Electrifying Away Climate Change:
Interactions of Heat Pump Adoption, Installation Capacity, Grid Load, and Costs in Massachusetts

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Abstract

Heat pumps (HP) can reduce residential greenhouse gas emissions, and many governments have implemented substantial subsidies to promote their adoption. However, installations lag in many areas, threatening emissions reductions targets. Previous studies of HP adoption focus on economic factors but have not considered operational issues such as HP installation capacity or behavioral decision processes such as consumer responses to long installation wait times. Here we develop a dynamic, behavioral model of residential HP adoption integrating the characteristics of existing housing and heating and cooling systems with HP installation costs, installation capacity, wait times, and homeowner responses to these attributes. We calibrate the model to Massachusetts and evaluate policies that shorten installation delays, lower costs, subsidize electricity, and incentivize fossil-fuel backup systems. We find the most effective policies address both operational and behavioral processes affecting adoption: boosting HP installer capacity lowers wait times, which drives higher demand and incentivizes further growth in installation capacity in a virtuous cycle. The impact of HP subsidies alone is blunted because they worsen installation delays, deterring adoption. Coupling policies that boost installation capacity with consumer incentives yields strong synergies enhancing adoption. Moreover, because homeowners can use existing fossil fuel heating systems as backups for HPs on the coldest days, subsidies for such dual-fuel systems increase their adoption but have minimal impact on greenhouse emissions and increase public expenditures. Methodologically, effective analysis of heat pump adoption requires integration of economic incentives with operational constraints and behavioral decision-making.

1. Introduction

Damage from climate change is worsening as the world passes 1.5°C of warming, underscoring the urgency of cutting greenhouse gas (GHG) emissions (IPCC, 2023). Residential heating, together with water heating and cooking, are major sources of GHGs, accounting for 6% of total U.S. emissions in 2021, three times as much as aviation (EPA, 2023). Heat pumps (HP) provide heating and cooling by transferring heat from ambient air into a building like a two-way air conditioner, reducing GHG emissions compared to gas furnaces by 40%-70% (IEA, 2023). Many jurisdictions seek to speed HP adoption through incentives including rebates and low-interest loans. Nevertheless, adoption lags in many regions (International Energy Agency, 2022). For example, in Massachusetts, despite substantial incentives, purchases must double to reach the state's target of 500,000 installations by 2030 (Mass. EEA, 2025).

Adoption is constrained in part by limited installation capacity and consumer aversion to delays (EnergySolutions et al., 2022; Outcault et al., 2024). In 2023, executives in the heating, ventilation, and air conditioning (HVAC) industry estimated a shortage of 110,000 installers (Belloli, 2023a), and 30% of consumers in the U.S. report that finding an installer is an obstacle to purchasing HPs (Antonopoulos et al., 2024).

Here we study policies to improve heat pump adoption by targeting operational and behavioral processes not considered in previous research. Many prior studies in the operations management (OM) literature consider the effects of installation capacity on the adoption of new technologies, including renewable energy generation and electric vehicles (Keith et al., 2017; Naumov et al., 2023; Xiao et al., 2020). However, we are not aware of prior OM work on the role of capacity in heating electrification.

In other fields such as energy system modeling, research on heating electrification policy (e.g., Bistline et al., 2023; Jenkins et al., 2025) focuses on HP adoption as determined by upfront and operating costs. These studies do not consider HP installation capacity or consumer sensitivity to wait times. Installation wait times are critical: a homeowner whose gas boiler fails in winter is unlikely to opt for heat pumps even if they are most cost effective because emergency replacement with a new boiler can be done rapidly, while it might take weeks to find qualified HP installers, get estimates, select a contractor, and carry out the work. In contrast, some homeowners may have the foresight to consider switching before an aging system fails. Such homeowners are more tolerant of delays because they can use their existing systems while waiting, but may still be deterred by the extra time and effort required to find qualified HP installers, get estimates, etc. Assessing HP adoption and the impact of policies therefore requires consideration not only of system costs but also operational and behavioral factors.

To address this gap, we develop a system dynamics model of residential HVAC purchases integrating these operational, behavioral, and economic factors. The model includes the construction and demolition of houses and tracks their size and energy efficiency, which vary with age, and the type, lifetimes, energy sources, efficiency, and GHG emissions of the HVAC systems in each. Homeowners consider whether to keep their existing heating and AC systems, replace them with the same type, or switch to other types. Purchases depend on the perceived capital and operating costs of each HVAC option, and the time needed to find qualified installers offering good prices and service, i.e., the installation wait time. Heat pump installation wait times depend on installation capacity relative to demand; both are endogenous to capture the delays in and feedbacks between them. High demand for heat pumps incentivizes HVAC installers to invest in the equipment, employee training, certifications, and relationships with HP distributors and manufacturers needed to offer heat pumps. Installation capacity therefore responds to the demand for HPs with a delay, creating a reinforcing feedback: higher capacity lowers wait times, increasing demand and inducing further expansion of HP installation capacity. Conversely, inadequate capacity and long wait times deter HP demand, reducing the incentives for HVAC contractors to invest in HP installation capacity in a vicious cycle.

We also model the impacts of HPs on the electric grid and public expenditures. Grid operators in cold-climate areas, including the US northeast, are increasingly concerned that demand from heat pumps on the coldest days may cause total power demand to approach grid capacity because heat pumps are less efficient in cold weather (Rojo, 2024; Specian et al., 2021). Further, rebates in the United States are commonly funded through charges added to utility bills (McNamara, 2024). Increased HP adoption therefore raises the cost of electricity, and policymakers are pressured to cut these programs to provide ratepayers relief (Wolman, 2025).

We apply the model to Massachusetts, which is reasonably representative of other cold-climate US states struggling to meet electrification targets (Mass. EEA, 2025), and has documented installer capacity shortages (BW Research, 2023). We focus on single-family homes, but the model can be adapted to other regions and types of housing. We simulate 11 policies and analyze their effects on heat pump adoption, electricity demand, emissions, and subsidy outlays, and conduct sensitivity analysis to examine whether the results are robust to major uncertainties.

The results suggest that heat pump adoption is strongly limited by installation capacity, and so increasing capacity in combination with cost-reductions may be an effective means to promote adoption. The feedback between installers and adoption blunts the benefits of improving financial incentives alone: subsidies mitigate the high installation cost of heat pumps and initially increase HP demand, but drive installation delays up, deterring adoption. In contrast, policies that expand HP installation capacity reduce wait times and boost adoption, though purchases remain constrained by the high upfront costs of HPs. Thus, policies that pair HP installation capacity improvements with HP cost reductions increase adoption beyond the sum of their individual effects. The synergy emerges because each policy offsets the other's drawbacks, delivering both lower installation costs and shorter delays.

To explore policies to reduce peak grid load, we also analyze subsidies for dual-fuel systems. Dual-fuel systems, which pair lower-capacity heat pumps with fossil backup for cold days, are promoted by some analysts to limit peak power demand on the coldest days, reducing stress on the grid (Biondi et al., 2025;

Dachis & Dulku, 2025). Incentivizing dual-fuels draws homeowners away from both full-load heat pumps and fossil fuel systems, raising total heat pump adoption and reducing peak load. However, the policy has minimal net effect on emissions and increases public expenditures.