STUDENTENERGY

Economics of Gas vs Electric in North America

USA Team

Prepared by:

Sanchita Sannigrahi - Policy Analyst | Project Manager

Mel Bezandry - Data Modeler | Partner Communications

Daniela Tabrea - Data Modeler | Internal Communications

Jiayuan Wang - Data Analyst

Xavier Zheng - Research Analyst

Priya Chundi - Copy Editor

Alemarnery Villalobos - Design/Graphics

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Executive Summary

The report delves into the dynamics of transitioning from gas to electric heating systems within North American C40 Cities, aligning with the global goal of reducing greenhouse gas emissions and fostering sustainable urban development.

Recognizing the imperative shift towards cleaner energy, especially in buildings contributing substantially to urban emissions, this literature review emphasizes the necessity of reducing fossil fuel dependency in heating systems. The report recognizes that transitioning to electric heating systems presents substantial lifetime cost savings and environmental benefits, supported by government incentives. It underscores the importance of informed decision-making based on the model's insights to drive the transition towards cleaner energy sources in North American cities.

A detailed Excel model evaluates the lifetime cost savings and environmental impact of transitioning from gas to electric heating systems. It considers various heating and cooling configurations, building characteristics, and utility rate structures to estimate costs and emissions.

The report showcases energy consumption patterns, the influence of insulation and utility rates on cost savings, and a sensitivity analysis demonstrating the significance of specific variables. Additionally, it highlights substantial reductions in CO_2 emissions when transitioning to electric heating, emphasizing the environmental benefits. It details various programs and rebates available in Chicago, New York City, and Los Angeles to encourage the shift towards cleaner energy.

The comprehensive analysis emphasizes the importance of understanding the initial investment, future savings, and non-monetary benefits of transitioning to electric heat pumps. It highlights the higher efficiency and long-term savings of electric heat pumps compared to gas furnaces despite the higher upfront cost, stressing the potential advantages for households across income levels.

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Introduction

I. Background

The transition to cleaner energy sources has become a focal point for global organizations like C40 Cities, aiming to curb greenhouse gas emissions and promote sustainable urban development. With a primary focus on reducing fossil fuel dependency, specifically in heating systems within North American C40 Cities, this literature review explores the dynamics between gas and electric heating methods.

Cities worldwide face a significant challenge in reducing carbon emissions, particularly from residential and commercial buildings. These buildings contribute substantially to urban greenhouse gas outputs, accounting for up to 80% of emissions in some C40 cities. Thus, a pivotal shift towards building electrification has been proposed as a viable solution.

Studies by the U.S. Census Bureau in 2021 revealed that nearly half of American households relied on natural gas for heating. The prevalence of fossil fuel-based heating suggests that an electric transition could substantially mitigate fossil fuel consumption, but it demands a multifaceted approach.

Decarbonizing heating systems requires comprehensive steps involving policy interventions, infrastructure updates, and workforce training. C40 Cities envision setting new building standards and integrating decarbonization measures into future energy infrastructures and tariffs to facilitate this transition effectively.

Globally, over 100 cities have enacted regulations to facilitate the shift towards all-electric buildings. The Inflation Reduction Act (IRA) of 2022 in the United States has further propelled clean energy investments and economic opportunities. However, despite these efforts, accessibility and affordability remain key hurdles, impeding a swift transition to cleaner energy sources.

II. Sources of energy in the US

The energy landscape in the United States is diverse, encompassing various sources such as fossil fuels, renewables, and nuclear power. Historically, natural gas has been a prominent energy source, particularly in heating systems across residential and commercial buildings. Its prevalence in nearly half of American households for heating purposes underscores its significance.

Conversely, electricity in the U.S. is generated from a mix of sources, including coal, natural gas, nuclear, and renewables like solar and wind. The recent emphasis on clean energy transitions has seen a gradual increase in the integration of renewable sources into the grid.

In 2022, the Inflation Reduction Act (IRA) marked a pivotal moment in U.S. clean energy policy, driving investments and innovations in the sector. However, the transition to electrification and energy efficiency upgrades remains economically challenging for the average American household.

This transition is crucial for reducing carbon emissions, particularly from buildings that contribute significantly to urban emissions. Understanding the economic implications and comparative advantages of gas versus electric heating systems is essential for C40 Cities to make informed decisions aligned with their climate policies and sustainability goals.

III. Selection of Cities

The decision to focus on North American cities for this study is not arbitrary. With its historically high reliance on gas for heating, North America represents a significant opportunity for reducing global carbon emissions. The region's energy policies, infrastructure, and consumer behaviors offer unique insights into the potential of transitioning to electric heating systems. Furthermore, the economic implications of this shift must be considered. For many families, heating electrification involves switching energy sources and adjusting household budgets. Cities must navigate the financial aspects of updating infrastructure and possibly offering incentives to encourage this shift. This dual perspective of individual and city-level financial considerations is crucial for understanding the holistic implications of the move toward electrification.

Economic Development and Population Size

Los Angeles, New York, and Chicago are chosen for our electrification project due to their significant economic prowess and substantial population sizes. These cities, with their robust GDPs and impressive growth rates, represent centers of economic vitality. The large populations in each city imply a vast consumer base and indicate scalable potential for energy reform. This combination of economic strength and large population presents an ideal landscape for implementing and assessing the impact of our project.

Existing Electrification Infrastructure

The current electrical infrastructure in Los Angeles, New York, and Chicago plays a key role in their selection. These cities have a diverse energy mix, setting a promising stage for heat pump technology adoption. Los Angeles, with its GHG emissions of 26.9 mmTCO2e, shows a predominant use of electricity over other energy sources. New York and Chicago, with 52 mmTCO2e and 31.04 mmTCO2e GHG emissions respectively, also present a significant opportunity for transitioning towards electrification. This infrastructure paves the way for examining the shift to an electrified model, offering insights into challenges and opportunities.

Political Will: A Catalyst for Change

The political climates in Los Angeles, New York, and Chicago underpin our decision-making. Despite varied political landscapes, these cities share support for sustainable energy policies.

Geographic Diversity: A Spectrum of Climates

The geographic diversity and range of climates in Los Angeles, New York, and Chicago are crucial. Los Angeles, with its mild Mediterranean climate, contrasts with New York's urban heat island effect and Chicago's extreme temperature variations. This range is critical for evaluating the performance of heat pump technology in different climates.

Model Development

I. Energy Costs

This model assesses the lifetime cost savings of electrifying gas space and water heating in existing single-family homes. All modeling scenarios assume that households are retrofitting gas heating systems with electric alternatives. For space heating, the model compares gas furnaces with AC to two electric heating configurations—all-electric ASHPs and ASHPs with a gas backup system. For water heating, it compares gas water heaters to electric HPWHs. The lifetime cost calculations are taken over a 15-year period, matching a heat pump's life cycle.

The table below summarizes the model's key inputs:

ASHP Space Heating Specifications	Heating efficiency (COP), Cooling efficiency (SEER), Setup (All-Electric or Gas Backup)
Gas Space Heating Specifications	Furnace heating efficiency (AFUE), AC cooling efficiency (SEER)
Water Heating Specifications	Average daily hot water consumption (gal/day), Inlet and outlet water temperatures (F), HPWH efficiency (UEF), Gas water heater efficiency (UEF)
Home Characteristics	Desired temperature, House size, Insulation condition, Income level

The heating efficiency of the heat pump appliances is described by the coefficient of performance (COP), which is a measure of the ratio between the output and the input energy. The COP is generally larger than one, and can be as high as 5 meaning that for one unit of consumed energy, the heat pump outputs five units of heat. Gas furnaces also have ratings for heating efficiency, which are called Annual Fuel Utilization Efficiency (AFUE). AFUE is always less than 100%. The cooling efficiency of both heat pumps and central ACs can be expressed in terms of the Seasonal Energy Efficiency Ratio (SEER). SEER is the ratio between cooling output and the total energy used. These values are typically greater than 13 for new equipment, but can be as low as 9 for old central ACs.

The Uniform Energy Factor (UEF) is a measure of efficiency for gas water heaters, and it is closely related to the COP of heat pump water heaters (HPWHs). The UEF Energy Star standard mandates a minimum of 0.81 for new gas storage water heaters (applicable to tanks smaller than 55 gallons) and 0.87 for gas tankless water heaters. In contrast, HPWHs can be 5 times as efficient. See *Appendix: Methodology* for the heating appliances' efficiencies, specifications, and the reasoning behind their selection.

To calculate the lifetime cost savings, the model undergoes the following process. First, it estimates a house's monthly heating and cooling load based on given building characteristics and desired temperature. A 2,000 sq ft single-family detached home is simulated with a desired temperature of 68°F at various insulation conditions. After finding the home's monthly heating load, the model determines the power inputs of the heat pump, furnace, and AC. Then, it computes their corresponding annual operating costs. These annual expenses account for different rate structures such as time-of-use (TOU), tiered, and flat rates. Finally, the model calculates and compares the heating appliances' lifetime costs to evaluate the cost savings. All computations are explained in the *Appendix: Methodology*.

II. Greenhouse Gas Emissions

As part of a non-financial benefit of electrification, our model assesses the environmental impact of the transition from gas to electric heating. This report aims to compare the GHG emissions of gas-based heating appliances with different types of air-source heat pumps (ASHP) and estimate the CO_2 emissions in the selected cities for several real-life scenarios.

Space heating is the largest component of energy use in a household. Across the US it represents 45% of the total consumed energy. To reduce GHG emissions it is therefore paramount to find energy efficient solutions that have the potential to become net-zero by decarbonizing the power grid. This report examines three types of ASHP technologies as low-emissions solutions: cold climate, conventional and less efficient. The selected technologies share similarities in their installation design, but they differ in terms of energy efficiency and performance under temperature variations. Details on technical ASHP specifications can be found in the *Appendix: Methodology*. This model aims to verify how these technologies perform in the selected cities and whether there is a net environmental benefit in choosing a certain type of heat pump to replace a gas furnace, whose AFUE can be adjusted freely. Old furnaces can have an AFUE as low as 57%, which greatly increases the emissions over time.

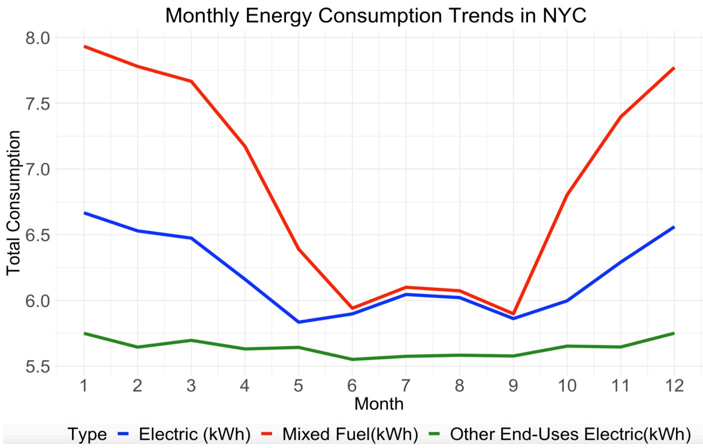
Water heating stands as the second-largest energy demand in a household, constituting 18% of the total energy consumption. As part of the efforts to achieve net-zero emissions, decarbonizing water heating becomes a pivotal component. The present model compares the CO_2 emissions associated with a gas boiler and a heat pump water heater (HPWH). The COP of the HPWH is considered to be constant at all times. Typical values range from 2.5 to 4. The UEF of the gas boiler is a free parameter and generally depends on the type of technology in use, as well as its age. The minimum UEF standard is 0.81 for new gas storage water heaters (for tanks smaller than 55 gallons), and 0.87 for gas tankless water heaters. This implies that new gas appliances are potentially up to 5 times less efficient than heat pump solutions. Such efficiency disparities significantly impact CO_2 emissions when transitioning from a gas water heater to a HPWH.

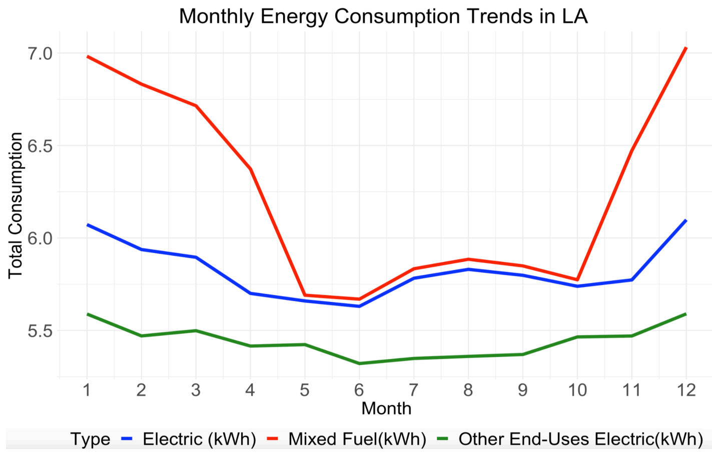
The calculation of CO_2 emissions per MMBtu of delivered heat involves two scenarios: the first year after installation and over the lifespan of the heat pump (assumed to be 15 years). To calculate the CO_2 emissions associated with combustion of natural gas we assumed a conversion factor of 117 lbs/MMBtu. Grid intensity emissions data used to estimate the present and long-run emissions associated with use of electricity was drawn from the 2023 RMI report on heat pump vs furnace emissions (Tan & Teener, 2023). In turn, the report derives the grid CO_2 emissions from the NREL's 2022 Cambium data sets, using the mid-case scenario.

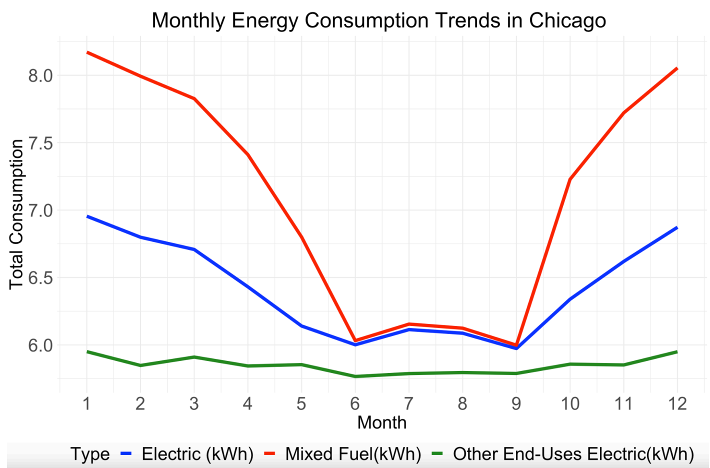
Results and Analysis

I. Energy Cost Factors

A. Energy Use Overview







The graphs above depict a clear trend in the consumption of three types of energy: electricity, mixed fuel, and other end-uses electricity over a 12-month period in New York City, Chicago and Los Angeles. Electric and mixed fuel consumption show similar trends, with peaks during the colder months, and reaching the trough between June to September. Mixed fuel consumption displays a radically steep downward trend from January to May, and a profoundly upward trend from September to December. During the cooling period between May and September, the electric heat pumps and central AC go into effect. During the heating period in the other months, the electric heat pumps and furnaces go into effect. The formulas for input power are shown as:

HP's heating power input = Output heating load / COP

Furnace's heating power input = Output heating load / AFUE

*HP's cooling power input = Output cooling load / SEER * 3.412*

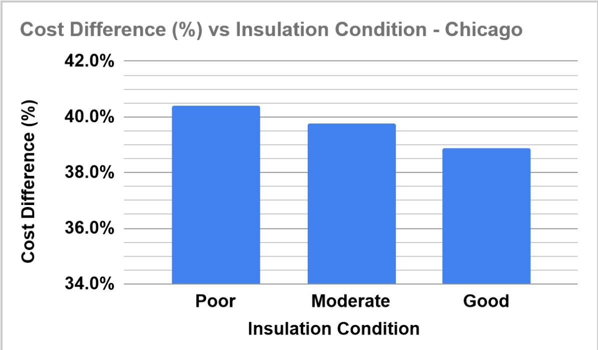
*AC's cooling power input = Output cooling load / SEER * 3.412*

In the colder months, COP and AFUE represent the heat pump and furnace's heating efficiencies. Under most circumstances, the value of COP is above 1 due to the fact that systems move heat rather than generating it directly. For each unit of energy consumed, the heat pump can transfer more than one unit of heat. On the other hand, AFUE is always below 100% because of the inherent energy losses in the combustion process and heat transfer. Therefore, gas heating consumption appears significantly higher than electric in all of the three cities in those months.

In warmer months, SEER describes both the heat pump and AC's cooling efficiencies. Their SEER values do not have starkly different cooling performance, compared to the previous case. Thus, the gas cooling consumption is only slightly higher than electric in all of the three cities. A noteworthy distinction in energy consumption pattern is that there's a longer cooling period in Los Angeles due to its Mediterranean climate, where air conditioning is utilized longer.

B. Insulation and Utility Rate Structure

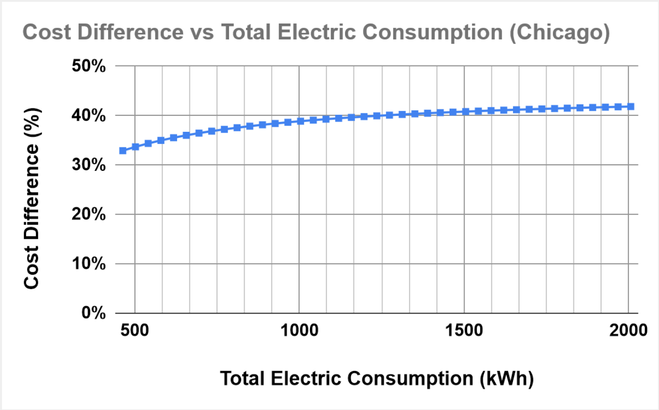
In general, a poorly-insulated home is expected to have higher cost savings than a moderately-insulated home. Poorer insulation causes higher heating load, so the difference between the heat pump's and furnace's energy usage will expand. When the difference in energy usage is large, it translates to high cost savings. The following plot illustrates how different insulation conditions affect January cost savings in Chicago. In this scenario, the heat pump is a cold-climate ASHP (ccASHP), and the gas furnace has an AFUE rating of 85%. The cost difference is the ratio between Chicago's residential gas and electricity flat rates. As expected, poorer insulation leads to higher cost differences.

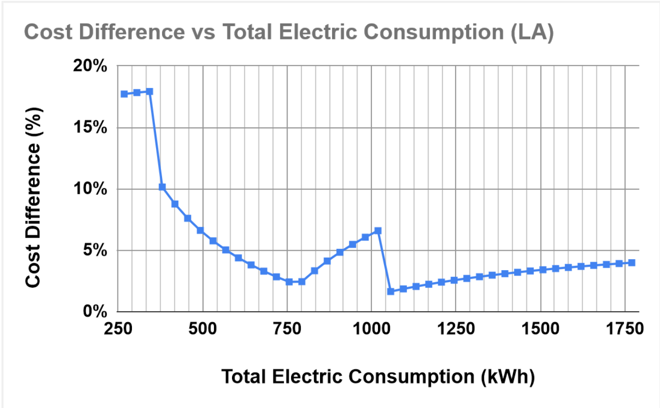


Rate structure also has a significant impact on costs. Chicago offers flat electric and gas rates. In comparison, Los Angeles has a tiered system for gas and electric rates. LADWP's electricity tiers are split as follows: under 350 kWh; between 350 and 1050 kWh; and over 1050 kWh. SoCalGas' gas rates increase when gas consumption is greater than its given baseline. In January, this monthly baseline usage was 2,361 kWh.

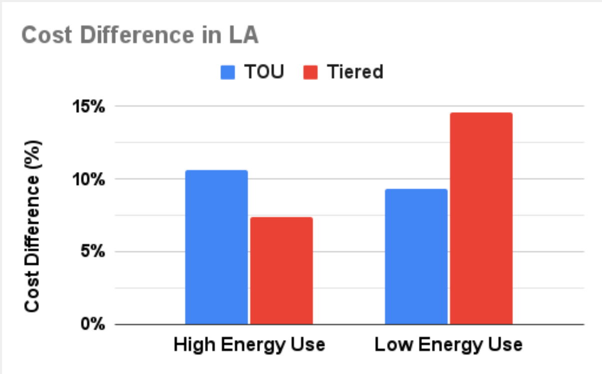
The graphs below depict how total electric consumption affects cost savings in Chicago and Los Angeles. It is assumed that the gas furnace's AFUE is 85% and a conventional heat pump is used. In Chicago, as the total heating load and electricity consumption increase, the cost savings also increase. For Los Angeles, the cost savings fluctuate based on the electricity tier. Once the total electric consumption exceeds the 350 kWh tier, the cost difference decreases as electricity usage increases. This trend reverses when a total electric consumption reaches 793.5 kWh. At this point, the total gas consumption has surpassed its monthly baseline and total gas costs are more expensive.

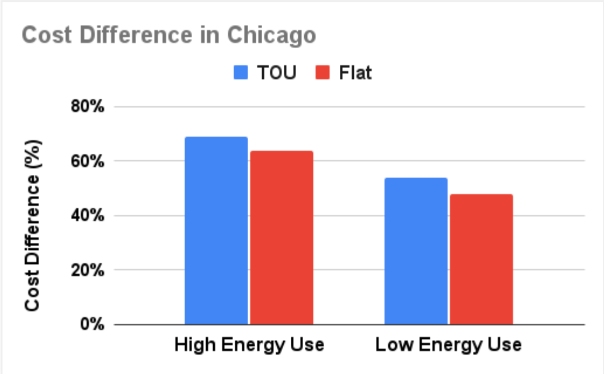
When the total electric consumption passes the last tier of 1050 kWh, the cost difference drops again, but still increases as electric usage rises. This indicates that gas costs are still larger than electricity costs. However, this region depends on the gas furnace and heat pump's efficiencies. If the furnace's AFUE rating is high and the heat pump is less efficient, the gas costs would be cheaper than electricity costs. As a result, the cost savings would decline in this region.





TOU rates can make a difference in cost savings, especially for high electricity consumption. In Chicago, TOU rates are consistently cheaper than flat rates by design. In Los Angeles, tiered rates are cheaper than TOU rates at low energy usage. However, TOU rates become more lucrative as electricity consumption exceeds the tier limit.





II. Sensitivity Analysis

Linear regression analysis is utilized for testing the significance of each independent variable. In each model, it can be written as:

$$Lifetime\ Cost\ Savings\% = \beta_0 + \beta_1 \times Furnace\_AFUE + \beta_2 \times COP\_ASHP + \beta_3 \times SEER\_ASHP + \beta_4 \times Mass\_Wall\_U\_Factor + \beta_5 \times Income\_Level + \beta_6 \times Total\_Heat\_Pump\_Incentives + \varepsilon$$

The outputs of p-values for each model in Los Angeles, Chicago and NYC are displayed below:

Predictors	*LA*	*Chicago*	*NYC*
Furnace_AFUE	<2e-16 ***	<2e-16 ***	<2e-16 ***
COP_ASHP	0.000794***	2.11e-06***	1.35e-07
SEER_ASHP	0.678530	0.805	0.238
Mass_Wall_U_Factor	0.219116	<2e-16 ***	<2e-16 ***
Income_Level	2.51e-09***	1.79e-12***	0.419
Total_Heat_Pump_ Incentives	<2e-16 ***	<2e-16 ***	<2e-16 ***
R^2	0.9973	0.9953	0.9891

The asterisks (***) are used to denote the significance level of the p-values. In the R programming environment, when you run a statistical test, the summary of the test often includes these asterisks as a quick visual cue to the significance of the test results. Here's what they typically represent: *** means that the variable is highly significant, where the p-value is less than 0.001. ** indicates that the variable is very significant, where the p-value is less than 0.01 but greater than or equal to 0.001. Then, * demonstrates that the variable is significant, where the p-value is less than 0.05 but greater than or equal to 0.01. Lastly, if there's no asterisk, the result is not statistically significant at the 0.1 level.

The variables that insert the greatest effect on estimating the lifetime cost savings are the ones with the smallest p-values(<0.05). In all cities, these variables include Furnace_AFUE, COP_ASHP, and Total_Heat_Pump_Incentives. Income_Level is statistically significant in Los Angeles and Chicago. Mass_Wall_U_Factor is a significant predictor in Chicago and NYC. The R-squared in each model are all approximately 99%, indicating that 99% of the variations are accounted for by the model. Therefore the models are accurate at predicting the lifetime cost savings through the established predictor variables.

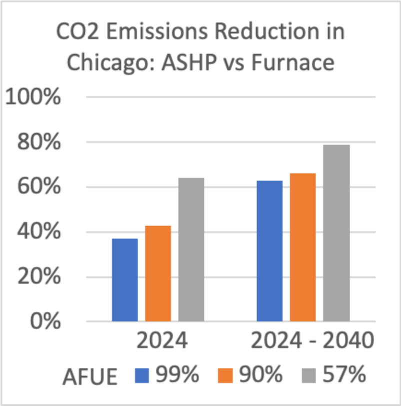
Income level may be statistically significant in Chicago and Los Angeles because the IRA's total rebates and tax credits are higher than local incentives. IRA's heat pump and HPWH rebates heavily depend on income level. For example, Chicagoan middle- and low-income families can receive federal rebates up to $5,934 and $9,436 respectively, based on average heat pump and HPWH costs. High-income households do not receive any rebates from the IRA. Locally, Chicago only offers heat pump rebates up to $1,400, not including HPWHs.

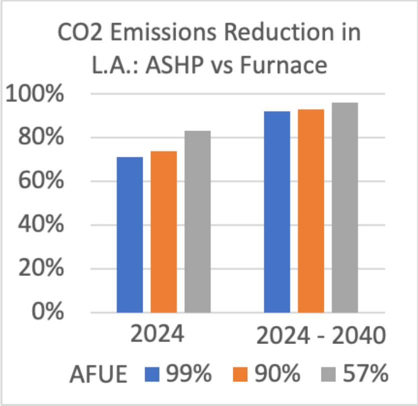
In total, Chicagoan high-income households can have tax credits and rebates up to $3,400 while low-income households can have up to $11,436, more than three times as much. In Los Angeles, low-income families obtain twice the amount of discounts on heat pumps and HPWH than high-income ones. New York's total incentives can be between about $8,320 and $13,160 total, a much lower difference than the previous cities. Hence, the income level becomes a pronounced indicator in Chicago's and Los Angeles' energy cost savings.

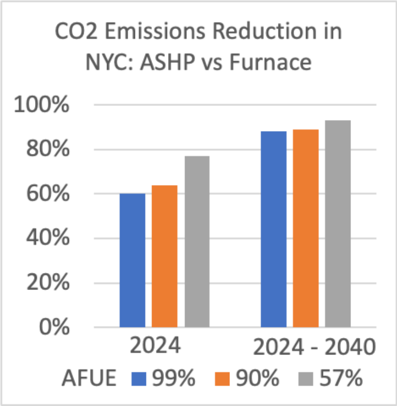
The mass wall u-factor measures the insulation performance of a house's exterior walls. It may not be a statistically significant variable in Los Angeles because of the city's climate. Los Angeles' temperatures are milder, so households require less heating load for the colder months. As a result, thermal insulation does not play as much of a role in Los Angeles' energy costs, compared to colder cities.

III. Environmental Impact

In terms of environmental benefits, the current model anticipates a substantial decrease in CO_2 emissions when replacing a gas-based appliance with a heat pump in all three cities under examination. The reduction in GHG emissions begins in the first year of installation, with a significantly higher impact observed over the appliance's 15-year lifespan. For instance, in Los Angeles, substituting an old furnace with an AFUE of 57% with a conventional ASHP can result in a 96% reduction in CO_2 emissions. The only scenario where the decrease in CO_2 emissions falls below 50% is when comparing a new furnace with an AFUE greater than 90% to a heat pump in Chicago. This result is attributed to the relatively high emissions intensity of the Chicago electricity grid. However over a 15-year forecast, the CO_2 emissions reduction exceeds 60%.







US Energy Policy Analysis

*specific information in appendix

I. Infrastructure Investment and Jobs Act(2021)

The Infrastructure Investment and Jobs Act (IIJA) of 2021, also known as the Bipartisan Infrastructure Law, represents a significant federal investment in energy infrastructure, playing a crucial role in the United States' transition towards more sustainable energy practices. These funds are geared towards conducting commercial and residential energy audits and implementing energy efficiency upgrades and retrofits of building infrastructure.

A notable feature of the IIJA's EE RLF Program is its emphasis on prioritizing heat pumps and heat pump water heaters (HPWHs) in state program designs. The IIJA emphasizes that heat pumps offer the best technology to reduce greenhouse gas emissions from on-site fuel combustion, making them a critical component in the nation's transition to cleaner energy. Additionally, these technologies can yield significant customer cost savings when integrated with demand response programs or time-varying rates.

The IIJA's support for electrification extends beyond financial incentives; The IIJA encourages states to calculate the life-cycle cost-effectiveness of energy efficiency measures, considering factors such as life-cycle energy savings, cost of measures, social cost of carbon, and health benefits. Additionally, states are allowed to use up to 25% of the funding provided by the Department of Energy for grants and technical assistance, targeting businesses with fewer than 500 employees and low-income individuals who own residential buildings. The Act facilitates a crucial shift towards electrification in residential and commercial sectors by encouraging the adoption of heat pumps and HPWHs and incentivizing their inclusion in energy audits. This shift is expected to enhance energy efficiency and contribute significantly to reducing greenhouse gas emissions, aligning with the nation's climate goals.

II. Inflation Reduction Act (2022)

To assist the country and individuals in transitioning away from fossil fuels, the federal government has included tax credits in the Inflation Reduction Act. These credits can aid in covering the expenses associated with purchasing and installing heat pumps and various energy-saving appliances.

HEEHRA offers point-of-sales rebates specifically for eligible electrification projects aimed at low- or moderate-income households. These rebates can reach up to $14,000 per household, providing substantial financial support for such initiatives (CleanEnergy.org, 2023).

Tax credits are available for those installing efficient heat pumps until 2032 (as of now), covering up to 30% of the cost and installation fees, capped at $2,000 annually. For those considering multiple energy upgrades, spreading out these improvements across years can maximize incentives. Heat pumps and heat pump hot water heaters must meet efficiency standards and belong to the Consortium for Energy Efficiency’s highest non-”advanced” tier to qualify (EnergyStar.gov, 2022).

Households meeting income criteria may also access rebates for heat pumps through state governments, varying in administration across states. Rebates could amount to $8,000 for heating and cooling heat pumps and $1,750 for heat pump water heaters. Eligibility for full rebates requires a household income below 80% of the state's median household income. Those within 80-150% of the median income qualify for 50% of rebates, while households above 150% do not qualify for heat pump rebates. Purchasing both a heat pump and a heat pump water heater could yield a total rebate of up to $9,750 for eligible households. Additionally to the IRA, local incentives also promote homeowners to transition to electric heat pumps in an effort to phase out fossil fuels on a state-level.

III. Local Rebates and Tax Credits (2023)

<u>Chicago, Illinois:</u>

The Multifamily Home Energy Savings Program in Chicago offers rebates of up to $1200 for eligible boilers, furnaces, and water heaters. Contractors participating in the program must be enrolled in the ComEd Energy Efficiency Service Provider (EESP) network (Illinois EPA, 2022). Verification of equipment eligibility is required through the Air Conditioning, Heating, and Refrigeration Institute (AHRI). To qualify for discounts, the equipment must be installed by a Service Provider and meet specific efficiency standards.

<u>New York City, New York:</u>

New York State utilities offer rebates for the installation of heat pump systems and equipment, catering to various building types and existing fuel systems, regardless of whether it's new construction or renovation. The extent of rebates is contingent upon a building's heating load/capacity, favoring systems that demonstrate optimal efficiency in colder temperatures. The rebates offered are up to $1650 (HeatSmartCNY, 2022). Contractors receive these rebates from utilities and subsequently pass on the benefits to their customers.

<u>Los Angeles, California:</u>

The Los Angeles Consumer Rebate Program (CRP) aims to encourage the adoption of energy-efficient products among residential consumers. As per the DSIRE database, 22 utility companies statewide offer rebate programs for heat pump installations, providing savings between $100 and $3,000 (EnergySage, 2023). Moreover, there's an AC Optimization program granting eligible Single Family units $3,000 per heat pump, whereas Multifamily units receive $2,000 per heat pump.

A. Cost Benefit Analysis

The development of models for heat pumps considered three types: cold-climate, conventional, and less-efficient models, factoring in city climates and cost-efficiency needs. Cold-climate pumps are pricier initially but have higher heating capacity, averaging a 10-year warranty. All are Energy Star rated and eligible for rebates. Installation costs vary by city and provider, with lower efficiency pumps generally cheaper.

Choosing a heat pump involves product comparison, cost estimation, and understanding rebates. Electric pumps offer more benefits in GHG emission ratios over gas furnaces despite higher initial costs. They yield greater long-term savings due to efficiency. The main barriers are high upfront costs and low efficiencies at cold temperatures, disqualifying them from IRA benefits.

Investing in electric heat pumps benefits all income classes monetarily and non-monetarily, though benefits may vary by income and pump type. Across utility rate types and with rebates, heat pumps show significantly higher lifetime savings for heating and cooling compared to gas furnaces in different cities.

B. Policy Recommendations

To foster building electrification, policymakers should consider phasing out tiered rates, as this promotes equitable access to electricity without penalizing increased consumption. Shifting towards time-of-use pricing incentivizes off-peak energy usage, encouraging consumers to adjust consumption habits and benefiting the grid by distributing demand more evenly. Introducing dynamic, location-based pricing aligns costs with real-time grid conditions, catering to diverse customer needs and reducing strain on the grid during peak hours. This multifaceted approach not only encourages energy efficiency but also accommodates varying consumer preferences and behaviors. A recent proposal by National Grid in Massachusetts stating discounting rates for low income households could also be used to baseline policies, that allows governments to create a more responsive and adaptable energy system that better aligns with contemporary needs while addressing environmental and grid reliability concerns (Miriam Wasser, 2023).

Conclusion

I. Key Insight Summary

The present report has found that electrification leads to savings on the energy bill for homeowners in all cases under study. However, the monetary benefits greatly depend on the local and federal incentives, appliances performance and the household level of income. The greatest cost benefit is experienced in low income households where old, inefficient gas-based appliances are replaced with heat pumps. The household insulation level plays only a secondary role in the total lifespan savings. When comparing the energy costs between a gas-based heating system with a heat pump, poor insulation generally leads to a higher difference. This is most pronounced in Chicago, where flat rates are available for both gas and electricity.

The energy rate structure also has a direct impact on the consumer's energy bill. Due to tiered rates and a relatively more expensive TOU rates option, citizens of L.A. may experience higher electricity bills than citizens of Chicago, where TOU rates are more affordable than the flat rates alternative.

The benefits of electrifying space and water systems go beyond monetary value. By replacing gas-based appliances with heat pumps there is a significant potential to reduce GHG emissions in all three cities under investigation. This effect not only aligns with the zero-emissions goal of the Paris Agreement, but it can also improve the air quality in some of the largest cities in the U.S.

II. Limitations & Research Gaps

The present report has a few limitations, which are outlined in this section. To provide a conservative estimate on energy costs, it assumes that the space heating systems run non-stop each day. Realistically, hourly temperature fluctuations affect load demand, which can decrease electricity costs. In addition, the model assumes that the utilities' escalation rates remain constant. However, if many households electrify their appliances, it would decrease the demand for gas and eventually lead to a price death spiral. The model's cost calculations use the heat pumps' average unit price and installation cost from Homewyse. In reality, the device cost and installation cost will depend on the region, vendor, and the heat pump's efficiency.

The GHG emissions model includes CO_2 emissions from natural gas combustion but overlooks methane leaks in gas delivery. A 2023 Environmental Defense Fund report (McVay, 2023) states that the U.S. gas pipeline system emits up to 2.6 million tons of methane yearly. Electrifying residential gas distribution could further reduce GHG emissions beyond the current report's estimates.

To assess the seasonal COP of chosen heat pumps, daily temperature data from NOAA was utilized, offering a general performance estimate. However, it may not capture performance during extremely cold hours below -13℉, requiring backup heating and elevating GHG emissions per MMBtu of delivered heat. Historical National Weather Service data confirms that Chicago, New York, and L.A. did not experience temperatures below -13℉ throughout 2022.

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Appendix

I. Acronyms

ASHP - Air Source Heat Pump
ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers
AFUE - Annual Fuel Utilization Efficiency
BTU - British Thermal Unit
BTUH- British Thermal Units per Hour
ccASHP - Cold-Climate Air Source Heat Pump
ComEd - Commonwealth Edison Company
ConEd - Consolidated Edison
COP - Coefficient of Performance
EER- cooling capacity/electrical input
EF - Energy Factor
HEEHRA - High Efficiency Electric Home Rebate Act
HP - Heat Pump
HPWH - Heat Pump Water Heater
HSPF - Heating Seasonal Performance Factor
IECC - International Energy Conservation Code
IRA- Inflation Reduction Act
kWh - Kilowatt-hour
LADWP - Los Angeles Department of Water and Power
MMBTU- Millions Metric of British Thermal Units
NREL - National Renewable Energy Laboratory
SEER - Seasonal Energy Efficiency Ratio
UEF - Uniform Energy Factor

II. Model Development

Air Source Heat Pump Selection

The ASHP models used as reference were selected to meet the needs of a one- or two-story single family detached building. They meet the following criteria:

- The rated heating capacity at 47℉ is between 20,000 - 22,000 Btu/h, sufficient to provide heating for a 2,000 sq ft home;
- The design is non-ducted, centralized and allows for multi-zone heating;
- The minimum requirements for each category are:
    - Cold climate ASHP: tax credit eligible in all of the US;
    - Conventional ASHP: tax credit eligible in the South of the US;
    - Less Efficient ASHP: Energy Star rated.
- All models are still active on the market.

The specifications of the selected ASHPs can be found in the table below. (NEEP, n.d.)

Label	Brand	Model	Ducting Config	Heating Capacity @ 47℉ (Btu/h)	COP @ 47℉	Tax Credit Eligibility	SEER	Unit Price
Cold Climate	Samsung	FJM Max Heat	multizone non-ducted	22,000	4.5	North & South	23	$4,772.00
Conventional	Mitsubishi Electric	M-Series	multizone non-ducted	22,000	3.9	South	20	$3,077.26

Less Efficient	Lennox	Lennox Real	multizone non-ducted	20,000	3.6	No	19	$2,250.00

ASHP Coefficient of Performance (COP)

For each heat pump, the COP at three or four different temperatures (depending on data availability) was used to calculate an interpolated average over the cold season; daily average temperature data was employed. Above the highest given temperature (typically 41°F) the COP was assumed to remain constant. Below the temperature of -13°F, unless the value is specified, the COP was considered to drop to 1. The ASHP specification data and eligibility verification were drawn from the NEEP ASHP list (NEEP, n.d.) and the CEE Directory.

Heating and Cooling Load Calculations

To calculate a home's monthly heating load, the model implements the ASHRAE zoning method (Bhatia, n.d. -b). The zoning method breaks up each story into thermal zones, and then summates the heat losses from materials in those zones. For simplicity, heat loss calculations are only performed for mass walls, ceiling, and doors. Cooling load calculations are performed in a similar manner, except it also includes solar radiation load from windows and ventilation load (Bhatia, n.d. -a). This procedure requires the desired temperature change and building insulation.

The desired temperature change is represented by monthly degree days. Monthly degree days are the difference between the desired indoor temperature (68°F) and the average daily outdoor temperature within a month. Temperature normals are sourced from weather stations at LaGuardia Airport for New York, O'Hare International Airport for Chicago, and University of South California for Los Angeles. Using this data, the model calculates the total degree days in each month.

The house's insulating performance is measured by its materials' u-values. In this model, a moderately insulated home complies with the 2021 IECC's u-value requirements. New York's building energy codes have more strict insulation requirements than the IECC, so the model employs those u-values instead. The insulation conditions are classified as poor, moderate, and excellent. The model assumes that poor insulation increases a moderately insulated home's heating load by 25%, while excellent insulation decreases it by 25%.

Annual Operating Costs Calculations

The annual operating costs involve the average local utility rates, maintenance fees, and total energy consumption. In cities with tiered electricity rates such as NYC and LA, households often consume more electricity than the minimum tier. To account for this, the model incorporates the monthly averages of other end-uses electricity consumption from ResStock (National Renewable Energy Laboratory, 2022) into the total energy consumption for each city. For example, gas heating scenarios apply gas utility rates to gas energy consumption and electricity rates to other end-uses electricity consumption. In all-electric cases, electricity rates are applied to the total electric consumption, including other end-uses electricity. Lastly, scenarios with a heat pump and gas backup include both the all-electric energy costs and minimum gas customer charges.

Lifetime Energy Costs Calculations

Lifetime cost calculations include upfront costs, annual costs, energy efficiency incentives, and escalation rates. Upfront costs encompass the average local heat pump prices, installation costs, and HVAC removal fees, where applicable. Energy efficiency incentives consist of local and federal heat pump rebates and tax credits. The escalation rate is estimated based on historical energy cost increases and local utility rate cases. Using this rate and the annual operating costs, the model calculates the expected future value of this annuity in 15 years. Then, it adds the upfront costs and subtracts available incentives to obtain the lifetime cost.

III. Federal and State Energy Rebates and Tax Credits

A. IRA Heat Pump requirements

Consortium for Energy Efficiency (Ductless/Mini-Splits)		
	North	**South**
SEER	>=16	>=16
EER	>=9	>=12
HSPF	>=9.5	>=9

B. HEEHRA Rebate/Tax Credits

Home Heating and Cooling (HVAC) Heat Pump		
Low Income	100% rebate	Up to US$ 8,000
Moderate Income	50% rebate	N/A
High Income	30% tax credit	Up to US$ 2,000
Hot Water Heat Pump		
Low Income	100% rebate	Up to US$ 1,750
Moderate Income	50% rebate	N/A
High Income	30% tax credit	N/A

C. Local Rebates and Tax Credits

Chicago:

<table>
<tr><th>System Type</th><th colspan="2">Rebate Amount</th></tr>
<tr><td rowspan="2">Air Source Heat Pump</td><td>≥ 16 SEER/15.2 SEER2</td><td rowspan="2">Discount up to:
$1400</td></tr>
<tr><td>Equipment must be installed by a Service Provider to qualify for discounts.</td></tr>
<tr><td rowspan="2">Mini- Split Heat Pump</td><td>≥ 17 SEER, ≥ 9.5 HSPF
≥ 16.1 SEER2, ≥ 9 HSPF2</td><td rowspan="2">Discount up to:
$1000</td></tr>
<tr><td>Equipment eligibility verified via the AHRI</td></tr>
<tr><td colspan="3">NOTE: Contractor must be enrolled in ComEd Energy Efficiency Service Provided network (EESP)</td></tr>
</table>

New York:

System Type	Rebate Amount	
Cold Climate Air Source Heat Pump	90-120% ("full load") of heating load < 300,000 BTUH	$1,000- $1,400 per 10,000 BTUH
Air Source Heat Pump Water Heater	< 120 gallons	$700 per unit
	> 120 gallons	$80 per MMBTU annual energy savings
BONUS for Cold Climate Air Source: Heat Pump + Water Heater installation	N/A	$250

Los Angeles:

System Type	Rebate Amount	
Central or Split Air Conditioner	15 SEER	$100/Ton
	≥16 SEER	$120/Ton
Central Heat Pump	≥8.5 HSPF, ≥15 SEER	$100 - $120 per ton
AC Optimization	Replace gas HVAC w/ electric heat pump (HP)	Single Family: $3000/HP Multifamily: $2000/HP