to upgrade at any pricing level, while space heating is slightly more costly to upgrade to electric heat pumps due to equipment costs (operating costs for purchasing electricity are far lower). Oil and propane water heating is cost effective to electrify. While heating costs with heat pumps are often lower than heating with oil or propane, electrifying oil and propane space heating was not found to be life-cycle cost effective *on average*.[25] The increase in cost at higher levels of electrification reflects our assumptions of stable oil and propane prices while electricity prices increase with widespread electrification in colder climates (due to increased heating-driven peak demands).

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[24] While these savings are included in "other end uses" in figure 13, space and water heating must be electrified also for these savings to be realized by the household.

[25] This, as with all the analyses presented here, is prior to including any state or federal incentives for heat pumps, which can significantly alter this calculation. Even without subsidies, electrifying space heating is life-cycle cost-effective for 23% of homes using fuel oil and 40% of homes using propane, with lower operating costs in 69% of oil heating homes and 93% of propane heating homes. Others have found electrifying fuel oil- and propane-heated homes to be cost effective in far more homes (Wilson et al. 2024). This finding is sensitive to the prices of these fuels relative to electricity prices.

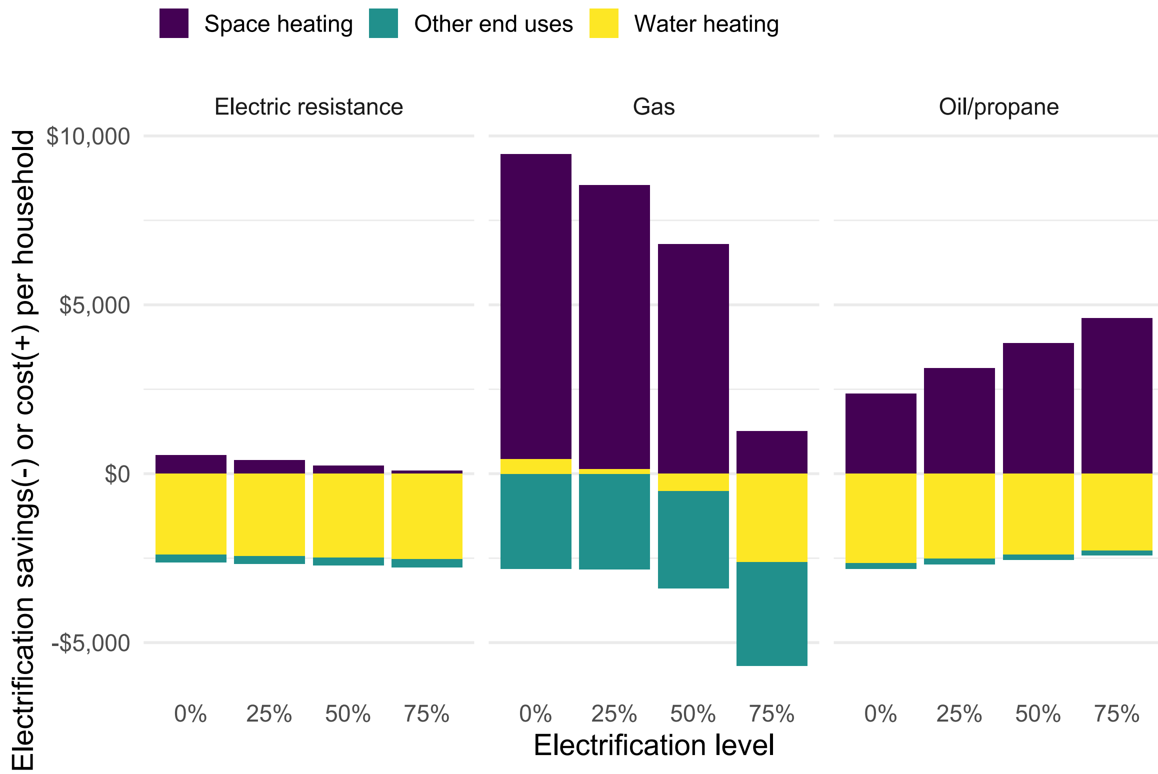

Figure 13. Cost-benefit by end use for single-family homes using gas, electric resistance, and oil/propane. For gas homes, savings associated with "other end uses" includes the elimination of gas service fees, so the full savings indicated can only be achieved when a gas home fully electrifies.

These costs vary by region (figure 14). The high costs for electrifying gas space heating nationally are driven by the costs in the Midwest and Northeast, while costs are somewhat lower in the West and especially South. Electric resistance space heating is cost effective to upgrade in all regions except the West. Electrifying oil space heating is cost effective in the South, unlike other regions.

Figure 14. Cost-benefit by end use for single-family homes using gas, electric resistance, and oil/propane broken out by Census region. For gas homes, savings associated with "other end uses" includes the elimination of gas service fees, so the full savings indicated can only be achieved when a gas home fully electrifies.

Comparing Electrification Measures in Multifamily Buildings

Multifamily buildings are generally more challenging to electrify (figure 15). The main differences are that electric resistance space heating and water heating overall are less cost effective to electrify, though upgrading electric resistance water heaters still provides a net savings.

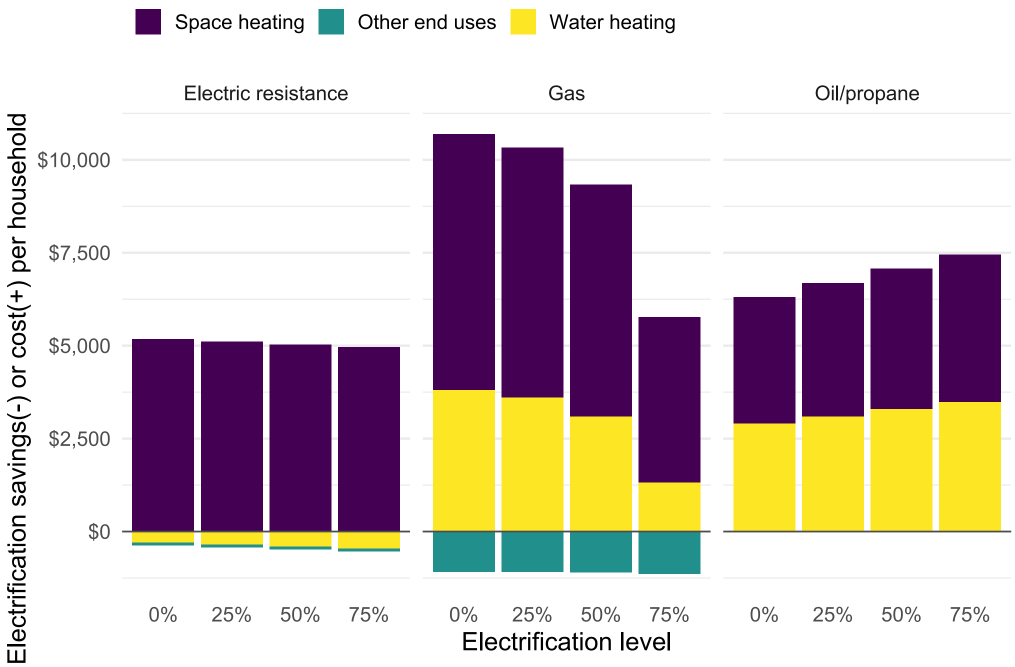

Figure 15. Cost-benefit by end use for homes in 5+ unit buildings using gas, electric resistance, and oil/propane

Incorporating Societal and Health Costs and Benefits

Incorporating societal impacts of fossil fuels such as extreme weather and health effects of air pollution[26] shows an overwhelming benefit for electrifying households with oil or propane space heating—nearly $50,000 for single-family households (table 3). Almost every end use is beneficial to electrify at any price.

The only exception is electric resistance space heating in multifamily buildings, even at 75% electrification levels: Equipment costs are high for multifamily buildings and usage is low enough to be relatively unaffected by electricity prices.

In general, the largest shifts are seen for oil and propane (illustrated for space heating in figure 16), with replacing oil space heating in single-family homes providing nearly $50,000 in net benefits. Single-family gas space heating also shows one of the largest shifts, from approximately $9,000 in net costs (at 0% electrification) to over $17,000 in net benefits. Even for the measures in the base cost-benefit analysis that are costliest to electrify at high levels of electrification—for example, gas space heating in multifamily buildings—the societal benefits of electrification are overwhelming, over $4,000 per household.

[26] See the Methodology section and Appendix A for further discussion.

Table 3. Cost-benefit analysis for electrification measures incorporating societal costs and benefits by building type, fuel, and end use

Building type	Existing heating/water heating fuel	End use to upgrade	Electrification potential	Cumulative potential	Rank (0%)	Cost per household (0%)	Rank (25%)	Cost per household (25%)	Rank (50%)	Cost per household (50%)	Rank (75%)	Cost per household (75%)
Single family	Oil/propane	Space heat	3.60%	3.60%	1	–$49,017	1	–$48,384	1	–$47,750	1	–$47,117
Single family	Oil/propane	Water heat	0.46%	4.06%	2	–$18,303	2	–$18,194	4	–$18,084	4	–$17,974
2+ units	Oil/propane	Water heat	0.14%	4.21%	3	–$17,632	4	–$17,478	2	–$17,323	6	–$17,168
Single family	Gas	Space heat	16.81%	21.02%	4	–$17,215	3	–$17,821	3	–$19,401	2	–$24,872
2+ units	Oil/propane	Space heat	0.19%	21.21%	5	–$15,183	5	–$14,891	5	–$14,598	3	–$14,305
2–4 units	Gas	Space heat	1.86%	23.07%	6	–$11,288	6	–$11,785	6	–$13,167	7	–$18,090
2–4 units	Gas	Water heat	0.79%	23.87%	7	–$11,053	7	–$11,363	7	–$12,098	5	–$14,528
Single family	Gas	Water heat	4.37%	28.24%	8	–$10,953	8	–$11,239	8	–$11,878	8	–$13,928
Single family	Elec. res	Water heat	3.68%	31.92%	9	–$8,605	9	–$8,696	9	–$8,788	9	–$8,880
Single family	Elec. res	Space heat	2.23%	34.15%	10	–$7,899	10	–$8,043	10	–$8,186	10	–$8,330
2–4 units	Elec. res	Water heat	0.48%	34.63%	11	–$6,437	11	–$6,516	11	–$6,595	12	–$6,675
5+ units	Gas	Water heat	1.25%	35.88%	12	–$5,353	12	–$5,519	12	–$5,939	11	–$7,372

Building type	Existing heating/water heating fuel	End use to upgrade	Electrification potential	Cumulative potential	Rank (0%)	Cost per household (0%)	Rank (25%)	Cost per household (25%)	Rank (50%)	Cost per household (50%)	Rank (75%)	Cost per household (75%)
Single family	Gas	Other	4.04%	39.93%	13	–$3,672	13	–$3,690	13	–$3,740	15	–$3,914
5+ units	Elec. res	Water heat	1.05%	40.97%	14	–$3,472	14	–$3,527	14	–$3,581	13	–$3,635
5+ units	Gas	Space heat	1.22%	42.19%	15	–$1,929	15	–$2,062	15	–$2,510	14	–$4,214
2–4 units	Gas	Other	0.32%	42.50%	16	–$1,750	16	–$1,756	16	–$1,777	16	–$1,859
5+ units	Gas	Other	0.46%	42.96%	17	–$1,568	17	–$1,573	18	–$1,584	18	–$1,619
2–4 units	Elec. res	Space heat	0.37%	43.33%	18	–$1,313	18	–$1,454	17	–$1,594	17	–$1,734
Single family	Oil/propane	Other	0.79%	44.13%	19	–$1,015	19	–$1,015	19	–$1,015	19	–$1,017
Single family	Elec. res	Other	2.41%	46.54%	20	–$720	20	–$723	20	–$726	21	–$731
2+ units	Oil/propane	Other	0.04%	46.57%	21	–$703	21	–$709	21	–$724	20	–$773
2–4 units	Elec. res	Other	0.25%	46.82%	22	–$397	22	–$398	22	–$400	22	–$405
5+ units	Elec. res	Other	0.59%	47.41%	23	–$275	23	–$276	23	–$276	23	–$277
5+ units	Elec. res	Space heat	0.60%	48.01%	24	$2,421	24	$2,345	24	$2,268	24	$2,192
All	Mixed	Other	0.06%	48.07%	25	–$2,102	25	–$2,112	25	–$2,137	25	–$2,224

Electrification measures (upgrading the existing system to an electric heat pump equivalent or other efficient electric appliance as appropriate) are shown ranked by order of cost effectiveness—including health and other societal costs and benefits—at 0% electrification compared to extending the status quo, except "other" end uses, which assume space and water heating have been electrified first. For 25%, 50%, and 75% electrification, upward changes in rank (that is, moving toward the highest rank of 1) are shown in blue bold text and downward changes in rank are shown in pink bold text. Colored text not in

bold indicates a change from the original ranking but not the next-lowest level of electrification. Oil and propane water heating in multifamily and 2–4 unit buildings goes up in rank between 25% and 50% but decreases in rank between 50% and 75% electrification. In addition, we highlight the electrification measures with at least $1,000 in benefits per household in yellow. The fuel shown for "other" end uses is the space heating or water heating fuel in the home, not necessarily the fuel for cooking or clothes dryers. (Cases where the home uses fuel, e.g., gas, for either space or water heating and electric resistance heating for the other are grouped under the fuel. "Electric resistance" represents homes with electric resistance for both space and water heating, while the small number of homes with combinations of oil, propane, and/or natural gas for heating and hot water is grouped as "Mixed" fuel and placed at the bottom.)

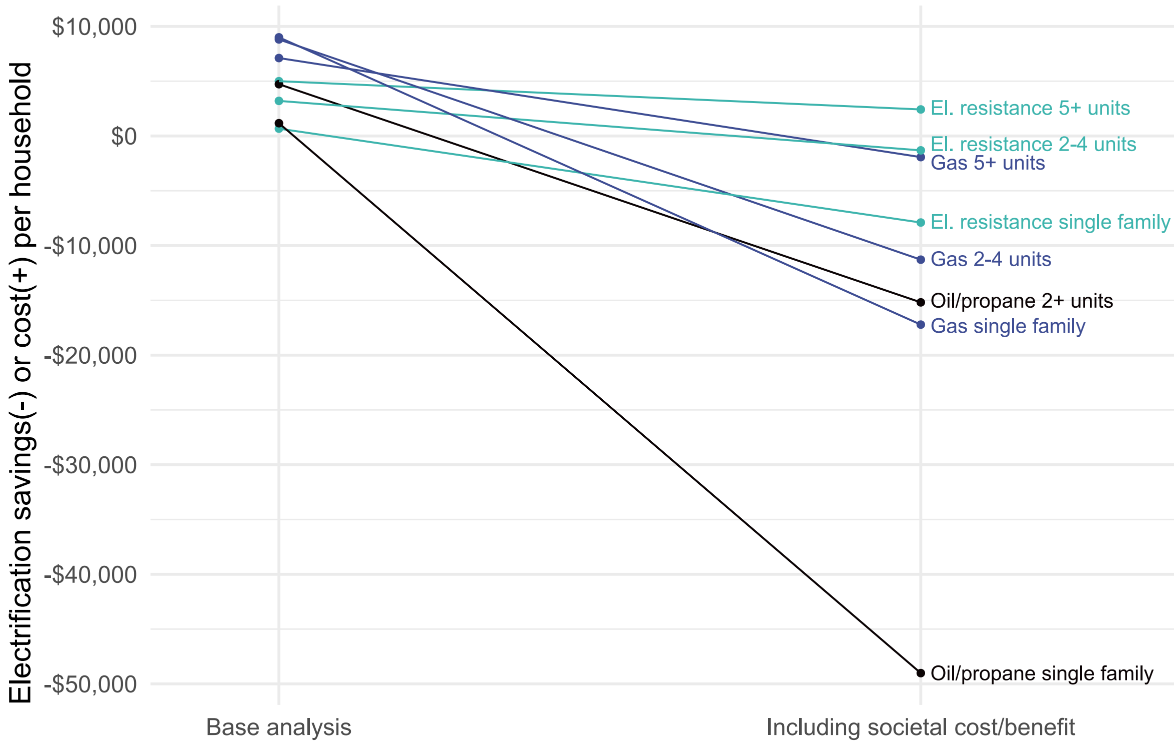

Figure 16. Comparing space heating electrification measures with different fuels and building types in the base cost-benefit analysis with the cost-benefit analysis that includes the social cost of GHG emissions and health impacts, at 0% electrification

PRIORITIZING EQUITABLE ELECTRIFICATION

Whether or not LMI households electrify along with their higher-income counterparts has implications for the overall national cost to electrify. To understand this effect, we consider two pathways for electrification, both for the base cost-benefit analysis and incorporating societal costs and benefits.

In an *LMI prioritized* pathway, we assume all homes (LMI or otherwise) electrify in order from highest life-cycle savings to highest life-cycle costs, without any consideration of barriers to LMI homes being able to electrify. In an *LMI excluded* pathway, we explicitly exclude LMI homes until all other homes have electrified.[27] We look at sequential electrification to overall

[27] While excluding all LMI homes is an extreme scenario, it is nonetheless useful for isolating the value of electrifying LMI homes and illustrating the costs to society if these households are not included in electrification.

electrification rates of 25%, 50%, and 75%.[28] For simplicity, we assume that all homes in the first 25% cohort fully electrify in 2027 (representing the period 2024–2029), the second 25% cohort electrifies in 2035 (representing the decade 2030–2039), the third in 2045 (representing 2040–2049), and the last group has not electrified by 2050. Figure 17 compares the electrification rates of LMI homes in the *LMI prioritized* and *LMI excluded* pathways.

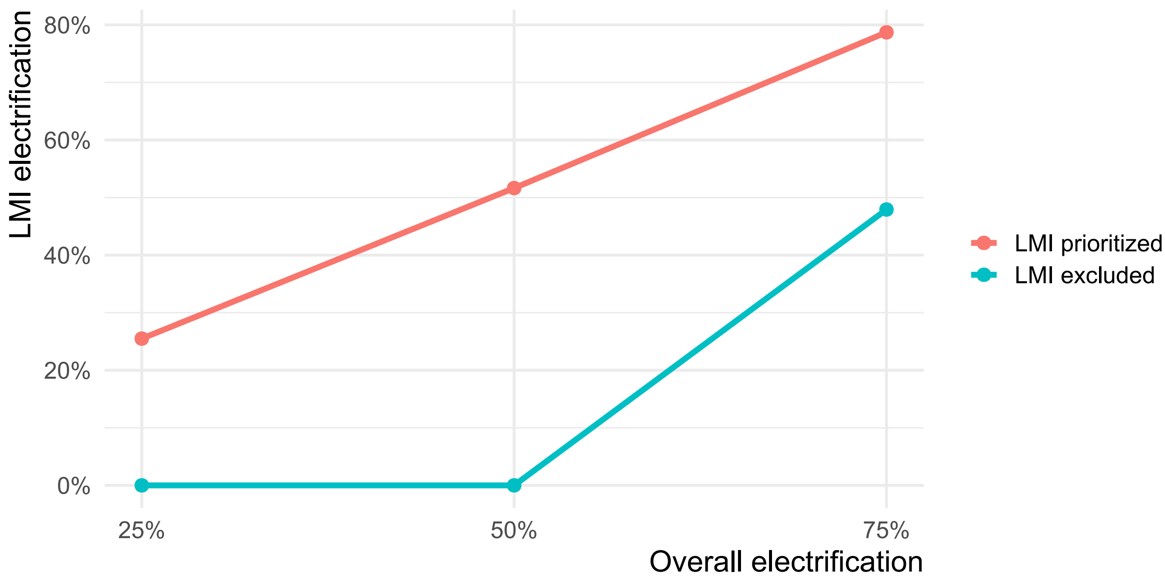

Figure 17. Proportion of LMI electrification versus overall electrification for the first, second, and third cohorts of homes. LMI prioritized assumes all homes (LMI or otherwise) electrify in order from highest life-cycle savings to highest life-cycle costs. LMI excluded excludes LMI homes from electrifying until all other homes have electrified.

We also evaluated the same *LMI prioritized* and *LMI excluded* pathways, including the social cost of GHG emissions and health impacts of fossil fuel combustion.[29] For each pathway, we compute costs and benefits to electrify nationally.[30] Based on comparing national life-cycle

[28] That is, homes electrify in order of the cost effectiveness of full electrification until 25% (or 50% or 75%) of thermal energy (from all fuels and end uses, including electric resistance) has been upgraded to heat pumps or other efficient electric appliances.

[29] These pathways are shown in appendix figure C5. The proportions of LMI electrification are similar to those shown in figure 17, though slightly lower.

[30] Net present value of electric equipment and installation costs for each electrifying cohort was discounted based on the years 2027, 2035, and 2045. The cost of fossil fuel equipment is included in 2024 for the non-electrifying cohort, but not included otherwise. We assume electricity and gas prices reflect 2020 electrification levels (i.e., 0% electrification) for the period 2024–2026. For subsequent periods, we calculate prices based on

costs for the two pathways, prioritizing equitable electrification would reduce the overall cost of electrifying 75% of residential energy consumption in the United States by about $183 billion (in 2020$)—about double the $88 billion total cost of electrification (equipment and energy costs) in the base analysis relative to the status quo.[31] This is achieved by ensuring that the most cost-effective homes to electrify do so, regardless of whether they are LMI households. In other words, equitable electrification transforms an $88 billion cost into a $96 billion savings. Including social and health impacts, equitable electrification would reap an additional $140 billion in benefits, 8% greater than the $1.8 trillion in benefits we calculate without prioritizing equitable electrification.[32] There may be additional benefits or costs not included in these numbers, which are not intended to represent a comprehensive assessment of societal costs and benefits.

usage of the homes in each cohort in accordance with table C1, similarly to what is described in the methodology for 25%, 50%, and 75% electrification.

[31] The $88 billion is computed as the cost of equipment and energy in scenario 2 (national equipment and energy costs excluding LMI households from electrifying), about $2.3 trillion, minus the energy and equipment cost of maintaining the status quo for all households until 2050 (about $2.2 trillion).

[32] The benefit without prioritizing equitable electrification is calculated as the societal and health costs in scenario 4 (national electrification cost incorporating societal and health costs, excluding LMI households from electrifying), which is $3 trillion, minus the societal and health costs of maintaining the status quo for all households until 2050, $4.8 trillion.

Prioritizing equitable electrification would reduce the cost of electrifying residential energy consumption in the U.S. by about

$180 billion

and would create an additional

$140 billion

in societal and health benefits.

Energy Burden

Energy burden refers to the percentage of household income spent on energy. To evaluate the effect of prioritizing equitable electrification (or not) on energy burdens of LMI households, we calculated approximate weighted average energy burdens for each LMI income group in each of the time periods described above (2024–2029, 2030–2039, 2040–2050), corresponding to 0%, 25%, 50%, and 75% total national electrification.[33] In the first panel of figure 18, we see that if LMI home electrification is prioritized, energy burdens decline as homes shift to less expensive forms of heating (from electric resistance and fossil fuels to electric heat pumps); the decline in energy burdens is most striking for very low-income households, which currently bear heavy energy burdens. As electrification advances to 75%, energy burdens stay about the same for moderate- and low-income households but increase modestly for very low-income households, though they remain well below the level in 2020. This slight uptick, which is due to an increase in both electricity and gas prices at

[33] Because income data in RECS are binned, these estimates should be considered highly imprecise.

75% electrification, is less of a concern because we can likely expect significant changes in the overall economics if the nation is able to achieve 75% electrification.

In contrast, the second panel of figure 18 shows energy burdens increasing for all LMI income groups if they are excluded from the monetary benefits of electrification (to say nothing of the considerable non-energy benefits described above). Again, the increase is most marked for very low-income households, for whom the average energy burden increases above 10%. When LMI households are finally able to electrify (at the 50–75% electrification transition), energy burdens decline precipitously, reflecting steep system costs for natural gas. However, energy burdens remain above the level they would have reached if LMI households were included equitably, reflecting that a larger number of LMI households must continue to support an expensive gas network.

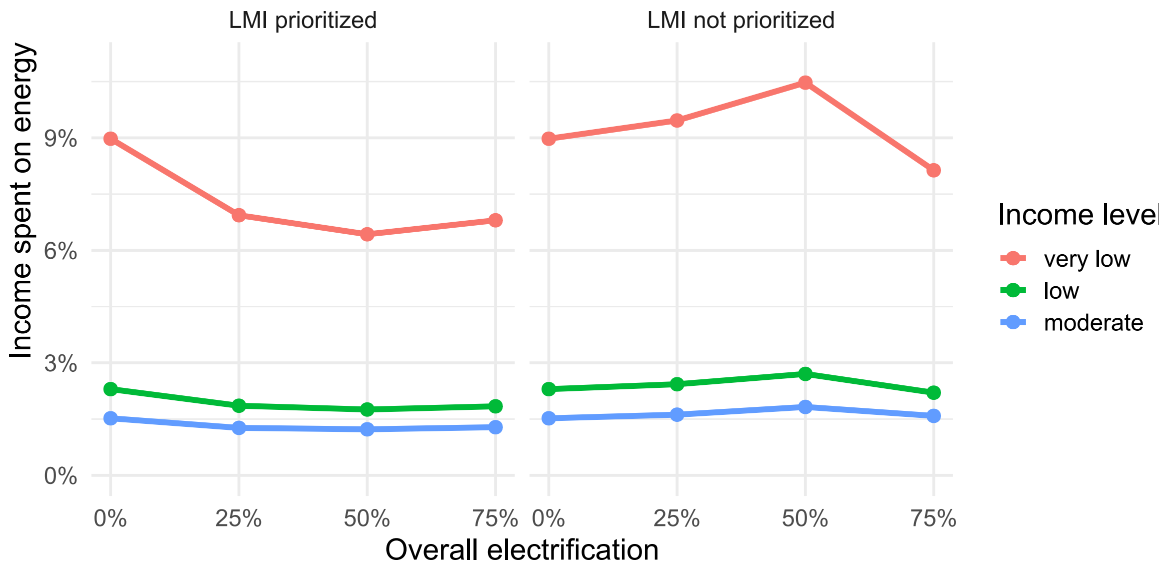

Figure 18. Approximate average energy burdens for LMI income groups as electrification proceeds

Thus, we see that electrification efforts, if they are equitable and inclusive, can lower energy burdens, but will likely raise energy burdens if they are not.

Conclusions

We systematically analyzed the household and societal economics of efficient electrification, including converting electric resistance to heat pumps. In this report, we present detailed results for LMI households based on a range of household characteristics, including income, region, current fuels, existing space and water heating equipment, and home type. The underlying analysis includes many additional dimensions, including home size, annual energy usage, fuel expenditures, climate, and regional electricity grid emissions rates; future work could reveal interesting additional insights on these aspects that were beyond the scope of the current work. We present the impacts on LMI households and on the United States as a whole of prioritizing LMI household electrification—ensuring that as cost-effective home electrification progresses across the United States, LMI homes that would benefit from electrification keep up with higher-income households.

An important finding of this study is that prioritizing equitable building electrification could ensure benefits of efficient electrification reach the most burdened communities while reducing the cost of achieving 75% total residential electrification across the United States by $183 billion. This represents an approximately 200% reduction from the $88 billion cost we compute to replace 75% of fossil fuel end uses and electric resistance heating with efficient electric technologies, such as heat pumps, or about $96 billion in savings.[34] Upfront costs are a major barrier to electrification: these results indicate that much greater public investment in LMI home electrification is warranted to enable greater uptake of cost-effective home electrification. When including the societal economic benefits of reducing greenhouse gases and other emissions, prioritizing equitable electrification would result in $140 billion in additional benefits, an increase of 8% over the already significant $1.8 trillion in benefits from electrification that does not prioritize LMI households. The benefits of investing in LMI home electrification therefore dwarf the costs.

We also show that prioritizing equitable electrification reduces energy burden—the percentage of income spent on energy—for LMI households, with a particularly strong benefit in the lowest-income homes. By prioritizing equitable electrification in achieving a 50% electrification rate overall, the weighted average energy burden for very low-income households drops from 9% to just over 6% when LMI household electrification is prioritized, but increases to 10.5% when these homes are not prioritized. At 75% electrification rate, energy burden decreases stabilize (or potentially increase slightly), indicating that the last 25% of homes to electrify may see higher energy prices; however, it is difficult to predict exactly what energy markets would look like under such a massive transformation.

It is therefore essential that policymakers prioritize LMI households in electrification and broader decarbonization policy. While the $4.5 billion in the IRA's "High Efficiency, Electric Home Rebate Program" marks an important down payment, we compute the total cost of installing efficient electric equipment in LMI households to be $630 billion.[35] While scaling

[34] However, we note that there may be additional costs, such as program administration or home repairs.

[35] This includes the total cost of installing efficient electric space heating, water heating, clothes drying, and cooking equipment in LMI households relative to maintaining the status quo ($470 billion) and the remaining value of existing equipment ($160 billion). This does not include any program costs associated with reaching LMI households who may not otherwise electrify. We compute the total cost of installing efficient electric equipment in all U.S. households as $1.0 trillion, including the total cost of installing efficient electric relative to maintaining the status quo ($710 billion), and the remaining value of existing fossil fuel or electric resistance equipment that would be replaced before the end of its useful life ($290 billion).

efficient electric retrofits and mechanisms such as modified utility rate design can reduce these costs, additional investments will be needed.

This study also provides important insight into which LMI households to initially prioritize that can guide home electrification program administrators, both now and as energy prices change, with customers leaving the natural gas system and increasing electricity system capacity needs. On a purely equipment and energy cost basis, water heating is the most cost-effective end use to electrify; homes using fuel oil, propane, and electric resistance are far more cost effective to convert to heat pumps and to fully electrify than natural gas homes, and single-family homes are less costly to electrify than multifamily homes. While these findings are generally in line with previous studies, the methodology presented here and the level of detail in our model can provide further guidance for targeted program design and implementation (e.g., electrification incentives tailored to specific home and system characteristics rather than income alone).

Incorporating societal costs and benefits illuminates the needs for adaptive policies and program targeting. Of all measures considered, the benefit per household from electrifying space heating increases the most when incorporating climate and health impacts. Our analysis suggests that programs targeting space heating heat pumps are likely to have the most positive societal impact. Programs should thus be targeted to fill the gap between the household costs and societal benefits of LMI household space heating electrification. The methodology and model underlying this report provide a framework that can be used to incorporate the health and broader societal economic impacts into cost-effectiveness analysis for policy development. For most individual LMI households as well as at a societal level, the benefits of public investment in electrifying space heating—which could be in the form of upfront investment, as well as electricity rate reductions—would dwarf the costs.

The benefits of electrifying natural gas vis-à-vis other current fuels also shifts considerably with the inclusion of societal costs and benefits, indicating that LMI households using natural gas may require unique programs to realize these benefits. In addition to offsetting the cost of heat pump installation, such programs would most likely need new rate designs to reduce costs of electric space heating and/or include increased home energy assistance for electricity for heating to avoid increasing (or to actually decrease) energy burden in service of the broader societal benefits (Yim and Subramanian 2023). Low-Income Heating Energy Assistance Program (LIHEAP) benefit caps are generally the same—and sometimes lower—for electricity as for natural gas (LIHEAP Clearinghouse 2023).

One important finding is that although natural gas homes are generally more costly to electrify, once a home electrifies gas water heating and space heating, there is a significant economic benefit to disconnecting from the gas utility altogether. Cooking and clothes drying use relatively little fuel, and replacing them is likely to be economical once the major end uses of space and water heating are electrified. This suggests that electrification policy and programs should target space heating and water heating and avoid an outsized focus on appliances like gas cookstoves. That said, programs would likely benefit from highlighting the cost savings of disconnecting from gas service altogether once these other measures are taken. Creative policy and program design should incorporate the household energy cost savings of disconnecting gas service in pursuit of broader electrification.

Natural gas conversions in LMI households will continue to present a challenge that requires effective planning and policy now, potentially including incorporating the value of such conversions presented in this report into emerging clean heat standards. Our analysis indicates that at very high electrification rates (somewhere between 50% and 75%), there begin to be economic benefits of converting from natural gas space and water heating to electric heat pumps; however, this is only once so many other natural gas homes have electrified that the gas service becomes very expensive for remaining customers. We need to ensure that LMI households using natural gas receive investments now—as well as the necessary support to reduce energy burdens, as noted above—so that those households left on the gas system when prices spike are those able to invest in cost-effective upgrades when they choose.

Because the benefits of investing in efficient electrification of LMI households far outweigh the costs, not investing in these households is a decision in itself: a decision to not pursue the most cost-effective approach, a decision to place some of those costs on the healthcare system—and a decision to burden ourselves with the costs of climate change.

There are also other important non-energy factors related to electrification and energy efficiency in LMI households that are not easily quantified, but which are well understood by these households. Considering these factors will be important to ensuring benefits accrue to their communities. In reviewing our findings, ACEEE's Equity Working Group—a group of representatives from community-based organizations (CBOs) and others from LMI communities that ACEEE convenes to inform our research and policy work—noted the particular importance of coupling efficient electrification with improved energy systems resilience in communities that have historically had less reliable services. Because electrification could shift utility costs to those renters that live in multifamily buildings with central heating and hot-water systems, including renter and tenant protections is also important. Some electrification programs require envelope upgrades before heat pumps can be installed, and while this makes sense, it can present another financial barrier. Overall, the biggest problem we heard is that funding is vastly inadequate to the need.

We also analyzed the inclusion of average aggregate costs and energy usage reductions associated with energy efficiency retrofits in conjunction with the electrification measures. At a national level, this analysis did not affect our overall findings. However, we did find that retrofits can lower household costs for electrification in colder climates (above about 6,000 HDD, or roughly the climate of Pittsburgh, Pennsylvania). We do not quantify benefits beyond household electrification costs, such as benefits to the electric grid.

Additional quantitative and qualitative research can build on this effort to effectively guide policies that properly value equitable electrification as identified here. The model and methodology underlying this report can be applied to specific states and the full range of household characteristics in the RECS dataset. Further developing the model into a technical assistance tool—and incorporating additional data sources, such as Census Bureau survey data and state and local databases—would thus provide policymakers and program administrators with actionable information in shaping programs and most effectively utilizing limited resources. There is also a need to systematically assess what approaches are successful in electrifying LMI households when the cost-benefit analysis does not work in their favor and/or when upfront costs are prohibitive.

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Appendix A: Methodology

CALCULATING AREA MEDIAN INCOME (AMI) BY STATE, URBAN STATUS, AND HOUSEHOLD SIZE

The median household income by state and urban status was estimated through the Public Use Microdata Sample (PUMS) from the American Community Survey (ACS) (U.S. Census Bureau 2022). The ACS is administered by the United States Census Bureau and gathers annual demographic data nationwide. Users are able to access tabulated data through the Census website. For custom tabulations, users must use the PUMS, which is an anonymized subset of the ACS, selected and weighted in order to produce similar results to the ACS without revealing identifying information of the survey respondents.

We used the complete microdata sample of households in our calculation of area median income (AMI). Geographically, the respondents are identified by Public Use Microdata Areas (PUMAs), which is a geographic designation used for the Census. In our analysis, we could not use the full granularity of PUMAs, so we split each state by its urban status, which is available in RECS microdata. Homes in RECS are classified as rural (less than 2,500 people), urban (greater than 50,000 people), or urban cluster (2,500–50,000 people), which we approximated using core-based statistical areas (CBSAs). CBSAs are another type of geographic designation used by the Office of Management and Budget (OMB). Under the CBSA definition, metropolitan areas have "at least one urbanized area of 50,000 or more population, plus adjacent territory that has a high degree of social and economic integration with the core as measured by commuting ties," while micropolitan areas "have at least one urban cluster of at least 10,000 but less than 50,000 population," and adjacent territory with commuting ties (U.S. Census Bureau 2021).

To convert PUMAs to CBSA types, we used Geocorr 2022: Geographic Correspondence Engine, an application from the Missouri Census Data Center which converts different types of geographic designations (Missouri Census Data Center 2022). Geocorr interprets PUMAs which are located in multiple CBSA types as a population ratio; for example, if a PUMA contains 100,000 people, 75,000 of which are located in a metropolitan CBSA and 25,000 of which are in a micropolitan CBSA, Geocorr will designate that PUMA as 75% metropolitan and 25% micropolitan. Within our analysis, we multiplied these ratios by the housing weights for each datum. For example, if a household is located in the aforementioned PUMA and has a housing weight value of 10, we interpret this household as having a weight of 7.5 within metropolitan analysis and 2.5 within micropolitan analysis. Using these weights, we then calculated the weighted median of household income by state and CBSA type, which is what we used for AMI.

To determine if households in RECS microdata were low or moderate income, we additionally applied HUD's household income percentage adjustments for different sizes of families to the area median income (calculated as described above) (U.S. Department of Housing and Urban Development 2023). Therefore, it is assumed that, all other variables equal, the six-person family requires 116% of the income of the four-person family to maintain the same quality of life.

Table A1.

Number of persons in family and percentage adjustments for AMI							
1	2	3	4	5	6	7	8
70%	80%	90%	Base	108%	116%	124%	132%

Each household was then classified following HUD's definitions as very low (earning less than 50% AMI), low (earning 50–80% AMI), moderate (earning 80–120% AMI), or not LMI based on the family-size adjusted area median income. Since RECS uses income bins for households, we use the midpoint of each bin to make this determination. Households in the highest income bin (earning over $150,000 in 2020) are all assumed to be not LMI. This may incorrectly categorize large households in a handful of the most expensive areas. For example, we calculated the AMI in metropolitan New Jersey to be $95,823; for a family of six, 120% of the family-size adjusted AMI is $151,784.

ELECTRIFICATION RETROFIT MAPPING

The electrification approach for space heating, water heating and other end uses in each home depends on the home/building type, existing system(s), fuel type(s), and climate. We isolated the following specific factors included in or derived from the RECS data that can affect retrofit options, though they do not necessarily affect all end uses:

- Housing unit type: single family detached, single family attached, apartments (2–4 unit buildings), apartments (5+ unit buildings), and mobile homes
- Main fuel for the end use (space heating, water heating, cooking, clothes dryers): natural gas, electricity, fuel oil or kerosene (FOK), propane, wood, or some other fuel
- Main end use equipment/system: central warm-air furnace, steam boiler, hot-water boiler, heat pump (ducted), ductless heat pump (mini-split), or other
- The presence of air-conditioning (AC) equipment: central AC, ductless heat pump (mini-split), room/window ACs, or other
- Whether an existing system serves multiple units or a single unit
- Climate, as indicated by heating degree days (HDD), with some consideration of heating design temperature

Space Heating Retrofits

Based on the factors above and after grouping existing conditions that we deemed to have similar retrofit considerations, we identified a total of 101 unique existing heating and cooling system arrangements that influence the electrified space heating system, though they all rely on five general post-retrofit electric heat pump systems:

- Ducted air-source heat pump (ASHP)
- Ducted cold climate air-source heat pump (ccASHP)
- Ductless mini-split ASHP
- Ductless mini-split ccASHP
- Air-to-water heat pump (AWHP)

Our analysis excluded existing homes with electric heat pumps as the main heating equipment and those using fuels other than natural gas, FOK, or propane (primarily wood and trace amounts of other fuels).

We considered the most straightforward heat pump retrofit to be a swap for an existing AC system, with additional considerations for the home's climate, as shown in Table A2. We further considered a dual-fuel scenario for very cold climates in which existing fossil fuel heating systems provide backup to the heat pumps at very low outdoor temperatures (current electric resistance systems are always considered to convert fully to heat pumps).

Table A2. Heat pump retrofits for homes with existing air-conditioning systems

		New electrified system	
Existing AC system	HDD	All-electric	Dual-fuel scenario
Central AC equipment	≤4,000 HDD	Ducted ASHP	N/A
	4,000–6,000 HDD	Ducted ccASHP	N/A
	>6,000 HDD	Ducted ccASHP	Ducted ccASHP with backup from existing fossil fuel heating system
Ductless mini-split HP	≤4,000 HDD	Ductless mini-split ASHP	N/A
	4,000–6,000 HDD	Ductless mini-split ccASHP	N/A
	>6,000 HDD	Ductless mini-split ccASHP	Ductless mini-split ccASHP with backup from existing fossil fuel heating system
None	See Table A3.		

Where homes did not have existing AC systems or used window or wall AC units, the heat pump retrofit depended entirely on the existing heating system, with the same climate considerations, as shown in Table A3. RECS does not distinguish hydronic heating systems between steam and hot water, indicating only "steam or hot water." To provide some diversity for consideration in our model, we assumed hydronic systems in buildings built before 1950 to be steam and in 1950 or later to be hot water (in line with Nadel and Fadali 2022).

Table A3. Heat pump retrofits for homes without existing air-conditioning systems

Existing heating system	HDD	New electrified system All-electric	Dual-fuel scenario
Fossil fuel *or* electric resistance warm-air furnace	≤4,000 HDD	Ducted ASHP	N/A
	4,000–6,000 HDD	Ducted ccASHP	N/A
	>6,000 HDD	Ducted ccASHP	Ducted ccASHP with backup from existing fossil fuel furnace
Fossil fuel hot-water hydronic heating system	≤4,000 HDD	AWHP	N/A
	4,000–6,000 HDD	AWHP	N/A
	>6,000 HDD	AWHP	AWHP with backup from fossil fuel boiler
Fossil fuel steam heating system	≤4,000 HDD	Ductless mini-split ASHP	N/A
	4,000–6,000 HDD	Ductless mini-split ccASHP	N/A
	>6,000 HDD	Ductless mini-split ccASHP	N/A
All other fossil fuel heating	≤4,000 HDD	Ductless mini-split ASHP	N/A
	4,000–6,000 HDD	Ductless mini-split ccASHP	N/A
	>6,000 HDD	Ductless mini-split ccASHP	Ductless mini-split ccASHP with backup from existing fossil fuel heating system
All other electric resistance heating	≤4,000 HDD	Ductless mini-split ASHP	N/A
	4,000–6,000 HDD	Ductless mini-split ccASHP	N/A

Existing heating system	HDD	New electrified system All-electric	Dual-fuel scenario
	>6,000 HDD	Ductless mini-split ccASHP	N/A

While the above general designations apply across all home types, we combined home types into two broad groupings that affect the specific performance and costs of space heating systems (see "Equipment, Installation, and Performance Assumptions" section below):

- Single-family detached and attached, apartments (2–4 unit buildings) and mobile homes
- Apartments (5+ unit buildings)

Water Heating Retrofits

We have far fewer unique arrangements affecting water heating retrofits based on data provided by RECS and our consideration of replacement systems. The systems described in Table A4 are again not meant to be the only options but as representative for our analysis in this report. We broadly considered unitary heat pump water heaters (HPWHs) and central HPWH systems.

Table A4. Heat pump retrofits for homes without existing air-conditioning systems

				New electrified system	
Housing unit type	Main water heating fuel	Serves multiple units	HDD	All-electric	Dual-fuel scenario
Single-family attached, detached, mobile homes	Natural gas, FOK, propane, electricity	All	All	Unitary HPWH, single unit	N/A
Apartment (2–4 unit building)	Natural gas, FOK, propane, electricity	Yes	All	Unitary HPWH serving average of 3 units	N/A
		All other	All	Unitary HPWH, single unit	N/A

				New electrified system	
Housing unit type	Main water heating fuel	Serves multiple units	HDD	All-electric	Dual-fuel scenario
Apartment (5+ unit building)	Natural gas, FOK, propane	Yes	≤4,000 HDD	Central HPWH system	N/A
			>4,000	Central HPWH system	Central HPWH system with existing fossil fuel backup
		All other	All	Unitary HPWH	N/A
	Electricity	Yes	All	Central HPWH system	N/A
		All other	All	Unitary HPWH	N/A

Existing main water heating systems using wood, solar-thermal, or some other fuel are excluded from our analysis.

Full Electrification

We did not investigate the standalone effects of electrifying other end uses, such as gas cookstoves or clothes dryers. However, we did consider full electrification scenarios that included electrifying remaining fossil fuel–based end uses after electrifying space heating and water heating (and the associated cost savings from no longer being gas customers). In these analyses, we included the following:

- Homes using natural gas or propane for cooking converted to fully electric ranges and ovens
- Homes using natural gas, propane or electric resistance clothes dryers converted to electric heat pump clothes dryers

We did not include analyses of other minor fossil fuel end uses, assuming these to have a negligible impact on our findings. For homes with any natural gas end uses, "full electrification" scenarios include the elimination of the assumed $20/month fixed customer cost.

EQUIPMENT, INSTALLATION, AND PERFORMANCE ASSUMPTIONS

We referred to several sources in establishing a set of equipment and installation costs and their associated efficiencies as well for our analysis. Given that our analysis included both existing and replacement systems for a wide range of fossil fuel and electric systems, we chose to root our analysis in one near-comprehensive dataset: the U.S. Energy Information Administration (EIA) 2023 Updated Buildings Sector Appliance and Equipment Costs and Efficiencies used in the National Energy Modeling System (NEMS) for the 2023 Annual Energy Outlook (U.S. Energy Information Administration 2023a, 2023b).

Space Heating Assumptions

Because our analysis is particularly focused on electrification, we referred to several other sources to compare costs for electrification retrofits. Our costs are generally in line with those of a previous study co-authored by one of us (Nadel and Fadali 2022), with some exceptions for cold climate space heating heat pumps. We also reviewed a study of New York State electrification costs by Rosen Consulting Group, data assumptions for Energy and Environmental Economics (E3) technical analysis supporting New York's Climate Action Scoping Plan, and E3's residential building electrification study for California (Rosen et al. 2022; Mahone et al. 2019; Wilcox, Hammer, and Patane 2022). The New York and California studies generally showed higher costs than our base assumptions for space heating in table A5. We identify several reasons for this:

- New York and California are generally more expensive markets than national averages would reflect.
- The California study has particularly high costs, with even gas furnace replacements at 3–6 times our base costs.
- The New York and California studies are whole home costs, whereas our base costs assume fairly modest size heat pump systems, which are then adjusted upward based on climate and home size (see "Space Heating Heat Pump Cost Adjustment" section below).
- The climate across New York State can be considerably colder than national averages (see "Space Heating Heat Pump Cost Adjustment" section below).
- This study is looking at pathways to widespread use of heat pumps across the United States with the lower costs that would be reflected in large volumes of a robust market.

Table A5. Space heating system cost per home and efficiency assumptions

System	Average efficiency or coefficient of performance (COP)	Total installed cost per home (2020$)	Notes
Replacement/Heat Pump Systems			
Ducted HP	2.7	$6,385	(a); consistent with (b)
Ducted ccHP	All-electric 2.80 Dual fuel 3.16	All-electric $9,453 Dual fuel $7,922	(a); low cost for ccHP in (c) Adjusted cost for dual fuel based on difference between (d) and (e) Increased dual-fuel COP by 13% as in (b)
Ductless HP	3.25	$5,603	(a); consistent with (b)
Ductless ccHP	3.37	All-electric $8,296 Dual fuel $6,952	(a); consistent scaling for cold climate as for ducted HP and (c) Adjusted cost for dual fuel based on difference between (d) and (e) Increased dual-fuel COP by 13% as in (b)
Ductless HP, 5+ unit multifamily	3.25	$7,131	(a) for efficiencies Scaled up from single family based on (c)
Ductless ccHP, 5+ unit multifamily	3.37	All-electric $10,558 Dual fuel $8,848	(a) for efficiencies Scaled up from single family based on (c)
AWHP	3	$8,038	COP assumed to be similar as for water heating; cost scaling in line with (b)
AWHP, 5+ unit multifamily	2.3	$5,286	COP based on review of available systems and personal conversations with designers; (a) air-cooled chiller cost basis scaled to capacity of gas boilers
Existing/Fossil Fuel and Electric Systems			
Ducted AC	4.07	$5,410	Efficiency (a) installed based (a) cost basis, in range of (b)

System	Average efficiency or coefficient of performance (COP)	Total installed cost per home (2020$)	Notes
Gas furnace	0.8	$3,818	Efficiency (a) installed based (a) cost basis, in range of (b)
Oil furnace	0.83	$4,738	Efficiency (a) installed based (a) cost basis, low range of (b)
Gas boiler	0.84	$5,814	Efficiency (a) current standard level

			(a) cost basis, low range of (b)
Oil boiler	0.86	$5,111	Efficiency (a) installed based Cost lower than (b) but using (a) for consistency
Central/MF5+ gas boiler	0.85	$4,254	Efficiency (a) installed based Cost lower than (b) but using (a) commercial boiler scaled to same household size for consistency
Central/MF5+ oil boiler	0.85	$6,466	Efficiency (a) installed based Cost higher than (b) but using (a) commercial boiler scaled to same household size for consistency
Other fossil fuel heating	0.8	$2,397	Efficiency same as gas furnace Current standard gas furnace equipment cost, plus ½ installation cost, both from (a)
Electric furnace	0.98	$1,362	(a) basis for efficiency and cost; cost generally in line with other sources
Electric baseboard	1.0	$996	(a) basis for efficiency and cost; cost generally in line with other sources
Electric boiler	0.96	$3,680	Consumer scale not included in references. Assumed slight efficiency derating vs. large/central boiler from (a); cost set at midpoint of homeadvisor.com range
Central/MF5+ electric boiler	0.98	$1,584	(a) basis for efficiency and cost
All other electric space heating	1	$996	Assumes electric baseboard efficiency and costs

(a) U.S. Energy Information Administration 2023b basis

(b) Nadel and Fadali 2022

(c) Wilcox, Hammer, and Patane 2022

(d) Rosen et al. 2022

(e) Mahone et al. 2019

Space heating heat pump coefficient of performance adjustment

We made an adjustment to the base average heat pump coefficient of performance (COP) values from table A5 to account for low-temperature effects. To do so, we extracted load profiles and COP temperature-dependence behavior from the industry standard for rating the performance of ASHPs, fitting the following resulting equation (AHRI 2020):

$$COP_{avg} = COP_{avg,base} \times \left[1.381 \times e^{(-5.976\times10^{-5})\times HDD}\right]$$

where:

$COP_{avg,base}$ = average base COP from Table A5

HDD = heating degree days for the home from RECS adjusted for 2020–2050

SPACE HEATING HEAT PUMP COST ADJUSTMENT

As noted above table A5, we adjusted heating equipment costs to reflect two effects on heating capacity needs: climate and home size. The following equation was derived from a peer-reviewed study by one of this report's authors (Waite and Modi 2020) and the underlying efficiency assumptions of table A5:

$$COST = COST_{base} \times max \begin{cases} 1 \\ (1.1 \times 10^{-5}) \times SQFT \times (65 - HDT) \times (1 - EFF/2) \end{cases}$$

where:

$COST_{avg,base}$ = average base cost from table A5

$SQFT$ = heated home square footage from RECS

HDT = heating design temperature from RECS

EFF = (if applicable) the home retrofit energy savings, for example, for 29% energy savings, EFF=0.29.

WATER HEATING ASSUMPTIONS

Fewer adjustments were necessary to develop efficiency and cost assumptions for water heating than for space heating as there were fewer differences among the reference material and less temperature sensitivity. Table A6 summarizes the water heating assumptions.

Table A6. Water heating system cost per home and efficiency assumptions

Equipment type	Average efficiency or COP	Total installed cost (2020$)	Notes
Replacement/Heat pump systems			
Unitary storage HPWH			
- Small	3.18	$1,846	(a) for medium, large and small +/– 10%
- Medium	3.28	$2,052	
- Large	3.38	$2,257	
Central HPWH	3.00	$4,963	(a)
Existing/Fossil fuel and electric resistance systems			

Gas storage water heater			
- Small	0.63	$1,777	Average of (a) for medium, large and small +/– 10%
- Medium	0.63	$1,973	
- Large	0.63	$2,171	
Gas tankless water heater	0.89	$1,983	Average of (a)
Gas central water heater	0.82	$1,197	Efficiency: commercial gas storage water heater from (a); cost scales (a) commercial down to per household based on heating capacity for residential size
Oil storage water heater			
- Small	0.67	$2,803	Average of (a) for medium, large and small +/– 10%
- Medium	0.67	$3,114	
- Large	0.67	$3,426	
Oil tankless water heater	0.89	$3,129	Efficiency same as gas tankless; cost scales same as oil/gas storage water heaters
Oil central water heater	0.81	$2,120	Efficiency: commercial oil storage water heater from (a); cost scales (a) commercial down to per household based on heating capacity for residential size
Electric storage water heater			
- Small	0.92	$750	Average of (a) for medium, large and small +/– 10%
- Medium	0.93	$833	
- Large	0.94	$916	
Electric tankless water heater	0.89	$478	(a)
Electric central water heater	0.82	$1,273	Efficiency: commercial electric storage water heater from (a); cost scales (a) commercial down to per household based on heating capacity for residential size

(a) U.S. Energy Information Administration 2023b basis

Additional Assumptions

Table A7 contains cost and efficiency assumptions for cooking and clothes dryers.

Table A7. Cooking and clothes dryers cost per home and efficiency assumptions

Equipment type	Efficiency	Total installed cost (2020$)	Notes
Replacement/Heat pump systems			
Electric range	(See notes)	$708	(a) for efficiency and cost. Energy usage is assumed to be 61% of that of cooking gas based on a blend of cooking appliances.
Electric HP dryer	5.32	$920	Cost from (a); efficiency metric is “energy factor” from (a)
Existing/Fossil fuel and electric resistance systems			
Gas range	(See notes)	$846	(a) for cost. See electric range notes on efficiency.
Electric resistance Dryer	3.93	$653	Cost from (a); efficiency metric is “energy factor” from (a)
Gas dryer	3.18	$800	Cost from (a); efficiency metric is “energy factor” from (a)

(a) U.S. Energy Information Administration 2023b basis

Electrifying end uses can also require upgrades to a building’s electrical service panel or interior wiring. Such needs and costs are highly building and retrofit dependent. We assume a base cost of $1,300 per household for electrical work, based on the medium cost assumption from Nadel and Fadali (2022). We then make various adjustments. The first is a multiplier of 2/3 for housing units in multifamily buildings with five or more units, which is in line with the scale difference in Rosen et al. (2022) and Mahone et al. (2019). Other adjustments are made based on the existing systems and climate, the latter being an indicator of higher heating capacity needs. Table A8 summarizes these cost assumptions.

Table A8. Cost adders per home for electrical upgrades

Existing situation	All homes except those in multifamily with 5+ units (2020$)	Homes in multifamily buildings with 5+ units (2020$)
Space heating		
Electrifying fossil fuel heating where home already has AC and HDD <4,000	$0	$0
Electrifying fossil fuel heating where home does not already have AC and HDD <4,000	$1,196	$798
Electrifying fossil fuel heating where home already has AC and HDD >4,000	$1,196	$798

Electrifying fossil fuel heating where home does not already have AC and HDD <4,000	$1,794	$1,196
Water heating		
Electrifying fossil fuel water heating	$1,196	$798
Additional for full electrification where other fossil fuel end uses		
Full home electrification	$598	$399

HEATING DEGREE DAYS AND CLIMATE CHANGE

RECS 2020 microdata includes annual heating degree days for each home (with random errors to protect the privacy of respondents) for the year of the survey (2020) and for the 30-year average annual heating degree days over the period 1981–2010. This period is unlikely to represent the climate of the analysis period well, so we adjusted the heating degree days included in RECS to account for climate change. All mentions of heating degree days refer to this adjusted average unless otherwise noted.

Specifically, to adjust annual heating degree days, we matched weather stations from NOAA's 1981–2010 and 1991–2020 climate normals datasets and performed a regression (National Centers for Environmental Information 2021). The linear model we use is given by

$$HDD_{1991-2020} = -70.007 + 0.997604\text{HDD}_{1981-2010}$$

with $R^2 = 0.9941$ and residual standard error 200.9 on 1,092 degrees of freedom (and both HDD in degrees Fahrenheit). We composed this function with itself to extrapolate to 2020–2050, assuming each decade experiences the same decline in heating degree days. In other words,

$$HDD_{2020-2050} = -279.023 - 0.9904504HDD_{1981-2010}$$

For example, Boise, Idaho, with 6,181 heating degree days on average for the years 1981–2010, experiences 5,843 heating degree days in our analysis for 2020–2050. For comparison, ASHRAE reports that between 1977–1986 and 1997–2006, heating degree days decreased by 427°F-days on average (ASHRAE 2021).

CLIMATE IMPACTS

Climate impacts were calculated separately for each GHG considered and quantified in dollar terms using publicly available data sources. For fossil fuels included in the analysis (natural gas, fuel oil, and propane/liquid petroleum gas), combustion-related emissions factors of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were taken from the EPA's 2022 GHG Emissions Factors Hub (U.S. Environmental Protection Agency 2023b). Precombustion (commonly referred to as "upstream") emissions factors for fuels other than natural gas are from NREL's "U.S. Life Cycle Inventory Database" (National Renewable Energy Laboratory 2012). Precombustion emissions factors for natural gas were taken from a National Energy Technology Laboratory study specific to natural gas to be consistent with other recent studies and with the assumptions underlying electricity emissions factors (Skone et al.

2019).[36] Fossil fuel emissions factors were assumed to be the same in every location and every analysis year.

Electricity grid emissions factors were average emissions factors—including both combustion and precombustion emissions—for each state in each year through 2050 from NREL's 2022 Cambium mid-case scenario (NREL 2023). Cambium models do not include Alaska, Hawaii, or DC; for this study, we assumed Alaska, DC, and Hawaii emissions factors in each year to scale linearly with Cambium's U.S. values in accordance with the ratio between each region's emissions factor and the U.S. average emissions factor in EPA's 2021 eGRID (U.S. Environmental Protection Agency 2023a).

The social costs of GHG emissions (CO_2, CH_4, and N_2O) used in this study were from the EPA draft "Report on the Social Cost of Greenhouse Gases" for each year through 2050 (U.S. Environmental Protection Agency 2022). Values were based on a real discount rate of 1.5%; the report also presents values associated with real discount rates of 2.0% and 2.5%. Because the impact of GHG emissions is shifted to society and not incorporated into fuel prices, we assume the economic costs to reflect a societal/governmental cost rather than a private cost; the U.S. government can borrow long-term at a real discount rate less than 1.5%, so these values are most appropriate to assume.

HEALTH IMPACTS

Health impacts were calculated and quantified in dollar terms using the EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). COBRA allows users to input changes of emissions on a sector and county level and outputs changes in air pollution levels, the health impacts of the pollution, and the monetary impacts of the health effects. The model uses a source-receptor matrix to calculate the dispersal of emissions from one county to nearby counties, accounting for meteorological airflow and atmospheric chemistry. Health and monetary impacts are calculated using a literature review by the developers of the correlations between pollutant concentration and various conditions, as well as studies which measure the monetary impacts of these conditions through lost wages and healthcare costs. We used COBRA's 2023 baseline for emissions, population, and health impacts.

We used COBRA to derive its estimated healthcare costs per unit of energy. In other words, we wanted a $/MMBtu figure for the monetary impacts of residential fuel use and a $/kWh figure for each state's electricity supply. This was found by comparing COBRA output to the

[36] Natural gas leakage assumptions are as a percentage of usage, consistent with the referenced sources. We did not explore how leakage in distribution systems might be affected by being maintained for limited use, either with greatly reduced customer connections or customers connected only for dual-fuel heating operation.

fuel use and power generation sources used in the model, which is provided by the U.S. Energy Information Administration (EIA).

Appendix B: Supplementary Heating Landscape Tables

We first examine heating systems by income group (very low, low, moderate, and those with incomes above 120% AMI adjusted for family size). Below, we provide tables examining heating systems for LMI households as a group by building type, region, and renter/owner status.

For all income groups, gas furnaces are the most common heating system (see table B1). In fact, the three most common systems are the same in each group: gas furnaces, electric resistance heaters, and electric heat pumps. In the lowest income group, however, electric resistance heaters are found nearly twice as often as heat pumps and two-thirds as often as gas furnaces.

In contrast, for the highest income group, electric resistance heaters are less than a third as common as gas furnaces and are actually slightly less common than heat pumps.

Across all income groups, gas furnaces are present more often and electric resistance is present less often as household incomes increases, while the proportion of electric heat pumps is nearly constant among income levels.[37] The proportions of propane and oil heating systems also vary only slightly with income.

For all LMI households as a single group, central gas furnaces are the most common heating system, followed by electric resistance heaters. Electric heat pumps come in third, and fourth most common is gas boilers (excluding those households with no space heating at all). The full ranking is given in the last column of table B2.

[37] This is a relatively recent and promising development as the 2020 RECS data were the first to show a significant uptick in heat pump adoption in lower-income households. For more research on the consistency of electric heat pump adoption between income levels; see Davis (2023).

Table B1. Percentage of homes with heating system by income group

	Very low	Low	Moderate	Above	Among all households
Central gas furnace	34%	41%	44%	48%	43%
Electric resistance (built-in)	23%	20%	17%	14%	17%
Electric heat pump	13%	14%	14%	15%	14%
Gas boiler	7%	4%	5%	5%	5%
Propane	3%	4%	4%	5%	4%
Oil	3%	4%	4%	5%	4%
Portable electric heaters	4%	3%	3%	1%	2%
Gas individual units	3%	3%	3%	2%	2%
Other[38]	3%	3%	3%	2%	3%
None	7%	5%	5%	4%	5%

Building Type

For LMI households living in single-family detached homes (the largest group of LMI households, or about half of households, according to our calculations with RECS 2020 data), gas furnaces are by far the most common, followed by electric heat pumps. In single-family attached homes, gas furnaces are also by far the most common system, followed by electric resistance heating. Homes in multifamily buildings have this reversed: Electric resistance heaters are most common, nearly twice as common as gas furnaces. In 2–4 unit buildings, electric resistance heaters are about as common as gas furnaces, and in manufactured

[38] "Includes electric boilers, wood or pellet stoves, and "other" responses in RECS.

homes, electric heat pumps, electric resistance heaters, and gas furnaces are all about equally common.

Unlike other building types, which all have gas furnaces, electric resistance heaters, and electric heat pumps as the three most common heating systems, homes in 2–4 unit buildings have gas boilers as the third most common heating system (slightly ahead of electric heat pumps).

Propane is more common for manufactured homes than other building types, likely a reflection of both being more common in rural areas. Portable electric heaters are also much more likely to be the primary heating system in manufactured homes than other building types.

We highlight the first and second most common systems in table B2, with some approximate ties.

Table B2. Percentage of LMI homes with heating system by building type

	Manufactured homes	Single-family detached	Single-family attached	2–4 unit building	Multifamily (5+units)	Among all LMI households
Central gas furnace	24%	51%	49%	29%	20%	39%
Electric resistance (built-in)	22.4%	11%	19%	28%	36%	20%
Electric heat pump	22.6%	13%	11%	11%	14%	13%
Gas boiler	1%	3%	6%	13%	9%	5%
Propane	9%	5%	1%	0%	1%	4%
Oil	4%	5%	2%	3%	2%	4%
Portable electric heaters	9%	3%	2%	4%	3%	3%
Gas individual units	1%	3%	3%	4%	3%	3%
Other	3%	4%	0%	2%	2%	3%
None	4%	3%	7%	6%	11%	6%
LMI households in building type	9%	51%	6%	11%	23%	

Location and Climate

See the main text for a map and descriptions of Census divisions. We highlight the first and second most common heating systems in each Census division in table B3.

For most Census divisions, gas furnaces are the most common system among LMI households and electric resistance is the second most common. However, there is some variation: In the East South Central and South Atlantic divisions, electric heat pumps are the most common system, followed by gas furnaces in East South Central and electric resistance in the South Atlantic.

Oil systems (both furnaces and boilers) appear nearly as often as gas furnaces in New England, while they are virtually nonexistent in the West and South. Gas boilers are the second most common system in the mid-Atlantic, significantly ahead of electric resistance and oil systems, the next most common.

Table B3. Percentage of LMI households with heating systems by Census division

	East North Central	East South Central	Middle Atlantic	Mounta in North	Mountain South	New England	Pacific	South Atlantic	West North Central	West South Central
Central gas furnace	62%	27%	35%	62%	40%	30%	42%	20%	56%	34%
Electric resistance	17%	23%	14%	20%	21%	14%	19%	26%	18%	26%
Electric heat pump	3%	31%	5%	2%	18%	3%	5%	30%	6%	19%
Gas boiler	6%	1%	23%	5%	1%	14%	1%	2%	5%	0%
Propane	5%	5%	3%	3%	2%	4%	2%	3%	8%	2%
Oil	1%	1%	13%	0%	0%	28%	1%	2%	1%	NA
Portable electric heaters	1%	5%	1%	1%	3%	0%	7%	3%	1%	8%
Gas individual units	2%	3%	3%	3%	5%	3%	7%	1%	1%	3%
Other	4%	3%	3%	4%	3%	4%	3%	2%	4%	2%
None	1%	1%	1%	1%	7%	0%	14%	11%	1%	5%
LMI households in division	15%	6%	12%	4%	4%	4%	15%	20%	7%	13%

Owner/Renter Status

About 55% of LMI households are homeowners and 43% are renters, according to our calculations.[39] Electric resistance heaters are the most common heating system among renters, followed by gas furnaces, whereas for homeowners, gas furnaces are by far the most

[39] The remaining 2% report occupying their homes without paying rent, neither renters nor owners.

common, followed by electric heat pumps, with electric resistance heating a close third. The proportion of homes using electric heat pumps is similar for both renters and owners, but gas systems are a much larger proportion for owners.

Table B4. Percentage of LMI households with heating system by owner/renter status

	Owner	Renter
Central gas furnace	47%	28%
Electric resistance	13%	31%
Electric heat pump	14%	13%
Gas boiler	4%	7%
Propane	5%	1%
Oil	4%	2%
Portable electric heaters	3%	4%
Gas individual units	2%	4%
Other	4%	2%
None	4%	8%

In table B5, we show percentages of water heating systems by fuel. We presume electric water heaters are almost entirely electric resistance at the current early stage of adoption for heat pump water heaters.

Table B5. Percentage of homes with hot-water fuels by income group

Water heating fuel[40]	Very low	Low	Moderate	Above	Among all households
Gas	44%	46%	47%	51%	48%
Electric	51%	49%	48%	42%	46%
Propane	2%	2%	3%	4%	3%
Oil	2%	2%	2%	3%	2%

[40] A small percentage of homes (0.3% of every income group, and overall) use wood, solar thermal, or "other" fuel for water heating.

Appendix C: Other Supplementary Figures and Tables

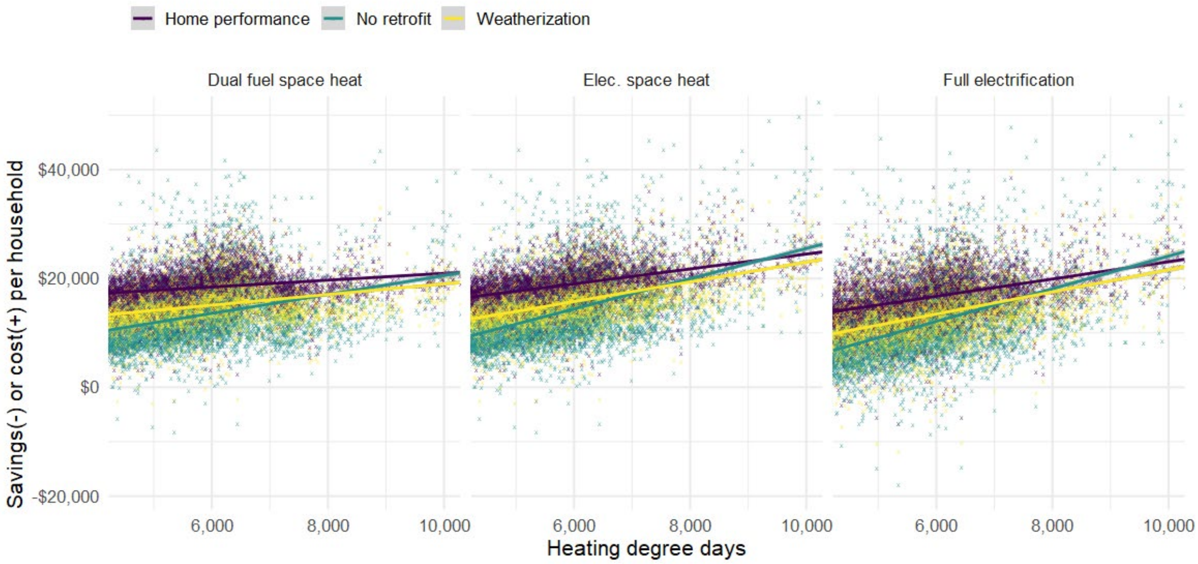

Figure C1. Benefits of efficiency for homes in 1–4 unit buildings with 0% electrification assumptions

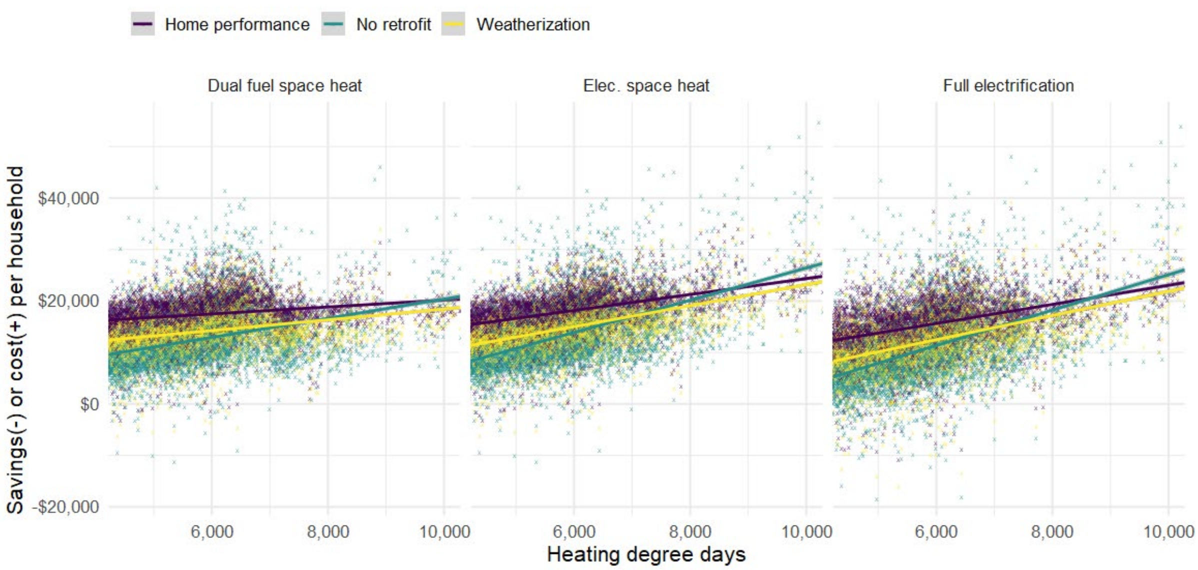

Figure C2. Benefits of efficiency for homes in 1–4 unit buildings with 25% electrification assumptions

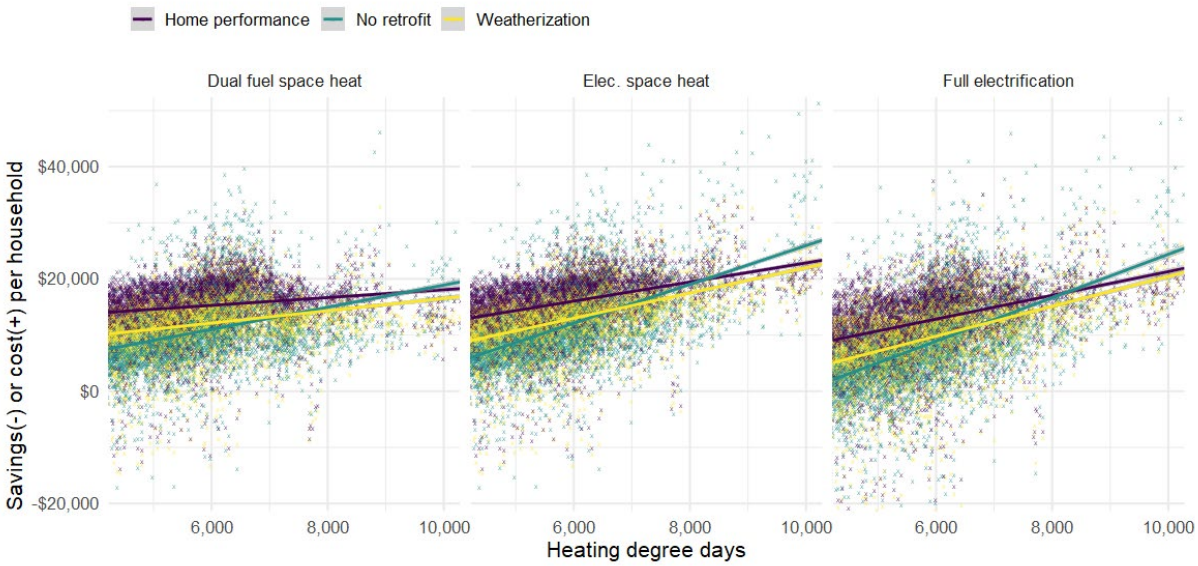

Figure C3. Benefits of efficiency for homes in 1–4 unit buildings with 50% electrification assumptions

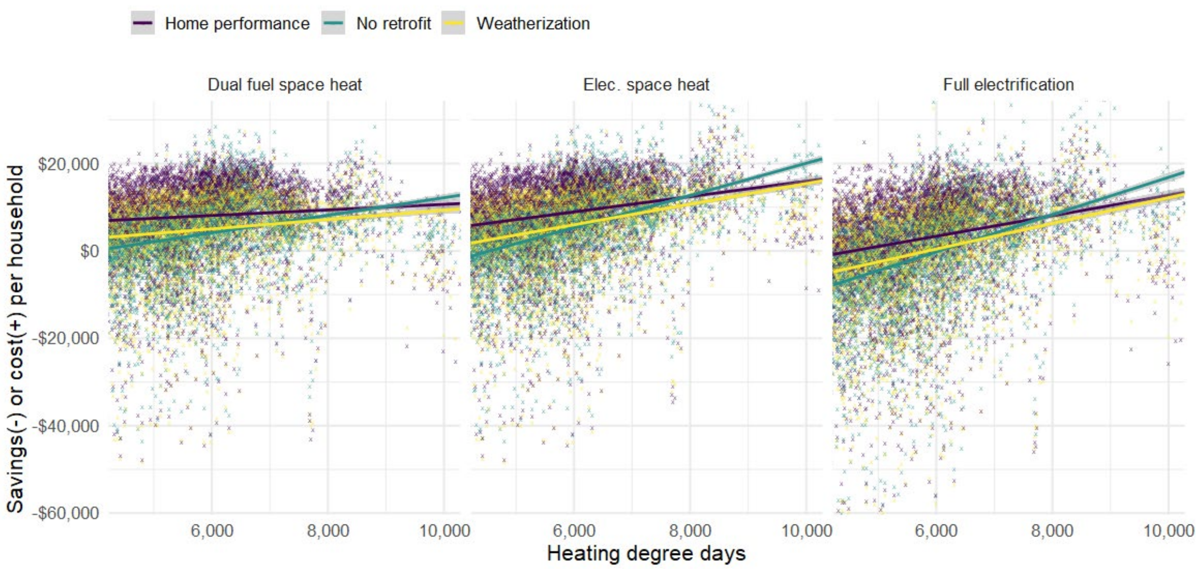

Figure C4. Benefits of efficiency for homes in 1–4 unit buildings with 75% electrification assumptions

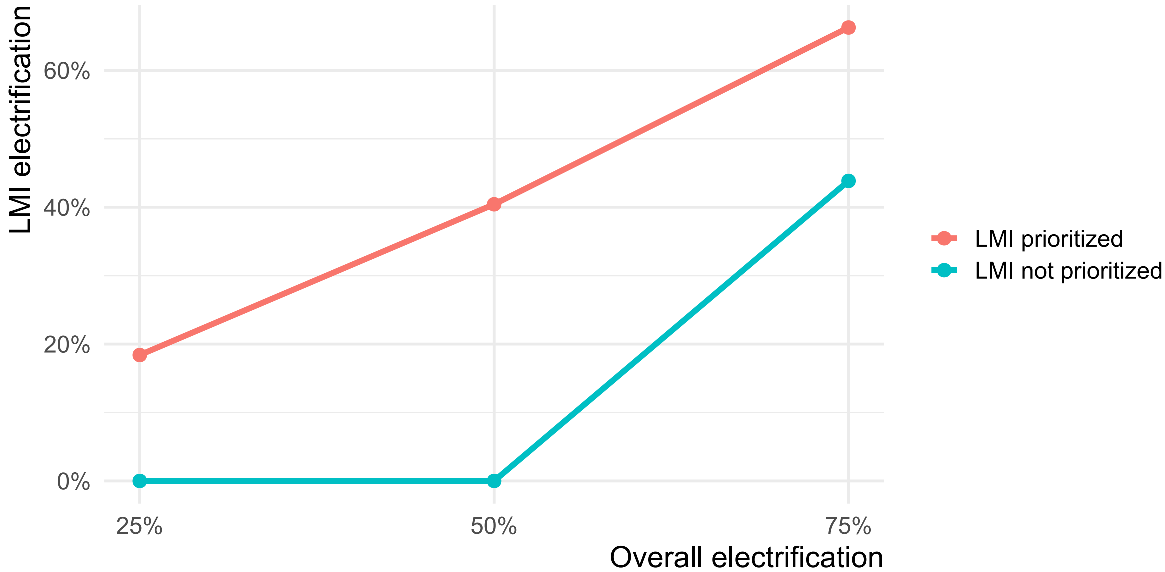

Figure C5. Proportion of LMI electrification versus overall electrification for the first, second, and third cohorts of homes when including societal and health costs associated with emissions

Table C1. Percentages of fossil fuel and gas electrification used to calculate electricity and gas prices in prioritization analysis

	2027–2034	2035–2044	2045–2050
s1: Base cost-benefit, including LMI			
Fossil fuel electrification	22.4%	49.9%	82.4%
Gas electrification	13.4%	36.9%	66.4%
s2: Base cost-benefit, excluding LMI			
Fossil fuel electrification	26.6%	60.3%	84.0%
Gas electrification	19.7%	50.7%	68.5%
s3: Cost-benefit including social cost of carbon and health costs, including LMI			
Fossil fuel electrification	33.7%	66.9%	98.8%
Gas electrification	22.0%	52.2%	82.8%
s4: Cost-benefit including social cost of carbon and health costs, excluding LMI			
Fossil fuel electrification	34.0%	62.6%	93.8%
Gas electrification	25.6%	52.7%	77.4%