Doing The Right Thing Now Will Eventually Pay Off: Cost-Effective & Equitable Building Decarbonization Requires (More) Proactive Planning and (Completely) Rethinking Rate Design

Mohit Chhabra, Natural Resources Defense Council (NRDC)
Jessica Russo, NRDC
Thomas Siafa, NRDC
Dylan Sullivan, Alphabet, formerly of NRDC

I. Abstract

Decarbonizing the economy requires increasing clean electricity generation and then substituting polluting fuel use with clean electricity. For building decarbonization to benefit both society and end-users of clean electricity, substituting gas appliance use with heat pumps should be cost effective from a societal and an end-user point of view. Our analysis first demonstrates that heat pump use has lower social costs than gas appliance use provided that clean energy penetration continues to expand. This requires proactive planning and economic build out of new generation, which is often not the case. We identify key states where stakeholders need to focus to ensure sufficient clean energy expansion.

As electricity gets cleaner, the cost to society of consuming additional electricity declines. This isn't true for natural gas due to increasing externality costs. However, utility rates don't reflect this important fact. Current utility ratemaking results in electric and gas usage prices that discourage efficient electrification. This distortion is greatest in states like California, New York, Massachusetts, and Colorado which have strong building decarbonization goals. Moreover, we also demonstrate that efficiently pricing electricity and gas is equity enhancing if fixed costs of the utility system are collected progressively.

The root cause of this mispricing is the proliferation of faulty rate design practice. The time to for the regulated energy industry to evolve its practices for rate design is now; inertia builds and change will be harder the longer the industry drags its feet.

II. Introduction and Key Concepts

Economywide decarbonization relies on powering the electric grid with clean energy and then electrifying new end-uses such as gas appliances in buildings and transportation. For electrification to be socially beneficial or cost-effective,[1] the electric grid needs to be clean enough so that the sum of private costs of additional consumption (mostly costs of generation and delivery losses) and externalities related with it should be lower than that of natural gas. In the next section we explain this further through the concept of social marginal costs.

Building electrification adoption relies on favorable customer economics. Hot water and comfortable indoor temperature can be achieved through multiple means. For customers to choose heat pumps over gas appliances, the operating cost of heat pump need to be substantially lower than that of gas appliances. This isn't often the case. Moreover, as electricity rates have risen faster than inflation in many parts of the country recently, heat pumps are increasingly less

[1] Whenever we say cost-effective, we mean cost effective from a social point of view. This includes all private costs of energy consumption and externalities thereof.

attractive for customers to adopt. This directly conflicts with the fact that electricity is getting cleaner and cheaper to produce because, once installed, renewables and clean energy resources have low operating costs. This isn't true for natural gas.

A. Private and Social marginal Costs of Electricity and Gas Appliance Use

The economic ideal is to set prices at social marginal costs (SMC).[2,3,4,5] SMC is equal to a utility's private marginal costs (PMC) plus the costs of externalities. PMC are the costs incurred by the utility to generate and deliver energy. In the electricity sector, PMC is equal to the costs of producing and delivering one more unit of electricity; or the sum of the wholesale locational price, (which is equal to the competitive clearing price of electricity generation plus high voltage transmission losses), and the costs of delivering that electricity to a customer (congestion pricing plus T&D losses). In the long run, the PMC should also account for any additional capacity expansion, or new resource buildout, caused solely by marginal electricity consumption.

The SMC is equal to the PMC plus the costs of associated environmental externalities. The SMC of electricity will decrease as the grid gets cleaner for two reasons. Renewables have high capital and low operating costs. Once a renewable is installed, the marginal costs of generating electricity are negligible. Accordingly, regions with high renewable penetration, such as the CAISO balancing area, have seen decrease in wholesale clearing prices as renewable penetration grows. (Berkely Lab, 2021) Renewables also don't emit carbon or pollution. Thermal fleet exhibit a similar trend; more efficient gas power plants cost less to operate and pollute less compared with inefficient coal power plants. Thus, as the grid gets more efficient and cleaner the SMC of electricity decreases. The same is not true for gas use. The SMC from gas is equal to the marginal costs of using gas plus all externalities associated with producing, delivering, and

---

[2] See, for example, A.E. Kahn, The Economics of Regulation (Vol. I), at 75. "The economic ideal would be to set all public utility rates at short run marginal costs (with appropriate adjustments for the problems of second-best); and these must cover all sacrifices, present or future and external as well as internal to the company, for which is production at the margin causally responsible."

[3] See, for example: Viscusi, Vernon and Harrington, Economics of Regulation and Antitrust, at 344-345. "The most obvious candidate for the efficient price is, of course, marginal cost." Viscusi specifically refers to marginal cost as the cost of producing the next unit of good. For the electric sector, this is SRSMC when externalities are included.

[4] Severin Borenstein, *The Economics of Fixed Cost Recovery by Utilities* (2016), at 2.
Borenstein explains that "the idea that economic efficiency is maximized when price reflects full short-run social marginal costs (SRSMC) is a bedrock principle of microeconomics, because it is straightforward to show that any departure from social marginal costs is likely to reduce the economic value that the industry can create. Producing a good requires inputs — labor, fuel, machinery, land, etc. — and those inputs have alternative uses. The price of an input is generally a good indicator of its value in its next best use, so economics suggests that the inputs should only be brought together to produce this good if the value of this good to whoever consumes it exceeds the value of all the inputs necessary to make it. Setting price equal to short-run social marginal cost creates the incentive to consume an incremental unit of the good if and only if one values it more than the value that the inputs would create in their next best use."

[5] For example, if the total societal cost to produce an extra unit of a good is $10 and it is priced at $10 then customers who value it at $10 and above will purchase it. An efficient outcome. If it is incorrectly priced at $20, then only those customers who value that good at more than $20 will purchase it. All the customers who value that good between $10 and $20 will forego consumption and there will be deadweight loss. On the other hand, if the good is incorrectly priced too low then it will induce overuse, which will lead to misallocation of resources and additional environmental externalities.

burning natural gas. And as the social cost of GHGs increases over time, the SMC of gas will increase as well (holding all else constant).

This makes the case for substituting gas appliance use with heat pumps. As electricity gets cleaner its SMC will decrease relative to gas. When the SMC for electricity use is lower than that from gas use, that means that its cost-effective for society to switch gas use to electric use. Regions where this isn't the case, i.e., electric SMC is greater than gas SMC, are candidates for policy and market intervention to ensure that low-cost renewables are being efficiently deployed.

A key determinant to SMC of electricity use is the estimate of GHG emissions associated with electricity use. There are two approaches to determine this: short and long-run marginal emissions (Fowlie, 2022). The rationale for applying short-run marginal emissions is that when electric load increases, the marginal or last resource in a balancing area increases production and increase in emissions is a function of the emissions rate of that marginal resource. The long-run marginal emissions methodology rationale is that over time new resources are built to economically meet new load, and the emissions due to this new load are a function of both the new resources built and the current state of the grid. E.g., a utility may determine that building more solar is more cost-effective than running gas power plants more. Based on this long-run marginal emissions methodology, a recent national lab study concluded that heat pumps are already projected to save GHGs in a range of future scenarios. A blend of short- and long-run marginal emissions should provide the most accurate estimate of emissions due to new electric load.

B. SMC and Utility Ratemaking

Recent research has quantified the SMC of electricity and natural gas and how much the SMC of each fuel differs from retail price (Bushnell, 2022). Although SMC is the economic ideal for setting prices, or the volumetric rate, there are practical and policy reasons to deviate from setting prices, or volumetric rates, at SMC. Most importantly, setting electricity prices at SMC may not recover a utility's authorized revenue; and additional sources of revenue are needed to make ensure that a utility can recover all its approved expenses. These residual fixed costs, the difference between authorized revenue and revenue collected when volumetric rates are set equal to SMC, need to be collected somehow. This is one of the central challenges of rate design (Borenstein, 2016).

Residual fixed costs should be collected in a manner that is compliant with policy goals, leads to fair and progressive outcomes. Most jurisdictions recover the vast majority of non-marginal residential revenue requirement via volumetric or usage-based rates. This, at least in California, does not lead to progressive outcomes as lower income customers end up paying a much larger share of their income to fund fixed costs of the grid and social policy goals funded through electric rates. This is in stark contrast to how we, as a society, progressively pay for other infrastructure like highways and schools – through the tax base. So, on the other end of the spectrum, an alternative but untested way of collecting these residual fixed costs progressively is through taxes. Although this may not be feasible, it provides a gold standard reference for understanding whether non-marginal costs of the grid are being fairly collected. (Lazenby, 2024).[6]

Electric fixed charges mostly consist of customer interconnection related and monthly meter reading costs only. These customer specific costs are the bare minimum of those costs that don't vary with usage. Revenue for sunk transmission and distribution costs, and costs to fund policy goals (such as low-income discounts and energy efficiency) are all collected through usage based or volumetric rates. As a result, volumetric rates deviate from the SMC (Bushnell, 2022). The same is true for natural gas retail rates; they don't represent the SMC of consuming gas either.

If electricity and gas prices reflect SMC, then as electricity gets cleaner, households will see increasing incentives to electrify. Utility bills are a much larger fraction of lower-income household expenses than that for middle- and upper-income household because electricity and gas use is not perfectly correlated with income. The EIA reports that energy bills are 3% of household expenditures on average across the U.S., but they are 6% of lower-income household expenditures. Therefore, possible savings from electrification upgrades will also disproportionately benefit lower-income customers more because marginal utility (in the economic sense) of an extra dollar varies greatly with household income; this also implies that bill increases will disproportionately harm lower income customers.[7,8]

C. Questions Addressed by This research

This research answers the following questions on the impacts of building electrification of space and water heating:

- Which regions should policymakers and advocates target for more stringent clean energy policy goals to ensure that building electrification truly results in societally cost-effective outcomes?
- What is the additional premium that customers across the country pay for using heat pumps relative to its SMC across the country due to distortions in electricity rates? What is the in-built subsidy that customers get for using gas appliances due to mispricing gas rates?
- Are the bill savings from space and water heating electrification meaningful enough to enhance equity? How would that change if electricity and gas were priced efficiently at their SMC?

---

[6] Lazenby quotes a forthcoming article to explain Hotelling's famous argument as: "In an important 1938 article, Harold Hotelling took this problem head-on arguing that the best way to maximize "the general welfare" with respect to infrastructure investments marked by declining costs was for the government to use taxes on income, inheritances, and land to pay for the fixed (overhead) costs of the physical assets and to charge the public a price that was set at marginal cost, which in the case of most infrastructure would be very low or even zero. According to Hotelling, two groups would be likely to object to such a scheme: the wealthy and land speculators. But any losses they incurred would be more than offset by benefits accruing to the public at large."

[7] United States Office of Management and Budget Circular A-4, at 65. https://www.whitehouse.gov/wp-content/uploads/2023/04/DraftCircularA-4.pdf

[8] Sample calculations by Washington Center for Equitable Growth demonstrate that, using A-4's guidance, an extra dollar is worth 2.6 times more to a lower wage earner who makes $35,000 than it is to a median wage earner who earns $70,000. https://equitablegrowth.org/proposed-update-to-federal-cost-benefit-analysis-guidelines-correctly-focuses-on-accounting-for-inequality-in-regulations/#footnote-14

D. Limitations of this Research

This research is an initial screen to identify regions where electricity is clean enough to justify initiating electrification, where it isn't; and where electric and gas rates are mispriced and to what extent. This analysis informs where regions that are candidates for intervention in utility resource planning and rate design.

Suffice to say, this research, due to its broad scope does not look at all expected variations in energy consumption, savings, and rates within a territory. We also use minimum federal efficiency equipment for our analysis; the rationale being that these are the most likely heat pumps customers will install, and if these equipment pass our beneficial electrification screens then higher efficiency equipment will as well. There are instances, such as extremely cold climates, where special high efficiency heat pumps may lead to better outcomes. We did not analyze those.

The results of this study are informative of what major policy lever should be pulled first and by how much. It does not provide precise results for estimating savings and developing retail rates for each region. Energy savings vary by configuration of home and efficiency of appliances. Retail rates are set to meet many objectives in addition to economic efficiency.

III. Methodology

The methodology generally follows these steps, each of which is explained in detail in the following section:

- Develop end use consumption (EUC) of gas and electric appliances.
- Calculate electric and gas SMC per unit energy consumed (kWh and therm).
- Calculate annual SMC of appliance use by multiplying EUC with per-unit SMC.
- Estimate electricity and gas volumetric rates for all locations analyzed. Multiply volumetric rates with EUC to determine annual costs borne by customers to operate electric and gas appliances.
- Compare the outputs of the previous two steps to answer research questions.

A. Estimating End Use Consumption

Space and water heating energy consumption are calculated using EnergyPlus models calibrated to Energy Information Administration's (EIA) 2020 Residential Energy Consumption Survey (RECS) data. Gas energy consumption data are readily available in RECS; however, heat pump consumption data applicable to this research aren't. For our research, we need to compare the energy consumption from a gas furnace or a water heater with the energy consumption from a heat pump that replaces those gas fired appliances and provides the same utility (indoor air temperature and hot water temperature). To accomplish this, we use RECS data to develop calibrated EnergyPlus models that provide accurate estimates of gas-powered space and water heating in 106 cities across the country. We then re-ran these calibrated models by replacing the gas appliance with a well-sized heat-pump. Details are presented in a publicly available technical appendix.[9]

[9] Technical Appendix.

B. Estimating Social Marginal Costs (SMC) of Electric Use.

NREL's Cambium dataset provide the inputs needed to calculate SMC of electricity. Cambium provides marginal costs of meeting additional load for all locations analyzed in our model. It also provides estimates of GHG emissions associated with these additional loads. (Pieter Gagnon, 2022). Two Cambium scenarios that represent different levels of future renewable penetration are analyzed: the Mid case and High renewable cost case. Both cases ensure that state level minimum renewable portfolio standard and clean energy policy requirements are met; any deployment in addition to those standards is done based on economic expansion. Combined, these two scenarios provide an upper and a lower bound on emissions reduction.

Total utility private marginal costs are the sum of marginal energy, capacity, and transmission & distribution costs of serving incremental load (NREL, 2023). In Cambium, energy costs are represent wholesale energy prices, marginal capacity costs are the costs of new capacity built to serve an increase in load, transmission & distribution costs include estimate of losses and congestion costs.[10]

SMC are calculated by adding costs of greenhouse gas (GHG) emissions to private marginal costs. GHG emissions include carbon dioxide from combustion and methane leakage. In the near-term, GHG emissions from additional load are emissions from the marginal power plant or short-run emissions. Over time, the emissions from sustained additional load are equal to the emissions form the mix of resources that are built to serve that additional load. Permanent additional load will change the structure of the grid, e.g., regions with clean energy policies will buy additional clean energy to serve that load.

This analysis calculates marginal emissions in each year through the assumed lifetime of the appliance, 15 years, by taking a blend of short-run and long-run marginal emissions rates from Cambium. The hypothesis being that the consequential emissions from new additional load in the near term, first two years in this analysis, will be short-run marginal emissions. Once that load is internalized in utility planning processes, then the emissions impact of that load will be long-run marginal. To our knowledge, this is the first analysis to estimate lifetime emissions in this manner.

GHG's are valued at EPA reported average of SC-GHG from three different damage modules at a 2.5% discount rate; $122 in 2022, $130 in 2025, etc.[11],[12] Social marginal costs were discounted using a real discount rate of 1.7 percent, as proposed in the recent public review draft of OMB Circular A-4.[13]

C. Private and social marginal cost of using gas appliances.

---

[10] Private marginal costs were discounted using a real discount rate of 4.29 percent, the calculated average effective real discount rate for consumers found in the U.S. Department recent rulemaking on consumer cooking equipment (Department of Energy (DOE), 2022).
[11] See EPA published annual SC-GHG at different discount rates here: https://github.com/USEPA/scghg/blob/main/EPA/output/scghg_annual.csv
[12] Our results are sensitive to the value of SC-GHG chosen. A lower value, like the previous Interagency Working Group value of around $50 in 2010, would show even higher distortion in electricity pricing and higher total distortion in electrification impacts.
[13] Management, Office of, and Budget. 2023. "Circular a-4, Draft for Public Review" https://www.whitehouse.gov/wp-content/uploads/2023/04/DraftCircularA-4.pdf.

Unlike electricity, natural gas marginal emissions and private marginal cost data aren't readily available. For natural gas we constructed our own data set of private marginal costs and then applied the SC-GHG to determine the SMC of natural gas use in homes.

Private marginal costs for natural gas are set equal to wholesale, or city gate, prices plus any transmission and distribution losses. The Energy Information Administration's (EIA) Annual Energy Outlook (AEO) provides estimates of future gas prices.[14] Annual average marginal private costs for natural gas for each region were developed by weighting gas use by each state and sector (residential, commercial, etc.) within each state. These were then modified to account for amounts of gas lost and unaccounted for on the gas system using data from Pipeline and Hazardous Materials Safety Administration's annual reports.[15]

SMC are calculated by adding the social cost of GHG to the private marginal costs. Externalities are equal to carbon dioxide from combustion of natural gas multiplied by the SC-GHG,[16] plus methane leakage amounts multiplied by the SC-CH4.

D. Annual Operating Costs of Electric and Gas Appliance Use

Appliance end use consumption estimates are multiplied with each fuel's SMC to determine lifetime SMC from appliance use. We do this for appliances installed in 2024 and 2030. Lifetime SMC divided by appliance EUL equals annual average SMC.

Average annual volumetric electric and gas volumetric rates were estimated for all locations by looking up any fixed charges included in tariffs of each individual utility, and total retail sales and revenue data from EIA. Average volumetric rate for a utility is equal to total residential revenue collected minus revenue collected via fixed charge, divided by total retail sales. These average volumetric rates are multiplied by consumption estimates to determine current customer operating costs. We assume that on average electric and gas rates will increase at inflation, so all future operating costs are also estimated using these data. All cost data presented in this research are in 2022 dollars.

E. Savings, potential savings, and distortion

Annual operating cost savings, or savings based on current volumetric rates, are equal to gas appliance operating costs less electric operating costs. Potential savings, if electricity were priced right, are equal to SMC of gas appliance operation less SMC of electric heat pump operation. Distortion is defined as the difference between current pricing and economically efficient pricing. So, total distortion for heat pump use is equal to annual operating costs under current electricity rates minus annual operating cost of a heat pump if electricity were priced efficiently at SMC. Total distortion for gas appliance use is calculated similarly.

---

[14] 2021-2050 forecast annual census division commercial delivered natural gas prices and commercial gas use.

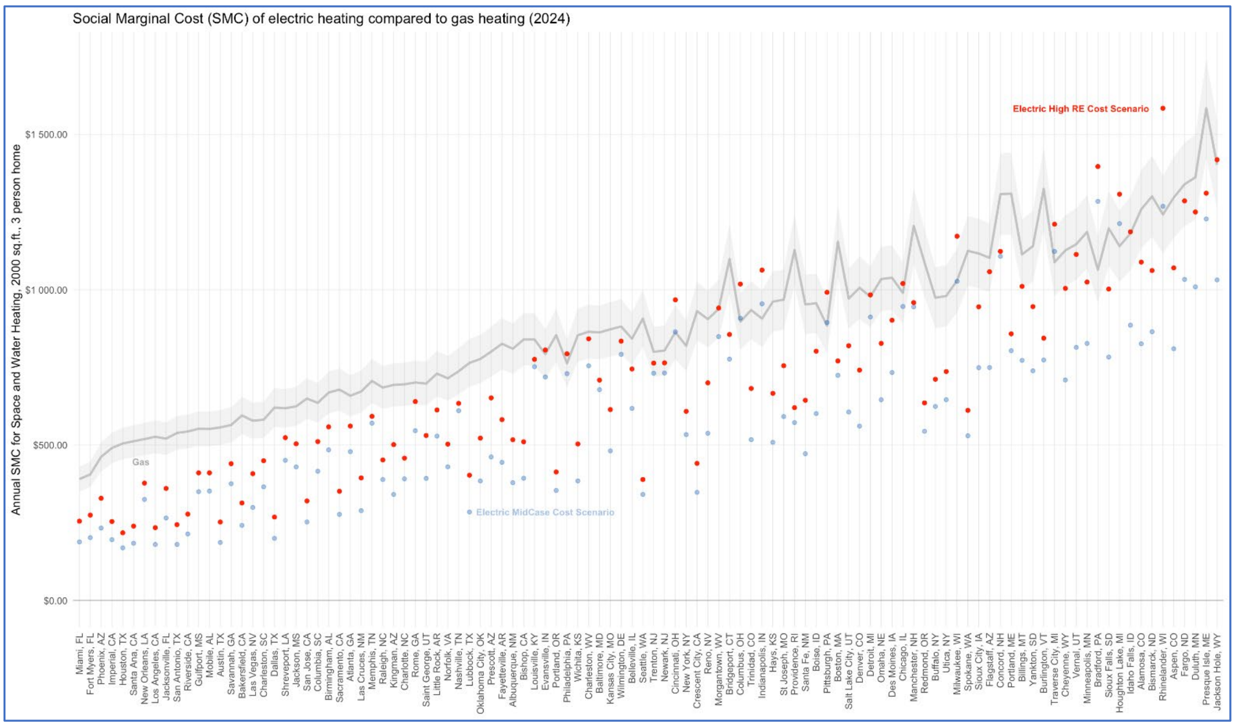
[15] Pipeline, and Hazardous Materials Safety Administration. "Gas Distribution, Gas Gathering, Gas Transmission, Hazardous Liquids, Liquefied Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data; Gas Distribution Annual Data - 2010 to Present (ZIP)." https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/data_statistics/pipeline/annual_gas_distribution_2010_present.zip.

[16] The same SC-GHG value is applied to both the electric and gas sector. Details of how the SC-GHG value is developed is provided in the methodology for calculating electric SMC. SC-GHG value was scaled to the GWP of methane to estimate the social costs of methane leakage.

IV. Social Marginal Costs of Electric HP and Gas Heating Appliances

Heat pump operation is projected to have lower SMC than gas appliances in almost all locations for heat pumps installed in 2024; this is even more true for appliances installed in 2030 as the electric grid gets cleaner. Figure 1 presents a comparison of annual average SMC for electric and gas space and water heating for an average existing single-family home (2000 square feet) with three occupants for appliances installed in 2024. The SMC values on the Y-Axis represent annual average of lifetime SMC. Electric SMC are presented for a future where renewable prices decrease as expected, Mid-case, and a scenario where renewable prices are higher than expected. Higher renewable prices imply relatively lower rates of renewable deployment over and above those required by state policy (e.g., RPS) than the mid-case.

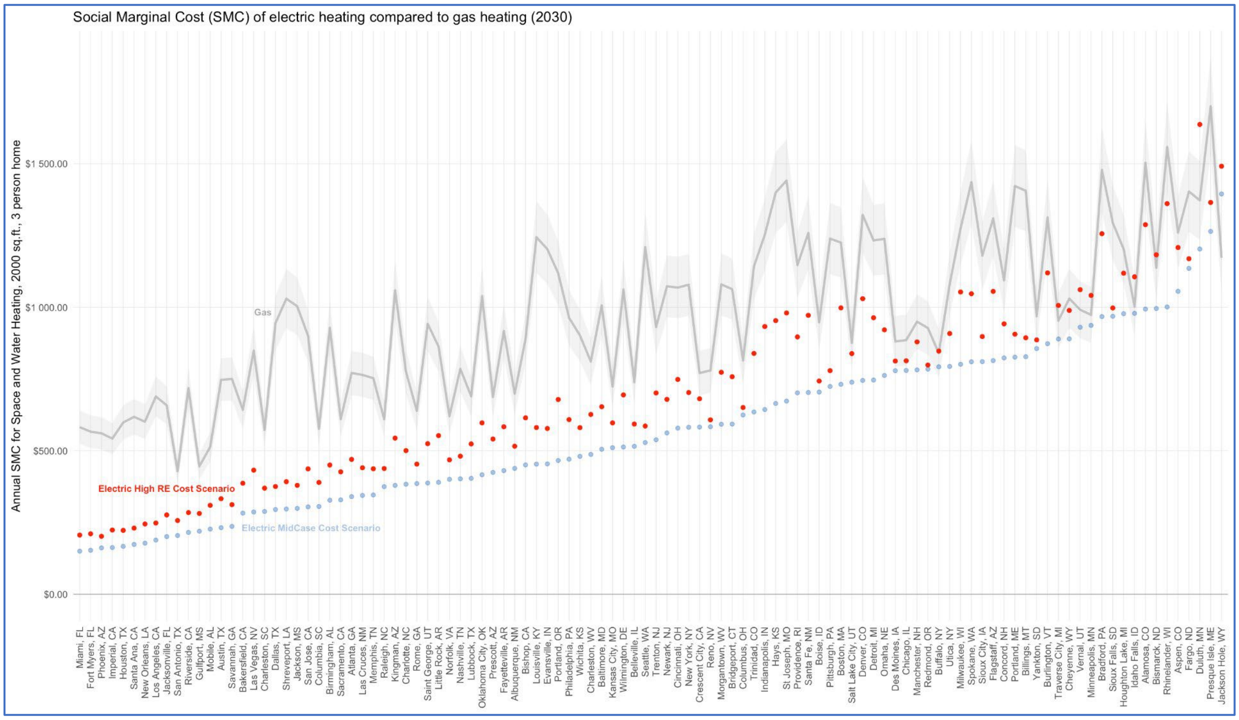
Figure 1. Annual Average SMC of Gas (Grey Line) Furnace Versus Electric Heat Pumps (Dots) for Appliances Installed in 2024



The exceptions such as Ohio, Wyoming, Pennsylvania, and a handful of other states, are colder states with more fossil intensive grids. These states should be considered prime candidates for clean energy procurement mandates to ensure that substituting natural gas use with electric use in buildings is cost-effective. Figure 2 presents the same for appliances installed in 2030. Provided that utilities conduct economic capacity expansion to meet additional electric demand, by 2030 almost all locations show that substituting gas appliance use with heat pump use is socially beneficial.

These results are contingent on utilities conducting economic capacity expansion as assumed by NREL in compiling their Cambium database. As renewable installation cost continues to decline, espescially due to federal tax incentives, it is becoming more cost-effective to meet additional load with new renewables than with running existing fossil fuel powered generators more. This, however, relies on utilities regularly conducting economic capacity expansion analyses to develop least cost pathways to meet future load, and also on renewable capacity coming online in a timely manner. Neither outcome is a given. Power sector advocates should apply these results to indentify states most in need of stakeholder intervention.

Figure 2. Annual Average SMC of Gas (Grey Line) Furnace Versus Electric Heat Pumps (Dots) for Appliances Installed in 2030.



V. Electricity is Almost Always Overpriced; Gas is both Over and Underpriced. The Combined Effect is Very Distortionary and Regressive

End-user operating costs, annual appliance energy use multiplied by the volumetric rate, are almost always much greater than SMC. For efficient outcomes, the SMC of using a heat pump would equal the operating costs incurred by an end user. If the operating cost of a heat pump is higher than SMC, then electricity is overpriced and vice versa. Figure 6 compares electric SMC with operating costs of heat pumps. The impact of distortion in electricity prices is especially pronounced in California, Colorado, New Mexico, New York, Massachusetts, Michigan, Minnesota, and Vermont. What's further concerning is that many of these states have aggressive building (and transportation) electrification policies. Overpricing electricity discourages electrification.

The results presented in Figure 6 represent SMC and operating cost projections for appliances installed in 2030. SMC estimates rely on utilities conducting economic capacity expansion as explained in the last section. Operating cost estimates assume that volumetric rates will increase at a rate equal to inflation for the next few years. The difference between operating costs and SMC presented here are thus illustrative of the magnitude in pricing distortion and not precise estimates.

Figure 3. Customers are always overcharged for Heat Pump Operation Relative to Social Marginal Costs Due to Electricity Mispricing

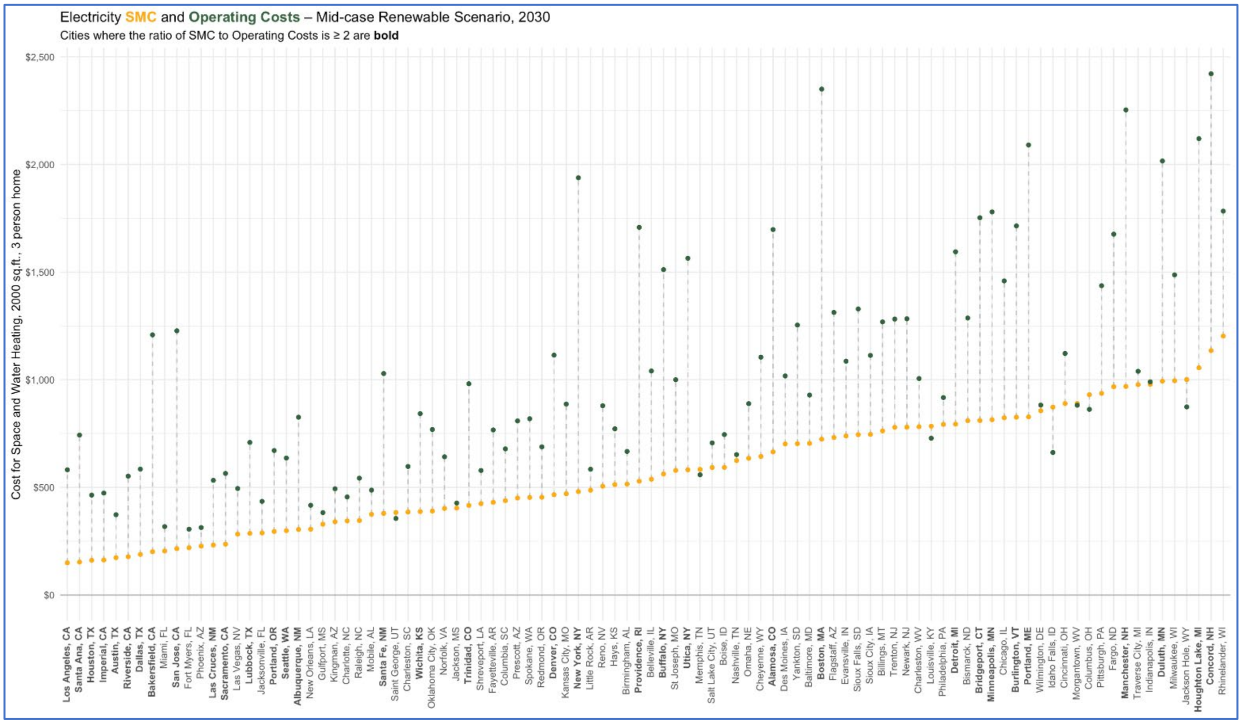


Figure 4. Customers are under- or overcharged for Gas Appliance Use Relative to Social Marginal Costs Depending on Local Utility Pricing; Customers are Undercharged More Often.

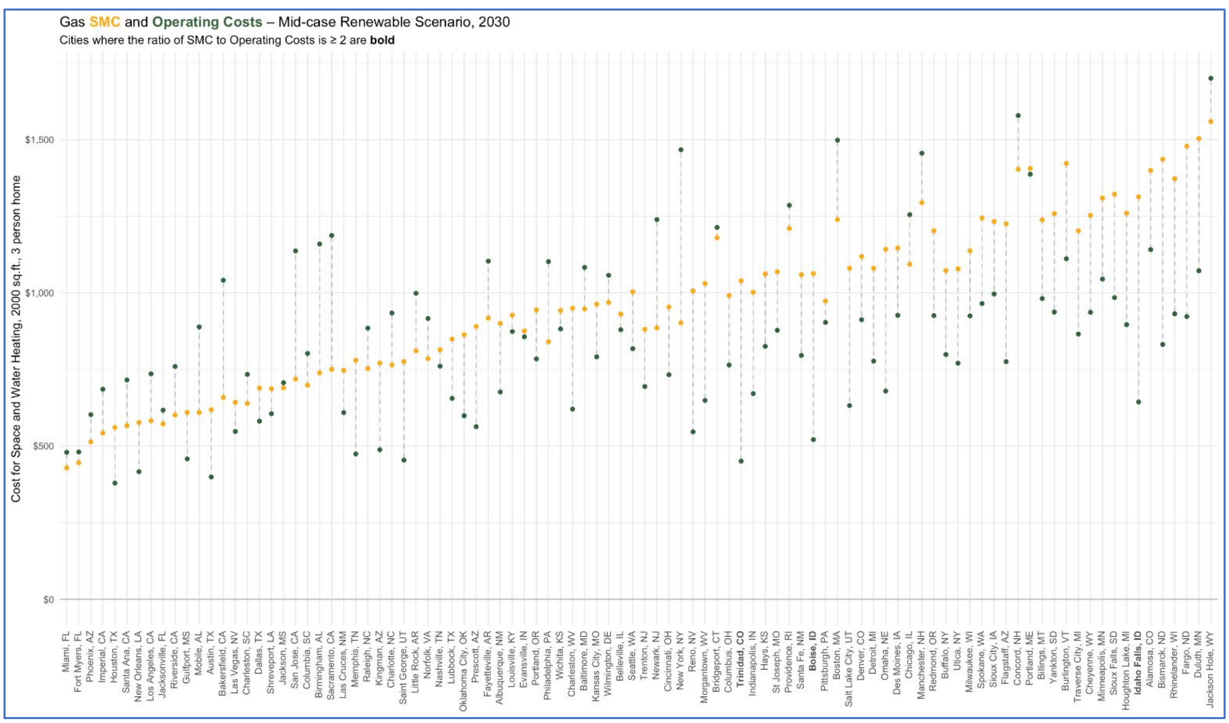


Figure 4 compares the annual SMC of using a gas appliance with the operating costs seen by the end-user. Unlike electricity, gas isn't always overpriced. Gas volumetric rates are however underpriced in more than half of the locations. A fair number of these locations also have over-priced electricity – this combination of factors leads to disincentives for electrificaiton.

The reason for this pattern of results is due to a combination of cleaner electricity having lower SMC and due to how fixed costs of the system are collected from customers or end-users. Electric utilities collect majority of fixed costs of the grid via volumetric rates; the result is that the price customers see for using electricity is higher than the SMC; and as electricity gets cleaner this trend will get worse if fixed charges don't rise commensurately. Natural gas on the other had has high SMC and oftentimes natural gas utilities have higher fixed charges than their electric counterparts. This often leads to underpricing polluting natural gas.

To understand how today's mis-priced electricity and gas rates impact incentives to electrify relative to what's socially beneficial, we compare how much a customer's utility bill changes when they electrify today versus how much it would have changed if electricity and gas volumetric rates were both priced appropriately at SMC. The difference in customer bill between the two scenarios, today's rates and if electricity and gas are priced accurately, is the total electrification distortion. Said another way, the electrification total distortion is equal to the difference in differences between gas and electric operating costs, and gas and electric SMC.

$$\textit{Total electrification distortion} = (O.C_{gas} - O.C_{elec}) - (SMC_{gas} - SMC_{elec})$$

Positive total distortion implies that the combined effect of electric and gas mispricing results in a disincentive to electrify. For example, if a customer electrifies today and sees their bill go up by $100 (based on today's gas and electric rates), but they would have saved $900 had both electricity and gas been priced accurately at SMC, then the total distortion is $1000. The higher the distortion, the greater the disincentive for electrification.

Figure 7 presents total distortion for all locations modeled, ordered by total distortion. The total distortion is significant; and in most locations around $500 per year or greater. Colder locations with cleaner grids generally show a higher distortion. This is because many of these locations have overpriced electricity and underpriced gas.

To understand whether and to what extent accurate pricing of electricity and gas is equity enhancing, we calculated the total distortion as a fraction of the income of lower quintile earners in each location analyzed. These results are presented in Figure 6. The total distortion is equal to or greater than 5% in almost a quarter of the locations and greater than 10% in a handful. This means that the collective impact of accurate pricing and substituting gas furnace and water heater use with heat pumps could make lower income customers significantly better off in many parts of the country provided residual fixed charges are collected progressively as well.

Figure 5. Total Electrification Distortion is High and Projected to be Greater than $500 per Year for Appliances Installed in 2030 in Most Locations

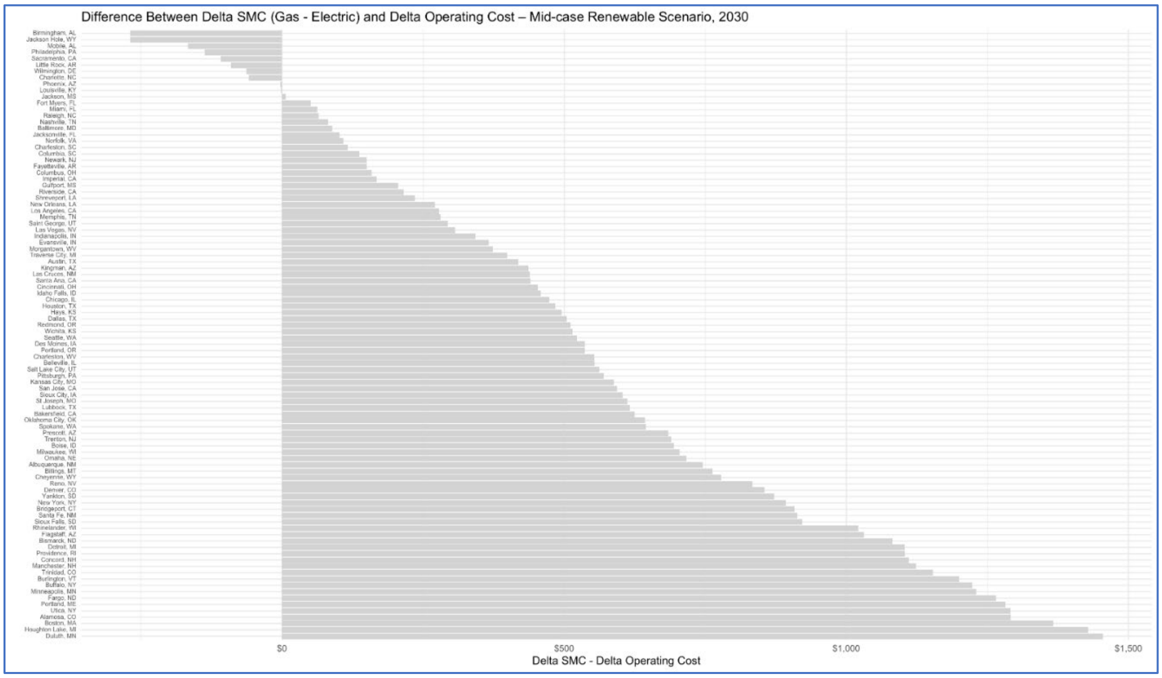
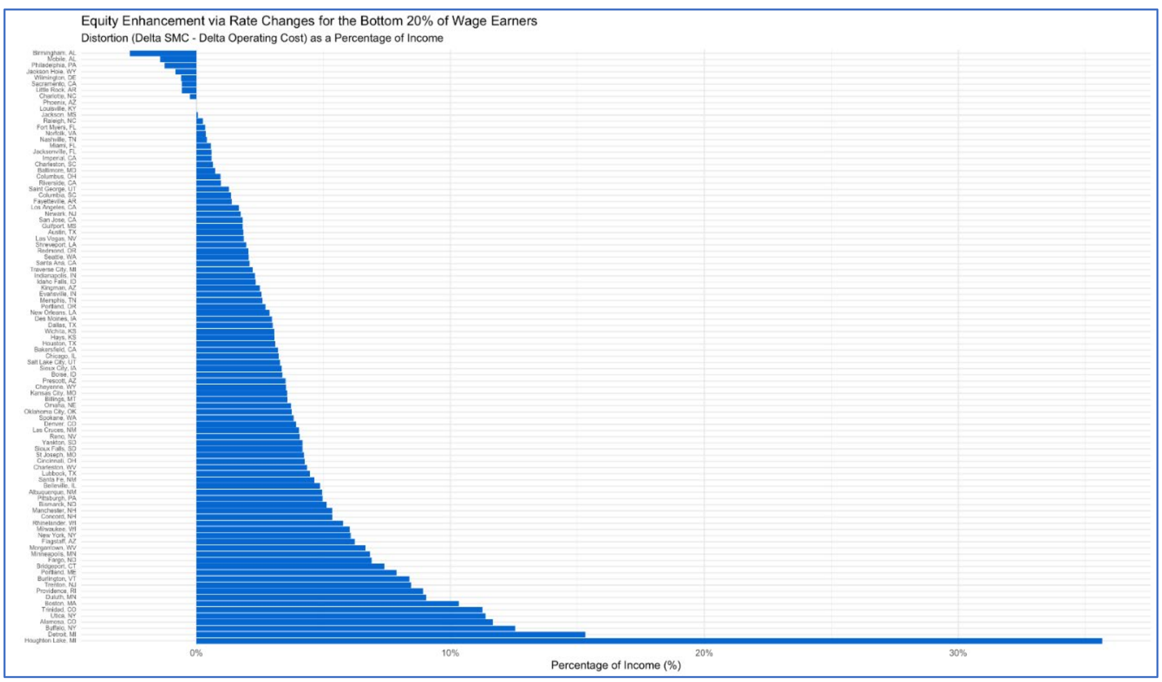


Figure 6. Total Electrification Distortion in 2030 is Projected to be Greater than 5% of Annual Income of the Lower Quintile in Almost a Quarter of the Locations



Here it is important to note that the total distortion only quantifies the impact to an end-user from electrifying space and water heating. Depending on remaining usage patterns and how fixed charges are collected, the total impact on electric and gas utility bills for low-income customers could be higher or lower. For example, if fixed costs of the electric and gas system are collected as progressively as federal income tax, then lowest quintile will pay very few of the fixed system costs. In that case, the impact on utility bills from a combination of electrifying space and water heating and accurately priced electricity and gas use would be as much or greater than the estimates in Figures 5 and 6.

VI. Conclusion and Recommendations

Conclusion 1: As renewable penetration increases, replacing gas appliance use with heat pump usage is cost-effective from a societal perspective almost everywhere in the United States.

As the electric grid gets cleaner, using heat pumps for space and water heating will continue to become more cost-effective for society than using gas due to decreasing electric SMC and increasing gas SMC. This is already true for many parts of the grid that are clean enough today and have temperate weather. Even with some real-world constraints on planning, electrifying with federal minimum efficiency heat pumps is cost-effective almost everywhere. In doing so, we identify priority states for stakeholder intervention to ensure economic and policy compliant clean energy expansion. These states are colder states where clean energy penetration is relatively low today like Ohio, Wyoming, Pennsylvania, and Michigan.

Recommendation 1: Advocates need to ensure that utilities regularly conduct policy compliant and least-cost resource planning.

Recent NREL analysis (Eric J.H. Wilson, 2024) demonstrates that a combination of perfect planning and proactive buildout of least cost renewables results in lower GHG emissions from substituting gas appliances with heat pumps all over the country. In the real-world, however, perfect foresight is impossible, and many disincentives exist to deviate from optimum economic resource buildout and contracting. To this end, advocates need to ensure that utilities conduct regular and accurate integrated resource planning to meet future energy needs in the most cost-effective manner. Decreasing renewable costs and federal tax incentives mean that least-cost generation expansion should mostly include renewable generation.

Conclusion 2: Electricity is almost always over-priced. Gas is mostly underpriced. This discourages efficient electrification.

As electric SMC decreases, the price to consume electricity should also decrease to reflect the change in SMC. This almost universally isn't the case. If electric rate design continues to reflect the status quo, then electricity rates will remain severely distorted and increasingly over-charge for electric consumption. To compound matters, gas rates are forecast to be both over- and underpriced relative to socially efficient levels, but mostly underpriced. A combination of overpricing clean electricity and underpricing polluting gas leads to disincentives for cost-effective electrification. This problem is the most pronounced in cold states with clean electric grids such as New York and Massachusetts; the per-unit distortion, or distortion per kWh of electric use, is worst in California.

Recently, especially in states with progressive climate and social policy goals like California and Massachusetts, many costs of social programs are funded through electric revenue requirement. Moreover, utilities are being asked to perform functions they hadn't in the past like hardening the grid for wildfires, run decarbonization programs, and buy increasing amounts of clean energy. Funding these through electricity revenue, and then collecting that revenue through volumetric rates makes the very product, clean electricity, that will drive economywide decarbonization prohibitively expensive. The impact of this malpractice is that it discourages electrification and makes electricity less affordable for lower income customers. A better approach would be to fund clean electricity initiatives through taxes on polluting fuels.

Recommendation 2: Revisit rate design to align customer costs to operate appliances with societal costs. The time to start making gradual improvements is now.

The only guidance that economics provides for rate setting is to set prices, or volumetric rates, at SMC. The question of how to collect residual fixed costs is the main challenge of rate design. With minor exceptions, most fixed costs are currently paid through usage charges; this mostly worked out when the grid was polluting because the externalities associated with electric consumption were high and conservation was a major priority. In the context of a rapidly decarbonizing grid, and with the imperative to electrify transportation and buildings this mis-pricing practice must change.

The most obvious way to collect residual revenue, after pricing electricity and gas use at SMC, is through fixed charges. Collecting these fixed charges progressively can be equity enhancing, as lower income customers will pay a smaller share of fixed charges, but the equity enhancing effects are much greater for electrification as electric SMC continues to decrease and gas SMC increases.

The root cause of this mis-pricing issue is the proliferation of faulty rate design practice that encourages jurisdictions go about rate design exactly backwards. See for example, work by Lazar et al (Lazar, 2015). Instead of starting with the efficient price to use electricity, or the volumetric rate, first and then working through pros and cons of collecting residual fixed costs via different means, most jurisdictions start by setting a minimum fixed charge amount and then collect remaining revenue requirement from volumetric rates. This leads to a price for consuming electricity that is close to the average cost of the utility.

Conclusion 3: Electrification can be significantly equity enhancing in most locations if electric and gas prices are set accurately.

Accurate pricing, setting electric and gas rates at SMC, would provide incentives to adopt heat pumps. As demonstrated by our analysis, the total combined distortion in electric and gas pricing is significant, and it is also a sizeable fraction of low-income customers' annual income and energy budget. To this end, provided that accurate electric and gas pricing is accompanied by collecting fixed costs progressively, electrification coupled with progressive rate design is equity enhancing.

Recommendation 3: In addition to setting prices at SMC, rate design needs to confront collecting fixed or non-marginal costs progressively to maximize equitable outcomes.

In the context of a rapidly decarbonizing grid, and with the imperative to electrify buildings and attain progressive outcomes, this mis-pricing practice must change. There are at least three challenges to overcome, first getting rate designers to understand that setting volumetric rates at SMC maximizes efficiency. Second, developing practical means of collecting remaining fixed costs progressively. Third, working through the politics of changing rate design which will always create new winners and losers.

Making changes to rate design isn't easy as recent experience in California demonstrates. California's residential rates have had no fixed charges for at least more than a decade. California recently instituted a minimal fixed charge, and income graduated it (in lieu of collecting the non-marginal costs via the tax base). This commonsense policy update created new winners and losers; and it was met with fierce opposition by the losers of this policy update. These include customers who would pay more under the new rate design, the energy efficiency, and rooftop solar industry. This is because sky high volumetric rates provide over incentivize energy efficiency and rooftop solar. Here it is also important to note that states with high overpricing of electricity, such as New York, California, and Massachusetts, are states with a strong legacy of energy efficiency. This means that there is less risk of backsliding on efficient use of electricity.

VII. Bibliography

Berkely Lab. (2021, 02). *Solar to Grid: Trends in System Impacts, Reliability, and Market Values*. Retrieved from https://emp.lbl.gov/publications/solar-grid-trends-system-impacts

Borenstein, S. (2016). The economics of fixed cost recovery by utilities. *Electricity Journal*, 5-12.

Bushnell, S. B. (2022). Do Two Electricity Pricing Wrongs Make a Right? Cost Recovery, Externalities, and Efficiency. *American Economic Journal: Economic Policy*, 14(4):80-110.

Department of Energy (DOE). (2022). *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Consumer Conventional Cooking Products.* Retrieved from https://downloads.regulations.gov/EERE-2014-BT-STD-0

Eric J.H. Wilson, P. M. (2024). Heat pumps for all? Distributions of the costs and benefits of residential air-source heat pumps in the United States. *Joule*.

Fowlie, M. (2022, 04). *If the Grid is Getting Cleaner How Can EVs be Getting Dirtier?* Retrieved from https://energyathaas.wordpress.com/2022/04/11/if-the-grid-is-getting-greener-how-can-evs-be-driving-dirtier/

Lazar, J. a. (2015). *Smart Rate Design for a Smart Future.* Retrieved from https://www.raponline.org/knowledge-center/smart-rate-design-for-a-smart-future/

Lazenby, R. (2024, April). Highly Charged: An Explainer on California's Income Graduated Fixed Charge Debate. *Pitzker Environmental Law and Policy Briefs*.

NREL. (2023). *2023 Standard Scenarios Report: A U.S. Electricity Sector Outlook.* Retrieved from https://www.nrel.gov/docs/fy24osti/87724.pdf.

Pieter Gagnon, W. C. (2022). Planning for the evolution of the electric grid with a long-run marginal emission rate. *iScience*.