Oh, You Thought Electrifying Buildings Would Be Easy? Lessons and Findings to Inform Electrification Strategies for Residential Buildings

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ABSTRACT

Electrifying residential space heating felt like low-hanging fruit in our otherwise formidable goal to decarbonize the economy, but it has also proven more difficult, expensive, and perhaps less beneficial than anticipated. What does this mean for all the work that remains?

This paper references research done for leading utilities across the U.S. characterizing key challenges, highlighting the approaches, and course corrections pioneering programs incorporated to electrify space heating in single and multifamily customer homes. Based on pilots and programs spanning the country, the authors will present case studies summarizing findings related to equipment and installation costs, actual customer bill impacts, the efficacy of customer targeting, and system performance. The authors also present specific approaches, findings and considerations for customers living in multifamily buildings and priority populations, like income eligible (IE) customers, and how programs are working to make these offerings cost-effective. These findings represent investigations of invoices for thousands of electrification projects, sub-metering for variable speed heat pumps (HP) under different control schemes in dual fuel and all-electric applications, recruitment findings for electrification pilots designed around targeting methods, and impacts created in electrification pilots of 100+ IE customer single- and multifamily homes.

Most importantly, the authors present how programs are taking these findings and using them to chart better paths forward, such as refining recruitment approaches, changing program designs, adapting savings calculations, partnering with other programs, refining workforce development approaches, and building better communication pathways within utility organizations and with customers.

Introduction

The authors present their findings and program implications for residential electrification by highlighting relevant background on Energy efficiency (EE) and demand side management (DSM) programs and then discussing the specific research areas of equipment and installation costs, customer bill impacts and screening, customer targeting, and equipment performance and installation before concluding the paper.

As the urgency of the climate crisis coincides with an unprecedented investment to transform our electricity sector, the energy industry has a critical opportunity to deliver equitable and scalable solutions rapidly. Through this paper, the authors seek to support the creation and implementation of successful residential electrification efforts via (1) documenting the historical context and precedents that EE programs must navigate in places where they are shifting focus to support decarbonization more directly, (2) sharing experiences and challenges supporting related efforts in practice, and (3) identifying potential solutions teams are exploring for barriers identified to date. The authors tie the context, barriers, and solutions together at the end to recommend broader strategies for the industry to pursue as we navigate challenges and seek an equitable, rapid clean energy transition.

Background

EE and DSM programs have been cost-effectively reducing energy demand in buildings, and thus decarbonizing energy use in buildings, for decades. However, due to several factors, utility commissions and federal, state, and local governments are asking these programs to do more to support efforts to transition the U.S. toward renewable energy (Citizens Utility Board). More specifically, many programs are being asked to support electrification as a near term step toward decarbonization. This change in goals reflects a pivot, arguably a reasonable pivot, for programs.

To provide context for the importance of the findings presented in this paper as they relate to the potential success of pivoting EE and DSM programs toward electrification, the authors provide background on traditional program operations and rules, key components of program economics, and recent changes to program operations.

Traditional EE and DSM Program Operations and Rules

EE and DSM programs have operated successfully for decades, creating a myriad of common practices, rules, and typical operations. For the purposes of this paper, the authors describe in this subsection a few traditional rules and common practices most relevant for residential electrification.

First, over the past couple decades, regulators largely prohibited EE and DSM programs from supporting measures that involve fuel switching between natural gas and electric energy, with a few well-defined exceptions. (ACEEE, 2022). The authors note this traditional limitation largely to emphasize that electrification signifies a significant pivot for EE and DSM programs.

Second, EE and DSM programs traditionally influenced the market to encourage EE consumer choices with financial incentives. Essentially, the program logic has often been that customer economics are the biggest driver of participation in EE measures, and as such, appropriately sized financial incentives and rebates could drive consumer choice toward EE product choices. In parallel to electrification, other methods for transforming markets have gained popularity, such as with workforce development and working with manufacturers to change product features (ENERGY STAR). The authors note this shift to a broader view of market levers and market transformation, because while it creates a wider range of tools for electrification programs to be successful, programs may experience barriers leveraging these tools in regions where processes around market transformation are not yet established.

Third, in many states, programs are carefully evaluated for *net* savings, or the difference in energy consumption with the program in place versus what consumption would have been without the program in place (Violette, Daniel, et al.). Evaluators and regulators emphasize net savings, because they seek programs to have an impact beyond external market trends. However, some regions intentionally take a different approach, in part because the program burden of accounting for net savings rather than gross savings can be substantial and may lead to ignoring program influence when and where it is hard to measure (Bonneville Power Administration). Lastly, when federal programs intersect with existing EE and DSM programs, like some state's Weatherization Assistance Programs, evaluators and regulators have often taken an approach to bypass the net savings question. For example, they may assume net savings are equivalent to gross savings for these programs. The authors highlight this topic for two reasons. If we consider

EE and DSM programs pivoting into one sphere of influence moving society toward decarbonization, does it change the importance of rigorously estimating net savings? Also, if other entities are also pursuing decarbonization, such as the federal government, can programs use similar logic for addressing net savings as they've used in other instances, or does the dynamic change for electrification and decarbonization?

Fourth, EE and DSM programs have largely been funded by states' EE resource standards, which set savings goals and spending requirements (ACEEE, Energy Efficiency Resource Standards). To support the spending requirements, utilities often collect funding via riders on customers' energy bills. While EE and DSM programs provide a variety of benefits, including a valuable customer service, EE and DSM programs could historically deliver savings at a cost per resource (i.e., dollars per therm or dollars per kilowatt hour) that was arguably competitive with generation resources. The authors note the traditional funding mechanism for EE and DSM programs and approximate cost per resource because later research findings may imply that significantly scaling electrification via EE and DSM programs may affect this balance, which could raise questions about whether the scale, source, or structure of funding should be reconsidered.

Key Components of Program Economics

For the purposes of this paper, the authors highlight certain components of program economics. Programs often have pre-established budgets, savings goals, and cost-effectiveness requirements. With pre-established budgets and savings goals, programs often seek to identify measures with the most savings at the lowest cost, or the lower cost per resource in units of cost per therms or kilowatt-hours saved. In this case, cost typically includes fixed costs, like program administrative costs, as well as variable costs, like rebates and incentives per measure. With this perspective, measures that can provide a lot of volume are valuable, because higher economies of scale help programs overcome fixed expenses. Similarly, as discussed before related to financial incentives, measures that require relatively small incentives to influence customers' choices yet provide considerable savings are often attractive. In short, programs want to achieve the greatest impact at the lowest cost possible. Lastly, programs also consider cost effectiveness metrics, which can mean societal or total resource cost test metrics (U.S. Department of Energy). These tests may be used to ensure that ratepayer dollars are prudently spent and the program benefits outweigh the costs. In some places these tests also serve to help programs identify measures with the greatest impact. The authors note these traditional components of program economics, because electrification may warrant discussion about their applicability for electrification and the feasibility of adjusting these tools to support pivoting EE and DSM programs toward electrification decarbonization. California has initiated a process for this adjustment, (California Public Utilities Commission) which represents progress, yet may be challenging for EE and DSM programs nationwide to follow and is providing a national test-case as costs for electrification grow and consumers seek lower energy costs (St John, Jeff).

Recent Changes to EE and DSM Program Operations

In this section, the authors identify changes in the EE and DSM landscape and broader market that are occurring in parallel to adding electrification into EE and DSM programs.

First, the federal government and other agencies are considering initiatives to mitigate climate change that could collide or interweave with EE and DSM programs and their changing goals. These initiatives could reduce programs evaluated *net* savings or they could represent opportunities for collaboration and co-funding, such as with FEMA's hazard mitigation efforts (Federal Emergency Management Agency).

Second, EE and DSM programs have benefited greatly from lighting efficiency, which paired very well with program economics. However, with new codes and standards, programs can no longer claim the bulk of their lighting savings. The loss of lighting savings creates an undercurrent throughout programs nationwide, where maintaining past savings goals and cost-effectiveness may be more challenging in future years.

Third, as noted previously, market transformation beyond financial incentives is gaining popularity within EE and DSM programs, which could create new tools and levers to help EE and DSM programs support electrification.

The authors note these three changes, because they all influence the role EE and DSM could ultimately play for electrifying customers and ultimately supporting decarbonization.

Equipment And Installation Costs

In this section, the authors discuss the costs of residential electrification installations and corollary electric service upgrades and the corresponding program implications. While electrification includes all end uses, such as electric stoves, water heaters and clothes dryers, the authors provide additional details for and considerations of space heating, as one of the main costs in fully electrifying residential buildings (Tudawe, Ranal).

Key Findings and Program Solutions

Program designs that will successfully create residential electrification at scale will need to understand costs and costs drivers with accuracy and reliability, as early efforts indicate higher costs than expected. Designs should also identify and consider the cost drivers, such as space heating system features, that improve performance as while these drive initial costs up, they might also better enable programs to meet cost-effectiveness and/or positive customer bill impact requirements.

Results from leading whole home electrification pilots and initiatives in the Midwest and California indicate the following cost drivers for single family and multifamily projects:

- **Home characteristics.** Home size, age, and the presence of ducts or AC are the biggest drivers of cost for whole home and space heating electrification projects (Sarkisian et al).
- **Electrical infrastructure upgrades.** The cost of the upgrades can increase project costs from $1,500 to $12,000 per project (Sarkisian, Dylan; Montesdeoca, Jackie). Home age appears to be one of the best indicators for the potential need for required electrical upgrades (Sarkisian, Dylan).
- **Space heating system performance.** ASHPs with high efficiency at low outdoor air temperatures, often characterized by manufacturers as hyper-heat, extended capacity or cold-climate systems, tend to be priced higher than systems that operate at lower efficiencies in the same temperatures (Sarkisian, Dylan)
- **Market maturity.** Contractor knowledge, availability and experience affect installation costs and, in some instances, performance (Montesdeoca, Jackie)
- **Negotiated vs. competitive prices.** One midwestern pilot found successful cost reduction of ASHP systems by getting competitive bids from contractors wanting to participate in the pilot. Another pilot had success in negotiating average system costs via a bulk

purchase agreement with one contractor, but noted this could be a barrier for small and/or diverse contractors (Montesdeoca, Jackie).

While the cost drivers for IE and priority populations do not vary widely from the categories listed above, the prevalence of them across populations does. According to analysis of TECH Clean California data, homes more than 50 years old needed a panel upgrade at a rate 1.75 times greater than homes less than 50 years old. Additionally, TECH Equity Community homes belong to census tracts with a median age of 58 years, nine years older than the median age for homes in the general population (Sarkisian, Dylan). Perhaps anecdotally, some level of electrical system upgrade was required in all participating homes in the IE SF and MF Chicago pilot (Montesdeoca, Jackie).

Cost drivers in multifamily electrification projects are less well understood than single family projects, as applications and conditions vary widely across this segment. More research is needed to provide enhanced design considerations for programs targeting this customer segment.

Methods and Research Background

The information presented in this section reflects the authors' work synthesizing costs across the following electrification efforts implemented in more than 15,000 homes between 2021 to present in the Midwest and California.

Whole home electrification in SF and MF Chicago customer homes

Elevate together with Commonwealth Edison (ComEd) and the Chicago Bungalow Association implemented a large-scale pilot demonstrating the feasibility of whole-home weatherization and electrification retrofits across more than 100 single and multifamily IE customer hones. These customers were offered combined weatherization and full electrification retrofits, as well as electrical upgrades as needed. Ultimately, the median total whole home electrification project cost was $41,800, with an average per project cost of $23,000 for the ASHP system (Montesdeoca, Jackie).

Whole home electrification in SF Midwestern customers' homes.

One midwestern utility partnered with an implementation contractor to pilot whole home electrification in single family homes throughout the state. This contractor negotiated a set of fixed prices for ASHP systems with a contractor for this pilot, with a median cost of $19,700.

Whole home electrification in 1-to-4-unit Minneapolis buildings

The Center for Energy and Environment (CEE) helped the City of Minneapolis consider pathways to decarbonization by creating a roadmap to weatherizing and electrifying one-to-four-unit residential buildings across the city (Jones, Katie). The team used actual installation cost data from contractor bids and price lists collected by utility and lending programs, 2022 retail product data and RSMeans cost data together with feedback provided through a stakeholder engagement process implemented between September through December 2022. The total average per building cost was $30,900, with the space heating cold-climate ASHP constituting the highest upfront and widest potential installation cost distribution ranging from $7,000 to over $20,000.

HP retrofits in California SF homes

California's HP market transformation effort, TECH Clean California, is designed to test and scale strategies to help meet the state's ambitious goal of installing six million HPs by 2030

(Office of Governor Gavin Newsom). As of July 2023, over 10,000 HPs were installed in over 9,700 projects. The TECH Clean California team has conducted various preliminary analyses with this rich data set to understand costs, as well as the prevalence and characteristics of projects that require panel upgrades (Sarkisian, Dylan). The team found ASHP retrofits have a median cost of almost $18,000.

Results

Results from leading pilots and initiatives in the Midwest and California indicate that whole home electrification costs range from $20,000 to $40,000 for single family projects and $20,000 to over $80,000 in multifamily units (multiple). The largest component of project cost is the cost of space heating systems, accounting for upwards of 80% of typical project costs (Tudawe, Ranal). Median costs range from $7,000 to over $23,000 for ASHPs in single family homes, and $15,000 to $45,000 in multifamily homes (multiple). It is critical to note that multifamily cost data remains highly variable, and program designs would benefit from further research here.

Partial displacement systems may be less expensive and are one option to lower costs when full electrification is not required. Additionally, policy is likely needed to fill gaps in funding required to sufficiently address upfront costs, notably for priority populations, and to be able to address required electrical service upgrades.

Customer Bill Impacts and Screening

In this section, the authors discuss relevant findings for customer bill impacts from electrification and customer screening, when positive bill impacts are required. These findings and program implications are based on the author’s experience evaluating a HP pilot and from a review of publicly available data. These results are consistent with and demonstrate trends the authors have observed in other related work.

Key Findings and Program Solutions

Understanding customer bill impacts from residential electrification is critical for EE and DSM programs working in this space. It both drives the market power and scalability of residential electrification offerings and is challenging to estimate accurately before installation. Similarly, energy prices in much of the country create a dynamic where negative bill outcomes are very likely for at least some portion of participants, where understanding bill impacts may help programs monitor and mitigate any potential negative bill impacts.

Bill impacts drive programs’ market power and scalability, because (1) it strongly influences traditional program economics and the required size of program incentives and rebates, and (2) some states require programs to screen IE customers for positive bill impacts before electrifying customers’ homes. While the relationship between bill impacts and scalability is straight forward when screening is required, the relationship between bill impacts and market power or scalability is more complex when screening is not required. In essence, bill impacts drive the size of the financial incentive required to make EE financially attractive to customers, which programs traditionally use as a main indicator of participation rates. Given that programs typically have limited budget, savings goals, and cost-effectiveness requirements, measures (like electrification) that require substantial financial incentives and provide moderate claimable savings can be challenging for programs to support, especially at scale.

However, while estimating customer bill impacts from electrification is critical, recent research and publicly available data clearly demonstrate the complexity of this task. In the table below, the authors provide key findings and potential program implications for customer bill impacts and screenings, separated into findings related to challenges for estimating customer bill impacts and common trends when estimating customer bill impacts.

Table 1. Customer bill impacts and screening key findings and program implications.

Finding	Potential Program Implications
Challenges Estimating Customer Bill Impacts	
Findings can vary drastically due to a variety of factors, such as volatile gas rates, customer specific and specialty rates, equipment performance, whether landlords or tenants pay the energy bills, customer behavior, and any active or planned rate changes.	While not solving the problem, programs can mitigate the issue of volatile rates by planning to update rates for bill impact estimates and screening on regular intervals (e.g., bi-annually) and use consistent methods and assumptions across offerings. Replacing electric resistance heating equipment with HP for space or water heating can serve to support the supply chain of this equipment broadly (e.g., workforce development and improving stocking practices). Optimizing rate changes as a part of an electrification program could positively impact customer bill savings.
Customers may not update their rates after electrification, breaking a common screening assumption (ComEd).	Build scalable processes for customers to transition to the modeled rates and consider scalable process to follow up with customers about these changes.
Common Trends for Customer Bill Impacts and Screening	
While exceptions exist, there are often challenging economics to move from natural gas to electricity.	Provide transparent communication on electrification bill impacts and identify promising applications. Ensure information points to relevant rebates, tax incentives, and other benefits, such as indoor air quality.
Eliminating fixed fees can be crucial (ComEd).	Estimate the effect of removing gas fixed fees in bill impacts, modeling cases with and without full electrification.
Electrification may add cooling for some customers.	Consider working with stakeholders to determine an approach for estimating bill impacts when customers have no-or-limited-AC prior to electrification; some customers may plan to add AC anyway or AC may be a safety concern.

Methods and Research Background

This section reflects the authors' work evaluating a HP pilot and analyzing publicly available data for a policy-related webinar.

Dual fuel and all-electric HP pilot evaluation.

In 2022, an EE program pilot team launched a pilot in which 40 inverter-driven, ducted HP systems were installed in 32 single-family homes. Both dual fuel and all-electric HP were installed. The authors and their research teams are conducting the evaluation, including estimating customer bill impacts for both retrofit and time of sale baselines. These results are preliminary yet demonstrate key trends the authors find throughout their work

SEEA webinar on "Maximizing Impact and Equity with Innovative Policy Strategies."

In December 2023, the Southeast Energy Efficiency Alliance (SEEA) hosted a webinar on "Maximizing Impact and Equity with Innovative Policy Strategies," where the authors presented. In preparation for that webinar, the authors gathered residential energy rate estimates to demonstrate some of the complications when electrifying customers, especially IE customers. More specifically, the authors collected residential rates for different energy sources (e.g., electric, and natural gas rates) historically and forecasted from the Energy Information Administration (EIA) (EIA 2023, EIA 2024). For the purposes of this paper, the authors summarize that information by state and in a national forecast. These results demonstrate key trends the authors find throughout their work that can inform program design, including the necessary HP efficiency required to overcome the cost disparity by energy source and the volatility of energy prices, and as a result, customer bill impacts.

Results

The authors provide results from their research below around customer bill impacts and screening for electrification.

SEEA webinar on "Maximizing Impact and Equity with Innovative Policy Strategies."

The authors leverage EIA data for three key purposes: (1) to demonstrate the difference in the retail cost of energy between electricity, natural gas, propane, and fuel oil; (2) to demonstrate the differences in these costs across the country; (3) to demonstrate a potential forecast for retail rates, and (4) to demonstrate the volatility in gas rates over time. While EIA data serves these purposes well, the authors note these data do not provide enough granularity to demonstrate two other notable findings on this topic from other research, such as the strong effect on customer bill impacts from (1) customer specific or specialty rates, and (2) eliminating fixed gas charges (Tudawe, Ranal; ComEd).

Figure 1 shows an EIA forecast for residential energy prices through 2050. While this forecast is simply a reference case and there are many factors at play that could change this trajectory, it demonstrates (1) the price disparity for electric energy compared to other fuel sources, especially natural gas, and (2) at this point, there is not yet compelling evidence that the price disparity we see now will change for the better in the near future (i.e., programs should plan as if energy prices will not drastically change in the near future, or at least they shouldn't expect energy prices to change in a favorable way – they will need to be mindful of this issue in their program operations and planning). While the EIA forecast may be overly conservative and forecasting gas rates includes considerable uncertainty, current gas rates and recent reductions in gas rates due to relatively low supply charges are somewhat aligned with their forecast, at least in the immediate near term (Illinois Commerce Commission 2024).

Figure 1. EIA forecasted residential prices.

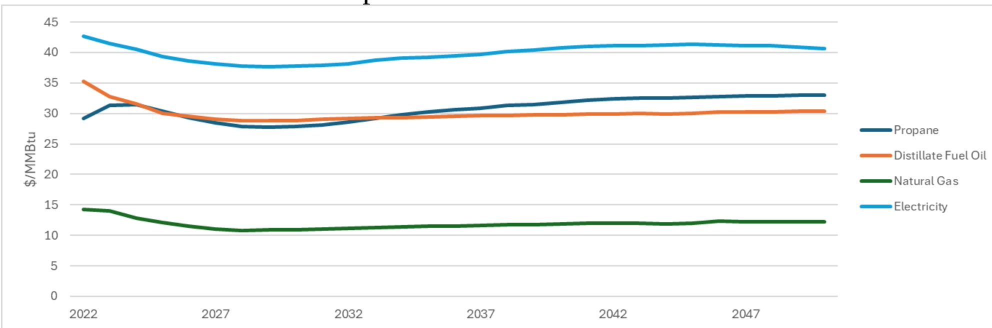
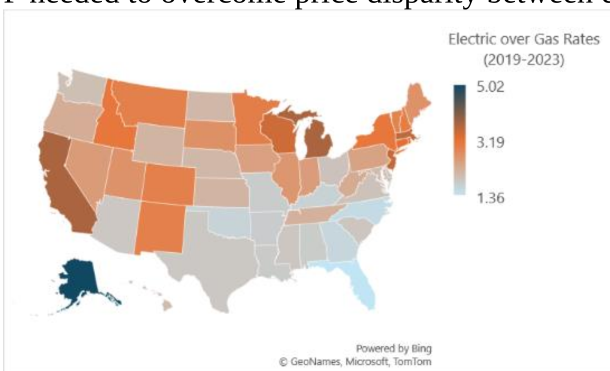


Figure 2 shows the seasonal HP coefficient of performance (COP) needed to achieve energy price parity between electricity and natural gas. In other words, it shows the normalized price of electricity (in $/MMBtu) divided by the normalized price of natural gas ($/MMBtu) times an assumed gas heating efficiency of 85%. The variability of this metric across the U.S. demonstrates the important local nature of this problem. Furthermore, looking historically at these prices from EIA indicates the volatility of gas rates, which more than doubled in some cases from 2021 to 2022 (Illinois Commerce Commission).

Figure 2. Equipment COP needed to overcome price disparity between electricity and natural gas



Dual fuel and all-electric HP pilot evaluation.

Participants in this pilot saved about $100/yr. in cooling energy costs on average and participants who replaced their all-electric HP with a variable speed HP saved about $300/yr, However, participants who switched from furnace and AC systems to dual fuel HPs had mixed heating results, which seem to vary strongly with installed controller settings., These results demonstrate the important role cooling savings from HP can play in bill impact estimates when customers have pre-existing AC. However, this reality also demonstrates the challenges of electrifying customers with no-or-limited pre-existing AC, which may be more prevalent with IE customers. It also speaks to the importance of equipment performance and control settings (affecting the dual fuel results), which the author's discuss in greater detail in sections below.

Customer Targeting

In this section, the authors discuss their experience evaluating two pilots that used customer targeting to overcome some of the barriers identified in this paper, notably around customer bill impacts and incentive sizing. One pilot is an electrification pilot, and the other is a whole home EE pilot, both for IE customers.

Key Findings and Program Solutions

While there is in-field evidence and theoretical reasoning that programs can identify the customers who are most likely to benefit from program offerings, the two pilots the authors are involved with have either ended or gone away from leveraging targeting in their pilot design. The pilot team that is transitioning from targeting has developed other design approaches to avoid refusing customers during screening and to manage costs by partnering with other EE program outreach, which allows them to share some of the fixed-cost burdens of outreach and offer other meaningful measures when the pilot offerings do not pass the screening.

The authors would like to note that we do not consider the evidence presented here as precluding targeting as an important component of program design, but that the evidence suggests that, at least for now, targeting does not represent a low risk silver bullet to overcome other barriers discussed in this paper and converting targeted customers into participants may be a challenge for programs to resolve in order to reap the benefits of targeting.

Methods and Research Background

This section reflects the authors' work evaluating an electrification pilot and a whole home EE pilot for IE customers, where the pilot designs centered around analytics-based customer targeting to identify customers who were likely to benefit most from the pilot offerings.

IE electrification pilot with customer targeting – Western U.S.

In early 2023, an EE and DSM program team launched a pilot to electrify IE customers who reside in disadvantaged communities. The program offers HPs, heat pump water heaters (HPWH), electric cooking equipment, and electric dryers. Given the eligible customer pool, the pilot performs bill screening before installation to determine if customers are likely to save money on their bills from electrification. Only those who pass the screening can participate in the pilot and receive electrification measures.

Due to the screening, the pilot attempted to leverage usage-based targeting to identify customers who are most likely to pass the screening and benefit from electrification. This targeting process included a variety of analytics, such as identifying customers with larger cooling loads. Large cooling loads potentially reflect an opportunity to save cooling energy with weatherization or efficient HPs to overcome any potential negative heating bill impacts for the customer resulting from the cost difference between natural gas and electric energy.

While the pilot is ongoing, early recruitment using the targeted list was largely unsuccessful and the implementation team started exploring other approaches. As a part of the evaluation team, the authors have conducted research with non-participants and the implementers' field teams to better understand participation barriers and to identify potential challenges with the targeting approach.

IE EE pilot with customer targeting – Eastern U.S.

In early 2021, an EE and DSM program team launched a pilot to provide weatherization and HVAC upgrades to IE customers. To achieve the greatest benefits possible for this customer segment with limited EE and DSM resources, the pilot attempted to use a design where customers would have no upfront costs and would pay back a proportion of the installation cost over time at no interest as they saved on their energy bills.

Given the eligible customer pool and the pilot design, the pilot performed bill screening before installs to determine if customers were likely to save enough money on their bills to pay the EE program team back for a proportion of the install and still achieve reduced annual energy costs. Only those who pass the screening could participate in the pilot. Due to the screening, the pilot attempted to leverage usage-based targeting to identify customers who were most likely to pass the screening and benefit from the pilot.

As the pilot evaluators, the authors have conducted research with non-participants and the implementers' field teams to better understand participation barriers and to identify potential challenges with the targeting approach. Furthermore, the authors have conducted an impact evaluation on the screened participants.

Results

For the purposes of this paper, the authors highlight only a consolidated and short list of key findings. While there is in-field evidence and theoretical reasoning that programs can identify the customers who are most likely to benefit from program offerings:

- Both pilots were largely unsuccessful in converting target-based leads into participants.
- The EE pilot regularly encountered customers from the target list that did not pass the screening, and in some cases, even those that passed did not ultimately save based on the impact evaluation.
- The EE pilot customers who did not screen were frustrated with program messaging that originally signaled that their usage was high, and they were likely to save.
- The electrification customers who chose not to participate were frustrated that their electric bills were already too high, and as a result, the pilot was suggesting they electrify more appliances.

Equipment Performance and Installation

In this section, the authors discuss the performance and installation of electrification equipment and the corresponding program implications. While electrification includes electric stoves, ovens and dryers, the authors focus their attention specifically on dual fuel and all-electric HPs for space heating and HPWH, as HVAC and water heating typically represent most of the energy consumption in residential buildings.

Key Findings and Program Solutions

In this subsection, the authors highlight key findings and program implications related to our research into equipment performance for residential dual fuel and all-electric space heating HPs and HPWH. Table 2 summarizes this information.

Table 2. Equipment performance key findings and program implications.

Finding	Potential Program Implications
HP	

The pilot received many more applications than it planned to support, and customers are interested in this equipment.	Program teams should be aware of this market and trend, and the potential net to gross implications for market rate programs.
Even within a product family, efficiency and capacity performance can vary substantially; differences of 50% are not uncommon.	Contractor training and/or support is important, and programs can consider leveraging similar previous efforts around Quality Install certifications and practices (EPA). When communicating bill impacts from electrification, contractors and program teams should recognize that system performance varies even within product families and some customers may experience negative bill impact outcomes even if the average outcome across customers is positive. Some implementers may use a "buffer" when screening or communicating bill impacts to safeguard against this variability.
Default HP settings may not be optimized, adjusting thermostat settings is brand specific, and improper settings may not be obvious.	Contractor training and/or support and customer education are important, especially around thermostat settings, where customers and installers may not immediately realize the energy impacts from improper settings. Monitoring usage data (ideally AMI data) may help programs identify installation challenges. This work can be conducted by teams outside of program operations.
HPWH	
Our team's research indicated that this technology may not be applicable to all retrofits, for reasons that might be particularly relevant in multifamily applications.	Contractor training and/or support is important, especially around the best applications for this technology, to ensure positive experiences for customers and contractors.

Methods and Research Background

The information presented in this section reflects the authors' work evaluating a HP pilot and HPWH supply chain research, including research with distributors and installers.

Dual fuel and all-electric HP pilot evaluation.

In 2022, an EE program pilot team launched a pilot in which 40 inverter-driven, ducted HP systems were installed in 32 single-family homes. The pilot's research objectives include verifying the field performance of these systems across a sample of representative customer home types, understanding the energy and bill impacts on participant homes, and assessing customer satisfaction with installation, operations, and overall pilot experience.

Both dual fuel and all-electric HP were installed, all HP were of the same product family, and the systems performed during three seasons. The systems operated under a default high switchover temperature for the first winter, then operated during a typical summer, and finally operated in a second winter season with a lower switchover.

The author's research team leveraged advanced metering infrastructure (AMI) data across 32 customers and submetering data for 15 sites. The team accesses each data source via application programming interfaces (API), which enables the research team to pull data automatically on semi-regular intervals. The research team uses the AMI data to estimate post-install heating and cooling loads across all pilot participants, to corroborate the submetering data, and to estimate seasonal changes in electric consumption due to the HP. The submetering data includes temperature, relative humidity, and air velocity in the return and supply ducts, as well as electrical consumption in the indoor and outdoor units and gas consumption for dual fuel HP. While measurement error cannot be ignored, the researchers use the submetering data to estimate the heat delivered or removed by the HP and the energy consumed, and thus, the HP's capacity and efficiency throughout the seasons.

HPWH supply chain research.

The authors and their colleagues have conducted research into components of the supply chain for HPWH, including interviews with customers who recently had HPWH installed, installer focus groups and interviews, and observational research (including observing HPWH installations). In total, the team engaged 38 installers and 10 homeowners across four states. The primary objectives of this research were to understand HPWH adoption barriers, assess the magnitude of already-known installation challenges, and inform plans to advance HPWH market adoption, including potential support for market actors.

Results

The authors provide equipment performance and installation results below for dual fuel and all-electric HPs, and separately, heat HPWH.

Dual fuel and all-electric HP pilot evaluation.

This research to date provides several clear results:

- The pilot received many more applications than it expected or planned to support.
- Broadly and on average, these systems performed well in the field and customers were happy with the equipment. However, the seasonal SEER and HSPF estimates were variable, with differences of 50% not uncommon.
- Thermostat controls and switchover temperatures are critical, especially for dual fuel systems. For this pilot, the dual fuel HP switchover temperatures for the first heating season showed usage patterns like furnace and AC usage patterns.
- Regarding winter peaks, the study period for this pilot included a several-day cold snap, providing insight into winter peaks for dual fuel and all-electric HP. The data shows that the high usage and peaks from this weather event for all-electric HP lasted well beyond several hours and remained high for days while the dual fuel systems required about half as much demand during this time.

HPWH supply chain research.

While this research covered a variety of topics, the authors focus on the findings most relevant to this paper. Interviewees expressed that this technology may not be applicable to all retrofits. For example, it may not be well suited in locations without adequate space and ventilation, where re-piping the water or electrical connections are problematic, or where the cold air discharge, noise or upfront cost would be unacceptable to the customer. Interviewees also expressed that distributors may not have a variety of HPWH well stocked, which can make it challenging to find the right HPWH to fit a space, especially in rural areas. Lastly, engaging with installers distilled some key pain points for installations. For example, installers may take additional time to set the larger and heavier HPWH into place, run the condensate line, connect additional electrical wiring, adjust the space for adequate ventilation or for the larger HPWH, wait for it to heat up, or re-plumbing the lines for a water heater of a different size and shape.

Conclusion

Residential building electrification is often seen as the near-term step on the path to decarbonization. As the authors have presented in this paper, early work electrifying residential buildings is consistently running into the following challenges:

- Appliances, installations, and required system and panel upgrades are proving expensive.
- One driver of costs, home age, tends to be higher in priority populations, making electrification costs particularly high for these customers.
- Costs for electrifying multifamily buildings are less well understood and highly variable.
- Customer bill impacts from electrification may not be positive for many customers.
- Estimating bill impacts when screening projects is challenging, potentially inaccurate, and the results can be sensitive to a wide range of factors, such as natural gas supply rates, customer-specific rate structures, equipment performance, customer behavior, whether landlords or tenants pay the energy bills, ongoing rate-cases, and the availability of special energy rates.
- Identifying customers who are the most likely to benefit from electrification may be feasible, but converting those customers into participants may be challenging and using a targeting approach may limit total savings potential.
- Electrified equipment performance can be variable.
- With HPWH as an example, electrified technology may not be a universal replacement for existing system types.

To exemplify the scale of some of these issues, it could cost hundreds of billions of dollars to electrify the roughly 50 million Americans with household incomes below 125% of poverty at a median whole home electrification project cost of $41,800 (Legal Services Corporation; Montedeosca, Jackie). This simple estimate excludes administrative costs as well as utility side of the meter costs, and ignores that some portion of these customers could face increased energy costs from electrification. This estimate is simplified and flawed but demonstrates the scale of this issue.

Within the sections above, the authors described potential solutions programs are exploring related to these findings within the confines of traditional EE and DSM program operations and economics. These potential program solutions include refining recruitment approaches, changing program designs, adapting savings calculations, partnering with other programs, refining workforce development approaches, and building better communication pathways within utilities and with customers. More broadly, the fact that these programs were able to leverage research demonstrates the importance of weaving research within programs.

Finally, in the bigger picture and in reference to EE and DSM program's role as a part of the clean energy transition, the authors encourage stakeholders to revisit funding mechanisms, program economics and cost effectiveness tests, market transformation, net-to-gross evaluation, and collaboration with other initiatives (like FEMA) participating in the clean energy transition. The findings from this paper (e.g., high costs, limited market power due to bill impacts, and supply chain barriers) indicate that pivoting these programs toward electrification may disrupt previous context for these programs, and as such, changes to program operations, rules, and precedents might help programs more successfully embrace this pivot.

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