THE UNIVERSITY OF CHICAGO

ELECTRIFYING RESIDENTIAL HEATING IN CHICAGO:

EQUITABLE DECARBONIZATION THROUGH HEAT PUMP TECHNOLOGIES

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ABSTRACT

Adverse effects of anthropogenic climate change spanning environmental, public health, and socio-political domains have motivated institutions around the globe to commit to a decarbonized future. Entities have consequently set climate goals to formally engage with and take responsibility for pursuing a more sustainable way of life. In Chicago, some pursuits involve reducing carbon emissions produced by residential buildings, which make up around twenty-seven percent of the city's annual greenhouse gas (GHG) emissions (City of Chicago, 2022). This paper examines how the decarbonization of residential heating using electric heat pumps powered by low-carbon energy presents many opportunities and serious challenges for Chicago. The city of Chicago relies overwhelmingly (up to 97% in some areas) on carbon-emitting natural gas to heat homes with furnaces and boilers (U.S. Census Bureau, 2021). The combination of Chicago's extensive natural gas infrastructure and the expensive nature of electrification could leave less financially equipped groups in the area struggling to keep pace with broader electrification efforts. This paper reveals the need for long-term, comprehensive, and proactive planning to navigate the equitable decarbonization of residential heating in Chicago. Proposed plans such as Chicago's 2022 Climate Action Plan are crucial to achieving a greener city. However, these plans often lack discussion of what the goals they lay out imply, the potential repercussions of poorly executed transition, and the steps that should be taken early on to avoid future hardship. To examine these potential consequences, this analysis explores decarbonization processes in Chicago. Through an assessment of the potential effects of a heat pump rollout, various community stakeholders such as electricity providers, legislative bodies, and technical workforces, and energy-related legislation, this paper argues that the transformative character of electrification necessitates that decisions made in Chicago today must both anticipate and inform a long-term decarbonized future.

INTRODUCTION

Climate change undoubtedly poses some of the most monumental risks for the future of our planet and its inhabitants. Public and private sectors are pouring record levels of investment into finding the most effective and efficient solutions to address the challenges set forth by climate change. These solutions take many forms, including but not limited to policy intervention, energy efficiency measures, and new technological innovation. While these solutions mature, it is paramount that the socioeconomic implications of techno-solutions like the heat pump are considered to ensure a just, equitable path forward.

In Chicago, anthropogenic climate change has already altered climate and health-related components of the environment: the frequency of heat waves has increased, air and water quality have worsened, and flood risk has intensified (USGRCP, 2014). Historically, such consequences have disproportionately affected minority, disadvantaged, and underserved communities (EPA, 2021). Socially vulnerable groups may be less equipped to prepare for and recover from the negative impacts of climate change. There is an immense risk that new residential heating infrastructure and its associated socio-economic systems may perpetuate a system where the burdens of climate change fall on such vulnerable communities (Donaghy et al., 2023; Weller et al., 2022). Thus, these groups should be centered in future actions used to combat the consequences of climate change.

A prime target of "greening" our way of life is altering the way we heat our buildings. At present, buildings produce around a quarter of all CO_2 emissions, and a substantial portion of this (around 40 percent) comes from heating, ventilation, and air conditioning (HVAC) (González-Torres et al., 2022). The focus of this essay will be on the most carbon-intensive of these three processes: heating. Residential homes in the United States provide space heating using a variety of methods, including natural gas oil, propane, wood, and electricity, though the vast majority (just under 90%) use

electricity or natural gas (Muyskens et al., 2023). These two resources require extremely intensive infrastructure systems to support transmission and delivery: natural gas systems are often antiquated and require heavy maintenance when leaks and other issues occur (Sider and Friedman, 2016). The process of decarbonizing residential heating through the adoption of electric heating will inevitably disrupt the status quo of the two million miles of natural gas distribution pipeline in the United States (NCSL, 2011).

As mentioned above, the transition from natural gas heating to electric heating will rely on one technology: the heat pump. Heat pumps utilize a chemical refrigerant with an extremely low boiling point (between -15℉ and -50℉) alongside simple principles of physics: that heat flows from warmer to cooler and that the pressure of a compressible substance is proportional to its temperature (Butbul, 2022). Refrigerants circulate through the heat pump, being compressed and expanded by an electric motor to move heat from outside one's home to inside. Even when temperatures are moderately cold, the low boiling points of the refrigerants allow them to source heat from the outside environment (Crownhart, 2023). Moving heat instead of solely generating through electric resistance heating implies that heat pumps can produce much more heat than the amount of electricity put in, resulting in efficiencies of up to 300 or 400 percent (Crownhart). Powered by renewable electricity sources, heat pumps could unlock substantial decarbonization of the heating sector, which accounts for 10% of 2022 global GHG emissions (Chu Minh, 2022).

As is the case with most emerging technologies, heat pumps are expensive and not always accessible to a broad consumer base; however, increasing demand and innovation drive the technology toward achieving cost competitiveness with other heating technologies. Heat pump sales nearly doubled between 2015 and 2020 and outperformed the sale of gas furnaces in 2022 and 2023 (Crownhart, 2024). Additionally, the processes to decarbonize and electrify an entire sector, like

residential heating, could take decades, if not longer, to complete (Neme et al., 2022). This means that Chicago's decisions today will dictate who is most prepared and able to thrive in both short and long-term decarbonized futures. So, when looking at this transition, the processes required to meet Chicago's climate goals should not put people's access to affordable, reliable heating at risk. This paper examines the forces that must work in concert to facilitate a just, equitable, decarbonized future residential heating sector across Chicago. This will include an examination of Chicago's current state of decarbonization, sourcing examples of successful decarbonization processes elsewhere in the United States, and ultimately discussing insights from these examples alongside one another.

BACKGROUND & CONTEXT

Conversations of electrification and decarbonization are rooted in the general conception of our current energy transition, often referencing a switch to "clean," "green," or "carbon-free" energy. Energy transitions are not a new phenomenon. Ever since wood was burned for fire, humans have constantly had to develop novel energy inputs and generation technologies catering to evolving needs. When people could not mill sufficient amounts of grain, they transitioned to animal power (horse and oxen) and eventually hydropower to mill grain and feed the growing population (Hayes, 2014). A similar path is observed for the transition to fossil fuels. Eighteenth-century England's wood shortage and need to drain water from mines necessitated the invention of coal-powered steam engines (Hayes). These were energy transitions, and they materialized out of economic efficiency, necessity, and convenience. It should be noted that these past transitions undoubtedly involved tradeoffs that, while fostering industrial advancement, have been critiqued for not being just or equitable, often disproportionately affecting disadvantaged populations (Yao, 2020; Sovacool, 2016).

However, our current situation differs in many ways, with the current transition to carbon-free electricity motivated by the adverse effects GHG emissions have on our bodies and environment. The way the present transition will be navigated will reflect its specific motivations; yet, past transitions have nonetheless set a precedent for the scale and timeliness with which transitions have the potential to unfold.

Chicago relies on natural gas-fueled furnaces and boilers to heat homes and buildings (Kaufman et al., 2019). Our current natural gas landscape is a relatively simple one consisting of three stages: production, transmission, and distribution. Here, we focus on distribution, where utility companies (People's Gas in Chicago) deliver ready-to-use natural gas to end consumers through extensive pipeline systems woven into the city's infrastructures. Distribution accounts for at least thirty-five percent of the total natural gas bill consumers receive, a primary reason being the People's Gas Qualified Infrastructure Plant (QIP) surcharge that covers pipeline replacement and maintenance costs (Neme et al.). This essentially socializes the distribution services (i.e., pipeline installation and maintenance and other processing functions) to where the cost of upkeep is ideally shared by an expansive consumer base (OCC, 2023). Immense fixed costs, along with extensive upkeep, lead to operating costs of natural gas distribution that are up to ten times more than those of hydro, wind, and solar energy technologies (Blumsack, 2020).

In an effort to decarbonize, Chicago has so far released two Climate Action Plans, with the most recent being published in 2022. Chicago's first plan was published in 2008, and the goal was to achieve an 80% reduction in GHG emission levels in 2050 compared to 1990. That goal was updated to a 62% reduction in GHG emission levels by 2040 compared to 2017 levels (City of Chicago 2022). These reductions will be the result of increasing the supply of clean energy, reducing waste, providing more access to renewable energy for households, and developing a zero-emission transportation

network. An increase in renewable energy supply in the city is paramount to advocating for electrification as a key decarbonization tool. Additionally, a focus on equity is much more present in the 2022 Climate Action Plan, with acknowledgment of energy burden disparities across the city, the need for more equitable funding of climate investments, and an emphasis on partnerships with community stakeholders across the entire city. One portion of the 2022 Climate Action Plan most applicable to this paper encourages "aligning building codes and standards with climate best practices" (City of Chicago). The plan states the need to track residential buildings' decarbonization metrics, such as the total percentage of electrified projects, building energy intensity, and the number of net-zero-carbon buildings built per year, to follow the city's progress. Briefly touching on the decommissioning of fossil power generation, the plan lacks any discussion of how or when to navigate the transition away from natural gas distribution infrastructure. Nevertheless, Chicago's decarbonization aspirations and the health consequences of natural gas exposure have prompted a widespread reconsideration of household appliances that are powered by natural gas.

Heat pumps offer the possibility of electrifying residential heating but will only have a positive impact on climate goals if electricity is generated by a majority low-carbon or renewable energy sources. An initial analysis of emissions from heat pump adoption in Chicago could suggest that they produce more emissions than a natural gas burner. This is because Chicago's marginal electricity supply (i.e., how power is generated when demand is at its highest) comes mostly from coal-fired power plants (Billimoria, 2022). If heat pumps increase demand on the electric grid today, it might be presumed that the extra electricity required will come from such carbon-intensive power plants. This perception could unfairly position heat pumps as an ineffective option for reducing emissions. However, heat pump adoption should be contextualized in the clean energy strategies outlined by the

2022 Climate Action Plan to illustrate their value alongside an assumption that renewable power supply in the city will increase (City of Chicago).

OVERVIEW OF RESEARCH: CONCEPTUAL FRAMEWORK

This paper attempts to address one main question: how might today's actions be better contextualized in a decarbonized future to promote equitable outcomes and provide all Chicagoans with secure, affordable, and clean residential heating?

The above driving question can be furthered by a number of more granular inquiries, including but not limited to the following: Might specific populations/areas be at risk of bearing the burden of building electrification? Who are the main actors (e.g., the city government, renters, landlords, community organizations, etc.) that are involved at present, and who should be included in the future? What assumptions must be made to consider today's efforts in the context of a decarbonized future? Which strategies might be most effective at simultaneously electrifying the city and dismantling leftover fossil systems?

Electrification of the residential heating sector will likely suppress natural gas demand, shrinking the consumer base for natural gas utilities. This could result in a relatively small group of consumers left to pay the immense costs associated with maintaining Chicago's aging pipelines. When navigating the transition to an electric heating sector, equity-first frameworks should be prioritized so the transition away from natural gas does not exacerbate existing socioeconomic inequities in Chicago. Additionally, the health implications of natural gas exposure could force those who are least able to afford the transition to continue bearing these health impacts while likely having less access to health care and more exposure to other environmental harms.

This research will use principles of energy justice, the economics of building electrification, and sound scientific motivation to engage with decarbonization efforts. Examination of peer-reviewed literature alongside government reports and legislation will help compose a narrative of equitable decarbonization, electrification, and heat pump adoption in Chicago. Building codes, climate action plans, and utility commission reports will provide insight into how city and state governments have attempted to regulate and facilitate just decarbonization efforts around the United States. More general research will reveal how electrification, residential heating, and Chicago's experience with the two will inform the next steps in the city's climate actions. This paper also employs two case studies, one on California's natural gas pipeline decommissioning efforts and one on heat pump adoption efforts in Maine. From these, I outline considerations that may help align the efforts of community stakeholders and encourage a more cohesive, proactive path toward residential building electrification in Chicago.

LITERATURE REVIEW

The question of decarbonizing a city is incredibly broad and rooted in the historical precedent that built and operates our current energy systems today. Thus, the literature reviewed in the following section is diverse and spans scientific, legislative, historical, and social-science-related research. It also provides context for the electrification of residential heating in Chicago. Sources were chosen not only to shed light on past experience with relevant fossil assets but also to anticipate future electrification endeavors. To offer a conceptual basis for the arguments presented, I briefly touch upon work in the energy justice field as a mindset in which decarbonization efforts should be situated. The sections that follow detail existing bodies of scholarship that inform how cities decarbonize, what entities are involved in guiding the process, and the consequences that may emerge. They ultimately support my

argument that more pervasive electrification efforts must be placed in dialogue with the natural gas decommissioning discussion in Chicago today to avoid unnecessary hardship in the future.

Energy Justice as a Frame of Reference

Energy justice emphasizes equitable access to clean, affordable energy while addressing the social and environmental impacts of our current energy systems. It is focused on fair distribution, inclusive decision-making, and recognizing the needs and rights of marginalized communities in energy policy and practice. Three main tenets have materialized as the core of energy justice: procedural justice, distributive justice, and recognition justice (Calver et al., 2022; Vega-Araújo & Heffron, 2022; Jensen & Jensen, 2023). The way in which problems are approached and navigated is the concern of procedural justice. Making sure all relevant parties have access and are able to participate in decision-making processes, procedural justice considers community values, data transparency, engagement of local stakeholders, and informed consent (Calver et al.; Jensen & Jensen). Distributive justice emphasizes a just allocation of costs and benefits across all members and encompasses the distribution of both capital and access. Finally, recognition justice refers to a concerted effort to understand and recognize the values, rights, and needs of all actors involved (e.g., individuals, the market, and technology choice) (Calver et al.; Jensen & Jensen). The interplay between these three main tenets is what makes energy justice a more comprehensive tool to assess projects that involve potentially vulnerable communities.

In practice, energy justice can take on many forms, but all revolve around how to better engage local communities and think proactively about the consequences of a particular development. In the Guajira region of Colombia, a transmission infrastructure project connecting highly productive wind projects with centers of demand utilizes the concept of free, prior, and informed consent (FPIC) to better the quality of community acceptance (Vega-Araújo & Heffron). Previous transmission

projects had disrupted the indigenous population's ancestral territories, so energy justice was used as an analytical tool to ensure public engagement and education, balanced negotiations, as well as thorough consultation processes between the company, community, and state. In the United Kingdom, Calver et al. look at the energy justice implications of heat pump adoption in urban social housing, with a particular focus on the social well-being and health impacts of residents (Calver et al.). By observing the impacts of value-based design (i.e., programs that are grounded in the values and preferences of individuals), the study emphasizes viewing distributional justice not just in terms of access to primary goods but also to thermal comfort and energy services. Calver et al. further highlight access to active participation in decision-making processes and transparent information as crucial to facilitating energy justice. Both of these examples demonstrate how energy justice can help guide processes toward more inclusive, comprehensive, and sustainable solutions in the energy transition.

The specific transition from natural gas to heat pump technologies in the residential heating sector is complicated by its sociotechnical nature. A sociotechnical transition refers to a profound and interconnected societal shift driven by some sort of technology or innovation. Energy justice makes clear that when socio-technical transitions intersect with sustainable action, equity should inherently be a primary concern; sustainable development is viewed through a "for all" mindset per the United Nations Sustainable Development Goals adopted in 2015 (United Nations, 2015). However, discussion of the "social" elements of sociotechnical transitions is often not as robust as it should be (Jenkins et al., 2018). Jenkins et al. write of the "Three A's": affordability, access, and availability, which help to consider a broader set of consequences for the "low-carbon transition." Because the current energy transition has the potential to perpetuate the uneven distribution of costs and benefits that exists in fossil-based systems today, discussion of the Three A's should be integrated into future literature.

Climate change layers scientific, socio-political, and technical complexity, leaving users of fossil fuels feeling disconnected from associated environmental impacts; consequently, situating climate-related efforts in ethical, equitable frameworks grounded in personal responsibility is difficult for most humans (Sovacool & Dworkin, 2015). This means that individuals often lack a sense of personal complicity in the climate crisis, preventing them from exercising proper moral consideration of actions and issues related to the subject (Sovacool & Dworkin). Energy justice offers a framework to bridge this disconnect, centering equitable allocation of both costs and benefits from energy systems and the impacts they have on the environment. Effective use of such a framework will be crucial in gathering widespread support and action to combat the perpetuation of often inequitable fossil fuel systems (Donaghy et al.). In his essay, *In Pursuit Energy Justice,* Michael LaBelle argues that bridging the gap between individual action and collective relies on viewing "energy as a basic right, underpinning health, economic advancement, and education" (Labelle, 2017). With this in mind, energy justice has the potential to act as an analytical and decision-making tool, resulting in viewpoints that lead to equitable decarbonization processes (Labelle; Sovacool & Dworkin).

Anthropogenic Climate Change and Natural Gas Usage

As aforementioned, the motivation for electrifying residential heating is to move away from carbon-intensive heating processes like those using natural gas as a fuel source. Methane, the primary product of natural gas combustion, contributes to global warming in an intense way; methane has a short-term global warming potential almost 90 times greater than carbon dioxide (Gallagher, 2015). For residential heating, successful decarbonization in response to carbon emissions and climate goals will rely on a number of factors. Nikos Tsafos, the chief energy advisor to the Prime Minister of Greece and Chair in Energy and Geopolitics at an American think tank, states that these factors for whether or not natural gas will be used in future buildings will depend on (1) technology choice (e.g.

using furnaces vs. electric heat pumps), (2) building envelope improvements, and (3) technology improvements (i.e. efficiency improvements and/or manufacturing cost decreases) (Tsafos, 2020). In Chicago, consideration and inclusion of these factors in legislation, planning efforts, and climate strategies will be pivotal to determining natural gas' future.

Additionally, negative consequences from the aging natural gas distribution infrastructure span public health issues, safety concerns in communities, and impacts on economic standing. Natural gas usage in the home has been proven to have serious potential impacts on the health of those exposed to combustion products. Primary pollutants include carbon monoxide, particulate matter, air toxics, aromatic compounds, and, notably natural gas, nitrogen oxides (Michanowicz et al., 2022; Lebel et al., 2022). They have been found to lead to the development and worsening of asthma symptoms in children, increased risk of lung cancer, and even cases of premature death (Belova et al.; Zhu et al., 2020). These unhealthy products of natural gas combustion in ground-level air have been recorded to be at their highest levels during the heating season, suggesting that air quality could be improved by less reliance on natural gas for heating (Michanowicz et al.). Furthermore, these concerns impact lower income/higher percent PoC communities at higher rates than the national average in the United States, while these communities likely lack adequate access to health care and appropriate coping mechanisms (Weller et al.; Tessum et al., 2021). Natural gas stoves and cooktops are more of a concern since combustion products are directly released into the home. Properly designed and functioning furnaces vent their potentially hazardous combustion products to the outdoors, though the presence of natural gas furnaces still holds the potential to contaminate air quality when leaks in the system occur. Also, in an economic sense, leakage from antiquated natural gas transmission and distribution infrastructure may cost the United States billions of dollars in escaped natural gas annually and lead to serious risks to the environment, economy, and health of citizens (U.S. EIA, 2023; Gallagher). This is

clearly a wide-reaching, complex issue that could have drastic impacts on the population at large, with varying levels of strain falling on communities based on financial and socio-political standings. Practical costs of inaction should be factored into decisions surrounding the sociotechnical transition to electrified heating, as public health and environmental downsides make natural gas a prime target for rapid decarbonization efforts (Gallagher).

Heat Pump Technologies

Heat pumps will play an immense role in the decarbonization of the heating sector by allowing widespread electrification and reliance on renewable energy generation (Kaufman et al., 2019). Heat pumps use refrigerants under a series of electrically powered compressions and expansions to move heat from one space to another. Though refrigerants have historically had extremely high global warming potentials if leaked into the atmosphere, recent work with natural refrigerants has begun to offer more environmentally friendly alternatives to commonly used hydrofluorocarbons (Vuppaladadiyam et al., 2022). The American Innovation and Manufacturing Act of 2020 tightened regulations on refrigerants to facilitate a transition to these less harmful compounds (Pistochini et al., 2022). Additionally, studies examining the efficacy and energy impacts of heat pumps on homes suggest that heat pump technologies offer energy-efficient and reliable space heating in most winter climates (Puttagunta and Shapiro, 2012). While this bodes well for the widespread adoption of heat pumps, Puttangunta and Shapiro acknowledge that the most intense winter climates, like that of Chicago, may necessitate more expensive and less accessible heat pump technologies. Regardless, Chicago-specific analyses have concluded that cold climate heat pumps will be effective in both providing reliable heat and cost savings when compared to the continued use of natural gas (Neme et al.).

Speaking to broader trends, a paper from Lucas Davis out of the Energy Institute at Haas titled "The Economic Determinants of Heat Pump Adoption" indicates that income level has not been a valid determinant for whether or not an individual will transition to electrified heating (Davis, 2023). At first glance, this may suggest that an equitable transition to heating is possible without careful planning consideration and that regardless of equity frameworks, lower-income households transition to heat pumps at similar rates to those of higher income levels. However, Davis takes a high-level, nationwide approach that loses the granularity of community- and neighborhood-level disparities in energy burden and heating trends.

Decarbonization Pathways, Infrastructure Decommissioning, and Equity Considerations

There are numerous approaches to promoting heat pump adoption through decarbonization efforts, and most likely, a combination of many strategies will yield the most effective and successful transition. These approaches include instituting building codes, government-imposed incentives, and city-wide action plans. However, unlike most approaches being pursued, these strategies need to be posed alongside the proactive and gradual decommissioning of fossil fuel infrastructure that underpins our society today.

For policy, targeting new construction buildings and instituting building ordinances are some of the most effective ways to enforce cleaner heating systems at the city level. A Rocky Mountain Institute report emphasizes the value of building ordinances' ability to be phased in over time and paired with location-specific programs (Louis-Prescott and Golden, 2022). Already, the Western Chicago suburb of Oak Park adopted a building electrification code in 2023, which requires that "the source energy for [...] building[s] shall be all-electric" and that "energy from fossil fuels may [only] be provided by generators for emergency backup power" (Village of Oak Park, 2023). Building ordinances and regulations could provide useful tools in breaking the natural gas status quo in Chicago

and mandating the adoption of cleaner heating technologies where easiest to implement. Regardless of the mechanism, a shift towards top-down electrification mandates or similar instruments is certainly probable, meaning today's planning initiatives should address the potential for a future (even one that is decades away) where natural gas infrastructure for residential use is obsolete.

Government incentives are also key to a successful rollout of heat pumps. The Inflation Reduction Act released in 2022 created the "high-efficiency electric home rebate program," which gives funding to states to award point-of-sale rebates for heat pumps (up to $8,000 USD). To receive the full rebate, a household must have an annual income below 80% of the area median income level. The IRA also gives up to $2,000 in tax credit to go towards heat pump purchases and installations. Local governments realize the potential that legislation like the Inflation Reduction Act (IRA) holds, as observed in an addendum to Chicago's 2022 Climate Action Plan. The addendum outlines opportunities created by the IRA, notably the Home Energy Performance-Based Whole House Rebate Program, the High-Efficiency Electric Home Rebate, and the Energy Efficiency Home Improvement Credit (City of Chicago, 2023). These programs prioritize low- to moderate-income households and make technologies like heat pumps more accessible, ultimately strengthening Chicago's ability to realize a decarbonized future. However, Lucas Davis explains that equity issues arise even with these incentive programs, as some are based on non-refundable tax credits (Davis). Non-refundable incentives leave large swaths of lower-income taxpayers ineligible and unable to take advantage of the incentive because they have insufficient tax liability (Heightley et al., 2019). Research on previous and existing clean energy-related tax credits, such as those for electric vehicles, solar panels, and energy efficiency investments, reveals the equity concerns of the credits in practice. In one study, Borenstein and Davis find that the vast majority of these credits go to the top quintile of income earners, while the bottom three quintiles received just 10% of the $18 billion of credits that were allocated between

2006 and 2016 when the study was completed. This split varied somewhat by credit type, with the worst results for EV tax credits, where the top income quintile received 90% of the credits (Borenstein & Davis, 2016). This demonstrates why cities and government agencies should consider tax incentives' accessibility as a top priority to ensure just use of these programs. As an alternative, analysis of electric vehicle incentives points towards rebates rather than tax credits as delivering more value to consumers and encouraging more equitable outcomes (Roberson & Helveston, 2022).

Even if incentives were equally accessible to all, the adoption of electric heat pumps could still lead to equity challenges. Individuals disconnecting from the natural gas system could leave a shrunken consumer base to pay for infrastructure repair costs. However, in the case that one particular geographic area has a clear advantage in its ability to transition from natural gas heating (e.g., favorable system structure, financial capability), there is potential that after electrification has occurred, natural gas infrastructure in that area could be decommissioned. This would lessen the burden for those still connected to the natural gas system, yet the idea of a stranded asset is a major concern for those considering a targeted decommissioning approach. Zwickl-Bernhard and Auer attempt to normalize this idea in their study "Demystifying Natural Gas Distribution Grid Decommissioning." The potential for stranded assets (i.e., natural gas infrastructure no longer in use) should not justify the maintenance and continued use of gas infrastructure for residential heating (Zwickl-Bernhard and Auer, 2021). Through a case study in an Austrian neighborhood, Zwickl-Bernhard and Auer suggest that deep decarbonization of residential heating is possible. This becomes clear when considering the potential of technologies like heat pumps and weighing the costs of removing decommissioned infrastructure with costs of inaction like leakage and repair costs. The study's findings echo sentiments found in a California Public Utilities Commission report on natural gas distribution infrastructure decommissioning. While the safety and reliability of infrastructure activities are clear motivators in the

proposal, climate goals are emphasized to justify decommissioning as a proactive, sustainable action. Also reflected in the decommissioning proposal is Zwickl-Bernhard and Auer's stress on the need for neighborhood-level planning. The proposal sorts census tracts into five tranches based on ease of electrification in a targeted decommissioning approach (California Public Utilities Commission Staff, 2022). With more analysis in the Chicago region, a similar framework could be applied to strategically disassemble the fossil infrastructure as electrification strategies are executed throughout the city.

In Chicago, the above-mentioned topics are complicated by its geography's intense climate and aging housing stock. These factors mean that in some cases, heating a Chicago home is up to twice as energy-intensive at the national average, with the bulk of that intensity resulting from how intense fossil fuel heating tends to be (Spanier et al., 2022). This presents a unique set of challenges for the city in the context of its decarbonization goals and necessitates well-thought-out planning efforts. However, cutting-edge electrification efforts in Chicago are already underway to provide faster, more efficient, and more capable electrification infrastructure including ComEd superconductor cable installation, development of a ComEd microgrid in Bronzeville, a new grid resiliency and modernization program funded by a DOE grant, and a ten year, $2.6 billion ComEd smart grid program (Allais et al., 2023; Business Wire, 2023; ICC, 2018; PR Newswire, 2011). These programs will serve as a solid foundation for the electrification of residential heating in the city.

Interventions

A multifaceted exploration of decarbonizing and electrifying residential heating in Chicago reveals the inherent complexity of such a transition. The literature reviewed spans scientific, legislative, historical, and social science perspectives, with energy justice emerging as a crucial framework for equitable decarbonization. The need to move away from carbon-intensive natural gas usage is evident and will be mediated by heat pump technologies. However, the potential equity challenges necessitate

careful consideration, particularly in infrastructure development and government incentives. The case of Oak Park's building electrification code highlights the role of specific, jurisdiction-wide policies and studies on decommissioning natural gas infrastructure, stressing the importance of neighborhood-level, targeted disassembling of fossil infrastructure. More research is needed to integrate these ideas alongside the proactive decommissioning of fossil infrastructure. As electrification initiatives progress in the city, informed decision-making and inclusive strategies will be key for a successful, sustainable, and equitable transition towards a decarbonized future.

METHODS & DATA

Situating Chicago's residential heating sector within both progressive electrification efforts and the proactive decommissioning of fossil assets will require extensive consideration of which frameworks, actions, and community stakeholders are most important. This analysis will ultimately clarify the following question: How can Chicago equitably electrify its residential heating sector while also anticipating the transition away from fossil infrastructure? Here, this paper primarily uses a qualitative examination of data, legislation, and literature to set the stage for Chicago's current state, extract lessons learned from electrification and decommissioning processes elsewhere, and map any insights to the specific case of Chicago. These lessons will allow this paper to provide a more comprehensive review of Chicago's decarbonization process, which the existing literature lacks, with a particular emphasis on incorporating natural gas pipeline decommissioning discussion.

Quantitative Data: Descriptive Statistics

The present state of Chicago's residential building and heating environment will come in the form of descriptive statistical visualizations prepared for the city of Chicago. The two visualizations presented in the results section include 1) a mapping of a Chicago-specific Environmental Justice (EJ)

Index by census tract and 2) a mapping of energy burden in Chicago by census tract. Data for the Chicago EJ index is prepared by the Chicago Department of Public Health and is based on the CalEnviroScreen model. The EJ index takes a weighted average of environmental exposure measurements (e.g., particulate matter 2.5, Ozone, air toxics cancer risk), environmental conditions (e.g., proximity to hazardous waste sites), sensitive populations (e.g., asthma, old age, disability), and socioeconomic factors (e.g., low-income households, less than high school education, people of color). This paper relies on the EJ index metric to visualize areas of Chicago feeling the most intense burden of climate change and environmental characteristics. These geographic areas may thus be potential targets to prioritize in the discussion surrounding electrification and fossil asset decommissioning.

I also look at Chicago's energy use trends via visualizations of the American Community Survey. The American Community Survey (ACS) is an annually released dataset from the U.S. Census Bureau collected through a nationwide survey (U.S. Census Bureau, 2023). A map prepared for the city of Chicago by Greenlink Analytics for the Climate action plan illustrates discrepancies in energy burden across the city. Greenlink Analytics is an Atlanta-based non-profit organization helping illustrate the economic, social, and environmental impacts of energy use around the United States. Knowing which communities are most impacted by energy consumption today will be useful in predicting which communities are most at risk when change is introduced.

Case Studies

Neither the transition to heat pumps nor the decommissioning of fossil assets are novel ideas in the United States. Thus, instances of accelerated action on these fronts may inform how Chicago approaches its own residential heating electrification process. This thesis explores two such case studies: (1) California as an exploration of how state and local governments are beginning to think

about natural gas infrastructure decommissioning alongside electrification efforts, and (2) Maine as an example of the successful advancement of heat pumps and their electric heating sector.

The California case can be thought of as an easy one. California has more energy justice programs than any other state in the U.S., and its climate is more temperate than Chicago's and less demanding of advanced heat pump technologies. (Carley et al., 2021). California's milder climate gives homes in the state the option to purchase less efficient and less expensive heat pump models compared to the cold climate heat pumps required for Chicago winters. This may allow California homes to have slightly more financial capacity to switch to electric heating. However, this essay utilizes California more for the light it sheds on natural gas pipeline decommissioning. California is reliant on natural gas to heat its homes and buildings to a similar (although slightly lesser) degree than Chicago, suggesting that Chicago could hold similar attitudes toward the future of natural gas infrastructure (Muyskens et al., 2023). California is one of the most progressive examples of pipeline decommissioning in the United States and offers a thought process considering the long-term impacts of climate change and how it will influence energy consumption.

The Maine case study may also be considered an easy case. Maine does not exhibit the natural gas distribution infrastructure that Chicago does; instead, Maine has historically heated the vast majority of its homes off the grid with heating oil delivered to households by truck (U.S. EIA, 2023; Muyskens et al.). For this reason, the state's fossil decommissioning aspect is far less complex. However, Maine's climate is similarly intense to Chicago's, with Maine and Illinois having 6,013 and 6,348 heating degree days by census division, respectively (U.S. EIA, 2023). Heating degree days measure the extent to which outdoor temperatures fall below a standard reference temperature, typically 65°F, providing a quantitative estimate of heating energy requirements for buildings (Climate Prediction Center, 2005). Still, Maine has been one of the most successful states in implementing heat

pumps to meet climate goals. Thus, the Maine case study provides valuable insight into how a community can popularize heat pumps and stimulate their electric heating industry.

Limitations

While data used in this paper gives a sufficient overview of Chicago's environmental characteristics, population demographics, and energy landscape, a lack of robust household-level data makes it difficult to know the true, current state of heat pump adoption and its distribution across space. Without a concrete starting point, it is difficult to accurately predict how developments in heating electrification will impact specific areas of the city. So, generalizations like those to broad geographic areas are often necessary.

It should be noted that while there are certain factors pertinent to natural gas usage and heating electrification contained in Chicago's Environmental Justice Index, there are also other factors like proximity to wastewater discharge or low birthweight that may not be as relevant to this discussion. The index also only details ambient pollutant levels for the outdoor environment. Yet natural gas combustion has been proven to have serious health implications relating to respiratory disease inside the home (Lebel et al., 2022). Without data detailing indoor natural gas levels, how these factors are involved in the decision to perpetuate or prevent continued natural gas use is lost in this discussion.

The lack of a city with an identical climate and historical residential heating environment requires this paper to utilize case studies that do not fully reflect the specific circumstances of Chicago. A less intense winter in California enables homeowners to select less costly heat pump technologies, potentially paving the way for an easier transition, especially for those who are less financially equipped. This is why the California case focuses less on its efforts in the heating electrification space (which are robust). Instead, a focus on dealings with natural gas distribution infrastructure that is

similar enough to Chicago's yields meaningful insights for the city. Similarly, though Maine does not have to grapple with the aftermath of heating electrification on natural gas infrastructure in the same way Chicago or California might, the state's work with heat pumps and electric heating workforce development is innovative and has allowed the state to take leaps towards climate goals that Chicago is in need of.

Additionally, this paper does not interview homeowners and/or landlords from communities that might have the potential to benefit from electrification processes. Without a government mandate, much of a city's decarbonization processes may be contingent upon actual community members engaging in electrification activities. Thus, the data analyzed lacks the perspective of consumer willingness to electrify.

RESULTS

Chicago's residential heating decarbonization journey will alter some of the most fundamental systems that power the city today, primarily through less reliance on natural gas distribution infrastructure. This essay attempts to clarify what will change, where this change might happen, and how it could unfold equitably and efficiently. First, a qualitative assessment of descriptive statistics spanning population characteristics, energy consumption, and housing characteristics reveals the current situation in Chicago. These descriptive statistics convey whether or not the distribution of environmental and socioeconomic burdens across Chicago is equitable. Then, an exploration of two case studies, one on California and one on Maine, highlights two of the most ambitious and thoughtful examples of residential heating decarbonization in the United States. California's case explores proactive planning for natural gas pipeline decommissioning, and Maine's case illustrates a concerted effort to advance heat

pump adoption in the state. Finally, key aspects of these two case studies will be discussed in the context of Chicago's heating electrification journey. Chicago may use these two cases to inform their short-term building decarbonization goals while also initiating discussion of long-term natural gas decommissioning.

Chicago Assessment

This section considers descriptive statistics and visualizations exposing an unequal distribution of the burden of climate change and energy consumption across Chicago. How and where these burdens persist in the future will most likely be impacted by residential heating decarbonization and thus centered when considering the transition to electric heating. The primary objective of this section is to convey that a blanket approach to electrification and decarbonization efforts in Chicago does not align with how need and circumstance are distributed across the city. After the two case studies are presented, I discuss how Chicago's electrification efforts might address the unequal distribution of socioeconomic and environmental conditions in the city. The following considerations are some of the most important to this discussion, as they are inherently tied to the impacts of fossil fuel combustion or one's ability to electrify home heating:

Area of Interest	**Reason for Concern**	**Assessment Metrics**
Environmental Conditions	Fossil fuel combustion and associated emissions create unhealthy conditions for the natural environment and the beings living in it	Ozone Levels, Methane Leakage Rates
Public Health	GHG emissions, both inside and outside the home, may induce negative health outcomes in the population, with some being impacted more	Asthma Rates, Particulate Matter 2.5 Levels, air toxins, cancer risk

	than others	
Financial Stability	Customers dropping off the gas infrastructure system could raise fixed fees for remaining customers paying for natural gas	Energy Burden, Rent Burden, Percentage Low-Income Households

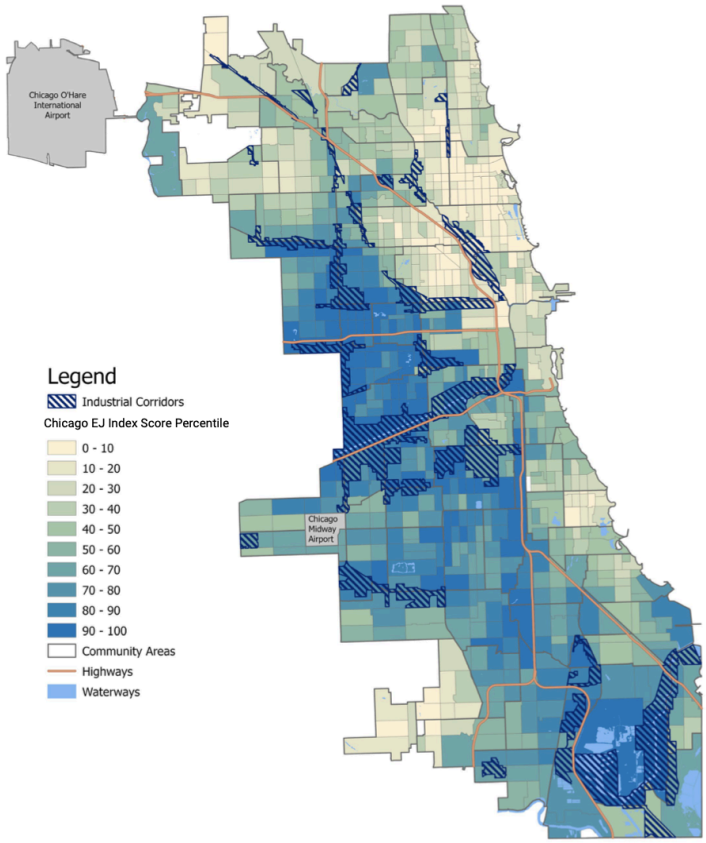

Figure 1. Chicago Environmental Justice Index Score by Census Tract (Source: Chicago Department of Public Health, 2023)

The visualization in Figure 1. combines the first three areas of interest as the Chicago Environmental Justice Index, which has been mapped by census tract (Chicago Department of Public Health, 2023). As mentioned in the methodology section, the two components that make up the index are "sensitive population/socioeconomic" and "environmental exposure/conditions." Most relevant to this paper are housing-burdened, low-income households, no health insurance, and people of color

(representing one's ability to adapt to the burden of climate change) as well as ground ozone levels, asthma rates, and particulate matter (i.e., products of natural gas combustion). Mapping by census tracts highlights Chicago's South and West as areas where environmental and socioeconomic conditions are noticeably poorer than others. Thus, these areas may necessitate more careful planning when it comes to electrification efforts, either when considering those areas specifically or when considering how changes in other areas might impact residents of the South and West.

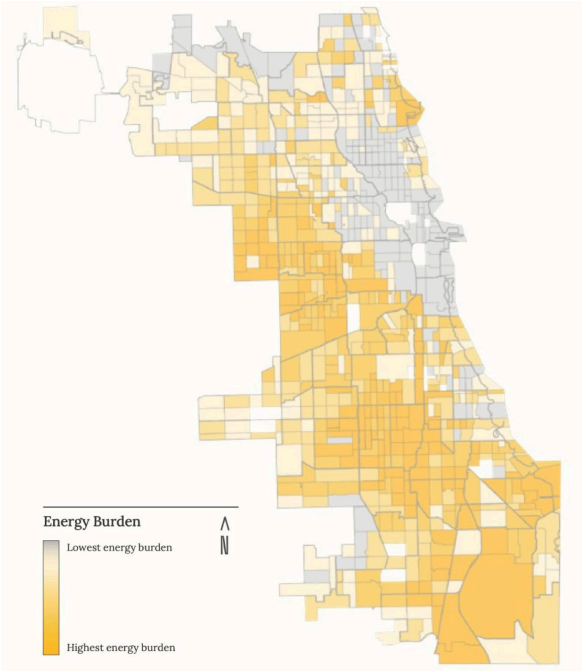

Figure 2. Energy Burden in Chicago by Census Tract (Source: City of Chicago, 2022)

Figure 2. visualizes energy burden across Chicago census tracts and is drawn from Chicago's 2022 Climate Action Plan. Energy burden is the percentage of income a household must spend on electricity and heating (Department of Energy, n.d.). According to a report published by Greenlink Analytics, Chicago's median energy burden in 2019 was 4.1% compared to a national average of 3.6% (Greenlink Analytics, 2021). This translates to Chicago homes experiencing energy burden at rates

14% higher than the national average. Furthermore, the disparity between the least and most burdened tracts pales in comparison to national trends: Chicago's 20% most burdened communities are five times as energy burdened as the 20% least burdened communities (typical national averages are around 2.5 - 3.5 times) (Greenlink Analytics). While the average energy burden has slightly dropped in Chicago recently, some communities with the highest energy burden still saw conditions get even worse. Figure 4. shows the change in energy burden in the highest-burdened tracts across the city. Conditions improved in some (shown in blue), though many saw conditions worsen between 2013 and 2019 (shown in purple) (Greenlink Analytics). Like Figures 1. and 2., Figure 3. again highlights the tendency for communities in Chicago's South and West sides to be the most burdened.

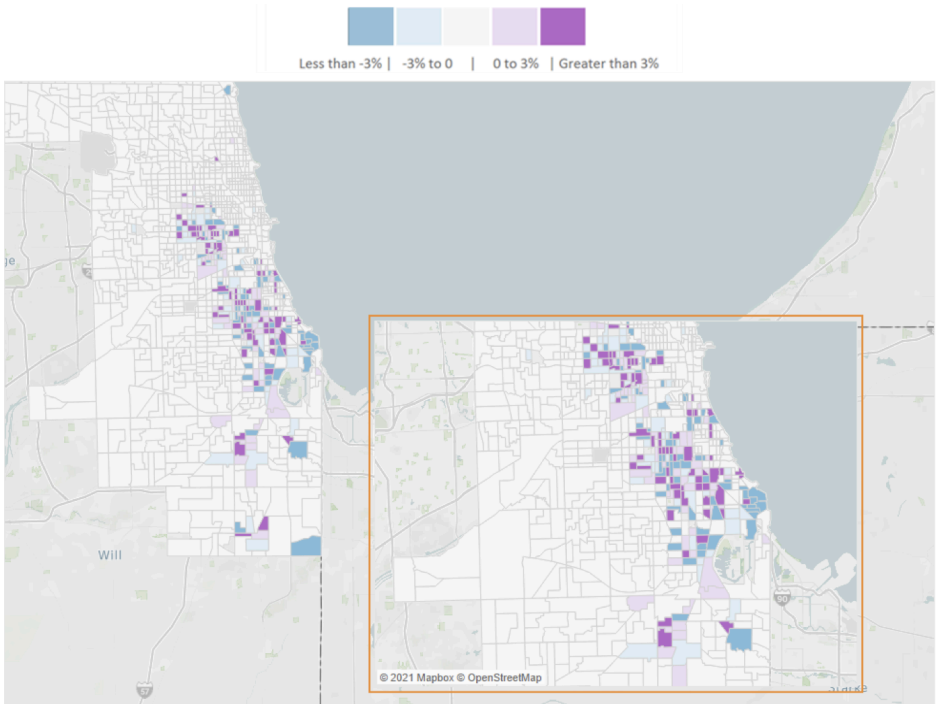

Figure 3. Change in Energy Burden in Highly Burdened Tracts 2013-2019 (Source: Greenlink Analytics, 2023)

The above visualizations should illustrate that Chicago's South and West sides are exposed to elevated levels of environmental injustices and public health risks (e.g., poor EJ index scores) and are

additionally less able to finance household energy costs (e.g., higher energy burden overall and especially among the most burdened tracts). Neighborhood-specific assessments, strategies, and programs should be undertaken to incorporate these realities when engaging in discussions of decarbonization activity.

State of Residential Heating Electrification in Chicago

The bulk of residential housing decarbonization efforts in Chicago have stemmed from the American Rescue Plan Act (ARPA) passed by the United States Congress as a stimulus bill following the COVID-19 pandemic. ARPA appropriated $1.887 billion to Chicago for use between March 2021 and December 2024, and the city also issued a general obligation bond worth $660 million to make sure ARPA funds catalyze meaningful change (City of Chicago, 2021). The city of Chicago created the Chicago Recovery Plan to lay out an investment strategy for the roughly $2.5 billion in total funding. After essential services were fulfilled, $1.227 in incremental investment was left over and was invested in communities that could benefit from additional assistance to recover from the pandemic (City of Chicago, 2023). One such form of additional assistance was the Residential Housing Decarbonization and Retrofits program. This program divides decarbonization efforts into three tiers based on the priority of decarbonization activity (i.e., each tier can only be accessed once all components of a higher tier are complete), with Tier 1 being the highest and first to be addressed (Chicago Department of Housing, 2023).

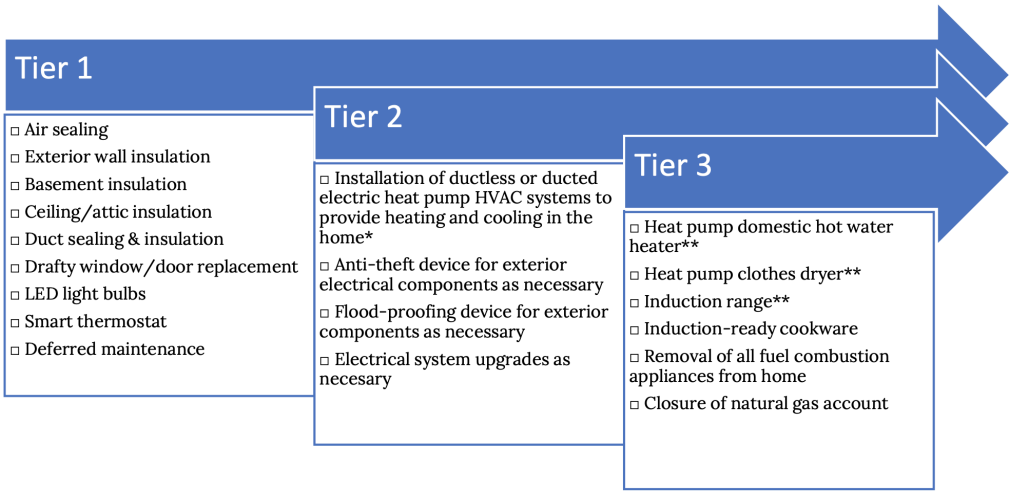

Figure 4. Residential Housing Decarbonization and Retrofit Program Levels of Intervention

(Source: Chicago Department of Housing, 2023)

Heat pump installation falls under Tier 2, while some other heating-related activities like wall insulation, duct sealing, and draft minimization are prioritized in Tier 1. The tier system was developed in partnership with the National Renewable Energy Lab, a federally funded research institute, and Elevate Energy, a Chicago non-profit focusing on equitable climate action. While this program is certainly a productive step in Chicago's decarbonization journey, it is only allocated $15 million from Chicago Recovery Plan Bonds, meaning its impact is limited in scope.

Case 1: California and Natural Gas Pipeline Decommissioning

California has taken some of the most progressive steps towards decarbonization, with its most recent 2022 Scoping Plan for Achieving Net Neutrality being touted as one of the most ambitious frameworks of its kind. The 2022 Scoping Plan sets out a path towards carbon neutrality by 2045 and is accompanied by a document strategizing how the state will implement the goals outlined in the Scoping Plan (California Air Resources Board, 2022). Like most climate action plans, California's strategy uses a multi-pronged approach and spans incentives, financial assistance,

building decarbonization, research initiatives, utility rate restructuring, and education efforts. Naturally, a primary component entails the electrification of residential buildings (California Air Resources Board, 2022). Fossil fuels supply about half the energy consumed in California's buildings, so a central goal of the plan is to switch to electric alternatives. Emissions standards established in the plan effectively ban natural gas-powered heating in homes by 2030, further solidified by a statewide goal of six million heat pumps being installed by the same date (California Air Resources Board). Such aggressive electric heating goals necessitate a discussion of how to deal with the state's existing heating infrastructure, which consists largely of natural gas pipelines. This case study focuses on this discussion and California's involvement with pipeline decommissioning research and action.

California takes an equity-first approach towards decarbonization with its $922 million Equitable Building Decarbonization Program, aiming to retrofit low-income households with electric appliances and energy efficiency upgrades (California Energy Commission, 2023). Crafted by the California Energy Commission staff in 2023, this program is made possible by a 2000 California State Assembly Bill, which added a surcharge on gas consumption to fund such programs that ultimately benefit the gas ratepayers (Molin, 2022). It is also partially in response to recent state and city actions mandating electrification standards in new construction and large-scale retrofit projects. Energy Commission staff write that the state can only effectively navigate cost and equity concerns associated with a gas-to-electric transition through thoughtfully planned and managed strategies (Molin). The primary goal of the Equitable Building Decarbonization Program is to "reduce greenhouse gas emissions and advance energy equity." The program is entirely focused on under-resourced communities that meet eligibility requirements relating to California's environmental justice indices and median household income levels (Molin). The program's initial phase uses these metrics to identify

"Initial Community Focus Areas." Most criteria for these focus areas directly relate to short-term or immediate impacts of building decarbonization: the presence of local organizations that can facilitate the process, areas where utility bill savings may be the largest, areas already vulnerable to climate risks, areas underserved by existing decarbonization programs, and areas with above average energy burdens. However, a clarification states that the program should simultaneously coordinate "reductions in gas infrastructure in specific geographic areas" (California Energy Commission). Thus, the initial focus areas may also be prime candidates for gas decommissioning projects.

The California Public Utilities Commission also released the Staff Proposal on Gas Distribution Infrastructure Framework in Support of Climate Goals in December of 2022. This proposal confronts the issue of an aging natural gas infrastructure in an increasingly electrified environment and evaluates whether maintaining and/or repairing pipelines is in the best interest of utility ratepayers. Consequently, the proposal considers which lines should have the highest priority for decommissioning when continued use of natural gas is deemed impractical (California Public Utilities Commission Staff, 2023). Central to the framework is the safety and reliability of the energy system, ensuring that decommissioning does not compromise the remaining infrastructure. The Staff Proposal plans for census tracts to be divided into five tranches, each projected to take many years to electrify, and the option to target subsets of tranches as well. Tranche 1 (High Benefits Early Adoption) focuses on just 5% of tracts with significant community burdens and higher than average potential for ratepayer cost savings. These areas may exhibit community champions (i.e., housing or environmental advocacy groups), elevated asthma and ozone rates, high natural gas-to-electricity usage ratios, and require above-average levels of investment. Tranches 2-4

address the next 70% of census tracts and ensure affordability and safety for the system that is left behind. Finally, Tranche 5 addresses the remaining customers: those hardest to electrify and with high potential for renewable natural gas. This framework also echoes related policy emphasizing the importance of electrification mandates in building codes, educational campaigns in local communities, and incentive or direct-install programs that make electric appliances more accessible (California Public Utilities Commission Staff, 2023).

Moreover, California engages community stakeholders through an ongoing Tactical Gas Decommissioning Project, also funded by the California Energy Commission. The project is a joint effort between energy consultants E3 and Gridworks, the local power supplier East Bay Community Energy, and the investor-owned utility company Pacific Gas and Electric Company (Halbrook, 2022). The project aims to address a shrunken customer base being left to cover the maintenance costs of distribution lines once homes and buildings disconnect from the natural gas system. There is special consideration for at-risk populations unable to afford electric alternatives for their home and forced to stay on the natural gas system. These remaining homes and buildings will also endure cost increases associated with fuel alternatives that could be introduced to the system, like renewable natural gas or hydrogen (California Public Utilities Commission Staff). The Tactical Gas Decommissioning Project hypothesizes that targeted electrification paired with natural gas infrastructure decommissioning could avoid some of the potential economic hardships of a gas-to-electric transition (Halbrook). Through local community engagement, the creation of deployment plans, identification of funding sources, and education/outreach to stakeholders and policymakers, the project hopes to identify three pilot sites to roll out a targeted electrification and natural gas infrastructure decommissioning strategy (one of which will be low-income) (Gridworks).

Case 2: Maine and Heat Pump Adoption

The heating landscape in Maine has historically been quite different from that of Chicago or California. Maine is almost exclusively dependent on petroleum products like heating oil to heat its homes and buildings. The state lacks crude oil or natural gas reserves, production facilities, or refineries, so any petroleum products must be imported via marine points of entry or from nearby regions via pipeline. They are then distributed within the state with limited scope, with Canada being the principal supplier (U.S. EIA, 2023). With a lack of extensive pipeline infrastructure, homes obtain fuel for their boilers from delivery vehicles servicing individual consumers (U.S. EIA). In 2021, petroleum was the largest energy source for Maine, with a significant portion used by the residential sector. Over 70% of Maine's households relied on petroleum products for heating–the most of any state in the U.S., while just 8% relied on natural gas (U.S. Census Bureau, 2021). This reliance on petroleum products for heating makes it vulnerable to supply disruptions and price spikes, both of which electrification efforts can help mitigate.

This case study stems from an act passed by the Maine Legislature to promote heat pump adoption and the efforts that followed to make the intended results of the act possible. Passed in 2019, An Act to Transform Maine's Heat Pump Market to Advance Economic Security and Climate Objectives ("The Heat Pump Act") outlines Maine's commitment to increasing energy efficiency with high-performance heat pump installations statewide (Maine Legislature, 2019). First, the act prevents electric resistance heating from being the primary heating source in new constructions, renovations, or remodels. Resistance heating is incredibly inefficient due to energy losses along the path from electricity generation to end consumption; Maine was careful not to let electrification efforts encourage this technology since it lacks the efficiency gain heat pumps offer. The primary purpose of the act was to establish a goal of

100,000 new high-performance heat pump installations across the state between 2019 and 2025 (Maine Legislature). In 2023, the governor announced that the state had surpassed this goal two years early and set a new goal of installing an additional 175,000 heat pumps by 2027 (Office of Governor Janet T. Mills, 2023).

Maine established its independent, "quasi-state" organization, Efficiency Maine, in 2009 through the Efficiency Maine Trust Act to operate as a central hub for energy efficiency and clean energy solutions across the state (Maine Legislature, 2009). The organization aims to reduce energy costs, improve the security of state and local economies, and reduce greenhouse gas emissions through various measures (Rewiring America, 2023). In addition to encouraging heat pump uptake, these include maximizing weatherization and efficiency of homes, enhancing heating improvements across income levels, and simplifying access to assistance with energy-related resources (Efficiency Maine, 2024). Efficiency Maine's contributions to stimulating the heat pump environment have been instrumental in achieving a high level of success. The organization orchestrates efforts that target both the residential and commercial sides of heat pump adoption. On the residential side, a heat pump rebate program offers up to $10,600 of assistance when combined with federal tax credits. Efficiency Maine itself contributes up to $8,000 per housing unit, with the amount varying based on income levels: up to $8,000 for low-income individuals, up to $6,000 for those with medium income, and up to $4,000 for high-income earners (Efficiency Maine). This is in addition to the $2,600 that could come from federal tax credits under the Inflation Reduction Act. On the commercial side, enrolling in Efficiency Maine's vendor network is mandatory for their clients to access the rebate program. The organization works hard to simplify general installer registration, product performance standards, and installation requirements. Once registered, Efficiency Maine supplies training videos and scholarships, vetted leads for potential customers, and reimburses for advertising

expenditures. The Maine Community College System also created comprehensive training programs to support the state's vendors (Rewiring America, 2023).

ANALYSIS & DISCUSSION

Maine and California are examples of how progressive politics and frameworks can facilitate significant and proactive action to achieve climate goals. Both of these cases have valuable insights for a city like Chicago in its earlier stages of electrification. California's progressive steps outlined in its 2022 Scoping Plan and Tactical Gas Decommissioning Project highlight the importance of pairing electrification efforts with targeted gas infrastructure decommissioning planning to mitigate economic hardships and maintain safety and reliability. The California Energy Commission realizes that achieving the state's climate goals necessitates large-scale decommissioning pilots to ensure the transition to electric infrastructure is cost-effective and equitable for the population at large. However, a large-scale pilot can not be safely pursued without substantial due diligence and multiple successful small-scale pilot projects. Thus, the earlier these smaller-scale projects can be tested, the more prepared California will be to manage a natural gas to electric transition once technologies and other electrification processes have matured. These initiatives demonstrate California's commitment to a systematic and inclusive approach to decarbonization and set a precedent for other regions to follow.

On the other hand, Maine's success in promoting heat pump adoption can be attributed to a comprehensive and well-coordinated plan of action led by Efficiency Main. The state's unique energy landscape, characterized by a heavy reliance on imported petroleum products and a lack of natural gas infrastructure, justified a shift towards more sustainable heating solutions. Efficiency Maine and the passage of The Heat Pump Act in 2019 played a crucial role in reducing energy costs, improving economic security, and reducing greenhouse gas emissions in the state. A robust rebate program,

technical and financial assistance, and a focus on quality installations are just some of the ways these efforts led to the premature achievement of the state's heat pump installation goal. Maine's experience demonstrates the importance of legislative support, coordinated stakeholder action, and targeted incentives to drive the adoption of heat pumps.

These instances should not be ignored when evaluating, and lessons should be extracted and applied to the best of their ability in Chicago's future. The following sections discuss just some of the potential consequences of residential heating electrification in Chicago and consider how the cases of Maine and California might or might not inform a smoother and more efficient process for the city. In addition to the applications of the two case studies, energy justice tenants have the potential to help guide Chicago's actions. The following table, prefacing a more in-depth discussion, provides some insight into how the three main tenets might be applied to Chicago's journey based on the above results and reviewed literature.

Energy Justice Tenant	**General Tenant Definition**	**Potential Application in Chicago**
Distributional	There is a just and equitable distribution of costs and benefits through promoting reliability, opportunity, and access for all members of the community.	- Promoting widespread access to clean technologies - Ensuring efficient and reliable heating across the city - Making sure communities with high energy burdens are not the last to electrify on their own - providing accessible financial assistance in the form of rebates, direct install programs, or refundable tax credits for heat pumps and other electrification activities - Exploring targeted electrification strategies to anticipate a reduction in reliance on residential fossil asset infrastructure - Preventing electric resistance heating from gaining traction in the case of electrification legislation
Procedural	There are inclusive, deliberate, and fair decision-making processes that facilitate balanced negotiation,	- Being transparent with the risks involved with both maintaining natural gas infrastructure and electrifying a household's heating

	increased access to information and legal processes, and collaboration between the state, community, and the commercial sector.	- carrying out thorough socio-political reviews of decarbonization activities before widespread electrification occurs - Encouraging heating electrification-related discussion between companies and corporations such as utilities and heat pump manufacturers and the communities of Chicago - Obtaining community consent before fossil infrastructure decommissioning pilot programs are rolled out - Ensuring balanced negotiation between all parties involved when planning efforts commence
Recognition	There is a concerted effort to use public engagement and education to both recognize the idiosyncratic behavior and understand the dynamics of specific individuals, communities, and markets involved.	- Educating communities on their rights - Engaging in public discussion to determine the values of the community - Recognizing the identities, rights, and needs of specific, neighborhood-level communities and understanding how they agree with or contrast the electrification goals of the city

Levels of Governance

A clear difference between Maine/California and Chicago is the levels of government involved in each. The above case studies looked at top-down efforts of collective state action, regulation, and strategic planning; the discrepancy between state and city jurisdiction is certainly a limitation to the application of the case studies to Chicago. For example, most activities relating to natural gas and electric utilities fall into the hands of state-wide regulators. The Illinois Commerce Commission's (ICC) Bureau of Public Utilities oversees the "provision of adequate, reliable, efficient and safe utility services at the least possible cost to Illinois citizens served by electric, natural gas, telecommunications, water and sewer public utility companies"' (ICC, 2024). Thus, high-level issues concerning rate regulation, infrastructure investment, consumer protection, and energy strategizing fall under its authority. At the city level, Chicago is in charge of enacting local ordinances (e.g., building codes, air

quality zoning, and waste management rules and regulations), constructing strategic plans (e.g., Chicago Recovery Plan, Climate Action Plan, Healthy Chicago 2025), and providing essential services (e.g., housing, transportation, and public safety services).

Considering the above regulatory landscape, Chicago's residential heating decarbonization journey will, in large part, be determined by how the state and Illinois Commerce Commission decide to progress forward. However, many of the actions taken by the state in California's case were prompted by local governments instituting their own electrification and emissions standards. There are still ways in which Chicago can tailor a unique path that works for the city and promote decarbonizing activities to progress at a more rapid pace (e.g., The Residential Housing Decarbonization and Retrofits Program). In this sense, the limited scope of city jurisdiction should be used to Chicago's advantage, as city-wide efforts directly engage local stakeholders and can be tailored to specific areas.

Heat Pump Adoption

The Clean Energy Jobs Act (CEJA) was signed into Illinois state law in September 2021, and a series of training programs were created to further the clean energy workforce. An "HVAC Installer & Technician Training Framework" component included in the Clean Jobs Workforce Network Program, which is the curricula accompanying CEJA, includes teaching basic technical and installation knowledge for heat pumps; however, it also provides training related to residential natural gas heating and boilers (Clean Jobs Framework, 2023). Comprehensive, electrification-specific workforce development programs are lacking, and there is an opportunity to provide such targeted efforts at a local level. Similar to Maine, Chicago could partner with local educational institutions like the City Colleges of Chicago to introduce additional pathways to grow the electrification workforce. The City Colleges of Chicago already offer a fossil-based heating certification program, yet nothing related to heat pumps (City Colleges of Chicago, 2022). Partnering with community colleges may also make it

easier for lower-income residents to participate in and reap the benefits of decarbonization efforts. The electrification workforce ultimately catalyzes and sustains the uptake of clean technologies, and Chicago must offer more accessible ways for Chicagoans to become involved.

A climate action plan with emissions reduction goals as ambitious as Chicago's should be able to hold themselves accountable by translating those high-level goals into actions at the consumer level. California and Maine's concrete targets for the number of heat pumps installed by a specific date reflect such mechanisms of accountability. They both contextualize the scale of workforce training efforts needed and cultivate a sense of urgency with which the community should consider electrification efforts. Like California and Maine, Chicago's emissions reduction commitments (62% GHG emissions reduction by 2040) should be combined with knowledge of the residential heating landscape to produce a substantive goal relating to heat pump adoption and climate commitments.

Building Regulation

Building ordinances are one of the most powerful tools to drive widespread change at the city level. An aggressive but potentially necessary first step in transitioning away from the natural gas status quo in Chicago would be to pass a natural gas ban in new constructions for some time in the near future. This is essential to avoiding the continued use of natural gas in the city and to serve as an impetus for the development of a solid electrification workforce. California's building emissions standards effectively ban natural gas-fueled appliances by 2030 and allow households to understand that change is coming soon and to act accordingly. Regulations on new constructions not only define the residential heating status quo at the time of construction but also potentially solidify it for as long as the building remains. In 2021, the median age for a 2-4 unit housing development in Chicago was 108 years (though these tend to be the oldest building type in a community), meaning that many of our homes were built to operate with technologies from a century ago (Institute for Housing Studies,

2021). Also of interest is that with current technologies, single-family homes are easier to electrify, especially when it comes to heating technologies, and may, therefore, be the first to transition from natural gas (City of Chicago, 2023). However, priority areas in Chicago (i.e., those with the most need and least resources) are often highly composed of multi-family homes (Institute for Housing Studies, 2012). These areas may, therefore, be left behind if expected to electrify on their own and should be prioritized and given special attention when organizing planning efforts or enacting legislation.

With current building emissions standards, natural gas usage and associated emissions could persist for longer than ideal to meet emissions reduction goals in the city. The average lifespan of a natural gas boiler used for residential home heating is between fifteen and twenty years (Addo-Binney et al., 2021). The installation of new boilers today translates to at least another decade of commitment to natural gas usage and is in complete tension with our climate goals, which are set for less than two decades in the future. Chicago must evaluate whether it can afford to knowingly guarantee high levels of natural gas consumption and still reach GHG emissions reduction goals by 2040. The city has already spent millions of dollars to electrify buildings through programs like the Health Department's Residential Housing Decarbonization and Retrofits. Should Chicago allow new constructions (i.e., buildings with equal opportunity to implement electric and natural gas heating systems) to engage with activities they are already spending taxpayer dollars to get rid of?

In January of 2024, Chicago Mayor Brandon Johnson introduced the Clean and Affordable Buildings Ordinance to the city council that would restrict natural gas usage in new constructions (City of Chicago, 2024). While not explicitly banning natural gas hookups, the ordinance establishes an emissions standard, which would effectively prevent the combustion of fossil fuel in new constructions and specific instances of renovation (DiChristopher, 2024). If passed, Chicago would be following in the footsteps of the two largest cities that have both already adopted versions of natural

gas bans or restrictions: Los Angeles (effective 2023) and New York (set to go into effect in 2026) (Winters, 2023). However, building ordinances hold the potential to discourage new construction for developers who are either unwilling or unable to meet the electrification standards (Listokin and Hattis, 2005). Some Chicagoans are concerned that the proposed ordinance will push developers to look outside the city's borders to develop new residential projects–something Chicago is in need of, especially those considered affordable (McFarlane et al., 2021; Chicago Metropolitan Agency for Planning, 2009; Chicago Tribune, 2024). Yet, cities just outside the borders, like Oak Park and Evanston, have begun to propose or have already enacted gas bans in new construction themselves (Village of Oak Park, 2023; DiChristoper). These smaller cities look to Chicago on how to guide their own decarbonization efforts, and Chicago could act as a sustainable leader in the region (Routliffe, 2023). Regardless, control over building codes is a powerful tool to stimulate decarbonization processes. The cases of Maine and California have shown this, but they also note the importance of making sure that electric resistance space heating is not the replacement for gas-powered heating. Any natural gas ban or phaseout should include this stipulation so the full efficiency gains of heat pumps can be taken advantage of. If this is guaranteed, the Clean and Affordable Building Ordinance could provide Chicago with the impetus it and surrounding areas need to ensure a successful decarbonization journey.

Natural Gas Infrastructure and Decommissioning

It is evident that Chicago must confront the relationship between natural gas consumption and residential heating powered by natural gas in the context of its climate goals. The first case presented above shows how California engaged in this confrontation and consequently began to take action toward meeting its climate goals. One reason California has had some of the most successful pipeline decommissioning efforts is because a combined natural gas and electric public utility, Pacific Gas and

Electric (PG&E), operates in much of the state. A combined utility means that the California Energy Commission can work together with the PG&E on both electrification and pipeline decommissioning efforts without jeopardizing its entire business. It is worth noting that the majority of the pipeline decommissioning efforts have occurred in PG&E's service territory, not where gas and electric utilities operate separately.

It is unlikely that People's Gas would, like PG&E, willingly collaborate with the city to disassemble their own systems–the same one they continue to spend outrageous amounts repairing and replacing (State of Illinois, 2023). As noted above, this means that any scaling back of natural gas infrastructure will most likely be mediated by the Illinois Commerce Commission. Although predicting statewide actions is out of the scope of this project, it seems the most promising path forward is to pursue small-scale, city, and community-led efforts to research how to best strategize the transition away from natural gas. California's case demonstrates the scale of policy and investment it takes to initiate just a few small-scale pilot programs and the research it demands. The work completed by staff of the California Energy Commission and California Public Utilities Commission to identify initial focus areas both for building decarbonization and for pipeline decommissioning could be used as examples for Chicago and help incorporate energy justice principles in planning efforts. For decarbonization, California's work emphasizes considering where utility bill savings are the largest, who is already vulnerable to climate risks, who is currently ignored by existing programs, and where energy burden is the highest. For pipeline decommissioning, California's tranched approach considers where ratepayer cost savings could be the highest, where severe health impacts of carbon emissions like asthma and respiratory illness are observed, where community champions like advocacy groups already exist, and where the scale of investment may overwhelm community ability. Identifying areas that exhibit these qualities is essential so that the research needed to know how to avoid energy

injustices can be completed. The Chicago Assessment above points towards taking special consideration of Chicago's South and West sides as potential focus areas. However, more in-depth and site-specific research should commence in Chicago so that when small-scale decommissioning pilot programs in these areas become feasible, the city will be poised to take action in the right places, having considered the consequences of that action. Later, when sufficient progress is made to decarbonize the grid, train an electrification workforce, and support a natural gas ban, lessons will have already been learned from smaller-scale projects. This piecemeal proactivity will be key to Chicago's decarbonization journey in the future–however far away that future may be.

Moreover, there is also an opportunity to take advantage of different federally funded programs to support smaller-scale projects in the city. The U.S. Department of Energy's Energy Efficiency and Conservation Block Grant Program supports decarbonization and energy planning efforts through the Bipartisan Infrastructure Law (Department of Energy, 2023). Funds are awarded either directly from the federal program or, for Chicago, through the Illinois Environmental Protection Agency. Projects funded in the past have already tackled block-scale electrification and natural gas pipeline decommissioning efforts in Albany, California, as well as pursued heat pump installations in Alabama, Minnesota, and New Hampshire (Department of Energy, 2023). Using grant programs like these or funds like those allocated by the American Recovery Plan Act are opportunities to begin accessing the funds necessary to thoughtfully decarbonize. Alternatively, Chicago could consider adding a surcharge on gas consumption similar to the one instituted in California to fund programs to research pipeline decommissioning potential. This, however, would have to be done extremely thoughtfully so as not to raise gas bills that are already too high for the less financially equipped.

CONCLUSION

When aligning with its climate objectives, Chicago will inevitably undergo significant transformations in fundamental aspects of its functioning as an urban center. This essay explores a critical step in achieving the city's decarbonization goals: the electrification of residential heating. Analysis of case studies and subsequent application of findings to Chicago's case uncover the opportunities and challenges associated with this transition. Findings suggest that Chicago should use a multipronged electrification strategy directed at both residential and commercial stakeholders and that the natural gas pipeline decommissioning discussion should be in concert with broader electrification efforts undertaken by the city. Chicago's unique climate and energy landscape elucidates the difficulty and complexities of transitioning away from natural gas in diverse urban environments. The city's position between a highly integrated natural gas system, a deeply rooted natural gas utility, and its aging housing stock suggests that any change in the city will be a gradual one.

Leaving decisions up to the state may seem like a logical answer from a regulatory and logistical standpoint; however, Chicago has outlined climate goals for itself that do not perfectly mirror those of the state. Accordingly, Chicago must take responsibility and align itself with its own climate aspirations. This may encourage state regulators to follow suit and make decisions that will help prepare Illinois as a whole for an equitably decarbonized future. In any case, both a timeline extending until 2040 (Chicago 2022 Climate Action Plan) or 2050 (Illinois Department of Natural Resources 2022 Climate Action Plan) are urgent in terms of building and decommissioning processes and communities should respond now.

This project does not advocate for the immediate shutting down of natural gas pipelines to prepare for the electrification of residential buildings. In fact, it is becoming increasingly apparent that utility-scale power plants fired by natural gas could be needed to "firm up" (i.e., provide a reliable

backup for) renewables (Brick et al., 2023; Gürsan & Gooyert, 2021; Guidolin & Alpcan, 2019; Citi Research Equities, 2012). This makes sure that enough power can be supplied at times of peak demand, even when the variability of renewable generation leads to shortages in supply. This project rather stresses the value of considering the *most likely* consequences of household-level climate goals and processes that have been set in motion today. A 62% reduction in GHG emissions from an increase in renewable energy supply would both necessitate and pave the way for technologies like heat pumps to take advantage of clean energy supply, increase energy efficiency, and solidify emissions reductions. Electrifying homes in Chicago should not only be considered for the immediate benefit it produces in the form of energy savings (Neme et al.). It is a way to unlock the benefits of clean-energy generation strategies included in Chicago's Climate Action Plan. In addition to increased renewable energy penetration, the plan's objectives suggest phasing residential natural gas usage to some degree in the coming decades. Chicago must begin to grapple with what less reliance on its natural gas system means for the city and its residents. The city can begin with a deeper interrogation of the questions posed in this paper: Which specific communities will feel the impact of this transition the most? Where might be the best place to initiate pilot programs? And which stakeholders stand to benefit most? These are questions that implicate all Chicago residents, but greater attention should be given to communities in the South and West–those facing greater energy burdens and environmental injustices today.

As with any research, this paper has its limitations. The lack of robust household-level data on heat pump adoption in Chicago restricts my ability to fully understand the current state of electrification and thus construct detailed predictions on where exactly to take the most effective step forward. A consequent reliance on generalizations and assumptions may not capture the nuanced realities of different communities. Furthermore, the absence of interviews with homeowners and

landlords means that the study lacks insights into consumer willingness to electrify and the potential barriers to adoption. Further research is needed to address the gaps in data and perform a more nuanced, in-depth analysis of the impact of heat pump rollout on natural gas and electric infrastructure in the city.

Despite these limitations, the conclusions presented above have important implications for policy and practice. They underscore the need for targeted programs that address barriers to heat pump adoption and highlight the importance of integrating fossil fuel decommissioning strategies into broader electrification efforts. Heat pump strategies must engage both residential and commercial sides, especially in low-income and marginalized communities, to ensure a just and equitable transition. Most importantly, context-specific information, including housing stock characteristics, energy burden disparities, and financial capacity among Chicago communities, must inform how stakeholders guide decarbonization processes. Chicago undoubtedly possesses the resources and the ability to anticipate the challenges of electrifying residential heating and meet its climate goals. It is now a question of whether or not stakeholders will work together, learn from ongoing electrification efforts around the country, and take the necessary action to facilitate a just transition for all.

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