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Ms. Lisa Felice
Executive Secretary
Michigan Public Service Commission
7109 West Saginaw Highway
Lansing, MI 48917

RE: MPSC Case No. U-21534

Dear Ms. Felice:

Please find enclosed the Official Exhibits DAO-117 to DAO-140 sponsored by Justin Schott (Part 3 of 10) on Behalf of Soulardarity and We Want Green, Too, along with proof of service for electronic filing in the above-referenced matter. Please do not hesitate to contact me with any questions or comments.

Sincerely,

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xc: Parties to Case No. U-21534



Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature

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Household energy is increasingly vital for maintaining good health. Unaffordable and inadequate household energy presents adverse consequences that are amplified by poverty and a changing climate. To date, the connections between energy, socioeconomic disadvantage, and well-being are generally underappreciated, and household energy connection with climate change is under-researched. Building on the energy insecurity framework, this review explores literature related to household energy, poverty, and health in order to highlight the disproportionate burdens borne by vulnerable populations in adequately meeting household energy needs. This paper is based on a comprehensive review of books, peer-reviewed articles, and reports published between 1990 and 2019, identified via databases including JSTOR and PubMed. A total of 406 publications were selected as having potential for full review, 203 received full review, and 162 were included in this paper on the basis of set inclusion criteria. From the literature review, we created an original heuristic model that describes energy insecurity as either acute or chronic, and we further explore the mediators and pathways that link energy insecurity to health. In the discussion, we posit that the extant literature does not sufficiently consider that vulnerable communities often experience energy insecurity bundled with other hardships. We also discuss energy, poverty, and health through the lens of climate change, making the criticism that most research on household energy does not consider climate change. This evidence is important for enhancing research in this field and developing programmatic and policy interventions as they pertain to energy access, affordability, and health, with special emphasis on vulnerable populations, climate change, and social inequality.

Keywords: energy insecurity, climate change, vulnerable populations, housing, health

INTRODUCTION

Global energy demand and consumption have increased substantially and are expected to continue rising (1); this is particularly evident in countries with strong economic growth such as China and India (2). The U.S. Energy Information Administration (EIA) has predicted that world energy use will increase by 28% by 2040 (2). In 2017 alone, global energy demand rose 2.1%—twice as much as in 2016 (3). As climate change worsens, the demand for more energy services and the strain on existing services will increase. As of 2017, residential energy consumption accounted for 20% of

the total energy consumption across all sectors in the U.S. (4). Ensuring affordability, access, and adequate production of household energy is vital for maintaining individual and population-scale health and well-being. Household energy uses include cooking, lighting, heating, cooling, cleaning, and technological, medical, and other life-sustaining devices (5–7). Yet, millions of households around the world live without an adequate amount of energy (8).

Adequate access to energy is encumbered by limited and faulty infrastructure, affordability challenges, and service disruptions due to disasters and extreme weather events, often linked to climate change. This phenomenon, known as energy insecurity, is defined as the “inability to adequately meet household energy needs” (9). The energy insecurity framework includes physical, economic, and behavioral dimensions that lead to or exacerbate adverse health issues (9). The physical dimension includes poor housing quality, the structure of the home environment, and inefficient appliances (9). The economic dimension consists of affordability challenges (though it is not based merely on an economic ratio or threshold), while the behavioral dimension focuses on coping strategies, social vulnerabilities, and indicators of resilience (9). This conceptual framework helps us to understand the phenomenon of energy insecurity and its consequences. This framework parallels that of food insecurity—the “disruption of food intake or eating patterns because of lack of money and other resources” (10)—in that it reflects cost, quality, and health impacts.

In this article, we present the results of our review of the existing literature on energy insecurity and demonstrate the range of concerns and of approaches to resolving them. We propose the new terms—“acute” and “chronic” energy insecurity to further understand and break down household energy issues. Our findings suggest that the literature does not sufficiently consider the intersectionality of vulnerability types and multiple hardships. Furthermore, the use of numerous terms for household energy insecurity further compartmentalizes energy issues by geography and discipline, hampering the possibility for a comprehensive, or systematic literature base. This compartmentalization foregoes the opportunity to address energy insecurity as a complex, interdisciplinary, intersectional, and multidimensional issue, especially in the context of the pressing threat of climate change. For the sake of clarity, we provide below a brief overview of terms currently used to describe household energy issues as they relate to socioeconomic disadvantage, and in some cases, health.

HOUSEHOLD ENERGY TERMINOLOGY

Many different terms have been used to describe the demand side of energy-related hardship. Researchers, policymakers, and practitioners have popularized terms such as fuel poverty, energy burden, energy vulnerability, and energy poverty, among others. These terms differ in their geographic usage and somewhat in their methods of measurement, but all similarly reference issues related to energy consumption and affordability. Energy burden and fuel poverty are mirroring terms that are used separately in different geographic regions; the former in the

U.S. and the latter mostly in the United Kingdom (U.K.), Ireland, and New Zealand. Both terms are generally defined by an economic ratio whereby households that allocate more than 10% of their gross income for indoor energy expenses are considered energy burdened or fuel poor (9, 11–13). Energy poverty is generally attributed to the Global South and refers to the lack of modern energy services and low energy consumption (5, 14–20). Outcomes and indicators of energy poverty center on socioeconomic development, well-being, and poverty (21). A newer term, energy vulnerability, was developed to bridge the geographical research gap between fuel poverty and energy poverty in order to shed light on energy hardship as a global problem (14, 21). Importantly, these terms and their definitions have not yet incorporated the uncertain realities of climate change and its impact on energy, even though climate impacts are fundamentally rooted in how energy is produced and consumed, and its availability is threatened by the aftermath of extreme weather events, often caused by climate change.

Despite evidence of a strong association between energy access, affordability, and health, none of the above terms inherently focus on health. Research and policy tend to focus on the economic factors of energy burden, fuel poverty, and energy vulnerability, leading to financially-motivated interventions. For example, household-level financial subsidies (e.g., bill assistance) are a popular intervention, as opposed to more structural measures such as energy efficiency upgrades or adoption of clean energy technologies. Moreover, such an economic focus does not address the full scope of the problem, as it leaves out psychosocial and behavioral factors, among others, that contribute to energy hardship. Even energy poverty’s focus on well-being and socioeconomic development omits housing quality and affordability constraints as a focus. By comparison, energy insecurity more broadly encompasses a wider spectrum of energy-related hardships that may be internal or external to an individual’s experience of the phenomenon and is attuned to an expansive range of socioeconomic, psychological, and environmental determinants that produce energy-related hardship. The energy insecurity framework offers the opportunity to evaluate health predictors and outcomes in the context of climate change (22).

The present review provides an encompassing account of the relationship between energy, health, poverty, and climate change and the pathways by which these factors are interlinked. We address the critical gap in the importance of energy for population health (15, 23) by focusing not only on medical issues but also on the cycles of social disadvantage implicated in the nexus of energy, health, and poverty. We outline the impacts of global climate change on household energy access and how it contributes to the severity of health effects and discuss the need to accommodate growing demand on energy systems. This review provides evidence that health is a necessary consideration amidst increases in global energy demand. This is particularly important when: (1) developing methods for energy efficiency and production; (2) deciphering how to distribute and provide energy to low-income, marginalized, and vulnerable households equitably; and (3) preparing for climate change and acute threats to energy access.

PAPER ORGANIZATION

We begin our analysis with a heuristic model linking the various factors that emerged during the review process, including the phenomena of chronic and acute energy insecurity (see **Figure 2**). This paper is organized into four thematic sections with subthemes. First, we propose new terminology to describe different manifestations of energy insecurity. Second, we review the evidence on energy insecurity and the social determinants of health by discussing the social patterning of energy insecurity by gender, age, health status, education, employment, socioeconomic status, and race. Next, we review evidence on the association between energy insecurity and place, noting the spatial inequalities in neighborhood resources and demographics that contribute to the increased likelihood that some community members will experience energy insecurity. Third, we outline findings regarding the connection between energy insecurity, housing quality, and home energy infrastructure by exploring the relationships between housing tenure, energy efficiency, and home age. Fourth, we highlight the salience of coping strategies and behaviors enacted by households experiencing energy insecurity and describe the health effects of temperature extremes, high-effort coping, and the depletion of resilience reserves. The *resilience reserve* is a framework that describes how resilience that should be preserved for use in a specific event, such as in response to a natural disaster, becomes depleted due to constant use in response to a greater prevalence of chronic daily struggles (24). To conclude, we summarize the findings of our review and describe the cumulative hardships of energy insecurity. In the discussion, we offer a critical analysis of the literature, highlighting that the research does not adequately consider the intersectionality of experiences of energy insecurity, infrequently employs an environmental justice framework, and lacks cohesive terminology. These critiques are discussed in relation to the growing wealth gap, increasing energy costs and demand, research into household energy in the Global South, and the inevitable impact of climate change.

METHODS

This review is based on a comprehensive search for relevant literature published between 1990 and 2018 and archived in JSTOR and PubMed. The literature review conceptually frames energy issues along the lines of climate change, health, and socioeconomic factors. The literature review search was conducted using a matrix of terms in varying combinations with one another. The search terms and their categories are outlined in **Table 1**. Terms from each category were searched along with terms from other categories. For example: (1) [(energy insecurity) AND (poverty) AND (climate change) AND (health)]; and then, (2) [(fuel poverty) AND (poverty) AND (climate change) AND (health)]. A term from the “Social,” “Health,” and “Energy” category was used in every search because one of our inclusion criteria is that articles discuss the relationship between household energy, health, and socioeconomic status. We did not include “climate change” as a required term for every search, as part of the review is analyzing the extent to

which the existing literature on household energy considers climate change. We excluded sources about energy and climate change that did not have a health outcome or a socioeconomic focus. Any source that did not discuss energy at the household, neighborhood, or community level was also excluded. Beyond this, our criteria were purposefully broad in order to capture the breadth of topics related to household energy use, health, and climate.

The search was limited to articles in English. Books, peer-reviewed articles, and reports were included, and all other source types were excluded. Our initial database search plus additional articles added from reviewing the reference sections of various sources yielded 750 results. After discarding duplicate sources and literature that was not relevant based on title, we had 406 sources. These sources underwent title and abstract screening. At this point, we identified 203 sources for full review. Of these, 162 were analyzed and incorporated into the final manuscript (**Figure 1**). Some sources out of the 203 identified were not included in the final manuscript due to the subsequent irrelevance of their topic once the topics discussed in the manuscript had been refined during editing.

HEURISTIC MODEL

Energy insecurity can impact health in a multitude of ways. Studies on energy insecurity encompass not only direct but also indirect health impacts because they consider social determinants of health and the coping strategies people use in response to energy insecurity. Inadequate household energy has been linked to the following health outcomes for both adults and children: cardiovascular, pulmonary, and respiratory illnesses; cancer; arthritis; acute hospitalization; excess mortality in summer and winter; and anxiety, depression, and stress (9, 13, 22, 25). Indirect health impacts, such as food insecurity, are also associated with energy insecurity (6, 26–30). It is important to highlight how indirect health problems contribute to and compound direct health impacts related to household energy insecurity. With health as an endpoint, our innovative, original heuristic model (**Figure 2**) tracks the multifaceted pathways that directly and indirectly link energy insecurity to health by distinguishing between chronic and acute energy insecurity.

DEFINING CHRONIC AND ACUTE FORMS OF ENERGY INSECURITY

Energy insecurity is a complicated, multifaceted issue that may be best understood by parsing out its various forms—acute and chronic energy insecurity. For this reason, we propose the incorporation of these terms into the lexicon of energy insecurity work. *Chronic energy insecurity* is a long-term issue that can arise from a consistent inability to afford or access adequate energy to meet household needs. An example of chronic energy insecurity would be living in a home that is consistently cold because the cost of heating is unaffordable. The lack of adequate household energy is often predicated on a number of social and demographic factors including age, gender, socioeconomic

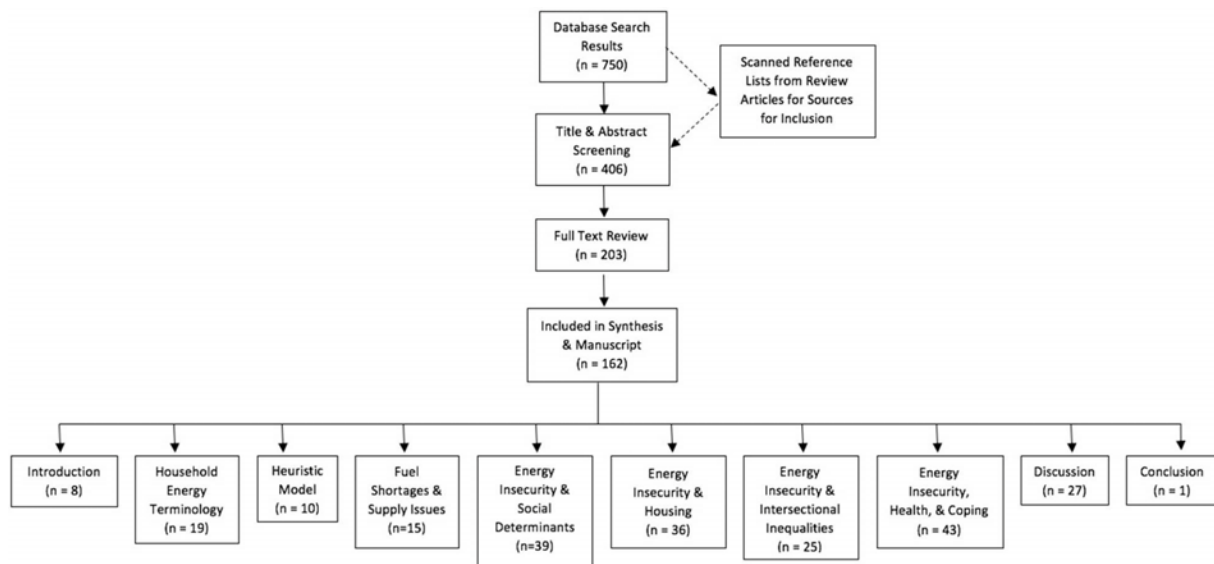


FIGURE 1 | Flow chart of literature selection and review process.

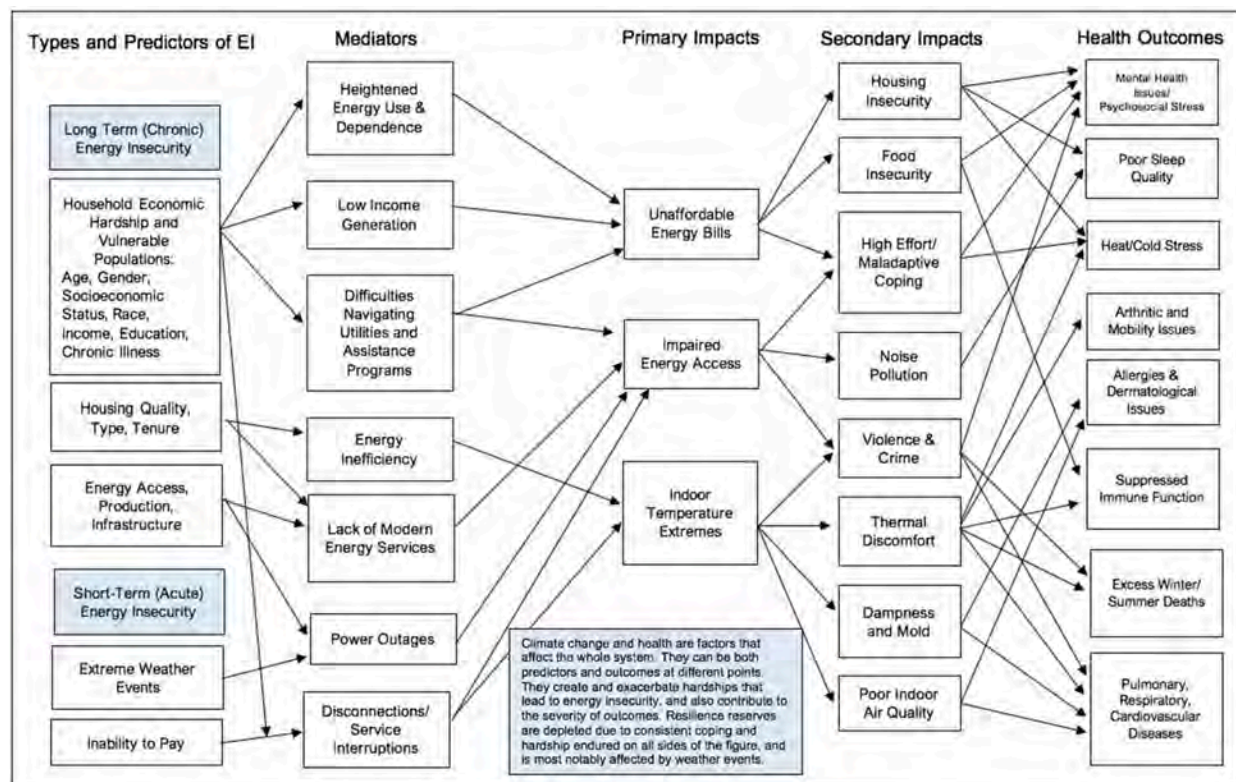


FIGURE 2 | Connection between household energy insecurity (EI) and health.

TABLE 1 | Search terms used in the literature review.

ENERGY TERMS
• Fuel poverty • Energy poverty • Energy burden • Energy vulnerability • Energy insecurity • Energy inefficiency
HEALTH TERMS
• Health • Chronic illness or conditions • Excess winter mortality, excess heat death
HOUSEHOLD TERMS
• Household, Housing, or Home • Neighborhood or Community
SOCIAL TERMS
• Low-income • Poverty • Socioeconomic Status • Vulnerable population • Social vulnerability • Resilience • Coping • Housing/Food insecurity
CLIMATE TERMS
• Natural disaster • Extreme Weather event • Climate change • Global warming • Heat wave • Hurricane • Power outage or shutoff

status, education, income, race, and employment status. These characteristics may have implications for earnings potential, can determine a household's ability to navigate available resources, and affect access to efficient housing and energy use patterns.

Acute energy insecurity is a short-term issue that tends to arise from infrastructural, maintenance, environmental, or other external sources that disrupt access to energy sources. Some examples of acute energy insecurity include a power outage from a hurricane or a gas shutoff from a reported leak. Interestingly, chronic energy insecurity can lead to a significant crisis point of acute energy insecurity, such as shut-offs due to non-payment. Shutoffs are an acute form of energy insecurity because, for the most part, they are short-lived, and services are reinstated upon cost recovery by the energy service provider. Three primary forms of acute energy insecurity—fuel shortages and supply issues, power outages, and shut-offs—and the links between service interruptions and ill health are described next.

FUEL SHORTAGES AND SUPPLY ISSUES

Health impacts from energy access issues (when infrastructure is available) can arise when demand exceeds supply via two

primary routes: (1) fuel shortages and (2) capacity of the energy infrastructure to handle excess demand during extreme weather. Fuel shortages across the world also indirectly impact health by increasing fuel cost and making sources unaffordable, leading to inaccessibility. Sometimes, other resources necessary for life are contingent on energy access. For example, during a fuel shortage, rural Inupiaq Eskimo villages in Alaska's Northwest Arctic Borough were unable to access clean water because they did not have heat or electricity to prevent pipes from freezing (31). The shortage led to increased rates of infectious disease, hygiene-related diseases, and pneumonia (31). Fuel shortages may become worse as climate change worsens, increasing the prevalence of health issues related to energy insecurity (32).

In other instances, the energy infrastructure has proven incapable of tolerating higher than normal demands. A polar vortex, which occurred in January 2019 across the United States, brought extremely cold temperatures that strained energy systems. Some parts of the Midwest reached temperatures as low as minus 38 degrees Fahrenheit (33). An estimated 21 people died across the country from causes directly related to the polar vortex, such as death by hypothermia while indoors (34). One woman in Milwaukee died from the cold when her thermostat malfunctioned (34). In many cities, gas companies ordered households and industry to lower their heat in order to prevent citywide gas shortages (33). This compromised capacity is related to reliance on an aging infrastructure and increased demand, which is likely to be an issue over time and as weather patterns become more extreme as a result of climate change.

Power Outages

Infrastructural issues, extreme weather, and natural disasters may result in power outages and energy service interruptions. Short-term power outages often occur for the following reasons: (1) older and less reliable infrastructure; (2) overloading from high electricity demand; (3) household maintenance defects; and/or, (4) other systems fail (35). Long-term power outages are typically a result of disasters such as hurricanes. In 2017, Hurricane Maria left Puerto Rico's residents without power for an unprecedented average of 84 days. An estimated 83% of these households were in the most remote regions of Puerto Rico (36). These outages interrupted healthcare for people with chronic illnesses who required care and medication (36). Moreover, the death toll attributable to Hurricane Maria in Puerto Rico was estimated to be 4,645 people, and 9.5% of those deaths were due to an inability to access electricity needed for respiratory equipment (36). The adverse impacts of service interruptions—both short- and long-term—are ubiquitous. Elevator shutdowns impede movement, transit systems close, medical device access can be cut off, blackouts can increase crime and cause accidents, food can spoil in warming refrigerators, temperature control can be lost, and much more (35, 37–39).

Shutoffs

Affordability challenges may lead to a different type of service interruption—shutoffs or disconnections due to non-payment. It is challenging to measure a national prevalence rate of shutoffs, because utility companies seldom, if ever, report which and

how many households are shut off, and these data are generally not publicly available. Hernández and Laird (40) used the Residential Energy Consumption Survey (RECS), administered by the Energy Information Administration (EIA), to analyze the prevalence of disconnection notices and service disconnections based on a nationally representative sample of US households. Hernández and Laird (40), presenting their results at the annual conferences of the American Sociological Association (ASA) and the American Public Health Association (APHA), demonstrated that in 2015 an estimated 3% of US households were disconnected and another 15% received a disconnection notice, suggesting that there is indeed some hardship. Consistent with previously observed patterns of inequality, the authors also found that low-income households, African-American and Latino households, households with children, renters, and people living in older and poorly insulated homes were most likely to receive disconnection notices and service interruptions. Hernández and Laird's (40) research further explores the coping strategies that families resort to, such as forgoing food and medicine and keeping homes at an unhealthy temperature, that compromise health and may even lead to death. Hernández and Laird (40) found that households rely on these strategies to prevent and respond to the threat and occurrence of shutoffs (40).

Service Interruptions and Health

Shutoffs and power outages have a number of direct health impacts (30, 35, 37). Temperature-related issues such as hypothermia and heat stress increase when interruptions occur at times of extreme outdoor temperature. Chronic health conditions are strained by short- and long-term service interruptions in electricity and hot water services (30, 41). Additionally, people with chronic illnesses, particularly those with cardiovascular, respiratory, and renal diseases, are often forced to seek outside medical care during interruptions, increasing the rate of hospitalization (35, 42). Rates of all-cause and external-cause mortality are significantly higher during power-outage periods, especially when outages are due to weather events such as hurricanes, heatwaves, and snowstorms (30, 35). Households that have faced threats of shutoffs have reported more long-term mental health issues stemming from financial, physical, and environmental stress, as well as fears and anxiety over potential future service interruptions (13, 43).

ENERGY INSECURITY AND SOCIAL DETERMINANTS

Both acute and chronic energy insecurity are influenced by the social determinants of health, which are defined by the Centers for Disease Control and Prevention (CDC) as the political, economic, and social circumstances in which people live, work, and play (44). These determinants include factors such as gender, age, health status, education, employment, socioeconomic status, and race. Here, we review literature indicating that the social determinants of health play an important role in predicting the existence of household energy difficulties and outline the importance of making a connection between the impact of

climate change on social determinants of health and energy insecurity. As climate change increases the frequency, duration, and magnitude of extreme weather events, it is important to consider the populations that are most vulnerable to the impacts of such events within the context of household energy use (45, 46).

Age and Life Course Vulnerability

Age-related vulnerabilities (i.e., being young or elderly) and exposure to environmental hazards are predictors of energy insecurity. The elderly, because they are at a higher risk of experiencing medical events during heatwaves than other populations due to a combination of social isolation, heightened physiological vulnerability, and the likelihood of not having air conditioning, are more likely to endure heat stress (46–48). Children are at risk of asthma, especially those living in urban, low-income communities, and are therefore in more need of adequate energy for ventilation and temperature control (49–51). Both the elderly and children spend more time in their home environments than other groups (1), increasing their exposure to the health risks of energy insecurity (52).

Education: Literacy and Impacts on Academic Achievement

Education, as it relates to energy insecurity, also has implications for health. Lacking sufficient knowledge and ability to navigate the bureaucracy of utility companies makes it difficult for less-educated households to address and prevent energy insecurity. Knowing how to access resources such as financial subsidies or medical certifications to prevent shutoffs requires knowledge of how such bureaucratic systems work. Understanding the risks associated with using alternative methods to address energy needs also requires education. On average, those with less educational attainment have more limited income potential, making it more difficult to afford and make energy payments (6, 15).

Energy insecurity also perpetuates a cycle of lower educational attainment, most notably for children. Environmental stress and financial insecurity can lead to mental health issues and result in worse educational outcomes (53). The stress of energy hardship is associated with behavioral problems in children, whereby they are more likely to have low academic motivation, difficulty concentrating, and often act out (54, 55). Children experiencing energy insecurity and food insecurity (discussed in detail in subsequent sections) are also more likely to experience intensified behavioral issues such as depression, rule-breaking behavior, and somatic complaints (54). Asthmatic children in energy-insecure households with poor air quality miss more days of school due to illness than do non-asthmatic children (55, 56). Homes that use unsuitable energy sources expose children to toxic gases that impair cognitive development. Additionally, children living in energy-insecure households often have trouble focusing on their homework due to noise pollution from generators, other loud energy sources, and open windows, which can lead to lower academic success (57). As a coping strategy, some households confine energy use to specific rooms to keep energy bills low or because there are limitations in their heating and cooling systems;

this forces all residents to be in the same room, resulting in homework distractions and crowding, among other issues. Poor or restricted lighting to certain rooms also makes schoolwork and reading for pleasure more challenging.

Employment

Energy insecurity perpetuates the detrimental health effects associated with low-income employment. Many low-paying jobs require work in extreme temperature conditions (58), such as farming in excess heat or working in refrigerated warehouses. Those working in extreme temperature conditions are also more likely to be experiencing energy insecurity at home because they are low-income. Exposure to thermal discomfort at work and at home has a cumulative effect on temperature-sensitive health problems. Members of low-income households are also more likely to work multiple jobs to pay bills and support their families, meaning they are often physically absent from the home. This absence of caretakers can affect children's developmental needs and contribute to social deprivation and caretaker stress. Single mothers are more likely to be primary caretakers and often experience augmented impacts because they do not have a partner with whom they can share the burden and responsibility. Single mothers are also more at risk of experiencing energy insecurity compared to other groups (9, 23).

Socioeconomic Status and Household Income

Socioeconomic factors are a predictor of energy insecurity. In most households, utilities make up a substantial portion of living costs, and in low-income households, this proportion is much greater (9, 30, 59). Therefore, it can be difficult for low-income households to pay for enough energy to meet household needs and also afford other expenses (9, 30). Households at or near the Federal Poverty Level (FPL) are significantly more burdened by energy insecurity than other socioeconomic groups (9). A brief look at 2011 American Community Survey (ACS) data on the characteristics of people experiencing the gap between energy affordability and unaffordability found that 44% of low-income families (defined as below 200% of the FPL) experience economic energy insecurity compared to 2% of families who are not low-income (60). A 2016 report by the American Council for an Energy-Efficient Economy (ACEEE) found that lower-income households experience higher median energy burden (7.2%), defined as the percentage of household income spent on energy bills, whereas non-low-income households experienced a median energy burden of 1.5% (61). Furthermore, a recent study found that low-income households in the studied U.S. cities spend on average from 10 to 20% of their income on energy bills, while wealthier households spend on average between 1.5 to 3 percent on energy bills despite being the higher consumers (59). The 2015 RECS found that the lower the income, the higher the energy expenditure and energy consumption per square foot of the home due to a number of potential factors (62). For example, socioeconomic status has major implications for affordability, access, and levels of environmental hazards in the home. Additionally, low-income households are often unable to afford utility bills and therefore live without adequate energy

due to heightened conservation and/or an inability to upgrade energy-related appliances and systems (59).

Race

Race is another social determinant of health that can predicate energy insecurity. Minorities tend to suffer from higher rates of energy cost burden than non-Hispanic whites in United States' cities (59). In the U.S., African Americans suffer more from energy insecurity than do any other racial groups (23, 60, 63). Of surveyed households with an African-American head of household (HOH) and children under the age of 18, 35% reported facing energy insecurity compared to 21% of Latino HOHs with children under 18 and 14% of Caucasian HOHs with children under 18 (60). Across all income levels, Black families still maintained the highest rates of energy insecurity (60). In the Washington Heights neighborhood in New York City, energy-insecure households were more likely to be black and Hispanic/Latino, low-income, and have less education (64). In Detroit, a study found that African-American households were twice as likely to be behind on utility payments and three times more likely to suffer from arrearage or shut-offs than white households (65).

When considering racial disparities, the association between environmental hazard exposure and geographical location is stronger for Black and Latino communities than for other racial groups (66). The health impacts of energy insecurity are compounded for racial-minority households that live in areas with high rates of exposure to environmental hazards energy inefficiencies (59, 66). The disparity in the impacts of acute energy insecurity is especially apparent for minority racial groups. For example, a study by O'Neill et al. (67) found that during heatwaves in four different cities across the U.S., the rate of air conditioning use was more than two times higher among the white population than the black population, suggesting that black residents did not have access to or could not afford to use air conditioning at the same rate as white residents. Additionally, the mortality rate of black residents was significantly higher than that of other racial groups across all four cities (67). This trend could be attributed to low income levels and unaffordable electricity, which disproportionately impact racial and ethnic minority households.

Gender

Gender is another social factor associated with energy insecurity that has direct and indirect health implications. In the Global South, women and girls, who are responsible for cooking, use biomass fuel, resulting in high rates of respiratory illness. Respiratory illness from solid-fuel cooking is one of the greatest causes of premature mortality globally (5, 7, 15, 68). In the Global North, women are more likely to be caretakers and spend more time at home, increasing their rate of exposure to other energy inefficiencies. Single mothers are especially vulnerable because they take on financial and psychosocial burdens alongside the responsibility of being the sole caretaker (23). It is important to note, however, that the literature in this review often fails to recognize that the separation of how gender relates to energy insecurity in the Global North vs. the Global South is reductive

and essentialized, as all of the mechanisms by which women and girls are impacted by energy issues crosscut both spheres of the world.

Health Status

Illness and chronic health problems often determine energy demand and have implications for energy consumption, thereby making poor health both a predictor and outcome of energy insecurity. Residents with health conditions such as cardiovascular, pulmonary, and respiratory diseases and arthritis are sensitive to temperature extremes, meaning that a home that is too cold or too hot can exacerbate and worsen symptoms (13, 69–71). People living with a chronic health condition may be especially reliant on energy-dependent devices for treatment or maintenance of their condition, lowering their ability to withstand inadequate or unavailable energy services. For example, patients with kidney disease, chronic obstructive pulmonary disease (COPD), and cardiovascular disease (CVD) rely on dialysis and oxygen machines that require electricity (72) and diabetics must refrigerate their insulin. Cancer patients in active treatment need more heat (73), and those suffering from hypertension are more susceptible to cold stress (74). Not only do people with chronic health conditions have an increased need for energy, but they also spend more time in their households, further increasing energy use (75).

ENERGY INSECURITY AND HOUSING

A number of household characteristics beyond location predict the existence of unmet household energy needs. The type of housing, whether owned or rented, its level of energy efficiency, and its age are all associated with energy insecurity. Low-income and minority residents face a higher proportion of difficulties related to these housing characteristics.

Housing Tenure and Type

Energy insecurity is affected by housing tenure because renting and owning can lead to unique challenges that perpetuate energy insecurity. Low-income renters often face difficulties affording household costs (76) and tend to spend the greatest portion of their income on energy bills when compared to other socioeconomic groups (77). They also tend to live in the most structurally deficient homes due to a lack of weatherization and efficiency upgrades (77). Energy insecurity can become a chronic issue, partly because low-income renters have limited ability to persuade landlords to maintain proper upkeep and implement effective modifications related to energy efficiency (43, 78). They also have limited social and economic capital to afford self-repairs or to hold landlords accountable through the court system (43). Low-income owners are also at risk for energy insecurity due to the high cost of upgrading homes to higher efficiency standards or because buying a home that is already efficient is expensive. Homeowners are often responsible for the entire burden of utility bills and other operational costs, including property taxes, home insurance, and water, garbage, and sewer costs. The stress of low-income housing on both renters and owners is associated with adverse mental health outcomes and poor self-rated health (43, 76).

Housing type also influences rates of energy insecurity. Similar to homeowners, renters of single-family units face difficulties because they are responsible for the entire cost burden. Multifamily housing can be more advantageous than single-family housing because there is a shared cost with property owners. However, residents in multifamily housing and low-income tenants often lack control over the conditions (e.g., heat) of their units and have restricted ability to combat energy insecurity, mostly due to financial constraints and lack of control over housing infrastructure (9). The New York City Housing Authority (NYCHA), the country's largest public housing authority, has faced notorious housing quality and energy infrastructure issues that have plagued residents by severely compromising their housing experience and, likely, their physical, and mental health. One challenge is that NYCHA is not subject to the same maintenance regulations as private housing or developers, resulting in structural deficiencies and energy inefficient housing, attributable in part to deferred maintenance (79). Public housing is not alone in this regard. Rental housing, including subsidized, or affordable housing, presents challenges for renters since the property owners determine the level of energy efficiency and other aspects of housing quality. In most cases, there are no guidelines that stipulate a minimum level of efficiency, particularly in older housing that was constructed when building codes were less focused on sustainability. This conundrum, known as the “split incentive,” occurs when the incentive structure for an asset is not equally beneficial to both parties. In such cases, the deciding actor works in their own best interest, as is the case with owners who dictate the terms of housing without consideration of tenancy. Previous research demonstrates that subsidized housing recipients face an increased burden because they are more likely to rent from private landlords who neither weatherize nor optimize energy efficiency due to upfront costs and administrative encumbrances, which generally privileges the property owners and negatively impacts the tenants both economically and experientially (77, 80).

Beyond rental and multiunit housing, people living in manufactured housing, such as trailers or mobile homes, are disproportionately impacted by physical energy insecurity. These housing structures are often not well-insulated or weatherized, so residents tend to spend a high proportion of their income on energy and heating bills. For example, the ACEEE found that mobile home residents are more likely to be energy burdened (61). Residents living in these manufactured housing types also tend to be low-income and therefore the least able to sustain high utility bill costs or afford general maintenance (81).

Energy Inefficiency

Energy inefficiency is a common housing problem and aspect of energy insecurity that has serious health implications. Energy inefficiency is marked by poor insulation, drafts, leaks, and other points of intrusion of the outside elements that make it difficult to control indoor temperatures (82–84). Other structural deficiencies and poor housing quality conditions, such as a lack of central air conditioning and proper ventilation, can also lead to high utility bills and unsafe conditions (85). Energy inefficiency caused by poor housing quality and structural deficiencies

spurs costly utility bills that are unaffordable for low-income people (86). Poor energy efficiency has been associated with an increase in household dampness (85), which is associated with worsened arthritis symptoms, dizziness, headaches, and fevers (79), and increases the presence of mold, exacerbating medical conditions such as allergies, eczema, and asthma (69, 87–90). Energy inefficiency is also associated with an increase in a number of thermal-related illnesses (85), and homes with poor ventilation and outside air infiltration have more dust mites and cockroach feces, which are known to exacerbate or lead to acute respiratory illnesses (27, 91–93). Households that are unable to open windows (see also the section entitled Heat Stress and Forbearance) have the additional risk of dampness as a result of obstructed airflow (57).

A popular intervention for older and/or poorly constructed homes is retrofitting (87). However, energy efficiency without attention to ventilation can lead to excess tightness in the building envelope, thereby obstructing airflow and exacerbating the aforementioned health issues related to ventilation and air quality (94). Air-tightness due to energy efficiency improvements is also associated with increased levels of radon, which significantly increases the risk of lung cancer (95, 96).

Age of Housing

Older housing is a frequent contributor to energy insecurity because much of the aged housing stock around the world is neither weatherized nor energy-efficient, which results in an increased prevalence of thermally inadequate home environments (97). Low-income, older and minority householders are often relegated to substandard living conditions, in part due to residence in older housing that has not been renovated (98). The effect of older, less efficient housing on energy insecurity has been studied mostly in the fuel poverty literature from northern Europe and New Zealand, where the regularity of colder outdoor temperatures heightens the need for consistent indoor heating (82, 99). Excess winter deaths are a measure of mortality as a result of cold homes, a problem known to be caused by a lack of insulation (13, 47, 69, 84, 99–101). Heat stress is a common health effect of hotter outdoor temperatures, whereas newer technology such as centralized air conditioning may not exist in older homes. A lack of air conditioning contributes to heat stress, excess deaths, and hospitalizations during heatwaves (67, 102). Therefore, the use of newer technology is important for health and safety, particularly as it relates to the prevention of premature death.

Newer homes are subject to current housing codes, many of which include public health considerations, and tend to be more energy-efficient and have fewer maintenance issues (97). Many states have ventilation standards, for example, which can combat mold from dampness and therefore reduce asthma symptoms (98). Regulations on toxin levels in homes, such as through initiatives for lead-free homes, also exist. It is, of course, easier to control risks that are never introduced into the housing sphere. Therefore, living in new housing stands to benefit occupants. However, the most vulnerable groups are often the least likely to benefit from such advantages.

ENERGY INSECURITY AND INTERSECTIONAL INEQUALITIES

Research has demonstrated that socioeconomic status and race are predictors of neighborhood, place, and presence of other hardships that can lead to or exacerbate energy insecurity. For example, residents in low-income and minority neighborhoods tend to experience issues such as increased exposure to environmental hazards, a lack of investment in housing maintenance, and poorer quality housing, all of which contribute to energy insecurity. Moreover, poverty and material hardship are complex issues in and of themselves, whereby the inability to meet basic needs extends far beyond any one category. In this section, we explore the overlapping issues that intersect with energy insecurity.

Socioeconomic Status, Race, and Place

The coalescence of socioeconomic status, race and neighborhood factors can lead to or exacerbate energy insecurity and present other hardships as well. For example, racial residential segregation, a proxy for concentrated neighborhood disadvantage, is a demonstrated predictor of energy insecurity (103). Black and Latino/a-headed households are more likely to live in an energy-insecure household because of their home's lack of energy efficiency (103). For example, NYCHA housing, predominantly inhabited by minorities, is facing a backlash over its dilapidation and lack of maintenance, which has resulted in widespread power outages, lack of heating, and the presence of mold and lead problems (79). Of these issues, NYCHA has been criticized severely for the persistent lack of available heat in its properties due to faulty boilers (104). In the winter of 2017/2018, ~80% of NYCHA residents faced a heat outage, which lasted 48 hours on average (105). Some advocates state that the difference in regulations for NYCHA housing compared to private housing is unjust and disproportionately disadvantages low-income communities of color (79, 106).

Low-income and minority neighborhoods collectively bear the brunt of more environmental hazards in and outside of their individual households (50, 107). For example, the siting of highly-polluting sources such as bus depots, landfills, highways, and plants or factories tend to be located in low-income communities. Low-income homes are also more likely to have maintenance defects, rodents, mold, and other poor housing conditions (66). Households in low-income and minority neighborhoods are also more likely to be overcrowded; this is especially true for immigrant populations in New York City and other urban areas. Overcrowded homes are associated with psychosocial stress, disease outbreaks, and higher asthma rates; they are also a predictor of the existence of other physical and social housing-related hardships that contribute to the burden of disease (93, 98, 108).

Furthermore, institutional and systemic racism and place-related social factors are drivers of higher rates of energy insecurity for minority populations. Ethnic minorities, immigrants, and indigenous groups are some examples of people who experience housing discrimination (57), a barrier to accessing more energy-efficient homes. Gentrification in many urban areas in the U.S is another social process that perpetuates

racial and ethnic disparities in energy insecurity prevalence. Gentrifying or newer residents are less likely to experience energy insecurity or have an energy inefficient home compared to longer-term residents who live in older households in the area (97). Long-term residents of Washington Heights in New York City, for example, are Dominican immigrants and African Americans, and they suffer far more energy insecurity than new neighborhood residents (64).

Neighborhoods and Spatial Inequality

Energy insecurity, as we have noted, is highly correlated with spatial inequality, where residents of different neighborhoods are more or less likely to experience energy insecurity due to their neighborhood's economic, environmental, and social makeup. The mean annual energy use intensity (EUI), which is a proxy for energy insecurity by way of high energy use from low housing efficiency, is much higher in urban areas that have lower socioeconomic status, less education, and more racial minority dwellers (65, 103). In cities that are more racially segregated, neighborhoods with low-income and minority populations are more likely to suffer from difficulties in affording or accessing energy (65, 109). As the gentrification of urban areas continues, racial residential segregation increases such that lower socioeconomic status populations are forced to live in areas that have substandard conditions both in housing quality and neighborhood characteristics.

Low-income and racial-minority neighborhoods in urban areas often suffer from the highest amount of environmental hazard exposure through air and noise pollution and substandard sanitation (110). This increased prevalence of environmental hazards can contribute to the health impacts of existing energy insecurities. For example, housing with poor ventilation in an area with high levels of air pollution can aggravate a child's asthma. There are well-established, clear disparities in neighborhood rates of asthma due to both indoor and outdoor environmental hazards (50), and there is an association between neighborhoods with energy insecurity and asthma prevalence (22). There is also spatial inequality and disparity in the prevalence of psychosocial stress. Low-income and minority neighborhoods suffer from higher rates of stress, which can compound the negative health effects that result from their already-increased exposure to environmental hazards (e.g., air pollution) (111). For example, family stress combined with exposure to neighborhood violence has been found to increase the incidence of traffic pollution-induced asthma in children, due to the strain on psychosocial pathways (112). The spatial disparities in energy insecurity and health also exist between urban and rural areas, where some low-income rural communities do not have access to natural gas or even electricity services, whereas lack of access to electricity services is rare in urban communities (113).

Bundled Hardships: Energy and Other Insecurities

As demonstrated by this robust review, energy insecurity is a complex problem, and it does not occur in a vacuum. The hardship of energy insecurity intersects with other hardships,

such that each compounds the severity of the others and contributes to detrimental health consequences. Competing needs and hardships, such as food insecurity, water insecurity, and housing insecurity, result in tradeoffs where basic needs are prioritized and sometimes foregone (9, 114, 115). The stress from having to make trade-offs between basic needs for food, water, housing, and energy profoundly affects adult and child mental health (116, 117), which can exacerbate many kinds of physical health and social issues.

With food insecurity, the "heat or eat" dilemma occurs when households must decide whether to expend resources on proper nutrition or adequate energy services because they cannot access or afford both (28, 30, 118, 119). Often, this dilemma leads to undernutrition, especially during the winter and summer months when there are higher energy use needs when it has been found that low-income adults and children have decreased caloric intake compared to lower-energy use months in the spring or fall (28, 118). Other health impacts from food insecurity include acute hospital visits, poor diabetes control, developmental delays, fatigue, and behavioral issues in children (54, 120, 121). In response to high energy bills, people also opt out of medical and dental care, which can lead to worse health outcomes in the future (119).

Water insecurity is another co-occurring hardship. Water and electricity tend to be dependent on one another. On a large scale, hydroelectric dams need water and electricity to function, power plants need cooling water when there are high temperatures, and nuclear plants use large volumes of water (122–124). It is not only water that is needed for energy, but the other way around as well. At the community and household level, access to hot water can be encumbered by energy insecurity (30, 41). When concerned about the cost of energy, some residents may cut back on hot water use (30). Furthermore, water pipes can freeze if there is a fuel shortage or shut-off in time of freezing outdoor temperatures (31). Without water, people's ability to access energy reduces.

Lastly, housing insecurity is a frequently cited competing hardship to energy insecurity (22). The dimensions of housing insecurity include frequent moves, lack of housing options, homelessness, high housing costs, overcrowding, and unstable neighborhoods (125–127). Households that do not have enough money to afford high-quality housing also suffer from an inability to pay high utility bills, which can result in household debt owed to utility companies. Low-income families juggling financial hardships often prioritize other financial obligations such as paying for rent or groceries, seemingly more immediate needs, over paying off debt; this behavior can leave families in prolonged debt cycles (128). Debt owed to utility companies often prevents low-income households from moving because utility debts are not transferable (9), forcing residents to continue living in poor-quality housing. A home cannot be rented without a utility account in the renter's name, which is not possible if they have arrears at another address (9). Frequent moving is also a common form of housing insecurity. Low-income families are five times more likely than higher-income families to experience eviction, resulting in a move (50, 129). Evictions generally occur when rent prices increase beyond what a family is capable of affording. Utility shut-offs play an important role in housing insecurity,

as they are often the precursors to eviction. In both instances, households may encounter the double burden of housing and energy insecurity (23). As gentrification spreads across US cities, urban housing affordability is unachievable for most low-income families, forcing evictions, moves, overcrowding, and an increase in homelessness, and while newer buildings often enjoy energy-efficiency upgrades, older homes and buildings, which are often less efficient and more expensive to operate from an energy cost perspective, do not receive such upgrades (64, 130). In short, energy cost burdens can increase housing affordability strains whereas lower energy bills can protect against high housing costs and promote residential stability.

ENERGY INSECURITY, HEALTH, AND COPING

Health issues are linked to energy insecurity. In particular, such direct health outcomes are often a result of indoor temperature extremes and inadequate energy access. Thermal stress occurs when residents are unable to heat or cool their homes properly, frequently due to unaffordable utility bills or an inability to access adequate services. As a result of inadequate home energy, residents resort to coping strategies, which, with chronic use, can be taxing and overburden resilience reserves.

Improvising and Coping Without Energy

Residents implement coping strategies to manage and respond to unmet energy needs; we consider this to be the behavioral dimension of energy insecurity. Despite the ingenuity and agency many people demonstrate in the face of suboptimal energy circumstances, these coping strategies have negative health implications. One such coping strategy is the use of emergency energy technology (i.e., generators), which is generally reserved for disasters but is often employed by energy-insecure households. Generator use is strongly associated with carbon monoxide (CO) fatalities, especially when the generator is placed incorrectly in the household (e.g., in the garage or outside of a bedroom window) (35, 37, 131). Even when placed correctly, generators constantly release CO, which in small, consistent doses can lead to cognitive decline, headaches, nausea, and dizziness. Maintenance issues can aggravate the health impacts of some coping methods, such as poorly maintained households exposing people to higher levels of toxins (50). For instance, some residents living in low-quality housing use unvented gas heaters as their primary heat source and/or hot air units that do not have ducts because they are unable to afford or access improvements. Both practices are associated with increased levels of nitrogen dioxide (NO₂) and volatile organic compounds (VOCs), which exacerbate allergies and respiratory illness symptoms, create ear, nose, and throat irritation, and contribute to cognitive delays (51, 132). People also resort to avoiding energy sources in their homes or use extreme conservation strategies to reduce energy expenditure. For example, some avoid using a refrigerator, which is associated with undernutrition due to a lack of fresh food in the diet, and/or avoiding hot water use, which can lead to infections and hygiene-related illnesses. Other survival strategies include

practices such as only heating one room of the house, going to bed early, and using low lighting (114).

Cold Stress and Coping

In the winter, cold homes due to a lack of proper heating lead to excess deaths and a number of health problems (13, 47, 69, 99, 100, 133, 134). Cardiovascular symptoms as a result of inadequately heated homes are a prevalent cause of medical issues (69, 135), and rates of hypertension increase in cold temperatures, which can lead to strokes and heart attacks (69, 74, 101, 135). The elderly and people that are already diagnosed with CVD are more at risk of heart attack and stroke due to cold stress (13, 47). Furthermore, research has found that arthritis symptoms worsen in cold homes (12). The rate of pneumonia and other infections, mostly among children, increases due to suppressed immune function from the cold (70), and upper and lower respiratory symptoms, such as coughing and wheezing, are worsened by the cold as well (69, 99, 100). Asthmatic residents and caretakers of asthmatic children living in inadequately heated homes report higher rates of poor well-being and more frequent hospital visits (27, 136). Alzheimer's patients have a higher rate of mortality from a combination of physiological and behavioral factors as a result of the cold (137). Poorer well-being and financial strain from an increased number of medical visits can exacerbate mental health issues, such as depression and anxiety, that may already be heightened due to the stress of energy insecurity (114).

In response to a cold home, many households cope by using alternative heating methods that have a direct impact on health (23). For example, using generators and stoves to provide heat also results in the release of toxic gasses such as NO₂ and CO that can impair cognitive function, exacerbate respiratory illnesses, and cause mortality (35, 49, 51, 138–140). The use of space heaters or ovens as alternative heat sources can also increase the risk of fire and injury, which could potentially lead to displacement or death (23, 104).

Heat Stress and Forbearance

Heat stress occurs when households are unable to afford or access energy to cool their homes. The health effects from this type of energy insecurity, such as increased morbidity and mortality rates, are most often seen during heatwaves when excess heat from outside conditions creates heat stress (135, 141, 142). Cardiovascular issues such as heat strokes, hypertension, and heart attack, dehydration, hyperthermia, and nervous system morbidities are examples of health impacts that occur under heat stress (69, 135, 143). Other health effects include a higher likelihood of acute renal failure (42) and increased sleep disturbances as a result of the extreme heat in inadequately cooled homes, which can exacerbate mental health conditions triggered by the stress of energy insecurity (53, 57). This increase in morbidity and mortality is motivated by other social determinants of health that predict energy insecurity (142).

Coping mechanisms for dealing with heat stress have their own related stressors and issues. For example, opening windows for ventilation and relief from heat may seem like an easy, free solution to cool down warm homes; however, in neighborhoods

that are perceived to be unsafe, many people cannot or do not travel to cooler locations nor do they leave windows open due to fear of crime and violence (141, 144). Furthermore, open windows expose households to noise pollution, particularly in urban areas where there is high traffic flow, which causes sleep disturbances and obstructed concentration on tasks (57). Open windows also increase the infiltration of outdoor air pollution, such as from motor vehicle exhaust, that is associated with respiratory and cardiovascular health risks (57).

High-Effort Coping and Resilience Reserves

Energy insecurity plays a role in depleting a person's resilience reserve (24). The *resilience reserve* framework offers a different lens than does past resilience research, which found that marginalized groups were less resilient because they had less social and material support and more life stressors (145). The resilience reserve framework argues instead that marginalized groups that contend with social, economic, medical, physical, and geographic vulnerabilities expend resilience resources to manage everyday hardships, leaving less opportunity to accumulate the psychological and material means with which to respond to and recover from large shocks such as extreme climate events (24). Therefore, after a disaster, marginalized groups have greater difficulty coping and rebounding, because they have already depleted their reserves. For example, years after Hurricane Sandy, which occurred in 2012, low-income NYCHA residents reported longstanding physical and psychosocial difficulties, citing the Hurricane's exacerbation of existing hardships and emotional trauma (24). Specifically, NYCHA residents cited the lack of electricity, heat, and functional elevators as a source of struggle, not just after the Hurricane, but before it as well. Housing, economic, and energy-related hardships had long been a source of chronic stress, constantly gnawing at their resilience reserve before the hurricane hit (24). One risk of an increased frequency of extreme weather events is the potential to exacerbate existing hardships and deeply impact the resilience capacity of vulnerable populations as they confront a growing number of social, economic, health, and energy challenges on a normal basis.

DISCUSSION

Energy insecurity is a multifaceted phenomenon with short- and long-term iterations influenced by social determinants and a changing climate, ultimately impacting health. This paper reviews existing literature in order to trace the pathways by which chronic and acute energy insecurity directly and indirectly result in various adverse health conditions. Our heuristic model is a unique contribution to the literature that intends to depict seemingly far-flung factors associated with energy, poverty, health, and climate change. We demonstrate the disproportionate effects on vulnerable populations and the mechanisms of household energy that lead to poor health and excess death. Contributors to acute energy insecurity include power outages, fuel shortages, supply issues, and shut-offs stemming from affordability challenges. For the most part,

these acute issues are short-lived, though their impact can still be significant for short- and long-term health, well-being, and survival. Meanwhile, the fundamental causes of chronic energy insecurity are rooted in socioeconomic disadvantage as determined by race, income, educational level, position within the life course, and medical conditions that affect energy needs and dependency. It is also deeply affected by housing quality and the concentration of inefficient housing at the neighborhood level that is unfortunately closely patterned along the axes of social inequality and racial residential segregation. The literature suggests that the social determinants of health, housing characteristics, and neighborhood quality seem to predict and/or exacerbate household energy insecurity. As a result, residents turn to coping methods that can have a number of negative health consequences, such as toxic exposure from generators, fires from space heaters, noise pollution and crime from open windows, and many more. Energy production and infrastructure, both globally and locally, contribute to energy insecurity in terms of access and environmental degradation. High energy demand can strain systems, weather events can create power outages, and affordability issues can lead to shut-offs and arrearages. The result of such energy insecurity contributes to outcomes such as psychosocial stress and mental health issues, poor sleep, cardiovascular and respiratory issues, and heat stress, among others. These energy-related difficulties can also deplete people's resilience reserves, such that affected populations are less able to bounce back from acute and chronic hardships. In the context of climate change, more wear-and-tear on the energy systems, housing infrastructure, and population health seems inevitable.

The following discussion offers a critical analysis of the vast but disjointed literature on energy insecurity. One critique of the present literature is that much of it lacks an environmental justice framework, which should be integral to energy insecurity research, and we exemplify this issue by discussing the lack of intersectional consideration of the rising wealth gap, coupled with increasing urbanization, and energy transitions. Second, we explore connections to energy-related issues in the Global South. Although the Global South was not the focus of this review, energy-related issues are prevalent across countries in Africa, Asia, and Latin America and must be taken into consideration when designing interventions, because energy reform anywhere has global implications. Lastly, we discuss the current and future impact of climate change on energy insecurity and the need for greater consideration of climate change when conducting research on energy insecurity. We contend that the use of acute and chronic energy insecurity terminology can be helpful to researchers using a climate change framework because it separates the direct energy-related effects of climate events (acute) from more long-term effects (chronic).

Wealth Inequality, Urbanization, Energy Transitions, and Environmental Justice

As energy becomes more expensive and the wealth gap increases in the U.S., poorer households may have greater difficulty affording adequate household energy. The difference in the

proportion of income allocated to paying for energy bills could grow wider between the rich and the poor; low-income households may increasingly spend a higher proportion of their income on energy bills, because energy bills may increase at a rate faster than does their income (22). In contrast, wealthier households may experience an increase in their income at a rate that can sustain the increased price of energy. Take, for example, the yellow vest protests in France, which were incited by increased fuel costs. Wealth inequality should be addressed in energy insecurity literature, not only to ensure that lower-income households can afford and access energy through evidence-based policy but because socioeconomic status plays a direct role in determining a persons' health environment beyond energy needs.

The growing wealth gap is influenced by the exponential influx of people to urban areas, which do not have adequate infrastructure to provide for the growing population. As urbanization increases, more people are expected to benefit from urban advantage—the idea that there are health benefits to living in urban vs. rural areas (146). However, higher-income urban residents tend to benefit more from the urban advantage, and more often, low-income residents are left in unhealthy, poorly maintained neighborhood and residential environments (146). Thus, poorer residents are left without support and endure intergenerational socioeconomic hardships that prevent families from accumulating wealth. Constantly coping with hardships is financially costly, and high energy bills can be an obstacle to saving money among low-income households (9). Higher-income residents, on the other hand, pay less of their household income toward energy bills and benefit from more efficient and comfortable living environments.

The growing wealth gap between black and white families could also worsen disparate racial impacts as it relates to the intersection of energy, health, and poverty (147, 148). Energy transitions from fossil fuels to renewables such as wind and solar may also contribute to a growing gap because white-collar businesses and wealthier households are able to control and obtain financing for renewable energy, whereas poorer, minority populations are unable to grow their use of renewable energy technology because the cost is prohibitive and access is difficult given the cost, lack of social capital, and lack of education around renewables (130). African Americans have been historically excluded from opportunities for social and economic mobility, and, in the energy sphere, they are also unduly burdened. The literature has failed to explicitly acknowledge the racial divides in energy-related hardship related to cost, comfort, and efficiency and the protracted uptake of the cleanest energy technologies among minoritized groups. It is important to recognize how an increasing wealth gap will perpetuate energy insecurity, further impacting the ability of low-income and minority families to afford adequate energy. Identifying racially based injustices has been critical to advances in environmental justice, and here too, we see a potential for greater analysis of the racial disparities in energy insecurity and related health and social outcomes.

Energy Insecurity and the Global South

While this review has focused on energy implications in the U.S. and the Global North, many of the same issues are relevant to the Global South. Few articles discussed in this review use a framework of intersectionality to discuss the burden that inordinately affects marginalized populations around the world. Research on global household energy insecurity that uses environmental justice and intersectional frameworks could more adequately analyze this topic. In the Global South, millions of households lack adequate energy sources (149). It is vital that we find methods to expand modern energy services to reach more of the population (150). However, more systematically speaking, energy is dispersed unjustly and inequitably around the world (151, 152). Some populations have greater energy access than they need, while others do not have enough (8). We know that reducing carbon emissions worldwide is vital for addressing climate change, but it is also important to address the unequal distribution of energy sources. Health impacts from energy poverty in the Global South exist partially due to limited access to modern energy technologies. One example is the increased risk of COPD and heart disease from air pollutants that stem from cooking with biomass fuels rather than using electric or gas stoves (7, 19, 153, 154). Households using biomass cookstoves, for instance, face the dilemma of inhaling toxic pollutants from cooking or not eating—both of which have significant health implications. About one-third of the world, almost entirely in the Global South, relies on solid fuel sources such as wood and crop waste for cooking fuel (5, 7). Burning solid fuels for cooking creates indoor air pollution, which is significantly associated with stroke, ischemic heart disease, COPD, lung cancer, and pneumonia. The health impacts of solid-fuel cooking disproportionately impact women and children, who are exposed to higher pollution due to spending a larger amount of their time cooking than do men. Of the 1.3 million COPD deaths among women, about 511,000 are attributable to indoor cooking pollution. In contrast, of the 1.4 million COPD deaths among men, a much smaller proportion—173,000 cases—are attributable to indoor cooking pollution (7). Increasing the prevalence of and access to cleaner fuels for stoves around the world could significantly reduce these negative health outcomes.

In the same way that people of color in the U.S. disproportionately experience energy insecurity, people of color and those living in lower-middle-income countries (LMICs) around the world disproportionately bear the burden of an inequitable global energy system. Globally, people of color bear the burden of household energy insecurity. To this day, 1.3 billion people, most of whom live in Asia, Latin America, and Africa, lack access to modern energy services (155). Of the total number of people lacking electricity access worldwide, 41.3% of the people live in African countries, 28.5% live in India, 27.3% live in other Asian countries, and 2.2% live in Latin American countries (155). Countries of color are also more likely to shoulder the impacts of climate change, though they are less responsible for carbon emissions and environmental degradation, and their ability to withstand and rebuild from weather events is lower than higher-income countries (156).

Climate Change and Energy Insecurity

The literature reviewed here does not adequately demonstrate a thoughtful link to climate change that goes beyond the concepts of adaptation and mitigation. Future research should examine the impact that climate change will have on energy insecurity. We propose that the concepts of acute and chronic energy insecurity may allow future researchers to expand upon and better evaluate the effects of climate change on household energy. Climate change worsens the direct and indirect health outcomes of energy insecurity and exacerbates cumulative risk, such that those already experiencing energy insecurity are most affected by climate events because they are less able to prepare for, respond to, and recover from disaster events (157). Communities that are most vulnerable to daily hardships are also most vulnerable to the impact of weather events, and the disparity worsens with repeated shocks from climate change (156). For instance, mortality from heatwaves disproportionately affects older, minority, and low-income residents who are less equipped socially, economically, and physiologically to withstand high temperatures. After the 1995 Chicago heatwave, there was clear demographic disparity in mortality rates—lower-income and older people died at much higher rates than the rest of the population (48). These populations were much more vulnerable to heat stress due to living in decaying housing, lack of access to medical services, and social isolation (48). Without movement toward addressing the world's substandard housing, medical, and financial systems, natural disasters could continue to disenfranchise marginalized populations, intensifying and worsening existing stressors. Though some of the literature critically appraised in this review discusses weather events, the vast majority did not explicitly discuss climate change. Research should incorporate and explore the detrimental implications of climate change when evaluating energy insecurity in order to better prepare for future climate scenarios.

While vulnerable populations tend to be hit harder by climate change-related weather events all people are affected by climate change. Climate change-related energy insecurity issues, therefore, could impact anyone regardless of socioeconomic status (158). Severe weather events will lead to acute energy insecurity such as power outages that can affect anyone. More frequent heatwaves will significantly increase energy demand, the need for expanded energy systems, dependence on household air conditioning for entire populations (45, 93, 141, 142, 159). Power outages from heatwaves and storms can put anyone at risk of medical difficulties. Furthermore, storms are increasing in frequency and severity all over the world, putting people at risk of cut off energy access. And regardless of socioeconomic status, people resort to using emergency energy systems (e.g., generators) or non-energy methods during storms or disasters, which puts residents at risk of CO poisoning (160). It is difficult for residents with chronic illnesses to withstand acute energy insecurity from storm-related power outages (141, 161). As shown in these examples, energy insecurity, particularly acute energy insecurity, may become more prevalent for all people as climate change worsens. Notwithstanding the importance of the issue, a demonstrable gap in the literature exists, given that only one-third of the sources

included in this review discuss climate change in relation to energy insecurity.

STRENGTHS AND LIMITATIONS

This review paper was inspired by a desire to comprehensively understand the predictors and outcomes of energy insecurity. The household energy literature spans many disciplines and research methods. As a result, we drew from a large interdisciplinary pool of research in order to capture enough relevant sources on this topic. The broad inclusion criteria allowed us to find articles that spanned many disciplines and methods to give us a realistic look at the full range of the household energy insecurity literature. Though the breadth of information about household energy is a strength, it was also challenging in that it demonstrated a clear lack of cohesion and systematic guidelines around research on household energy. Therefore, making connections and critiques across these fields of research and sources presented a formidable challenge, though we have done our best to synthesize the literature and draw conclusions from it. The papers vary significantly not only in focus but in scientific quality and rigor—some are more descriptive in nature, while others are more empirical. Many of the studies were not rigorously designed, and for the most part, the literature proved to be quite underdeveloped overall. This review did not assess for quality or eliminate studies on the basis of potential bias. The challenge of a highly dispersed evidence base led us to develop our heuristic model, which attempts to conceptually unify the literature on household energy and health.

CONCLUSION

When considering the substantial impact that inadequate household energy can have on population health, we recognize the need to adopt policies and practices that protect people from energy insecurity. This review sought to highlight how energy needs are important for all aspects of daily living and for protection against the effects of acute insecurities in the context of climate change. Climate change threatens life on earth as we know it, and our collective vulnerabilities to energy hardship need to be addressed with extreme urgency (162). By using energy insecurity as a framework for understanding the nexus of effects of unmet household energy needs, we can draw connections between the direct effects of inadequate household energy, such as hypertension from a cold home, and how social vulnerabilities and co-occurring hardships contribute to the problem. With this broader framework, we can begin to understand how policies that address food insecurity, housing insecurity, structural and institutional racism, neighborhood segregation, education inequality, income inequality, and so many other social issues, will also affect energy insecurity and together impact population health. Studying the energy–health–justice nexus through the lens of acute and chronic energy insecurity presents a novel and innovative direction for public health research, advocacy, and policy that can be used to improve the health of people in the U.S. and around the world.

AUTHOR CONTRIBUTIONS

SJ, SS, and DH contributed to the conception and design of the review, performed the analysis, contributed to manuscript revision, response to comments from reviewers, read and approved the submitted version of the review, and all accountable of all aspects of the review, including its accuracy and integrity. SJ organized the database and wrote the first draft of the manuscript. SS and DH wrote sections of the manuscript.

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REFERENCES

- Tonn B, Eisenberg J. The aging US population and residential energy demand. *Energy Policy*. (2007) 35:743–5. doi: 10.1016/j.enpol.2005.12.011
- Doman L. *EIA Projects 28% Increase in World Energy Use by 2040*. U.S. Energy Information Administration (EIA). Retrieved from: <https://www.eia.gov/todayinenergy/detail.php?id=32912> (accessed September 14, 2017).
- International Energy Agency. *Global Energy Demand Grew by 2.1% in 2017, and Carbon Emissions Rose for the First Time Since 2014* (2018, March). Retrieved from: <https://www.iea.org/newsroom/news/2018/march/global-energy-demand-grew-by-21-in-2017-and-carbon-emissions-rose-for-the-first.html>
- U.S., Energy Information Administration (EIA). *U.S. Total Energy Statistics*. (2018). Retrieved from: https://www.eia.gov/energyexplained/?page=us_energy_home#tab3 (accessed March 19, 2019)
- Adusei LA. *Energy Poverty: Exploring Households Energy Constraints and Coping Strategies - Epsilon Archive for Student Projects*. Swedish University of Agricultural Sciences (2012). Retrieved from: <https://stud.epsilon.slu.se/5105/>
- Cook JT, Frank DA, Casey PH, Rose-Jacobs R, Black MM, Chilton M, et al. A brief indicator of household energy security: associations with food security, child health, and child development in US infants and toddlers. *Pediatrics*. (2008) 122:e867–75. doi: 10.1542/peds.2008-0286
- Rehfuess E, World Health Organization. *Fuel for Life: Household Energy and Health*. Geneva: World Health Organization (2006). Retrieved from: <https://www.who.int/indoorair/publications/fuelforlife/en/>
- Birol F. Energy economics: a place for energy poverty in the agenda? *Energy J*. (2007) 28:1–6. doi: 10.5547/ISSN0195-6574-EJ-Vol28-No3-1
- Hernández D. Understanding 'energy insecurity' and why it matters to health. *Social Sci Med*. (2016) 167:1–10. doi: 10.1016/j.socscimed.2016.08.029
- Nord M, Andrews M, Carlson S. Household Food Security in the United States, 2004. *SSRN Electr J*. (2005) 11:1–6. doi: 10.2139/ssrn.878333
- Boardman B. *Fuel Poverty: From Cold Homes to Affordable Warmth*. London: Belhaven Press (1991).
- Gilbertson J, Stevens M, Stiell B, Thorogood N. Home is where the hearth is: Grant recipients' views of England's Home Energy Efficiency Scheme (Warm Front). *Soc Sci Med*. (2006) 63:946–56. doi: 10.1016/j.socscimed.2006.02.021
- Liddell C, Morris C. Fuel poverty and human health: a review of recent evidence. *Energy Policy*. (2010) 38:2987–97. doi: 10.1016/j.enpol.2010.01.037
- Bouzarovski S, Petrova S. A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Res Soc Sci*. (2015) 10:31–40. doi: 10.1016/j.erss.2015.06.007
- González-Eguino M. Energy poverty: an overview. *Renew Sustain Energy Rev*. (2015) 47:377–85. doi: 10.1016/j.rser.2015.03.013
- Khandker SR, Barnes DF, Samad HA. *Energy Poverty in Rural and Urban India: Are The Energy Poor Also Income Poor?* (Policy Research Working Paper No. WPS5463). India: The World Bank (2010). Retrieved from: <http://documents.worldbank.org/curated/en/920901468259774557/Energy-poverty-in-rural-and-urban-India-are-the-energy-poor-also-income-poor>
- Nussbaumer P, Bazilian M, Modi V. Measuring energy poverty: Focusing on what matters. *Renew Sustain Energy Rev*. (2012) 16:231–43. doi: 10.1016/j.rser.2011.07.150
- Pachauri S, Mueller A, Kemmler A, Spreng D. On measuring energy poverty in indian households. *World Dev*. (2004) 32:2083–104. doi: 10.1016/j.worlddev.2004.08.005
- Sher F, Abbas A, Awan RU. An investigation of multidimensional energy poverty in pakistan: a province level analysis. *Int J Energy Econ Pol*. (2014) 4:65–75.
- Barnes DF, Khandker SR, Samad HA. Energy poverty in rural Bangladesh. *Energy Policy*. (2011) 39:894–904. doi: 10.1016/j.enpol.2010.11.014
- Day R, Walker G, Simcock N. Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy*. (2016) 93:255–64. doi: 10.1016/j.enpol.2016.03.019
- Hernández D. Energy insecurity: a framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change. *Am J Public Health*. (2013) 103:e32–4. doi: 10.2105/AJPH.2012.301179
- Hernández D, Jiang Y, Carrión D, Phillips D, Aratani Y. Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States. *J Child Poverty*. (2016) 22:77–92. doi: 10.1080/10796126.2016.1148672
- Hernández D, Chang D, Hutchinson C, Hill E, Almonte A, Burns R, et al. Public housing on the periphery: vulnerable residents and depleted resilience reserves post-hurricane sandy. *J Urban Health*. (2018) 95:703–15. doi: 10.1007/s11524-018-0280-4
- Gilbertson J, Grimsley M, Green G. Psychosocial routes from housing investment to health: Evidence from England's home energy efficiency scheme. *Energy Policy*. (2012) 49:122–33. doi: 10.1016/j.enpol.2012.01.053
- Corman H, Curtis MA, Noonan K, Reichman NE. Maternal depression as a risk factor for children's inadequate housing conditions. *Soc Sci Med*. (2016) 149:76–83. doi: 10.1016/j.socscimed.2015.11.054
- Evans J, Hyndman S, Stewart-Brown S, Smith D, Petersen S. An epidemiological study of the relative importance of damp housing in relation to adult health. *J Epidemiol Commun Health*. (2000) 54:677–86. doi: 10.1136/jech.54.9.677
- Nord M, Kantor LS. Seasonal variation in food insecurity is associated with heating and cooling costs among low-income elderly Americans. *J Nutr*. (2006) 136:2939–44. doi: 10.1093/jn/136.11.2939
- Taylor DR, Bernstein BA, Carroll E, Oquendo E, Peyton L, Pachter LM. Keeping the heat on for children's health: a successful medical–legal partnership initiative to prevent utility shutoffs in vulnerable children. *J Health Care Poor Underserved*. (2015) 26:676–85. doi: 10.1353/hpu.2015.0074
- Anderson W, White V, Finney A. Coping with low incomes and cold homes. *Energy Policy*. (2012) 49:40–52. doi: 10.1016/j.enpol.2012.01.002
- Eichelberger LP. Living in utility scarcity: energy and water insecurity in Northwest Alaska. *Am J Public Health*. (2010) 100:1010–8. doi: 10.2105/AJPH.2009.160846
- Denton F. *Climate Change Vulnerability, Impacts, and Adaptation: Why Does Gender Matter?* *Gender Dev*. (2002) 10:10–20. doi: 10.1080/13552070215903

33. Smith M, Bosman J, Davey M. *Extreme Cold Weather Spreads East. The New York Times*. (2019). Available online at: <https://www.nytimes.com/2019/01/31/us/weather-polar-vortex.html> (accessed February 9, 2019).
34. Gajanan M. *21 People Died in Weather-Related Incidents During the Polar Vortex. TIME*. Retrieved from: <https://time.com/5518469/21-people-died-cold-polar-vortex/> (accessed February 1, 2019).
35. Dominianni C, Lane K, Johnson S, Ito K, Matte T. Health impacts of citywide and localized power outages in New York City. *Environ Health Perspect.* (2018) 126:067003-1–12. doi: 10.1289/EHP2154
36. Kishore N, Marques D, Mahmud A, Kang MV, Rodriguez I, Fuller A, et al. Mortality in puerto rico after Hurrigan Maria. *N Engl J Med.* (2018) 379:162–70. doi: 10.1056/NEJMsa1803972
37. Klinger C, Landeg O, Murray V. Power outages, extreme events and health: a systematic review of the literature from 2011–2012. *PLOS Curr Disast.* (2014) 6:1–23. doi: 10.1371/currents.dis.04eb1dc5e73dd1377e05a10e9edde673
38. Marx MA, Rodriguez CV, Greenko J, Das D, Heffernan R, Karpati AM, et al. Diarrheal illness detected through syndromic surveillance after a massive power outage: New York City, August 2003. *Am J Public Health.* (2006) 96:547–53. doi: 10.2105/AJPH.2004.061358
39. World Health Organization. *Energy Access and Resilience*. Retrieved from <http://www.who.int/sustainable-development/health-sector/health-risks/energy-access/en/> (accessed August 9, 2018).
40. Hernandez D, Laird J. *Disconnected: Estimating the National Prevalence of Utility Disconnections and Related Coping Strategies*. Philadelphia, PA: American Public Health Association (2019).
41. Centers for Disease Control and Prevention. *Community Needs Assessment and Morbidity Surveillance Following an Ice Storm – Maine, January 1998*. Retrieved from: <https://www.cdc.gov/mmwr/preview/mmwrhtml/00052581.htm> (accessed May 8, 1998).
42. Semenza JC. Acute renal failure during heat waves. *Am J Prev Med.* (1999) 17:97.
43. Hernández D, Phillips D, Siegel EL. Exploring the housing and household energy pathways to stress: a mixed methods study. *Int J Environ Res Public Health.* (2016) 13:916. doi: 10.3390/ijerph13090916
44. Centers for Disease Control and Prevention. *NCHHSTP Social Determinants of Health* (2014, March 10). Retrieved from: <https://www.cdc.gov/nchhstp/socialdeterminants/index.html> (accessed April 17, 2019).
45. Bassil KL, Cole DC. Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: a structured review. *Environ. Res. Public Health.* (2010) 7:991–1001. doi: 10.3390/ijerph7030991
46. Farbotko C, Waitt G. Residential air-conditioning and climate change: voices of the vulnerable. *Health Promotion J Aust.* (2011) 22:13–5. doi: 10.1071/HE11413
47. Healy J. (2004). *Housing, Fuel Poverty and Health: A Pan-European Analysis*. London: Routledge.
48. Klinenberg E. *Heat Wave: A Social Autopsy of Disaster in Chicago*. Chicago, IL: University of Chicago Press (2003).
49. Chauhan AJ, Inskip HM, Linaker CH, Smith S, Schreiber J, Johnston SL, et al. Personal exposure to nitrogen dioxide (NO₂) and the severity of virus-induced asthma in children. *Lancet.* (2003) 361:1939–44. doi: 10.1016/S0140-6736(03)13582-9
50. Evans GW, Kantrowitz E. Socioeconomic status and health: the potential role of environmental risk exposure. *Annu Rev Public Health.* (2002) 23:303–31. doi: 10.1146/annurev.publhealth.23.112001.112349
51. Gillespie-Bennett J, Pierse N, Wickens K, Crane J, Howden-Chapman P. The respiratory health effects of nitrogen dioxide in children with asthma. *Eur Respir J.* (2011). 38:303–9. doi: 10.1183/09031936.00115409
52. Kaplan G. Social Determinants of Health, 2nd Edition. In: M Marmot and R Wilkinson eds. Oxford: Oxford University Press, 2006, pp. 376, \$57.50. ISBN: 9780198565895. *Int J Epidemiol.* (2006) 35, 1111–1112. doi: 10.1093/ije/dyl121
53. Peek L. Children and Disasters: understanding vulnerability, developing capacities, and promoting resilience — An introduction. *Child Youth Environ.* (2008) 18:1–29. Available online at: <https://www.jstor.org/stable/10.7721/chilyoutenvi.18.issue-1>
54. Fernández CR, Yomogida M, Aratani Y, Hernández D. Dual food and energy hardship and associated child behavior problems. *Acad. Pediatr.* (2018) 18:889–96. doi: 10.1016/j.acap.2018.07.002
55. Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T, et al. Effect of insulating existing houses on health inequality: cluster randomised study in the community. *BMJ.* (2007) 334:460. doi: 10.1136/bmj.39070.573032.80
56. Free S, Howden-Chapman P, Pierse N, Viggers H, Housing H, Health Study Research Team. More effective home heating reduces school absences for children with asthma. *J Epidemiol Commun Health.* (2010) 64:379–86. doi: 10.1136/jech.2008.086520
57. Howden-Chapman P. Housing standards: a glossary of housing and health. *J Epidemiol Commun Health.* (2004) 58:162–8. doi: 10.1136/jech.2003.011569
58. Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health.* (2008) 29:41–55. doi: 10.1146/annurev.publhealth.29.020907.090843
59. Kontokosta CE, Reina VJ, Bonczak B. Energy cost burdens for low income and minority households. *JAPA.* (2019) 1–17. doi: 10.1080/01944363.2019.1647446.
60. Hernández D, Aratani Y, Jiang Y. *Energy Insecurity Among Families With Children*. Columbia: Academic Commons (2014).
61. Dreihobl A, Ross L. *Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low Income and Underserved Communities*. American Council for and Energy-Efficient Economy (2016). Retrieved from: <https://aceee.org/sites/default/files/publications/researchreports/u1602.pdf> (accessed April 17, 2019).
62. U.S. Energy Information Administration (EIA). *Summary Annual Household Site Consumption and Expenditures in the U.S.—Totals and Intensities, 2015, from 2015 Residential Energy Consumption Survey (RECS)*. U.S. Energy Information Administration (2018b, May). Retrieved from: <https://www.eia.gov/consumption/residential/data/2015/index.php?view=consumption#summary> (accessed April 17, 2019).
63. Hernández D. Sacrifice along the energy continuum: a call for energy justice. *Environ Justice.* (2015) 8:151–6. doi: 10.1089/env.2015.0015
64. Hernández D, Siegel E. Energy insecurity and its ill health effects: a community perspective on the energy-health nexus in New York City. *Energy Res Soc Sci.* (2019) 47:78–83. doi: 10.1016/j.erss.2018.08.011
65. Bednar DJ, Reames TG, Keoleian GA. The intersection of energy and justice: modeling the spatial, racial/ethnic and socioeconomic patterns of urban residential heating consumption and energy efficiency in Detroit, Michigan. *Energy Build.* (2017) 143:25–34. doi: 10.1016/j.enbuild.2017.03.028
66. Adamkiewicz G, Spengler JD, Harley AE, Stoddard A, Yang M, Alvarez Reeves M, et al. Environmental conditions in low-income urban housing: clustering and associations with self-reported health. *Am J Public Health.* (2014) 104:1650–6. doi: 10.2105/AJPH.2013.301253
67. O'Neill MS, Zanolletti A, Schwartz J. Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. *J Urban Health.* (2005) 82:191–7. doi: 10.1093/jurban/jti043
68. Sagar AD. Alleviating energy poverty for the world's poor. *Energy Policy.* (2005) 33:1367–72. doi: 10.1016/j.enpol.2004.01.001
69. Bull A, Mahmood H, Cush N. Identifying people at risk of fuel poverty to prevent excess winter deaths. *Nursing Times.* (2010) 106:12–3.
70. Burton A. Built environment: turn up the heat for respiratory health. *Environ Health Perspect.* (2008) 116:A291. doi: 10.1289/ehp.116-a291
71. World Health Organization. *Housing, Energy and Thermal Comfort: A Review of 10 Countries within the WHO European Region* (2017, March 18). Retrieved from: <http://www.euro.who.int/en/health-topics/environment-and-health/Housing-and-health/publications/pre-2009/housing,-energy-and-thermal-comfort-a-review-of-10-countries-within-the-who-european-region-2007> (accessed July 27, 2018).
72. Viggers H, Howden-Chapman P, Ingham T, Chapman R, Pene G, Davies C, et al. Warm homes for older people: aims and methods of a randomised community-based trial for people with COPD. *BMC Public Health.* (2013) 13:176. doi: 10.1186/1471-2458-13-176
73. Macmillan Cancer Support. *Cancer Patients Twice as Likely To Be Fall into Fuel Poverty as the General Population* (2009, October 27). Retrieved from: https://www.macmillan.org.uk/aboutus/news/latest_news/

- cancerpatientstwiceaslikelytobeinfuelpoverty.aspx (accessed September 20, 2018).
74. Ikäheimo TM, Lehtinen T, Antikainen R, Jokelainen J, Näyhä S, Hassi J, et al. Cold-related cardiorespiratory symptoms among subjects with and without hypertension: the National FINRISK Study 2002. *Eur J Public Health*. (2014) 24:237–43. doi: 10.1093/eurpub/ckt078
75. Büchs M, Bahaj A, Blunden L, Bourikas L, Falkingham J, James P, et al. Sick and stuck at home – how poor health increases electricity consumption and reduces opportunities for environmentally-friendly travel in the United Kingdom. *Energy Res Soc Sci*. (2018) 44:250–9. doi: 10.1016/j.erss.2018.04.041
76. Pollack CE, Griñ n BA, Lynch J. Housing affordability and health among homeowners and renters. *Am J Prev Med*. (2010) 39:515–21. doi: 10.1016/j.amepre.2010.08.002
77. Bird S, Hernández D. Policy options for the split incentive: Increasing energy efficiency for low-income renters. *Energy Policy*. (2012) 48:506–14. doi: 10.1016/j.enpol.2012.05.053
78. Hernández D. Affording housing at the expense of health: exploring the housing and neighborhood strategies of poor families. *J Fam Issues*. (2016) 37:921–46. doi: 10.1177/0192513X14530970
79. La Mort JR. *Public Housing and Public Health: The Separate and Unequal Protection of Private and Public Housing Tenants*. New York, NY: Brooklyn Law School Legal Studies Research Papers: Accepted Paper Series (2018). p. 580.
80. Hernández D, Bird S. Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy. *Poverty Public Policy*. (2010) 2:5–25. doi: 10.2202/1944-2858.1095
81. Sullivan E. *Manufactured Insecurity: Mobile Home Parks and Americans' Tenuous Right to Place*, 1st Ed. Berkeley, CA: University of California Press (2018).
82. Marmot Review Team and Friends of the Earth. *The Health Impacts of Cold Homes and Fuel Poverty*. London: Friends of the Earth and the Marmot Review Team (2011). Retrieved from: <http://www.instituteofhealthequity.org/resources-reports/the-health-impacts-of-cold-homes-and-fuel-poverty>
83. Milne G, Boardman B. Making cold homes warmer: the effect of energy efficiency improvements in low-income homes a report to the Energy Action Grants Agency Charitable Trust. *Energy Policy*. (2000) 28:411–24. doi: 10.1016/S0301-4215(00)00019-7
84. Wilkinson P, Armstrong B, Landon M. *Cold Comfort: The Social and Environmental Determinants of Excess Winter Deaths in England, 1986-1996*. Joseph Rowntree Foundation (2001). Retrieved from: <https://www.jrf.org.uk/report/cold-comfort-social-and-environmental-determinants-excess-winter-deaths-england-1986--1996>
85. Clinch JP, Healy JD. Housing standards and excess winter mortality. *J Epidemiol Commun Health*. (2000) 54:719–20. doi: 10.1136/jech.54.9.719
86. Dowler E, Spencer N. (editors). *Challenging Health Inequalities: From Acheson to Choosing Health*. Policy Press at the University of Bristol (2007). Retrieved from: <http://www.jstor.org/stable/j.ctt9qgvbt>
87. Barton A, Basham M, Foy C, Buckingham K, Somerville M. The Watcombe Housing Study: the short term effect of improving housing conditions on the health of residents. *J Epidemiol Commun Health*. (2007) 61:771–7. doi: 10.1136/jech.2006.048462
88. Boomsma C, Pahl S, Jones RV, Fuertes A. “Damp in bathroom. Damp in back room It's very depressing!” exploring the relationship between perceived housing problems, energy affordability concerns, and health and well-being in UK social housing. *Energy Policy*. (2017) 106:382–93. doi: 10.1016/j.enpol.2017.04.011
89. Bornehag CG, Blomquist G, Gyntherberg F, Järholm B, Malmberg P, Nordvall L, et al. Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on associations between exposure to “dampness” in buildings and health effects (NORDDAMP). *Indoor Air*. (2001) 11:72–86. doi: 10.1034/j.1600-0668.2001.110202.x
90. Dales RE, Zwanenburg H, Burnett R, Franklin CA. Respiratory health effects of home dampness and molds among Canadian children. *Am J Epidemiol*. (1991) 134:196–203. doi: 10.1093/oxfordjournals.aje.a116072
91. Bornehag CG, Sundell J, Hägerhed-Engman L, Sigsgaard T. Association between ventilation rates in 390 Swedish homes and allergic symptoms in children. *Indoor Air*. (2005) 15:275–80. doi: 10.1111/j.1600-0668.2005.00372.x
92. Breyse J, Jacobs DE, Weber W, Dixon S, Kawecki C, Aceti S, et al. Health outcomes and green renovation of affordable housing. *Public Health Rep*. (2011) 126:64–75. doi: 10.1177/003335491112605110
93. Jacobs DE, Breyse J, Dixon SL, Aceti S, Kawecki C, James M, et al. Health and housing outcomes from green renovation of low-income housing in Washington, DC. *J Environ Health*. (2014) 76:8–16.
94. Bone A, Murray V, Myers I, Dengel A, Crump D. Will drivers for home energy efficiency harm occupant health? *Perspect Public Health*. (2010) 130:233–8. doi: 10.1177/1757913910369092
95. Shaw M. Housing and Public Health. *Annu Rev Public Health*. (2004) 25:397–418. doi: 10.1146/annurev.publhealth.25.101802.123036
96. Milner J, Shrubsole C, Das P, Jones B, Ridley I, Chalabi Z, et al. Wilkinson P. Home energy efficiency and radon related risk of lung cancer: modelling study. *BMJ*. (2014) 348:f7493. doi: 10.1136/bmj.f7493
97. Agyeman J, Evans T. Toward just sustainability in urban communities: building equity rights with sustainable solutions. *Ann Am Acad Political Soc Sci*. (2003) 590:35–53. doi: 10.1177/0002716203256565
98. Krieger J, Higgins DL. Housing and health: time again for public health action. *Am J Public Health*. (2002) 92:758–68. doi: 10.2105/AJPH.92.5.758
99. Howden-Chapman P, Viggers H, Chapman R, O'Sullivan K, Telfar Barnard L, Lloyd B. Tackling cold housing and fuel poverty in New Zealand: a review of policies, research, and health impacts. *Energy Policy*. (2012) 49:134–42. doi: 10.1016/j.enpol.2011.09.044
100. Howden-Chapman P, Crane J, Chapman R, Fougere G. Improving health and energy efficiency through community-based housing interventions. *Int J Public Health*. (2011) 56:583–8. doi: 10.1007/s00038-011-0287-z
101. Rudge J, Gilchrist R. Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough. *J Public Health*. (2005) 27:353–8. doi: 10.1093/pubmed/ldi051
102. Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, et al. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environ. Health Perspect*. (2008) 117:61–7. doi: 10.1289/ehp.11594
103. Reames TG. Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy*. (2016) 97:549–58. doi: 10.1016/j.enpol.2016.07.048
104. Hernández D. What ‘Merle’ taught me about energy insecurity and health. *Health Aff*. (2018) 37:504–7. doi: 10.1377/hlthaff.2017.1413
105. Newman W. *As 4 of 5 in Public Housing Lost Heat, a Demand for an Apology Is Unfulfilled*. The New York Times (2019). Available online at: <https://www.nytimes.com/2018/02/06/nyregion/heat-cold-nycha-nyc-olatoye.html?rref=collection%2Fsectioncollection%2Fnyregion> (accessed March 16, 2019).
106. Green New Deal for 5 Public Housing Act, S. n.d., 116th Cong., 1st Sess. (2019).
107. Stephens B, Carter EM, Gall ET, Earnest CM, Walsh EA, Hun DE, et al. Home energy-efficiency retrofits. *Environ Health Perspect*. (2011) 119:a283–4. doi: 10.1289/ehp.1103621
108. Schill MH, Friedman S, Rosenbaum E. The housing conditions of immigrants in New York City. *J Hous Res*. (1998) 9:201–35.
109. Morello-Frosch R, Jesdale BM. Separate and unequal: residential segregation and estimated cancer risks associated with ambient air toxics in U.S. Metropolitan Areas. *Environ Health Perspect*. (2006) 114:386–93. doi: 10.1289/ehp.8500
110. Casey JA, Morello-Frosch R, Mennitt DJ, Frstrup K, Ogburn EL, James P. Race/ethnicity, socioeconomic status, residential segregation, and spatial variation in noise exposure in the contiguous United States. *Environ Health Perspect*. (2017) 125:077017. doi: 10.1289/EHP898
111. Clougherty JE, Kubzansky LD. A framework for examining social stress and susceptibility to air pollution in respiratory health. *Environ Health Perspect*. (2009) 117:1351–8. doi: 10.1289/ehp.0900612
112. Morello-Frosch R, Zuk M, Jerrett M, Shamasunder B, Kyle AD. Understanding the cumulative impacts of inequalities in environmental

- health: implications for policy. *Health Aff.* (2011) 30:879–87. doi: 10.1377/hlthaff.2011.0153
113. Walker G, Day R. Fuel poverty as injustice: integrating distribution, recognition and procedure in the struggle for affordable warmth. *Energy Policy.* (2012) 49:69–75. doi: 10.1016/j.enpol.2012.01.044
114. Brunner K-M, Spitzer M, Christanell A. Experiencing fuel poverty. Coping strategies of low-income households in Vienna/Austria. *Energy Policy.* (2012) 49:53–9. doi: 10.1016/j.enpol.2011.11.076
115. Chilton M, Rabinowich J, Breen A, Mouzon S. *When the systems Fail: Individual and Household Coping Strategies Related to Child Hunger.* Presented at the Workshop on Research Gaps and Opportunities on the Causes and Consequences of Child Hunger (2013).
116. Hadley C, Tegegn A, Tessema F, Cowan JA, Asefa M, Galea S. Food insecurity, stressful life events and symptoms of anxiety and depression in east Africa: evidence from the Gilgel Gibe growth and development study. *J Epidemiol Commun Health.* (2008) 62:980–6. doi: 10.1136/jech.2007.068460
117. Knowles M, Rabinowich J, Cuba SE, de Cutts DB, Chilton M. “Do You Wanna Breathe or Eat?”: Parent Perspectives on Child Health Consequences of Food Insecurity, Trade-Offs, and Toxic Stress. *Matern. Child Health J.* (2016) 20:25–32. doi: 10.1007/s10995-015-1797-8
118. Bhattacharya J, Currie J, Haider S. Poverty, food insecurity, and nutritional outcomes in children and adults. *J Health Econ.* (2004) 23:839–62. doi: 10.1016/j.jhealeco.2003.12.008
119. Banash AK, Holben DH, Basta T. Food insecurity is associated with household utility insecurity among individuals living with HIV/AIDS in rural appalachia. *J Hunger Environ Nutr.* (2013) 8:242–55. doi: 10.1080/19320248.2013.786662
120. Frank DA, Neault NB, Skalicky A, Cook JT, Wilson JD, Levenson S, et al. Heat or eat: the low income home energy assistance program and nutritional and health risks among children less than 3 years of age. *Pediatrics.* (2006) 118:e1293–1302. doi: 10.1542/peds.2005-2943
121. Berkowitz SA, Meigs JB, DeWalt D, Seligman HK, Barnard LS, Bright OJM, et al. Material need insecurities, diabetes control, and care utilization: results from the measuring economic iNsecurity in Diabetes (MEND) study. *JAMA Intern. Med.* (2015) 175:257–65. doi: 10.1001/jamainternmed.2014.6888
122. Webber ME. *Thirst for Power: Energy, Water, and Human Survival.* Danbury, CT: Yale University Press (2016).
123. Finkel ML, Law A. The rush to drill for natural gas: a public health cautionary tale. *Am J Public Health.* (2011) 101:784–5. doi: 10.2105/AJPH.2010.300089
124. Finkel ML, Law A. The rush to drill for natural gas: a five-year update. *Am J Public Health.* (2016) 106:1728–30. doi: 10.2105/AJPH.2016.303398
125. Johnson A, Meckstroth A. *Ancillary Services to Support Welfare to Work (Ojce of the Assistant Secretary for Planning and Evaluation).* U.S. Department of Health and Human Services (1998). Retrieved from: <https://aspe.hhs.gov/report/ancillary-services-support-welfare-work>
126. Hernández, D, Swope, C. Housing as a Platform for Health and Equity: Evidence and Future Directions. *Am J Public Health.* (2019) 109:1363–6. doi: 10.2105/AJPH.2019.305210
127. Swope, C, Hernández, D. Housing as a determinant of health equity: A conceptual model. *Soc Sci Med.* (2019) 243:112571. doi: 10.1016/j.socscimed.2019.112571
128. Tach LM, Sara Sternberg Greene SS. “Robbing Peter to Pay Paul”: economic and cultural explanations for how lower-income families manage debt. *Soc Prob.* (2014) 61:1–21. doi: 10.1525/sp.2013.11262
129. Desmond M, Gershenson C. Who gets evicted? Assessing individual, neighborhood, and network factors. *Soc Sci Res.* (2014) 62:362–77. doi: 10.1016/j.ssresearch.2016.08.017
130. Lennon M. Decolonizing energy: black lives Matter and technoscientific expertise amid solar transitions. *Energy Res Soc Sci.* (2017) 30:18–27. doi: 10.1016/j.erss.2017.06.002
131. Centers for Disease Control and Prevention. *Carbon Monoxide Poisoning from Hurricane-Associated Use of Portable Generators — Florida, 2004(2005, July 22).* Retrieved from: <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5428a2.htm> (accessed July 27, 2018).
132. Ware JH, Spengler JD, Neas LM, Samet JM, Wagner GR, Coultas D, et al. Respiratory and Irritant health effects of ambient volatile organic compounds the Kanawha County health study. *Am J Epidemiol.* (1993) 137:1287–301. doi: 10.1093/oxfordjournals.aje.a116639
133. The Eurowinter Group. *Cold Exposure and Winter Mortality From Ischaemic Heart Disease, Cerebrovascular Disease, Respiratory Disease, and All Causes in Warm and Cold Regions Of Europe.* (2003). Retrieved from: [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(96\)12338-2/abstract?code=lancet-site](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(96)12338-2/abstract?code=lancet-site) (accessed July 17, 2018).
134. Healy JD. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *J Epidemiol Commun Health.* (2003) 57:784–9. doi: 10.1136/jech.57.10.784
135. Berko J, Ingram DD, Saha S, Parker JD. Deaths attributed to heat, cold, and other weather events in the United States, 2006–2010. *Natl Health Stat Rep.* (2014) 30:1–15.
136. Evens A, Garascia M, Isaacson M. Utilities and health: energy eý ciency as a common link. *Electricity J.* (2017) 30:10–4. doi: 10.1016/j.tej.2017.04.009
137. Gray B, Allison B, Thomas B, Morris C, Liddell C. *Excess Winter Deaths Among People Living With Alzheimer’s Disease or Related Dementias.* Chesshire Lehmann Report (2015). p. 55.
138. Garrett MH, Hooper MA, Hooper BM, Abramson MJ. Respiratory symptoms in children and indoor exposure to nitrogen dioxide and gas stoves. *Am J Respirat Crit Care Med.* (1998) 158:891–5. doi: 10.1164/ajrcm.158.3.9701084
139. Wilkinson P, Smith KR, Beevers S, Tonne C, Oreszczyn T. Energy, energy eý ciency, and the built environment. *Lancet.* (2007) 370:1175–87. doi: 10.1016/S0140-6736(07)61255-0
140. Anderson GB, Bell ML. Lights out: Impact of the August 2003 power outage on mortality in New York, NY. *Epidemiology.* (2012) 23:189–93. doi: 10.1097/EDE.0b013e318245c61c
141. The Institute of Medicine (2011). *Climate Change, the Indoor Environment, and Health.* Washington DC: The National Academies Press.
142. Putnam H, Hondula DM, Urban A, Berisha V, Iñiguez P, Roach M. It’s not the heat, it’s the vulnerability: attribution of the 2016 spike in heat-associated deaths in Maricopa County, Arizona. *Environ Res Lett.* (2018) 13:094022. doi: 10.1088/1748-9326/aadb44
143. Canoui-Poitaine F, Cadot E, Spira A, Groupe Régional Canicule. Excess deaths during the August 2003 heat wave in Paris, France. *Revue D’épidémiologie Et De Sante Publique.* (2006) 54:127–35. doi: 10.1016/S0398-7620(06)76706-2
144. Gronlund CJ. Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review. *Curr Epidemiol Rep.* (2014) 1:165–73. doi: 10.1007/s40471-014-0014-4
145. Bonanno GA, Galea S, Bucciarelli A, Vlahov D. What predicts psychological resilience after disaster? *The role of demographics, resources, and life stress.* *J Consult Clin Psychol.* (2007) 75:671–82. doi: 10.1037/0022-006X.75.5.671
146. Rydin Y, Bleahu A, Davies M, Dávila JD, Friel S, De Grandis G, et al. Shaping cities for health: complexity and the planning of urban environments in the 21st century. *Lancet.* (2012) 379:2079–108. doi: 10.1016/S0140-6736(12)60435-8
147. Oliver ML, Shapiro TM. *Black Wealth, White Wealth: A New Perspective on Racial Inequality,* 2nd Edn. Taylor and Francis (2006). Retrieved from: https://books.google.com/books/about/Black_Wealth_White_Wealth.html?id=4ksJuX02DNwC
148. Loving AC, Finke MS, Salter J. *Does Home Equity Explain the Black Wealth Gap?* (2011). doi: 10.2139/ssrn.1986813
149. Guruswamy L. *Energy Justice and Sustainable Development.* Colorado *J Int Environ Law nd Policy.* (2010). Retrieved from: <https://scholar.law.colorado.edu/articles/231>
150. Bradbrook AJ, Gardam JG. Placing access to energy services within a human rights framework. *Hum Rights Q.* (2006) 28:389–415. doi: 10.1353/hrq.2006.0015
151. Donohoe M. Causes and health consequences of environmental degradation and social injustice. *Soc Sci Med.* (2003) 56:573–87. doi: 10.1016/S0277-9536(02)00055-2
152. Arto I, Capellán-Pérez I, Lago R, Bueno G, Bermejo R. The energy requirements of a developed world. *Energy Sustain Dev.* (2016) 33:1–13. doi: 10.1016/j.esd.2016.04.001
153. Gordon SB, Bruce NG, Grigg J, Hibberd PL, Kurmi OP, Lam KH, et al. Respiratory risks from household air pollution in low and

- middle income countries. *Lancet Respirat Med.* (2014) 2:823–60. doi: 10.1016/S2213-2600(14)70168-7
154. The World Bank. *Death in the Air: Air Pollution Costs Money and Lives*. World Bank (2016, September 8). Retrieved from: <http://www.worldbank.org/en/news/infographic/2016/09/08/death-in-the-air-air-pollution-costs-money-and-lives>
155. Li K, Lloyd B, Liang X-J, Wei Y-M. Energy poor or fuel poor: What are the differences? *Energy Policy.* (2014) 68:476–81. doi: 10.1016/j.enpol.2013.11.012
156. Wisner B, Blaikie P, Cannon T, Davis I. *Natural Hazards, People's Vulnerability, and Disasters*. In *At Risk* (2006). p. 7.
157. Fothergill A, Peek L. Poverty and disasters in the United States: a review of recent sociological findings. *Natural Hazards.* (2004) 32:89–110. doi: 10.1023/B:NHAZ.0000026792.76181.d9
158. Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. Climate change and human health: impacts, vulnerability and public health. *Public Health.* (2006) 120:585–96. doi: 10.1016/j.puhe.2006.01.002
159. Cartalis C, Synodinou A, Proedrou M, Tsangrassoulis A, Santamouris M. Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region. *Energy Convers Manage.* (2001) 42:1647–56. doi: 10.1016/S0196-8904(00)00156-4
160. Ghanem DA, Mander S, Gough C. “I think we need to get a better generator”: household resilience to disruption to power supply during storm events. *Energy Policy.* (2016) 92:171–80. doi: 10.1016/j.enpol.2016.02.003
161. Kleinpeter MA. Disaster preparedness for dialysis patients. *Clin J Am Soc Nephrol.* (2011) 6:2337–9. doi: 10.2215/CJN.08690811
162. Keim ME. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *Am J Prev Med.* (2008) 35:508–16. doi: 10.1016/j.amepre.2008.08.022

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The local death toll from the July 8 storm could continue to climb as medical examiner's offices continue to investigate.

Adam Zuvanich (<https://www.houstonpublicmedia.org/articles/author/adam-zuvanich/>) | July 18, 2024, 5:15 PM



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Colleen DeGuzman/Houston Public Media

A tree was blown into powerlines by Hurricane Beryl in a Cypress neighborhood.

Hurricane Beryl has caused at least 20 deaths in the Houston area, and widespread power outages during and after the July 8 storm contributed to half of those fatalities.

More than 2.2 million homes, schools and businesses – representing about 80% of the electricity customers served by CenterPoint Energy – lost power at the peak of the Category 1 hurricane that was particularly damaging because it passed almost directly over Houston (<https://www.houstonpublicmedia.org/articles/news/hurricane/2024/07/12/493415/hurricane-beryl-path-houston-damaging-category-1-hurricane/>). Hundreds of thousands remained without electricity more than a week afterward, and there still were about 10,000 outages as of Thursday afternoon.

Six of the 13 storm-related deaths in Houston and Harris County were caused by heat exposure tied to a power outage, according to information released by the Harris County Institute of Forensic Sciences (https://ifs.harriscountytexas.gov/Portals/IFS/Documents/Beryl_Storm_Related_Deaths_06.pdf). Chief investigator John Florence of the Galveston County Medical Examiner's Office said Thursday that electricity losses contributed to all three of the confirmed, hurricane-related deaths there, adding that doctors were still working to determine the causes of death of three other people who were found in homes without power.

In Matagorda County, where the hurricane made landfall before proceeding north through Houston, a 60-year-old Bay City man who was bed-ridden and paralyzed from the waist down died from heatstroke on the evening of July 8, in a home that lost power, according to county spokesperson Mitch Thames.

"It's tragic," Thames said. "Our hearts and prayers go out to the family."

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The Houston-area death toll from Beryl – which according to the Associated Press killed at least 11 people in the Caribbean before swirling its way through the Gulf of Mexico and into Texas – could continue to climb in the aftermath of the storm.

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Scott Yao, a spokesperson for the Fort Bend County Medical Examiner's Office, said Thursday that no storm-related deaths there had been confirmed – yet. The eye of the storm passed over the county, which is southwest of Houston.

"There might be some, but we're still gathering information right now," Yao said.



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Houston Police Department

Russell Richardson, 54, was a Houston Police Department employee who drowned during Hurricane Beryl on July 8, 2024.

Three of the storm victims in Harris County drowned, with two Houston men, including Houston Police Department employee Russell Richardson, getting caught in vehicles that were submerged by floodwaters. Two other Harris County residents were killed by fallen trees on the day of the hurricane, and two Houston men died in the days that followed when they fell while trimming damaged trees.

All three of the storm-related deaths that have been confirmed in Montgomery County, which is north of Houston, were caused by fallen trees on July 8, according to Judge Wayne Mack, the Justice of the Peace for Precinct 1. Two of the victims were apparently homeless and inside a tent in Magnolia, Mack said, and another man who died was struck by a falling oak tree while riding his tractor in the eastern part of the county.

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Mack said Richard Ross, 41, was on his way home after using his tractor to help clear a nearby road.

"He was being a good Samaritan," Mack said. "He was helping neighbors clear trees from the roadway so EMS and fire could get through. The storm wasn't quite over."

Ross was the youngest hurricane victim in the Houston area, according to local authorities. The other 19 people were age 50 or older, and 13 of the victims were in their 60s or 70s.

Below is a list of the 20 storm-related deaths that have been confirmed by Houston-area authorities:

Name	Age	Date of death	Location	Cause of death
Harris County				
Maria Loreda	73	July 8	Houston	Blunt force injuries (crushed by fallen tree)
Russell Richardson	54	July 8	Houston	Drowning (submerged vehicle)
Sara Elizabeth Elston	76	July 8	Clear Lake	Complications of drowning (sunken boat)
Johnnie Courtney	77	July 8	Houston	Drowning (submerged vehicle)
Jay Michael Taylor	53	July 8	Humble	Mechanical asphyxia with blunt trauma (pinned under collapsed house and fallen tree)
Charles Richard Anderson Sr.	76	July 10	Pasadena	Hyperthermia (heat exposure due to electricity loss)
Candie York	50	July 10	Houston	Hyperthermia (heat exposure due to electricity loss)
Oscar Rodriguez	78	July 10	Houston	Hyperthermia (heat exposure due to electricity loss)
James Edward Butcher	75	July 11	Pasadena	Hyperthermia (heat exposure due to electricity loss)

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Bryan Keith Taylor	66	July 11	Houston	Hyperthermia (heat exposure due to electricity loss)
Pamela Jarrett	64	July 11	Houston	Hyperthermia (heat exposure due to electricity loss)
Tomas Fermin Vergara	59	July 12	Houston	Blunt trauma (fell from ladder while cutting tree limbs)
William Correrias	53	July 14	Houston	Blunt force injuries (fell while trimming damaged tree)
Galveston County				
Judith Greet	71	July 8	Crystal Beach	Complications of COPD and lack of supplemental oxygen due to electricity loss
Leroy Lyons	77	July 10	Galveston	Cardiovascular disease (heat exposure due to electricity loss was contributing factor)
Michael Lahr	71	July 11	Galveston	Cardiovascular disease (heat exposure due to electricity loss was contributing factor)
Matagorda County				
Charles Yañez	60	July 8	Bay City	Heatstroke (was in home that lost electricity)
Montgomery County				
Ethel Carter	66	July 8	Magnolia	Blunt force trauma (struck by fallen tree)
Michael Privett	52	July 8	Magnolia	Blunt force trauma (struck by fallen tree)
Richard Ross	41	July 8	East Montgomery County	Blunt force trauma (struck by fallen tree)

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How Blackouts during Heat Waves Amplify Mortality and Morbidity Risk

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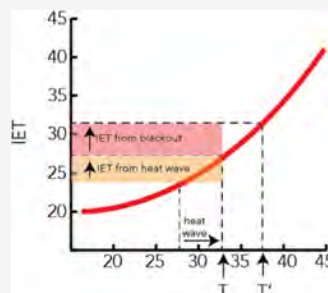
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ABSTRACT: The recent concurrence of electrical grid failure events in time with extreme temperatures is compounding the population health risks of extreme weather episodes. Here, we combine simulated heat exposure data during historical heat wave events in three large U.S. cities to assess the degree to which heat-related mortality and morbidity change in response to a concurrent electrical grid failure event. We develop a novel approach to estimating individually experienced temperature to approximate how personal-level heat exposure changes on an hourly basis, accounting for both outdoor and building-interior exposures. We find the concurrence of a multiday blackout event with heat wave conditions to more than double the estimated rate of heat-related mortality across all three cities, and to require medical attention for between 3% (Atlanta) and more than 50% (Phoenix) of the total urban population in present and future time periods. Our results highlight the need for enhanced electrical grid resilience and support a more spatially expansive use of tree canopy and high albedo roofing materials to lessen heat exposures during compound climate and infrastructure failure events.

KEYWORDS: extreme heat event, infrastructure failure, heat-related mortality, climate change, urban heat management, compound climat, infrastructure failure events



INTRODUCTION

The incidence of electrical grid failure or “blackout” events is increasing across the United States. Since 2015, when the U.S. Energy Information Administration commenced monthly reporting on major blackout events (defined as power outages lasting more than 1 h and impacting more than 50,000 customers), the number of such events nationwide has more than doubled, increasing by 151% between 2015–16 and 2020–21 (Figure 1). The majority of these events occurred during the summer months, when the annual demand for electricity is maximized and electrical grids are further stressed by extreme weather in the form of heat wave, hurricane, tornado, and wildfire events. Prior work finds the concurrence in time of two or more extreme weather events, such as a hurricane and heat wave, also to be on the rise,¹ further enhancing potential health impacts of compound climate and infrastructure failure events. Most recently, in June of 2021, electrical grid failures associated with a heat wave of historical intensity in the Pacific Northwest of the United States resulted in a loss of power to tens of thousands of customers, at least 600 excess deaths, and more than 3500 emergency department visits for heat illness.^{2–4} Persistent drought conditions in the Western United States are further reducing the capacity of regional electrical generation and distribution systems to manage surges in electrical demand in this and other regions confronting climate-driven pressures on critical infrastructure.⁵

Despite a rising incidence of electrical grid failures, few studies have sought to directly assess the public health risks of compound climate and infrastructure failure events. Here, we estimate heat-related mortality and morbidity resulting from heat wave events of historical duration and intensity occurring simultaneously with simulated blackout conditions for the full urban populations of Atlanta, Georgia; Detroit, Michigan; and Phoenix, Arizona. Building on prior work modeling building-interior heat exposures resulting from concurrent heat wave and blackout events across these three cities,^{7,8} in this paper, we estimate the likelihood of health impacts through the development of an individual-level heat risk model accounting for hourly indoor and outdoor heat exposures and person-level risk characteristics. We then simulate the influence of urban heat management strategies on heat-related mortality and morbidity, as well as the impact of more intense heat wave events projected with continued global scale warming in future time periods.

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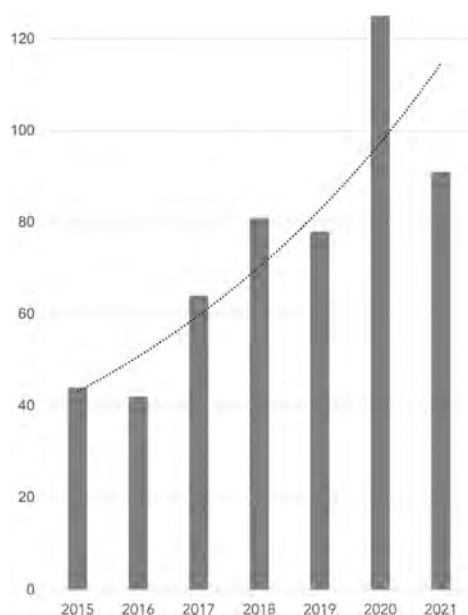


Figure 1. Total number of major electrical grid failure events for U.S. power utilities (2015–2021).⁶

This paper reports results from the Three-City Heat and Electrical Grid Failure Adaptation Study (3HEAT), which is focused on compound climate and infrastructure failure events in three large U.S. cities characterized by distinct regional climates and population characteristics. The cities of Atlanta, Georgia; Detroit, Michigan; and Phoenix, Arizona were selected to include three distinct climate zones in which approx. 75% of the U.S. population resides, as well as variable demographic and climatic risk factors for heat illness. [Table 1](#)

Table 1. Key Characteristics for Each City of Relevance to Heat Vulnerability

attribute	Atlanta	Detroit	Phoenix
population size ⁹	420,000	713,770	1,445,630
male population ⁹	49%	48%	51%
population > 65 years of age ⁹	10%	12%	9%
nonwhite population ⁹	62%	89%	34%
persons in poverty ⁹	26%	38%	23%
central air conditioning in home	94%	53%	99%
mean summer daily temperature range ¹⁰	21–32 °C (71–89 °F)	17–28 °C (63–82 °F)	28–41 °C (82–105 °F)
climate zone ¹¹	mixed-humid	cold	hot–dry

presents key characteristics for each city of relevance to heat vulnerability. We limit our study to three cities due to the extensive data inputs required to model both outdoor and building-interior heat exposures for more than 2.5 million residents across the three cities.

A collaboration between Arizona State University, the Georgia Institute of Technology, and the University of Michigan, the 3HEAT study examines three questions largely

unaddressed by the literature on climate and health: (1) How does individual heat exposure change during concurrent heat wave and blackout events, relative to heat wave conditions with a fully operational electrical grid? (2) How do estimated public health impacts, including heat-related mortality and morbidity, change during concurrent heat wave and blackout events, relative to heat wave conditions with a fully operational electrical grid? (3) How do these estimated health impacts change in response to citywide urban heat management planning and to a growing intensity of heat wave conditions over time?

The first of these three study questions requires that we model heat exposure for both outdoor and building-interior environments. Established approaches to estimating health impacts associated with heat exposure are typically reflective of outdoor temperatures only, often measured at a single location, such as a metropolitan airport weather station, and therefore do not account for variable exposures for individuals in different locations of the city.¹² Given that a grid failure has only limited impacts on outdoor temperatures but may substantially elevate building-interior temperatures, a reliance on outdoor temperature alone also fails to capture the changing nature of heat exposure during concurrent heat wave and blackout events.

To address this limitation of conventional approaches to assessing heat risk, we derive for this study a heat exposure metric referred to in prior work as “individually experienced temperature” or IET.^{13,14} IET provides a metric of human heat exposure that accounts for exposure changes as individuals move between indoor and outdoor environments during a 24 h period. Under blackout conditions, indoor heat exposures will rise, particularly for individuals who would otherwise have access to mechanical air conditioning in the home when the electrical grid is operational. The result is a rise in their IET and subsequent heat risk. We report the magnitude of this exposure change for different building types in a series of prior papers.^{7,8,15}

To assess how elevated heat exposures during concurrent heat wave and blackout conditions may impact health outcomes, we devise a novel approach to estimating individual heat risk. Established exposure-response functions widely used in heat risk assessment are responsive to outdoor temperature measurements only, often derived from the same single location for a full urban population.^{16–19} Using urban-scale climate models, in combination with building energy simulation tools, we spatially disaggregate heat exposure to the level of the residential parcel, accounting for both how ambient temperatures vary across the urban environment and how these environmental temperatures influence building-interior temperatures for different classes of residential structures.

Health impact exposure-response functions for IET—reflective of both outdoor and building-interior temperatures—are not currently available. Therefore, we derive an “analog” outdoor temperature (T') for each resident through the statistical association between estimated building-interior temperatures and a single airport weather station temperature (T) for every hour of the day during heat wave conditions with an operational electrical grid (the normal operating conditions captured by published exposure-response functions). Based on this statistical association, we then adjust outdoor temperatures to scale with rising IET (due to building-interior temperatures) during blackout conditions, yielding an analog outdoor

temperature that can be used with established exposure-response functions for heat-related mortality and morbidity. The result is an outdoor temperature metric (T') adjusted to reflect an elevated indoor heat burden during blackout conditions (Figure 2).

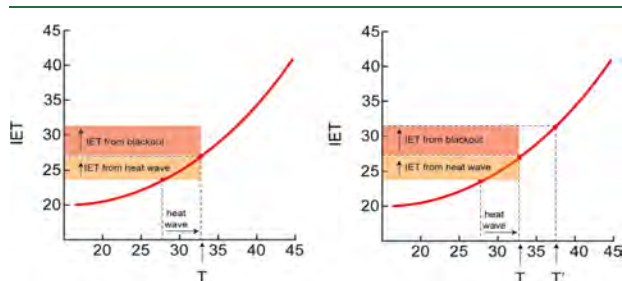


Figure 2. Estimation of “analog” temperature (T'). Weather station temperature (T) underestimates individually experienced temperature (IET) during blackout conditions (left panel). T' adjusts T to capture both outdoor and building-interior heat burden reflected in IET (right panel). The red curve depicts the statistical association between IET and T under heat wave conditions with an operational grid, measured in celsius.

We address the last of these three questions—How do health impacts change in response to urban heat management strategies and future period warming?—through the re-simulation of IET in response to a modified built environment (in the form of enhanced tree canopy and high albedo roofing materials). The modified built environment has the general effect of lowering the analog air temperatures used to estimate individual heat risk. However, more intense heat waves in future time periods result in elevated analog temperatures, serving to enhance heat risk.

MATERIALS AND METHODS

Our research accomplished two principal tasks: (1) estimation of individually experienced temperature (IET) and (2) estimation of population health impacts from a concurrent heat wave and blackout event. Each of these tasks is described in turn.

Individually Experienced Temperature (IET). Estimation of IET required three sets of data inputs: (1) modeled outdoor ambient temperatures, (2) modeled building-interior temperatures, and (3) daily activity patterns for each resident, allowing for the individual assignment of location-specific outdoor and building-interior temperatures by time of day. We simulated outdoor and building-interior temperatures during historical heat wave events in each city with the Weather Research and Forecasting (WRF) model and the U.S. Department of Energy EnergyPlus building energy model (version 8.6), respectively. Historical heat wave events were classified as any 5 day period between 1980 and 2009 in which daily average air temperatures met or exceeded the 97.5th percentile of daily average temperature. Subsequently, the 90th percentile heat wave from each 30 year period in each city was selected and considered representative of the base period climate. The resulting heat wave periods identified were August 14–18, 1995 (Atlanta); June 15–19, 1994 (Detroit); and July 20–24, 2006 (Phoenix). Projected future heat waves representative of ~2055 (mid-century) and ~2085 (late century) were identified in the same way (i.e., 90th percentile

5 day heat waves in the global climate model output²⁰) and subsequently simulated with WRF.

To capture the dynamics of an urban setting, the building effect parameterization (BEP) multilayer urban canopy model was selected in WRF. High-resolution (1 km² grid spacing for the inner domain) two-way coupled WRF + BEP simulations were carried out using a nested grid configuration, enabling the downscaling of the large-scale synoptic flow from the coarsest outer grids to the finest inner grids across each of the three study regions. We made use of RCP 8.5 for both mid- and late-century time periods to assess the highest emission scenarios and to incorporate continuing uncertainty over achievable global emission reductions this century. Trees are represented in WRF-BEP as a simplification of the BEP-Tree model.²¹ Tree shading of impervious surfaces (streets and building walls) is calculated according to Beer’s law, accounting for forward transmission of shortwave radiation through leaves. For simplicity and to conserve energy, all shortwave radiation intercepted by tree foliage is assumed to be converted to transpiration and therefore does not impact air temperature via sensible heat flux. This represents a maximum impact scenario of well-watered trees on air temperature. In the current formulation, trees do not impact wind or longwave radiation, both factors that can slightly counter the shading and transpiration cooling effect. A more complete description of the tree implementation is given in Stone et al.⁷

To simulate building-interior exposures, we adapted the EnergyPlus model to simulate indoor temperatures within distinct residential building types, including 1-story, single-family houses; 2-story, single-family houses; and multistory apartment buildings. Building prototype parameters, including age, size, construction materials, and insulation values, were selected to reflect the local residential building stock in Atlanta, Detroit, and Phoenix. In addition to building prototype characteristics, the building energy model simulations were driven by the ambient weather output at the neighborhood (1 km) scale derived from the WRF model runs in each city. The location-specific effects of tree shading and shading from adjacent buildings were not captured in our modeling. For a complete description of our approach to building-interior temperature simulation, please see Stone et al.⁷

Individual hourly exposures to outdoor and building-interior temperatures were constructed from a synthetic population dataset for each city and national time–activity pattern survey data. The unavailability of location-specific identifiers for individuals in U.S. Census data requires that “synthetic” population datasets be developed for a range of demographic and economic analyses linking individual residents to geographic boundaries more disaggregated than Census blocks. For this study, we acquired synthetic population data from RTI International (RTI Synthpop), which depicts each resident of a Census block group as a randomly positioned point within the block group boundaries and assigns to these points demographic characteristics including age, sex, race, and income. As the total number of residents per block group is reported by the U.S. Census Bureau, but not the specific address of each resident, each person included in the RTI Synthpop digital map must be assigned to a specific address, enabling a set of building characteristics to be associated with each resident.

To carry out this task, we made use of a geographic information system (ESRI ArcGIS) to assign each resident to a unique address and residential structure through the creation

Table 2. Exposure Scenarios

scenario name	time period	electrical grid status	scenario conditions
power on	present day	operational	thermostat set point of 24 °C (75 °F) for residential structures with central AC systems.
power off	present day	nonoperational	no mechanical cooling for any structures for 48 h; power restoration sequenced by proximity to electrical substations over 72 h.
street trees	present day	nonoperational	all roadways with exception of interstate highways assumed to be 50% covered by tree canopy (tree characteristics are broadly representative of each region).
cool roofs	present day	nonoperational	roof material albedos for all buildings set at 0.88.
mid century	2050s	nonoperational	outdoor temperatures representative of a modeled heat wave in ~2055 in each city for the RCP 8.5 scenario; no heat management strategies in effect.
late century	2080s	nonoperational	outdoor temperatures representative of a modeled heat wave in ~2085 in each city for the RCP 8.5 scenario; no heat management strategies in effect.

Table 3. Ambient Heat Wave Temperatures and Mean IET under the Power On and Power Off Scenarios by City

attribute	Atlanta	Detroit	Phoenix
heat wave temperature range	25–36 °C (77–97 °F)	22–35 °C (72–95 °F)	32–45 °C (90–113 °F)
mean IET for Power On scenario	25.9 °C (78.7 °F)	25.3 °C (77.5 °F)	26.3 °C (79.3 °F)
mean IET for Power Off scenario	28.1 °C (82.5 °F)	26.9 °C (80.4 °F)	32.7 °C (90.8 °F)
mean IET for Street Tree scenario	27.6 °C (81.7 °F)	26.5 °C (79.7 °F)	32 °C (89.6 °F)
mean IET for Cool Roof scenario	27.5 °C (81.5 °F)	26.3 °C (79.3 °F)	31.4 °C (88.6 °F)

of a circular buffer around each multifamily building or single-family house. First, any synthetic persons located within a 500-foot radius of a high-rise multifamily building (defined as more than five stories in height) were assigned to that building. Second, any synthetic persons located within a 250-foot radius of a low-rise multifamily building (defined as five stories in height or less) were assigned to that building. Lastly, all remaining synthetic persons were assigned to the nearest single-family home. This procedure resulted in the assignment of specific residential structure characteristics, including building-interior temperatures, to each resident of the three cities.

Individual time–activity patterns were derived from the American Time Use Survey (ATUS), conducted annually by the U.S. Bureau of Labor.²² We extracted time use data from respondents in each of the three study cities during the period 2004–2015. There were 2958 respondents that met the inclusion criteria and completed a total of 59,774 logged activities on the survey. Each activity was assigned to one of five location categories based on the nature of the recorded activity code, using guidance from Hoehne et al.²³ The location categories include indoor home, indoor away (e.g., at a workplace), outdoor home, outdoor away, and vehicle. The time–activity profiles of ATUS respondents from each respective city were then assigned to each synthetic resident based on common attributes between the two datasets, including age, sex, occupation, and income. In assigning time–activity profiles to synthetic residents of each city, we drew randomly from the ATUS respondents who were assigned to the same combination of age, sex, occupation, and income categories. IETs for each hour were calculated for each synthetic person as the proportion of time spent in each of the five environmental conditions (indoor home, indoor away, outdoor home, outdoor away, vehicle) multiplied by the temperature in each of the respective environment and then summed for each hour of the day.

Building-interior temperatures were simulated in response to ambient heat wave conditions for two sets of electrical grid scenarios for the same 5 day heat wave period: (1) the grid is

assumed to be fully operational (Power On) and (2) the grid is assumed to be fully nonoperational (Power Off) across the municipal extent of each city. For the Power On scenario, we made use of a mechanical air conditioning prevalence model to estimate the probability that central air conditioning, partial air conditioning (window AC units), or no mechanical air conditioning is available within each residential structure. Requiring as input parcel tax records reporting the home value, owner-occupied status, housing age, and housing structure type, combined with data on cooling-degree days within each city, AC prevalence was estimated with a regression model found in prior work to predict the presence of central or partial AC systems at the parcel level with a model accuracy of 84 and 82%, respectively.²⁴ Building-interior temperatures during the Power On scenario are responsive to the type (or absence) of air conditioning system assigned to each structure. For structures with central AC systems, we assumed a constant set-point temperature of 24 °C during Power On conditions.⁷

For all scenarios in which the electrical grid is nonoperational, we assume 48 h of complete blackout conditions for every residential structure across the three cities and then restore power over the remaining 72 h of the heat wave based on the proximity of each structure to electrical grid substations. Electrical power is assumed to be restored to residential structures most proximate to these substation nodes first, with structures more distant from these nodes assigned a lower temporal priority in power restoration.²⁵ In prior work, we found the median duration of recent U.S. blackout events impacting 1 million customers or more to be approx. 120 h, consistent with the large-scale events simulated herein.⁸ During blackout conditions, building-interior temperatures are responsive to localized outdoor temperatures and the specific characteristics of the building prototype (e.g., single vs multistory). For all residential structure types, windows are assumed to be opened at any time during concurrent heat wave and blackout conditions that ambient ventilation would have the effect of lowering indoor temperatures. Under the Power Off scenario, all residents of each city were assumed to remain in their residential structures (the indoor home location) due

Table 4. Details on Exposure-Response Functions

study	city and time period	health outcome	age and sex	threshold high T (°C)	RR for high vs threshold T	ln(RR) for 1 °C increase
Gasparrini et al. 2015 ¹⁸	Atlanta, 1985–2006	nonexternal all-cause mortality	all	25.6–32.5	1.064	0.0129
Gasparrini et al. 2015 ¹⁸	Detroit, 1985–2006	nonexternal all-cause mortality	all	23.9–31.3	1.58	0.110
Gasparrini et al. 2015 ¹⁸	Phoenix, 1985–2006	nonexternal all-cause mortality	all	33.3–40.6	1.21	0.0539
Winqvist et al. 2016 ²⁷	Atlanta, 1993–2012	heat-related ED visits	all	27–32	4.59	0.305
Petitti et al. 2016 ¹⁷	Phoenix, 2000–2011	heat-related ED visits	all	33–40	3.50	0.179

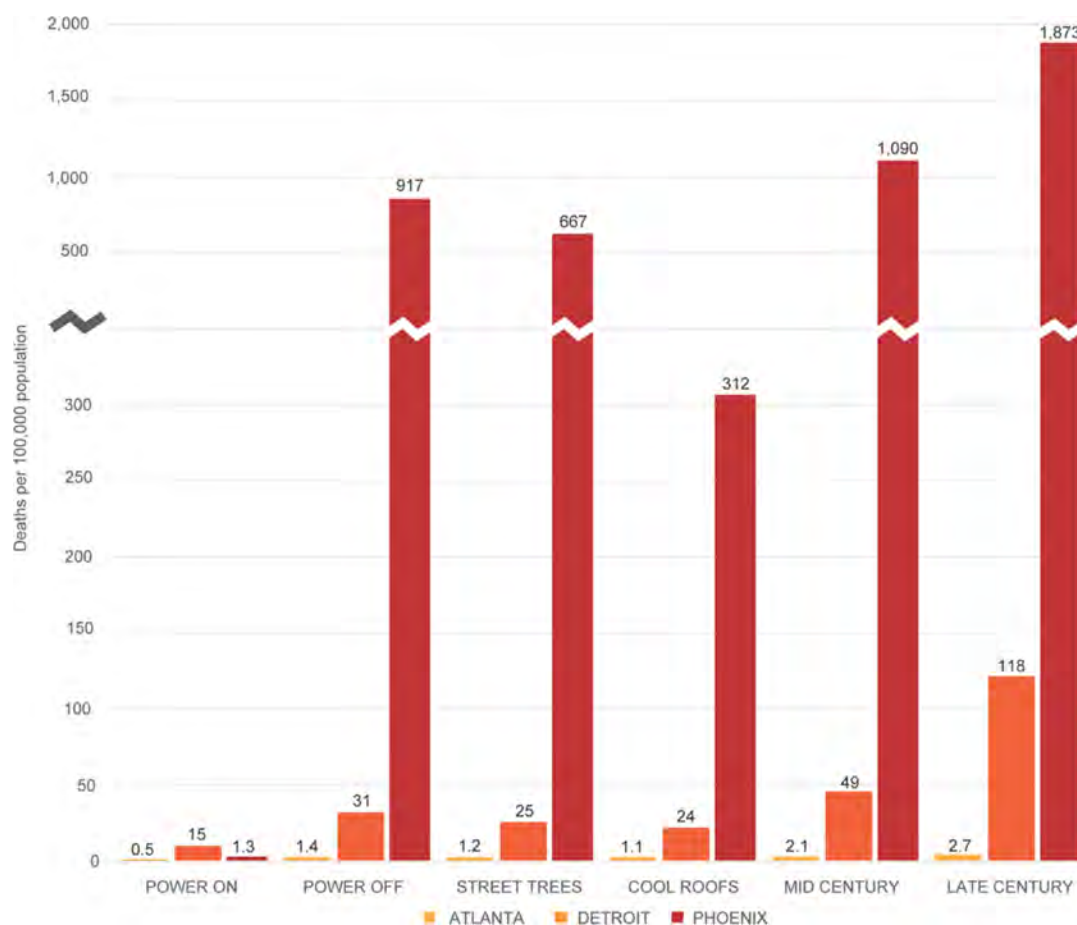


Figure 3. Rate of heat mortality during concurrent 5 day heat wave and blackout events in Atlanta, Detroit, and Phoenix by scenario. The Street Trees, Cool Roofs, Mid Century, and Late Century scenarios reflect blackout conditions.

to the assumed inoperability of transportation systems and blackout conditions at the workplace.

IET is estimated for each synthetic resident based on daily time–activity patterns, simulated outdoor and building-interior temperatures associated with each activity, and outdoor and building-interior temperatures associated with variable heat exposure scenarios. Each exposure scenario is detailed in Table 2. We report ambient heat wave temperatures and mean IET under the Power On and Power Off scenarios by city in Table 3 and illustrate the distributions of these scenarios in Supporting Information Figure S1.

Health Impact Assessment. We estimated the probability of heat-related mortality or morbidity for each resident during the 5 day heat wave and in response to each of the scenario

conditions presented in Table 2. The health impact assessment consists of the following steps:

Step 1: Hourly outdoor temperatures from the nearest airport weather station in each city were downloaded from the Integrated Surface Database²⁶ for a 10 day period, including five consecutive days of historic heat wave conditions and five subsequent days not characterized by heat wave conditions. We make use of airport weather station data to match the meteorological data used in the derivation of RR for emergency department visits in Atlanta and Phoenix and most commonly used to derive RR for heat-associated mortality.

Step 2: For both the extreme heat and nonextreme heat days, average daily IETs were joined with average daily airport

temperatures for each resident by day (i.e., each day's average outdoor temperature was associated with an individual's estimated average IET for the same day).

Step 3. We then used the derived IET-outdoor temperature associations for unique combinations of building type, age, sex, income, and occupation to estimate "analog" outdoor temperature (T') or the inflated temperature corresponding to blackout IET values, for these building type and demographic combinations. To do so, a mixed effect linear regression was fit to model IET as a function of outdoor airport temperature and building characteristics, age, sex, income, and occupation as follows

$$[\text{IET}]_{\text{pd}} = \beta_0 + \beta_1 X_{\text{pd}} + \beta_2 T_{\text{pd}}$$

where p indexes persons, d indexes days, and X is a vector of individual characteristics (age, income, sex, occupation categories, housing categories).

The regression equation was rearranged to estimate an analog daily T , or T' , for each person's daily IET

$$T'_{\text{pd}} = \frac{1}{\beta_2} \times [\text{IET}]_{\text{pd}} - \frac{\beta_0 + \beta_1 X_{\text{pd}}}{\beta_2}$$

In this resulting equation, T' for each person for a given IET is the estimated rate at which T increases with each degree of IET, or $\frac{1}{\beta_2}$, and $\frac{\beta_0 + \beta_1 X_{\text{pd}}}{\beta_2}$ is a constant, or intercept, specific to that type of person.

Step 4. We next substituted T' for airport temperature in exposure-response functions to capture the effects of blackout conditions on individual heat risk. Gasparrini et al.¹⁸ derived nonlinear exposure-response functions for heat-related mortality for a large number of global cities, including Atlanta, Detroit, and Phoenix. Exposure-response functions for heat-related emergency department (ED) visits are only available for two of our three study cities: Atlanta²⁷ and Phoenix.¹⁷ Details on each of these exposure-response functions are provided in Table 4.

Step 5. The total daily burdens were calculated as the product of the age/sex/race category population and the category-specific incidence rate obtained for each health outcome: mean daily all-natural-cause mortality²⁸ and cause-specific ED visits.²⁹ The attributable fractions, derived from the nonextreme heat relative risks (RRs) for each person-day, were then multiplied by the total daily burdens. This estimated the fractional burdens for each person-day on a nonextreme heat day.

Step 6. For the extreme heat days in each city, the heat-attributable burdens were subtracted from the total daily burden to derive the "baseline health burden" or non-heat-associated burden for each age/sex/race category.

Step 7. The extreme heat days in our study were unusually high-temperature events and may therefore have resulted in mortality and morbidity beyond the annual rates observed in the total health burden data. Therefore, rather than using the attributable fractions from step 5, which assume that the attributable burdens were fractions of observed total burdens, we multiplied the extreme-heat-event RRs by the baseline burdens from step 6 to estimate the extreme-heat-event-attributable burdens for each person-day. Thus, the baseline burdens from step 6 allow estimated attributable burden to exceed the observed historical total burden (please see Supporting Information Figure S2). As a final step, we sum

the heat-attributable burdens over the 5 day heat wave to estimate the total risk of heat-related mortality or morbidity. Estimated aggregate risks are limited to a maximum of 1 per person.

RESULTS AND DISCUSSION

We find a substantial increase in heat-related mortality and morbidity across each of the three cities with a loss of electrical power during heat wave conditions. As presented in Figure 3, the rate of mortality (per 100,000 population) under conditions of an operational electrical grid (Power On) shows substantial variation between Atlanta and Phoenix, cities with a citywide prevalence of central AC in residential structures of greater than 90%, and Detroit, which exhibits a population rate of AC prevalence of less than 60%.⁸ During a heat wave event of historical intensity with an operational electrical grid, Detroit experiences a rate of heat-related mortality many-fold greater than the cities with high AC prevalence due to a lower adaptive capacity for heat in the form of mechanical cooling.

The estimated rate of heat-related mortality (per 100,000 population) for each city during simulated heat wave conditions with an operational electrical grid (Power On scenario) is 0.5 in Atlanta (total = 2), 15 in Detroit (total = 107), and 1.3 in Phoenix (total = 19) (Note: Total heat-related deaths are not reported in Figure 3). In addition to AC prevalence, the relatively low level of mortality in Atlanta can be attributed to maximum heat wave temperatures 9 °C lower than observed in Phoenix, which reaches 45 °C in the late afternoon.

We find a citywide loss of electrical power during a 5 day heat wave of historical intensity (Power Off scenario) to more than double the estimated rate of heat mortality in Atlanta and Detroit, where maximum outdoor and building-interior temperatures reach about 35 °C in the late afternoon and remain above a daily minimum temperature of 25 °C (Atlanta) or 22 °C (Detroit). In Phoenix, where the lowest daily high temperature over the 5 day heat wave is 43 °C and daily minimum temperatures average 32 °C, the rate of heat-related mortality increases by about 700% relative to the Power On scenario, reflecting the extremity of heat exposures in a desert city in the absence of mechanical AC. As reported in Figure 3, the estimated rate of heat-related mortality for the Power Off scenario in Phoenix is 917 (approximate total = 13,250 deaths), which approaches 1% of the synthetic population. The estimated rate of heat-related mortality for comparable 5 day events in Atlanta and Detroit is 1.4 (total = 6) and 31 (total = 221), respectively.

Heat management strategies in the form of street trees and cool roofing measurably reduce heat-related mortality across the three cities, particularly in Phoenix. An increase from present-day tree canopy shading of roadways to an average of 50% across all streets is found to reduce the estimated rate of heat mortality by 14 and 19% in Atlanta and Detroit, respectively, and by 27% in Phoenix. In response to the installation of highly reflective cool roofs for all building types citywide, the rate of heat-related mortality falls by 21% in Atlanta, 23% in Detroit, and 66% in Phoenix. We attribute the disproportionate benefits of cool roofing in Phoenix to the extremity of temperatures during heat wave conditions, during which rates of evapotranspiration from trees may be reduced, lessening the cooling effects of tree canopy.³⁰

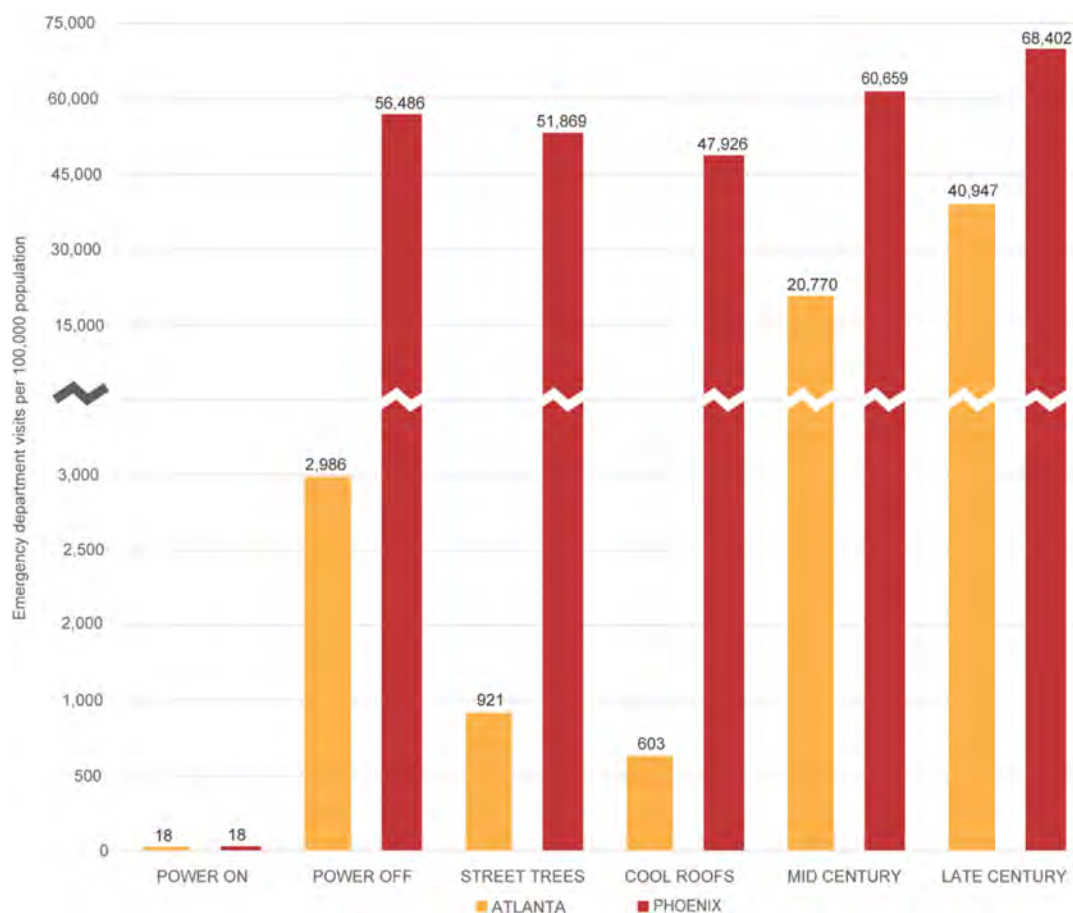


Figure 4. Emergency department visits per 100,000 population during concurrent 5 day heat wave and blackout events in Atlanta and Phoenix by scenario. The Street Trees, Cool Roofs, Mid Century, and Late Century scenarios reflect blackout conditions. No published exposure-response function for emergency department visits is available for Detroit.

Projected warming by middle (~2055) and late (~2085) century under the RCP 8.5 global emissions trajectory further amplifies estimated heat-related mortality, particularly by late century. In response to a mid-century heat wave of comparable intensity to the historical event modeled in the base period, the rate of heat-related mortality increases by 50% in Atlanta, 58% in Detroit, and 19% in Phoenix relative to the base period. By late century, the rate of heat-related mortality increases by 93%, 281%, and 104% in Atlanta, Detroit, and Phoenix, respectively. Relative to population size, which remains fixed at present-year levels for the future warming scenarios, the rate of heat mortality in Phoenix from a concurrent heat wave and blackout event is projected to exceed 1% of the total modeled population in mid-century and approach 2% of the population by late century.

The estimated number of ED visits resulting from a 5 day heat wave substantially increases in response to simulated blackout conditions. Based on health surveillance data recording daily emergency department visits for heat-related conditions, exposure-response functions have been derived to associate daily ED visits with temperature change in two of our three study cities: Atlanta and Phoenix.^{17,27} Employing the same analog temperature approach used to estimate heat-related mortality, we estimate the number of ED visits in response to our six scenarios in Figure 4. Under current conditions, a citywide blackout increases the rate of heat-

related ED visits (per 100,000 population) in Atlanta from 18 (total = 76) to almost 3,000 (approximate total = 12,540) over the 5 day event, representing approx. 3% of the population. In Phoenix, the estimated rate of heat-related ED visits increases from 18 (total = 260) under the Power On scenario to more than 56,000 (approximate total = 816,570) visits under the Power Off scenario, representing more than 50% of the population.

Citywide urban heat management strategies reduce heat-related morbidity associated with a concurrent heat wave and blackout event in both cities. An expansion of street trees to 50% shading over roadways reduces the rate of ED visits by almost 70% in Atlanta and 8% in Phoenix. The conversion of all building roofs to cool materials reduces the rate of ED visits by 80% in Atlanta and 15% in Phoenix.

Accounting for more intense heat waves in future years, a concurrent heat wave and blackout event by mid-century increases the ED visit rate in Atlanta approx. 7-fold to more than 20,000 per 100,000 population. The ED visit rate in Phoenix increases by 7% over the base year Power Off scenario. By late century, the fraction of the urban population requiring emergency medical services from the simulated compound climate and infrastructure failure event is estimated as more than 40% in Atlanta and 68% in Phoenix.

DISCUSSION

We estimate a magnitude of health risks associated with a compound climate and infrastructure failure event across the three large U.S. cities that is well in excess of prior work focused on extreme heat events in urbanized areas.^{31,32} Our measure of IET, accounting for individual-level heat exposures responsive to localized outdoor and indoor climates, provides a more accurate metric of individual heat exposure than the use of single, stationary outdoor temperature sensors at regional weather stations. While the substitution of IET in exposure-response functions does not result in elevated estimates of heat wave mortality or morbidity relative to prior studies when electrical grids are assumed to be operational,^{33,34} the simulated loss of mechanical AC for residents with access to AC systems greatly elevates indoor heat exposures, serving in turn to elevate the analog temperatures used herein to estimate health impacts. Simulated blackout conditions for a historical 5 day heat wave more than doubled the rate of heat mortality in Atlanta and Detroit and increased the rate of heat mortality in Phoenix—where average heat wave temperatures exceed 37 °C—to almost 1% of the total urban population.

The more pronounced risk of heat mortality and morbidity in Phoenix relative to Atlanta and Detroit can be attributed both to the higher temperatures experienced during an extreme heat wave event and a disproportionate impact of blackout conditions for cities with a high AC prevalence. Ambient heat wave temperatures in Phoenix reach a maximum intensity 9–10 °C greater than daily high temperatures in Atlanta or Detroit, while minimum temperatures only fall to 32 °C, sustaining high heat exposures over a full 24 h period for successive days. In addition to more intense heat wave conditions for residents of Phoenix, the loss of electrical power produces a disproportionately greater shift in individual heat exposures than estimated for residents of Atlanta or Detroit. Reported in Table 3, the shift in IET resulting from a loss of electrical power during heat wave conditions is 2.2 and 1.6 °C in Atlanta and Detroit, respectively, and more than 6 °C in Phoenix. Phoenix is not only hotter than Atlanta or Detroit, the shift in individual heat exposures in response to a loss of AC is about 3-fold greater, on average, than for residents of Atlanta or Detroit—an outcome that results from both high heat wave temperatures and an AC prevalence rate that approaches 100%. Protective of health during heat wave periods with an operational electrical grid, high AC prevalence may have the unintended effect of amplifying heat vulnerability during grid failure events.

While none of the cities included in the study has experienced a concurrent heat wave and blackout event of the intensity and duration modeled herein, recent surveillance data focused on the unhoused population in Phoenix find a heat-mortality rate comparable to that estimated to result from a citywide compound climate and infrastructure failure event. The Maricopa County Public Health Agency, which serves more than 90% of the Phoenix metropolitan population, reported 130 heat-related deaths among an unhoused population of approx. 8200 during 2021 or a heat-mortality rate of 1580 per 100,000.^{35,36} Representing approx. 1.6% of the estimated total unhoused population, this estimate of the heat-mortality rate among a population lacking regular access to shelter or mechanical air conditioning falls within the same order of magnitude of what we estimate to result from a concurrent heat wave and blackout event for the full Phoenix

population (~1%). An important limitation of this reference dataset for the Phoenix population, however, is the surveillance period, which is reflective of a full warm season as opposed to a single, intense heat wave event. In addition, differences in the baseline health and acclimatization to extreme heat between these two populations may yield different outcomes.

Our estimates do not account for individuals' behavioral adaptations or the actions of first responders during such a severe heat crisis. In reality, if a blackout event was regionally localized, many individuals would be able to leave their homes and travel to cooler locations. We also do not account for potential governmental responses to a concurrent heat wave and blackout, such as evacuation of the most vulnerable to heat illness or the deployment of mobile power generators for cooling centers. Other important sources of uncertainty in our analysis include (1) the degree to which measures of relative risk based on outdoor temperatures are reflective of indoor heat exposures, (2) uncertainties in the precision of the ambient and indoor temperature models used for the study, (3) uncertainties in behaviors and locations of individuals throughout the day and hence their daily IETs, and (4) uncertainties in the exposure-response functions in the applied epidemiology studies (including the changing nature of population susceptibility with a period of prolonged heat exposure).

These limiting assumptions notwithstanding our results suggest that the extent of heat morbidity in Atlanta and Phoenix resulting from a concurrent heat wave and blackout event carries the potential to overwhelm regional emergency medical systems. With almost three percent of the urban population in Atlanta estimated to require emergency medical care and more than half of the Phoenix population, the capacity of regional emergency departments to effectively treat heat illness would be exceeded in both cities (Atlanta has less than 2000 emergency department beds;³⁷ Phoenix has less than 3000 emergency department beds³⁸). Importantly, the exposure-response functions used in this study reflect heat morbidity rates during historical surveillance periods in which regional electrical grids are fully or largely operational. The inability of regional emergency medical systems to treat widespread heat illness during periods of electrical system inoperability due to the large number of residents requiring medical care may indicate that a higher rate of heat mortality than estimated by our approach would result.

The substantial magnitude of heat risk in Phoenix, with more than 50% of the population at risk of heat illness from blackout conditions during a heat wave of historical intensity, suggests the imperative for a high level of electrical grid resilience and back-up power generation, particularly for critical facilities such as hospitals. Burillo et al.³⁹ found the potential for cascading electrical grid failures across Arizona to increase 30-fold in response to a 1 °C rise in average annual temperatures, suggesting a growing potential for compound events over time. Most critical is investments in back-up power generation at regional cooling centers to ensure critical public health protections during blackout conditions and an expansion in the number of cooling centers to accommodate larger populations during compound climate and infrastructure events. We estimate that the total number of cooling centers in each of the three study cities would likely accommodate less than 1–2% of the urban population in the event of a concurrent heat wave and blackout event.⁸ As the frequency and intensity of extreme heat events continues to rise, all cities

should be working to enhance electrical grid resilience during heat wave conditions.

The extremity of the estimated risk for heat-related mortality in Phoenix and of heat morbidity in both Atlanta and Phoenix, highlight the need for more comprehensive emergency response preparations by local, state, and federal officials. Such plans should address emergency cooling needs, the provision of drinking water should water treatment and delivery systems fail, and the potential need for evacuation and temporary housing for residents lacking access to personal vehicles. At present, state-level hazard mitigation plans in Arizona, Georgia, and Michigan do not identify an electrical grid failure during an extreme heat event as a defined class of hazard. The Arizona Department of Health Services identifies an electrical grid failure event during the summer months as requiring the highest level of governmental emergency response but offers limited details on what responses would be deployed.⁴⁰ In light of the rising frequency of electrical grid failure events, in concert with a rising incidence of extreme weather events nationwide, compound climate and infrastructure failure events should be directly addressed through governmental hazard mitigation and emergency response planning.

Conventional urban heat management strategies, including an enhancement of citywide street tree canopy and the use of high albedo roofing materials, potentially carry significant benefits for lessening heat risk during concurrent heat wave and blackout events. Across the three study cities, street trees lessened heat-related mortality by an average of 20%, while cool roofing could lessen heat-related mortality by an average of 37%. Both strategies also were highly effective at reducing estimated heat morbidity in Atlanta and Phoenix, with the modeled increase in street trees and cool roofing associated with an average reduction in ED visits of 39 and 48%, respectively. While we did not simulate the effects of both enhanced street tree area and cool roofing simultaneously, other studies have found the combination of these strategies to yield a marginally lower cooling effect than the sum of these two strategies modeled independently.^{41,42} Importantly, our approach estimates benefits of cool roofing for both reduced ambient and building-interior temperatures, while street trees are not assumed to shade buildings in our modeling, and thus, no building-interior reductions in temperature from direct tree shading were considered. Prior work accounting directly for the benefits of tree shading for indoor climates finds significant cooling benefits that are not reflected in our results.⁴³ Moreover, our estimate of reduced mortality from expanded tree canopy does not account for direct radiative effects on (i.e., direct shading of) pedestrians and thus may underestimate the full benefits of this strategy.

We assume an extent of tree canopy shading over roadways that exceeds present canopy extents in each of the study cities but likely would be achievable over time for all but the largest roadways. While citywide data on street tree coverage over roadways are not available for Atlanta, Detroit, or Phoenix, data for Chicago, as an example, find streets to be shaded by an average of 35% when measured at the Census block group level, with 14% of all block groups found presently to have tree shading of roadways at 50% or greater,⁴⁴ illustrating the potential to achieve this level of canopy cover over streets in a highly urbanized environment. Likewise, we set roof albedo values at levels presently achievable with commercially available products for both commercial and residential roofs.

We believe the heat management targets set in this study are ambitious but physically attainable over time in each of the study cities, albeit with differing levels of investment needed in supporting infrastructure and more pronounced constraints on water resources for irrigation in Phoenix.

A rising potential for compound climate and infrastructure failure events in large cities of the U.S. highlights a pronounced vulnerability of urban populations confronting more extreme heat in all regions of the country.⁴⁵ In this study, we find the health impact of a multiday electrical grid failure event during heat wave conditions, and in the absence of cooling interventions, to be substantially greater than the estimated levels of heat mortality and morbidity associated with a heat wave alone. We further find this amplifying effect of infrastructure failure on health outcomes to rise rapidly by middle to late century, as heat wave intensities exceed historical levels. Widespread physical changes to the built environment of cities, enhancing evapotranspiration, shading, and solar reflection, carry the potential to measurably reduce estimated levels of heat illness and death.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.est.2c09588>.

Distribution of IET by city for the Power On, Power Off, Cool Roof, and Street Tree scenarios in the present time period (Figure S1) and extrapolated RR curves based on ref 18 for Atlanta, Detroit, and Phoenix (Figure S2) (PDF)

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Notes

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REFERENCES

- (1) Chen, Y.; Liao, Z.; Shi, Y.; Tian, Y.; Zhai, P. Detectable increases in sequential flood-heatwave events across China during 1961–2018. *Geophys. Res. Lett.* **2021**, *48*, No. e2021GL092549.
- (2) Geranios, N. Washington state blackouts hit same customers repeatedly, 2021. <https://apnews.com/article/washington-health-business-9eac0088672bd70f273fc9b7a4c19656>. Associated Press 2021 Jul 1 [Cited 2022 July 19].
- (3) Popovich, N.; Choi-Schagrin, W. Hidden toll of the Northwest heat wave: Hundreds of extra deaths, 2021. <https://www.nytimes.com/interactive/2021/08/11/climate/deaths-pacific-northwest-heat-wave.html>. New York Times 2021 Aug 11 [Cited 2022 July 19].
- (4) Schramm, P. J.; Vaidyanathan, A.; Radhakrishnan, L.; Gates, A.; Hartnett, K.; Breyse, P. Heat-Related Emergency Department Visits During the Northwestern Heat Wave - United States, June 2021. *MMWR Morb. Mortal. Wkly. Rep.* **2021**, *70*, 1020–1021.
- (5) Patel, S. Rolling blackouts triggered as historic heatwave grips Pacific Northwest, 2021 <https://www.powermag.com/rolling-blackouts-triggered-as-historic-heatwave-grips-pacific-northwest/>. Power Magazine 2021 Jun 30 [Cited 2022 July 19].
- (6) US Energy Information Administration (USEIA). Electric Power Monthly. 2016–2022, 2022 <https://www.eia.gov/electricity/monthly/>. (accessed online June 1, 2022).
- (7) Stone, B.; Mallen, E.; Rajput, M.; Broadbent, A.; Krayenhoff, E. S.; Augenbroe, G.; Georgescu, M. Climate change and infrastructure risk: Indoor heat exposure during a concurrent heat wave and blackout event in Phoenix, Arizona. *Urban Clim.* **2021**, *36*, No. 100787.
- (8) Stone, B.; Mallen, E.; Rajput, M.; Gronlund, C.; Broadbent, A.; Krayenhoff, E. S.; Augenbroe, G.; O'Neill, M.; Georgescu, M.

Compound climate and infrastructure events: How electrical grid failure alters heatwave risk. *Environ. Sci. Technol.* **2021**, *55*, 6957–6964.

(9) US Census Bureau. 2010 Decennial Census, 2022. <https://data.census.gov/>. (Accessed online September 8, 2022).

(10) National Centers for Environmental Information, National Oceanic and Atmospheric Administration. U.S. Climate Normals, 2022. <https://www.ncei.noaa.gov/access/us-climate-normals/>. (Accessed online September 2, 2022).

(11) Baechler, M.; Gilbride, T.; Cole, P.; Hefty, M.; Ruiz, K. *Guide to Determining Climate Regions by County*; US Department of Energy, 2015. PNNL-17211 Rev. 3.

(12) Thomas, N.; Ebel, S. T.; Newman, A. J.; Scovronick, N.; D'Souza, R. R.; Moss, S. E.; Warren, J. L.; Strickland, M. J.; Darrow, L. A.; Chang, H. H. Time-series analysis of daily ambient temperature and emergency department visits in five us cities with a comparison of exposure metrics derived from 1-km meteorology products. *Environ. Health* **2021**, *20*, No. 55.

(13) Runkle, J. D.; Cui, C.; Fuhrmann, C.; Stevens, S.; Del Pinal, J.; Sugg, M. M. Evaluation of wearable sensors for physiologic monitoring of individually experienced temperatures in outdoor workers in southeastern US. *Environ. Int.* **2019**, *129*, 229–238.

(14) Hondula, D. M.; Kuras, E. R.; Betzel, S.; Drake, L.; Eneboe, J.; Kaml, M.; Munoz, M.; Sevig, M.; Singh, M.; Ruddell, B. L.; Harlan, S. L. Novel metrics for relating personal heat exposure to social risk factors and outdoor ambient temperature. *Environ. Int.* **2021**, *146*, No. 106271.

(15) Rajput, M.; Augenbroe, G.; Stone, B.; Georgescu, M.; Broadbent, A.; Krayenhoff, S.; Mallen, E. Heat exposure during a power outage: A simulation study of residences across the metro Phoenix area. *Energy Build.* **2021**, *259*, No. 111605.

(16) Gronlund, C. J.; Zanobetti, A.; Schwartz, J. D.; Wellenius, G. A.; O'Neill, M. S. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. *Environ. Health Perspect.* **2014**, *122*, 1187–1192.

(17) Petitti, D. B.; Hondula, D. M.; Yang, S.; Harlan, S. L.; Chowell, G. Multiple trigger points for quantifying heat-health impacts: new evidence from a hot climate. *Environ. Health Perspect.* **2016**, *124*, 176–183.

(18) Gasparrini, A.; Guo, Y.; Hashizume, M.; Lavigne, E.; Zanobetti, A.; Schwartz, J.; Tobias, A.; Tong, S.; Rocklöv, J.; Forsberg, B.; Leone, M.; De Sario, M.; Bell, M.; Guo, Y. L.; Wu, C.; Kan, H.; Yi, S. M.; Coelho, M.; Saldiva, P. H.; Honda, Y.; Kim, H.; Armstrong, B. Mortality risk attributable to high and low ambient temperature: A multi-country observational study. *Lancet* **2015**, *386*, 369–375.

(19) Dimitrova, A.; Ingole, V.; Basagana, X.; Ranzani, O.; Mila, C.; Ballester, J.; Tonne, C. Association between ambient temperature and heat waves with mortality in South Asia: systematic review and meta-analysis. *Environ. Int.* **2021**, *146*, No. 106170.

(20) Broadbent, A. M.; Krayenhoff, E. S.; Georgescu, M. Efficacy of cool roofs at reducing pedestrian-level air temperature during projected 21st century heatwaves in Atlanta, Detroit, and Phoenix (USA). *Environ. Res. Lett.* **2020**, *15*, No. 084007.

(21) Krayenhoff, E. S.; Jiang, T.; Christen, A.; Martilli, A.; Oke, T. R.; Bailey, B. N.; Nazarian, N.; Voogt, J. A.; Giometto, M. G.; Stastny, A.; Crawford, B. R. A multi-layer urban canopy meteorological model with trees (BEP-Tree): Street tree impacts on pedestrian-level climate. *Urban Clim.* **2020**, *32*, No. 100590.

(22) Hamermesh, D. S.; Frazis, H.; Stewart, J. Data watch: the American Time Use Survey. *J. Econ. Perspect.* **2005**, *19*, 221–232.

(23) Hoehne, C. G.; Hondula, D. M.; Chester, M. V.; Eisenman, D. P.; Middel, A.; Fraser, A. M.; Watkins, L.; Gerster, K. Heat exposure during outdoor activities in the US varies significantly by city, demography, and activity. *Health Place* **2018**, *54*, 1–10.

(24) Gronlund, C. J.; Berrocal, V. J. Modeling and comparing central and room air conditioning ownership and cold-season in-home thermal comfort using the American Housing Survey. *J. Expo. Sci. Environ. Epidemiol.* **2020**, *30*, 814–823.

- (25) Gholami, A.; Seyedi, T.; Grijalva, S. Proactive management of microgrids for resiliency enhancement: an adaptive robust approach. *IEEE Trans. Sustainable Energy* **2019**, *10*, 470–480.
- (26) Smith, A.; Lott, N.; Vose, R. The Integrated Surface Database: Recent developments and partnerships. *Bull. Am. Meteorol. Soc.* **2011**, *92*, 704–708.
- (27) Winquist, A.; Grundstein, A.; Chang, H. H.; Hess, J.; Sarnat, S. E. Warm season temperatures and emergency department visits in Atlanta, Georgia. *Environ. Res.* **2016**, *147*, 314–323.
- (28) US Centers on Disease Control and Prevention. Underlying cause of death 1999–2016 on CDC WONDER online database, 2017. <http://wonder.cdc.gov/ucd-icd10.html>. (Accessed online March 21, 2018).
- (29) U.S. Department of Health and Human Services (USDHHS). Hcupnet: Healthcare cost and utilization project free healthcare statistics, 2016. <http://hcupnet.ahrq.gov>.
- (30) Teskey, R.; Wertin, T.; Bauweraerts, I.; Ameye, M.; McGuire, M. A.; Steppe, K. Responses of tree species to heat waves and extreme heat events. *Plant, Cell Environ.* **2015**, *38*, 1699–1712.
- (31) Gronlund, C. J.; Sullivan, K. P.; Kefelegn, Y.; Cameron, L.; O'Neill, M. Climate change and temperature extremes: A review of heat-and cold-related morbidity and mortality concerns of municipalities. *Maturitas* **2018**, *114*, 54–59.
- (32) Saha, M. V.; Davis, R. E.; Hondula, D. M. Mortality displacement as a function of heat event strength in 7 US cities. *Am. J. Epidemiol.* **2014**, *179*, 467–474.
- (33) Royé, D.; Codesido, R.; Tobías, A.; Taracido, M. Heat wave intensity and daily mortality in four of the largest cities of Spain. *Environ. Res.* **2020**, *182*, No. 109027.
- (34) Nitschke, M.; Tucker, G. R.; Hansen, A. L.; Williams, S.; Zhang, Y.; Bi, P. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environ. Health* **2011**, *10*, 1–9.
- (35) Maricopa County Public Health. Heat-Associated Deaths in Maricopa County, AZ: Preliminary Report for 2021, 2022. <https://www.maricopa.gov/ArchiveCenter/ViewFile/Item/5404>. (accessed online August 31, 2022).
- (36) Maricopa Association of Governments. 2022 Point in Time (PIT) Count Report: Maricopa Regional Continuum of Care, 2022. <https://azmag.gov/Portals/0/Documents/MagContent/2022-PIT-Count-Report-Final.pdf?ver=mHBvGa3hHNtmeOOfMZxtA%3D%3D>. (accessed online August 31, 2022).
- (37) Georgia Geospatial Information Office. Covid-19 Georgia Geospatial Data Hub, 2022. <https://covid-hub.gio.georgia.gov/>. (accessed online July 19, 2022).
- (38) Arizona Department of Health Services. Covid-19 Data, 2022. <https://www.azdhs.gov/covid19/data/index.php#hospital-bed-usage>. (accessed online July 19, 2022).
- (39) Burillo, D.; Chester, M.; Ruddell, B. Electric grid vulnerabilities to rising air temperatures in Arizona. *Procedia Eng.* **2016**, *145*, 1346–1353.
- (40) Arizona Department of Health Services. Extreme heat incident annex, 2021. <https://www.azdhs.gov/documents/preparedness/emergency-preparedness/response-plans/extreme-heat-incident-annex.pdf>. (accessed online July 19, 2022).
- (41) Jacobs, S. J.; Gallant, A. J. E.; Tapper, N. J.; Li, D. Use of cool roofs and vegetation to mitigate urban heat and improve human thermal stress in Melbourne, Australia. *J. Appl. Meteorol. Climatol.* **2018**, *57*, 1747–1764.
- (42) Krayenhoff, E. S.; Broadbent, A. M.; Zhao, L.; Georgescu, M.; Middel, A.; Voogt, J. A.; Martilli, A.; Sailor, D.; Erell, E. Cooling hot cities: a systematic and critical review of the numerical modelling literature. *Environ. Res. Lett.* **2021**, *16*, No. 053007.
- (43) Morakinyo, T. E.; Dahanayake, K. W.; Adegun, O. B.; Balogun, A. A. Modelling the effect of tree-shading on summer indoor and outdoor thermal condition of two similar buildings in a Nigerian university. *Energy Build.* **2016**, *130*, 721–732.
- (44) USEPA. EnviroAtlas, EnviroAtlas Data, 2022. <https://www.epa.gov/enviroatlas/enviroatlas-data> (accessed online July 19, 2022).
- (45) Habeeb, D.; Vargo, J.; Stone, B. Rising heat wave trends in large US cities. *Nat. Hazard.* **2015**, *76*, 1651–1665.

Energy Burden and Economic Poverty in the US

Do Energy Burdens Contribute to Economic Poverty in the United States? A Panel Analysis

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For many households, energy consumption represents a non-discretionary portion of their budget and directly relates to quality of life. As researchers continue to study the environmental impacts of energy behavior, it is important to explore how energy consumption relates to socio-economic wellbeing. This paper examines the economic impacts of being energy-burdened in the United States, defined as spending at least 10% of household income on heating and electricity services; energy burdens are partially, but not entirely, driven by income, since energy needs and costs can vary substantially due to housing characteristics, utility rates, and other factors. Using panel data of US household income and energy expenditures during 1999–2017, this analysis demonstrates that energy-burdened households were at about 150%–200% greater risk of transitioning into or extending the duration of economic poverty over a two-year timeframe relative to non-burdened households. This analysis indicates that dedicating inordinate amounts of income to energy services can threaten a household's economic well-being over time, possibly by preventing a household from engaging in other economic activities or compounding existing economic hardship. These results emphasize the importance of energy assistance and energy efficiency for low-income households, drawing attention to how structures of energy consumption, the welfare state, and social stratification intertwine.

Introduction

Energy consumption in the United States is often viewed in terms of excess. But energy scarcity—that is, access to affordable energy—will become increasingly relevant if policies internalizing the environmental costs of energy production lead to increased prices and leave some households vulnerable to energy burden

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(Price, Brazier, and Wang 2012). Non-discretionary energy consumption can impose financial hardships for many US households despite rationing and efficient behavior intended to minimize spending (Hernández and Bird 2010; Evens 2015). Rather than behavioral overconsumption, the financial burdens from energy use for these households primarily result from inefficient housing and insufficient capital to invest in improvements (Boardman 2012). Although scholarly attention to energy burdens in the industrial and post-industrial world is growing, fewer studies have examined energy burdens in the United States. Given the relatively weak US welfare state, where benefits often flow toward more affluent households (subsidizing for energy efficient appliances, e.g.), we should expect rising energy costs to push vulnerable populations to remain or fall into economic insecurity.

In this paper, we examine household energy costs in the United States, focusing on households that spend 10% or more of their total income on heating and electricity. Using longitudinal data, this analysis investigates the relationship between household energy burden and vulnerability to future economic poverty. While households vulnerable to economic poverty are by definition vulnerable to energy burdens, we assume that since energy budgets are at least partly beyond the agency of individual households, they present barriers to activities that help households avoid or transition out of economic poverty. In other words, by demonstrating an association between energy burden and future economic poverty, this analysis suggests that energy burdens serve as an obstacle to preventing or transitioning out of poverty. We conclude with future lines of research considering these results, making connections between energy burden, social stratification, and environmental social science.

Energy Burden and Poverty

Transitions into poverty and economic insecurity constitute a vast and important area of research in sociology and related disciplines. Without reviewing this scholarship in full, it is fair to state that researchers often focus—with good reason—on changes to earnings and employment status as the predominant predictors of poverty entry (Bane and Ellwood 1986; Ruggles and Williams 1987; Jenkins 2000; McKernan and Ratcliffe 2005; Brady, Finnigan, and Hübgen 2017). In addition to these major factors, researchers have examined “trigger events” that put households at greater risk of poverty entry or bankruptcy, such as family dissolution, injury, or ill health (DiPrete and McManus 2000; Smith 2004; Himmelstein et al. 2009; Maroto 2015; Tach and Eads 2015). Despite the rich body of work in this area, the complexity of unraveling the causal pathways to poverty entry leaves room for additional research connecting events to economic insecurity (Western et al. 2012).

Energy burdens may constitute a risk factor that has received less attention in the existing research. Research on energy insecurity lends insight into how this experience may lead to future poverty spells. Hernández (2016) provided a conceptual framework, outlining the economic components of energy insecurity

and the various burdens to which it exposes households. In addition to the health consequences of living in cold, dark, and damp conditions, which can lead to debt accumulation or lost wages, [Hernández \(2016\)](#) found that many energy insecure residents prioritize housing payments and food costs over utility bills when forced to choose (a point reinforced by [Finnigan and Meagher 2019](#)). The resulting utility debt can lead to an economic cycle of “playing catch up.” Such debt can limit the ability to secure new housing as arrears can prevent the transfer of utility services to new addresses, potentially locking households into structurally inefficient homes, and demanding resources that households could otherwise invest in avoiding or transitioning out of poverty (work-related capital, schooling, or training, etc.). Utility disconnection is also linked with increased risk of eviction ([Desmond 2016](#); [Finnigan and Meagher 2019](#)), food insecurity, telephone disconnection, unmet medical needs, and other forms of material hardship ([Heflin 2006](#)).

In the case of eviction, [Desmond’s \(2016\)](#) qualitative research in Milwaukee, Wisconsin finds that evictions spike in the summer and early fall when low-income households prioritize catching up on their utility bills to avoid disconnection before the winter shut-off moratorium begins, and evictions decline over the winter when households can stop paying their utility bill without risking a disconnection. Interviews conducted by [Hernández \(2016\)](#) of low-income families revealed utility bills cumulating to thousands of dollars, restricting discretionary income, and putting households into long-term debt. In their ethnographic research, [Harrison and Popke \(2011\)](#) shed light on the challenges of energy-burdened households deciding between paying utility bills and covering their medical and nutritional needs.

At a meso-level, the experience of energy burden can prevent families from moving out of low-resource neighborhoods and establishing social connections that facilitate economic opportunity. While social networks can provide private safety nets that help mitigate the consequences of triggering events ([Heflin, London, and Scott 2011](#)), a large majority of Americans experiencing missed utility payments report receiving no outside help; of those who do, about half receive support from friends and family ([Finnigan and Meagher 2019](#)). Researchers have linked inadequate access to affordable energy with household food insecurity ([Cook et al. 2008](#); [Bhattacharya et al. 2003](#)), health and child development risks ([Cook et al. 2008](#); [Hernández 2013](#); [Hernández 2016](#)), social network disruption ([Harrison and Popke 2011](#)), and mortality during heat waves ([Klinenberg 2002](#)).

The trade-off between paying energy bills and sacrificing basic needs is documented across several pieces of research. A US Energy Information Administration report indicated that about a third of households faced challenges in paying their energy bill in 2015, and about a fifth of households reduced or forwent basic necessities for at least a month to pay their energy bill ([U.S. EIA 2015](#)). A whitepaper produced for the Senate Committee on Energy and Natural Resources explored how energy costs can push families to poverty entry or cause food insecurity ([Murkowski and Scott 2014](#)). A statewide report in Colorado

found the inability to pay utility bills as one of the leading causes of homelessness behind job loss and family breakup (Center for Education Policy Analysis 2006). Utility shutoffs can exacerbate or cause illness (Hernández and Bird 2010), and landlords may use disconnection as grounds for eviction in some circumstances (Verclas and Hsieh 2018).

Eviction, food insecurity, and other material hardships often associated with energy burdens could initiate or prolong a cycle of poverty. The inability to access affordable energy services can prevent participation in certain economic activities and serve as a barrier to upward mobility (Sovacool, Sidortsov, and Jones 2014). We suggest that energy burdens may be one of several triggering events preceding poverty entry (Bane and Ellwood 1986; DiPrete and McManus 2000).

The concept of energy burden provides a structure for theoretical and empirical analysis of energy access and its implications for human welfare. We can conceptualize energy burden in terms of access to affordable, safe, and sufficient energy services or as a disproportionate (and non-discretionary) share of household resources dedicated to energy needs. A key part of this concept is that, to a certain extent, energy consumption is non-discretionary. Just as some basic amount of food consumption is essential for human welfare, some basic amount of energy consumption is essential for maintaining well-being, such as for heating and cooling, cooking, and lighting. Households are constrained in how much energy use can be reduced without compromising health and well-being, while energy efficiency improvements can both reduce energy needs and improve health (Wilson et al. 2016; Büchs et al. 2018). Various researchers have defined burdens in terms of actual expenditures using 6%, 10%, or 20% thresholds, estimated energy costs associated with heating a home to a particular temperature, or combinations of high costs with low incomes (Boardman 1991; APPRISE 2005; Moore 2012). While energy burdens are clearly linked with income and thus economic poverty, the two are not perfectly aligned. Moderate income households may be susceptible to energy burdens just as households living in economic poverty are not necessarily dedicating a large share of their income to energy needs. Furthermore, focusing on expenditures fails to capture energy rationing among lower income households; energy expenditures are thus distinct from “affordable warmth” discussed in the fuel poverty literature (Boardman 2010), which takes into account necessary costs to reach a particular temperature.

The amount of total income resources dedicated to energy varies across class boundaries, with middle- and upper-income households typically spending 5% or less while poor households may spend 10%, 20%, or even greater proportions of their income on energy services (Evans 2015; Drehoobl and Ross 2016). Income dedicated to energy services limits the resources available for other actions, so fluctuating energy costs can greatly affect resources available to satisfy other basic needs, including food (Bhattacharya et al. 2003). At the same time, energy consumption does not increase in a simple linear fashion with income, and some low-income households use more energy per square foot of housing space due to less efficient appliances and temperature control systems (Evans 2015, using electricity data for Chicago-area households).

Qualitative research in the United States indicates that low-income households experiencing high energy burdens are not profligate in their behavior, displaying high levels of rationing energy consumption in everyday life. Some low-income households restrict energy use to the point where they are unable to maintain World Health Organization recommended minimum home temperatures (Hernández and Bird 2010; Middlemiss and Gillard 2015). The relationship between energy burden and poverty is not simply a matter of income, but also a function of home characteristics and related factors that influence energy needs (the Methodology section provides further details on the correlation between energy burdens and poverty). Research in the United Kingdom has identified constraints on controlling energy costs driven by: housing quality; tenancy relations and the “split incentive” problem (see below for details); utility rates (which vary substantially across the United States) as well as fees and debt; and non-negotiable energy needs of household members (Middlemiss and Gillard 2015). Poverty clearly increases the likelihood of energy burden simply due to low income, but may also exacerbate energy burden on the cost side through these factors. Recent research has found that energy use intensity, or the consumption of heating or cooling energy per square foot of living space, is higher in lower income neighborhoods in Detroit, Michigan (Bednar, Reames, and Keoleian 2017) and Kansas City, Missouri (Reames 2016). On the other hand, experiencing energy burden may place a household at greater risk of poverty, since reduced discretionary funds can limit a household’s ability to invest in education, job training or economic capital, or make contributions to savings. Energy-burdened households may become vulnerable to utility debt, further adding to these constraints.

Parallel research on housing affordability has found that families facing housing cost burdens (commonly defined as costs greater than 30% of household income) face a variety of challenges: increased odds of poor self-rated health and various medical conditions (Pollack, Griffin, and Lynch 2010); less ability to invest in child education (Newman and Holupka 2014); and less money set aside in savings (Mendenhall, Kramer, and Akresh 2014). Like housing costs, energy costs are at least partially fixed and essential to household wellbeing. Although energy costs are usually substantially smaller than direct housing costs (i.e., rent, mortgage payments), higher energy costs nonetheless reduce discretionary funds and likely impact low-income families in similar ways to housing cost burdens. Additionally, housing is a productive asset that can support investments in social or human capital, or generate income (Moser 1998). Applying the asset vulnerability framework, energy inefficient housing may less effectively guard against poverty spells.

In general, housing is a critical factor on both the energy and poverty sides and has a significant impact on household energy needs. Tenants in rental housing face additional hurdles to managing their energy costs, since they are typically unable to invest in energy efficiency upgrades for their homes. This situation compounds behavioral and other barriers to energy efficiency that poor households face, since most households within 150% of the federal poverty level reside in rental housing and about 75% of renters pay their own utility bills (U.S.

EIA 2015). From an ownership standpoint, landlords have minimal incentive to improve the energy efficiency of the units they oversee. This falls under a “split incentive problem,” where landlords do not accrue direct benefits from their investments in energy efficiency, while occupants responsible for paying energy bills do not have the opportunity to make structural changes to their dwelling (Gillingham, Newell, and Palmer 2009; Hernández and Bird 2010). Thus, the rental homes that many poor households occupy are often less efficient and subject to higher energy costs for heating and cooling, which may contribute to higher levels of energy rationing and less healthy home temperatures (Gillingham, Harding, and Rapson 2012; Middlemiss and Gillard 2015).

Energy Assistance and the Welfare State

The US has had a federally coordinated energy assistance policy since 1981, when the Low Income Home Energy Assistance Program (LIHEAP) was established to assist low-income households in meeting their home energy needs. The most common LIHEAP qualification threshold for household income is 150% of federal poverty guidelines, although many states use other thresholds. LIHEAP typically covers only a small portion of total energy bills and has historically reached only a fraction of eligible households, between 10% and 20% (APPRISE 2005; Kaiser and Pulsipher 2006). There are various other federal, state, local, and utility programs that encourage energy efficiency and renewable energy or provide assistance to low-income households. However, assistance programs generally do not have sufficient funds to serve all applicants, while energy efficiency programs often require partial payments from customers that present a barrier to low-income households (Evans 2015).

Since Lutzenhiser and Hackett’s (1993) call for sociologists to connect environmental problems and energy with stratification and social welfare, relatively few scholars have answered. Welfare state research includes diverse contributions on tax systems (Prasad 2011, 2012), health care reform (Hacker 2004), and other topics, but little consideration to date regarding energy burdens. A comprehensive review of the welfare state literature lies beyond the scope of this paper, but it is worth highlighting the theoretical framework developed by Weir, Orloff, and Skocpol (1988), who explain the relatively weak US welfare state in terms of institutional structure: unlike the centralized bureaucratic states of Western Europe and their comparatively generous welfare expenditures, regional patronage networks and piecemeal bureaucratic-professional reforms characterize US history, preventing a robust welfare state from developing. Consistent with this, Hacker (2002) and Mettler (2011) both emphasize the extent to which US policy operates via indirect benefits (a tax break rather than direct provision, for example), which can easily fail to reach vulnerable populations in favor of the relatively affluent. These perspectives are also consistent with the various energy efficiency and clean energy tax credits and deductions, and the fact that these benefits primarily go to wealthy households (Borenstein and Davis 2016). Given such trends, we should expect that many households negatively impacted

by energy burdens find insufficient welfare state resources available to help, and the patchwork of federal, state, local, and utility programs are unlikely to fill the gap (Evans 2015).

We can logically assume that at the level of households, transitioning into economic poverty and the lower income it entails will increase the likelihood of experiencing energy burden. If the transition into economic poverty is preceded by a loss of household income, then—following the logic of Engel’s law of food elasticity (Engel 1857)—we can assume that the share of income dedicated to energy consumption will rise above operational definitions of energy burden. Yet the reverse direction has not been investigated, leading to the key research question here: does energy burden increase the likelihood of extending or entering economic poverty? In this analysis, we test the hypothesis that it does. Given the relatively non-discretionary nature of energy consumption, the cycles of debt energy burdens can initiate, and the social and health consequences of energy insecurity, we expect to find connections between energy burdens and future economic poverty status.

Data

Data for this project come from the Panel Study of Income Dynamics (PSID), a longitudinal survey of households that began in 1968 with an initial sample of nearly 5,000 US families. Data for this analysis come from household energy consumption gathered between 1999 and 2017 (waves 31–40).

Three measures of poverty serve as dependent variables, using income thresholds for defining poverty according to whether a household lives within 100%, 150%, or 200% of per capita household poverty guidelines contained in the PSID. These thresholds are based on detailed poverty tables from the Census Bureau that account for family size and number of related children.^{1,2} (In 2017, families of four with two children and a total income of \$24,944 or less fell within 100% of poverty guidelines.) Most households living within 150% of the poverty level qualify for LIHEAP subsidies, although different states use different thresholds.³ Additionally, it is common practice when using PSID data in particular to operationalize poverty at greater than 100% of federal guidelines (Cellini, McKernan, and Ratcliffe 2008) or when studying US poverty in general to analyze it according to multiple indicators (Ruggles 1992).

Respondents were asked how much they spend on heating or gas fuel and electricity per month.⁴ Although energy costs are expected to fluctuate across seasons, the PSID survey does not capture this seasonality but instead asks about typical monthly costs.⁵ To test the effect of energy burden, this amount was calculated as a share of total household monthly income from the previous year. A dummy variable was created with 1 = households that spend at least 10% of their monthly income on heat and electricity combined, conceptualized as households that face energy burdens. Respondents whose utility bills are included in their rent were dropped from analysis (accounting for about a fifth of all renters). This metric uses energy expenditures, and does not account for

the level of energy use necessary for a household to maintain healthy home temperatures, such as the “low income/high cost” measurement modeled by Hills (2011). The PSID data likely suffer from a “rounding strategy” used by respondents to self-report consumption expenditures (Pudney 2008), although the binary measure of energy burden should minimize this concern. Additionally, the PSID does not instruct respondents in how to handle utility subsidies when estimating monthly expenditures. Other independent variables are included to control for common predictors of poverty status. Since loss of income is an obvious potential cause for entering economic poverty, a dummy variable was created where 1 = a loss of at least 10% of household income from the previous wave. Ill health status was measured according to whether household heads assessed their health as fair or poor, with “good health” (those self-assessing as excellent, very good, or good) as the reference category. Both concurrent and lagged ill health were analyzed to control for the impacts of household heads’ ill health on economic wellbeing over time.

Several dummy variables were created to account for social structural location. These include whether household heads are female (which is time-varying in cases where female respondents become household heads for the first time), young (under 30), senior (65 or older), college graduates, and own their home. Dummy variables were also created for the type of health insurance a respondent had: private health insurance, other health insurance (provided for military veterans, e.g.), Medicare and/or Medi-Gap, or Medicaid, with uninsured as the reference category. Since economic poverty is measured on a per capita basis, new additions to the family unit could qualify a household as living in poverty even if their income remains stable. To account for this, a dummy variable was created, where 1 = households that reported new family members since the previous wave. Marital status is also controlled for, with concurrent dummy variables accounting for whether the household head is married, divorced, separated, or widowed, with single as the reference category. Lagged variables for marital status are not included because of likely collinearity with female head of household: since the PSID defined the head of household as male for all opposite-sex married or long-term cohabitating couples across all but the most recent wave included in this analysis, a household that transitions from a male head in a previous wave to female head concurrently would also experience a related change in marital status. Table 1 shows descriptive statistics of variables used in this analysis.

Methodology

A challenge of this research area is the role of income: it determines whether a household falls below the poverty thresholds, and by definition, energy burden is a function of income. Income is therefore part of the outcome (i.e., poverty), and included among the predictors as a component of energy burden. To address this mechanical correlation, we restrict inclusion of energy burden to its lagged state (two years prior), so that income is not used to calculate both concurrent poverty

Table 1. Descriptive statistics

Variable	Proportion (200% poverty rate _{t-1} = 1)	Proportion (200% poverty rate _{t-1} = 0)
Energy-burdened _{t-1}	0.46	0.09
10% income loss	0.23	0.45
Ill health	0.23	0.14
Private Insurance	0.24	0.44
Other Insurance	0.03	0.03
Medicaid	0.20	0.06
Medicare	0.04	0.05
New family member	0.19	0.18
Married	0.53	0.68
Divorced	0.14	0.11
Separated	0.07	0.05
Widowed	0.05	0.04
Homeowner	0.49	0.68
Female HH	0.39	0.23
Young HH	0.19	0.17
Senior HH	0.07	0.08
College grad	0.11	0.26

status and state of energy burden. When inspecting the relationship between lagged energy burden and corresponding poverty status after each model, all correlations were below 0.11.

Furthermore, by themselves, these poverty thresholds explain only a small proportion of the variation in energy burdens: we ran a series of logistic regressions predicting energy burden from different levels of poverty, predicting energy burden from total family income, and predicting each level of poverty from energy burden, resulting in a pseudo r^2 between 0.2 and 0.3. In other words, we cannot characterize the relationship between poverty and energy burden as a simple mechanical or spurious correlation due to low income. While our measure of energy burden is operationally tied to income, as is poverty, these data support our arguments that energy burden and poverty are neither conceptually nor empirically reducible to each other, and thus it is appropriate to use them in the same statistical model.⁶ This characterization is consistent with research on material hardship; although income loss is obviously and consistently related to medical, food, or housing hardship, such experiences are not reducible to income alone and can also be impacted by factors such as changes in health status, caring for family members with a disability, or drug use (Heflin and Butler 2012; Heflin 2016).

Given the binary dependent variables and panel structure of the PSID data, fixed effects logistic regression is utilized in this analysis (Allison 2009). Fixed

effects models offer the ability to measure within-unit change in the outcome over time, taking the following form:

$$\log\left(\frac{p_{it}}{1-p_{it}}\right) = \mu_t + \beta\mathbf{X}_{it} + \gamma\mathbf{Z}_i + \alpha_i, t = 1, 2, \dots, T$$

where p refers to the probability of household i at time t of displaying a positive outcome, μ is the intercept that may vary over time, $\mathbf{X}$ represents a vector of time-varying predictors, $\mathbf{Z}$ represents a vector of time-invariant predictors, and α represents the total effects of unobserved variables that remain constant over time. One consequence of restricting analysis to within-unit change is the inability to estimate time-constant variables such as race. Additionally, any unit that displays no variation in the outcome over the course of data collection is dropped from analysis. However, if researchers can partial out unobserved and time-constant heterogeneity while focusing on within-unit change in the outcome, they can make stronger claims to causal inference not available with cross-sectional survey analysis. While it is difficult to make direct claims about causality with observational data, by establishing a statistically significant relationship between dependent and independent variables, accounting for omitted variable bias, and establishing a temporal ordering of events, fixed effects panel designs offer more rigorous analysis than cross-sectional approaches (Finkel 1995; Frees 2004).

An additional challenge regards distinguishing between poverty entry and poverty extension. Prior and current states of poverty are correlated. To understand the relationship between energy burden and poverty status, it is important to know whether prior experience with energy burdens increases the likelihood of new entry into poverty, extends the duration of poverty, or both. With continuous outcomes, researchers often address this by estimating dynamic panel models that include lagged states of the dependent variable as predictors, using Arellano-Bond estimators to deal with resulting bias (Arellano and Bond 1991). However, there is less consensus regarding dynamic logit models. Instead of including lagged dependent variables as predictors, and taking inspiration from Stewart and Swaffield's (1999) study of low pay transitions in Britain, we restrict samples to whether a household was below a poverty threshold at the previous wave (models predicting the endurance of poverty), or above a poverty threshold at the previous wave (models predicting poverty entry). Sociologists working with repeated binary outcomes characterized by state dependence should consider adopting this stratifying approach, which is not commonly employed in the discipline.

Temporal ordering is established through the inclusion of lagged independent variables, including energy burden. For all models, unstandardized regression coefficients are presented in tables, while substantive discussion reports odds ratios. Finally, we ran sensitivity tests with several alternative model specifications:

- The addition of geographic controls, specifically fixed effects for state of residence.

- Operationalizing energy burden at 6% rather than 10% of household income, and as a continuous variable, to account for the depth of energy burden.
- The addition of housing type (single family homes, mobile homes, and multiunit structures).
- The addition of subsidies for rental housing and heat (as a continuous variable; about 5% of the sample received a government-funded heat subsidy, with an average annual payment of \$390).⁷
- A subset model: predicting 100% poverty within the population of families with income below 200% of the poverty threshold. This approach was used as an additional check regarding the role of income.

Results for these alternative model specifications were consistent with the results presented below. Stata code for the full analysis is available online.

Results

Table 2 presents results from fixed effects logistic regression estimating whether households fall within various poverty thresholds, restricted to households below the corresponding poverty level at the previous wave. These models represent whether a household endures a poverty status across concurrent waves. For context, most households in the positive outcome for Models 1 and 2 qualify for federal heating assistance.

The key variable of interest—whether a household was energy-burdened in the prior wave—is statistically significant in all models. Net of other factors, we see in Model 1 that energy-burdened households had about 175% greater odds of remaining in poverty two years later relative to their non-burdened peers. In Model 2 among households previously within 150% of the poverty threshold and net of other factors, those with prior energy burdens were about twice as likely to endure this economic status compared with households without prior energy burdens. In Model 3, we again see the impact of prior energy burdens resulting in over 100% greater odds of enduring a status below 200% of the poverty threshold. As noted above, this energy burden metric does not account for rationing or the level of energy use needed to maintain healthy home temperatures. Given the energy rationing described in qualitative studies, if data were available to capture the higher cost of “necessary” energy use, we would likely see an even more deleterious impact on economic status.

Several household demographics historically associated with economic poverty are controlled in these models. Unsurprisingly, adding new family members increased the odds of staying in poverty. Women who became new household heads had about triple the odds compared with male household heads of staying within 100% of the poverty threshold.

Focusing on transitions into poverty, table 3 presents results from fixed effects logistic regression, restricted to households above the corresponding poverty level at the previous wave. Across all three models, lagged energy burden had

Table 2. Unstandardized coefficients (and robust standard errors) for time-varying predictors from fixed effects logistic regression predicting different levels of poverty among households below the corresponding poverty level at the previous survey wave. Models control for year (not displayed)

	<i>Model 1: 100% poverty rate_{t-1} = 1</i>		<i>Model 2: 150% poverty rate_{t-1} = 1</i>		<i>Model 3: 200% poverty rate_{t-1} = 1</i>	
	Coef.	Robust St. Err.	Coef.	Robust St. Err.	Coef.	Robust St. Err.
Energy-burdened _{t-1}	1.019***	0.090	0.674***	0.06	0.761***	0.048
10% income loss	3.286***	0.132	3.219***	0.099	3.139***	0.093
Ill health _{t-1}	0.210*	0.097	0.064	0.065	0.035	0.057
Ill health	0.080	0.083	0.223***	0.064	0.039	0.054
Private Insurance _{t-1}	-0.593***	0.175	-0.232*	0.099	0.108	0.076
Private Insurance	-0.682***	0.157	-0.338***	0.086	-0.431***	0.068
Other Insurance _{t-1}	1.148***	0.218	0.581***	0.139	0.516***	0.129
Other Insurance	0.189	0.200	0.100	0.15	0.202	0.133
Medicaid _{t-1}	0.247*	0.106	0.108	0.076	0.466***	0.07
Medicaid	0.487***	0.100	0.692***	0.074	0.686***	0.071
Medicare _{t-1}	0.412	0.220	0.366*	0.158	0.328*	0.15
Medicare	0.198	0.220	0.576***	0.155	0.373**	0.137
New family member	0.194*	0.092	0.045	0.059	0.195***	0.05
Married	0.192	0.198	0.907***	0.148	0.266*	0.115
Divorced	-0.716***	0.201	-0.716***	0.14	-0.400***	0.107
Separated	-0.079	0.180	-0.072	0.157	-0.282*	0.127
Widowed	-0.942***	0.266	-0.571**	0.203	-0.201	0.177
Homeowner _{t-1}	-0.485***	0.122	-0.100	0.086	-0.310***	0.068
Homeowner	-0.269*	0.111	-0.233**	0.079	-0.443***	0.067
Female HH	1.286***	0.205	1.842***	0.153	1.081***	0.11
Young HH	-0.326**	0.101	-0.286***	0.074	-0.207**	0.065
Senior HH	-0.060	0.279	0.159	0.168	0.813***	0.145
College grad	-1.034***	0.254	-1.073***	0.134	-0.772***	0.112
N	7,971		13,982		19,589	

* p < 0.05, ** P < 0.01, *** P < 0.001

Table 3. Unstandardized coefficients (and robust standard errors) for time-varying predictors from fixed effects logistic regression predicting different levels of poverty among households above the corresponding poverty level at the previous survey wave. Models control for year (not displayed)

	<i>Model 4: 100% poverty rate_{t-1} = 0</i>		<i>Model 5: 150% poverty rate_{t-1} = 0</i>		<i>Model 6: 200% poverty rate_{t-1} = 0</i>	
	Coef.	Robust St. Err.	Coef.	Robust St. Err.	Coef.	Robust St. Err.
Energy-burdened _{t-1}	1.109***	0.068	0.921***	0.072	0.453***	0.076
10% income loss	4.050***	0.087	3.598***	0.067	3.091***	0.054
Ill health _{t-1}	0.243***	0.07	0.028	0.066	0.144*	0.069
Ill health	0.157*	0.066	0.248***	0.064	0.184**	0.064
Private Insurance _{t-1}	-0.072	0.085	0.015	0.076	0.093	0.072
Private Insurance	-0.546***	0.083	-0.448***	0.071	-0.329***	0.064
Other Insurance _{t-1}	0.103	0.186	0.440**	0.162	0.501**	0.152
Other Insurance	0.540***	0.146	0.459**	0.145	0.636***	0.140
Medicaid _{t-1}	0.098	0.093	0.619***	0.098	0.744***	0.113
Medicaid	0.642***	0.084	0.576***	0.083	0.814***	0.092
Medicare _{t-1}	0.060	0.171	0.316*	0.155	0.182	0.133
Medicare	0.105	0.157	0.194	0.139	0.131	0.123
New family member	0.499***	0.067	0.702***	0.060	0.714***	0.056
Married	-0.743***	0.112	-0.596***	0.095	-0.657***	0.098
Divorced	-0.407***	0.117	-0.692***	0.113	-0.345**	0.117
Separated	-0.729***	0.125	-0.477***	0.122	-0.043	0.138
Widowed	-0.369*	0.187	-0.032	0.170	0.038	0.180
Homeowner _{t-1}	-0.152*	0.071	-0.205**	0.067	-0.055	0.067
Homeowner	-0.702***	0.072	-0.903***	0.067	-0.859***	0.061
Female HH	0.319**	0.101	0.695***	0.098	0.272**	0.094
Young HH	0.379***	0.074	0.401***	0.071	0.440***	0.069
Senior HH	-0.039	0.156	0.044	0.136	0.071	0.126
College grad	-0.722***	0.111	-0.659***	0.095	-0.499***	0.086
N	23,531		28,517		30,406	

* p < 0.05, ** P < 0.01, *** P < 0.001

a statistically significant relationship to concurrent poverty status. Relative to non-burdened households, those with prior energy burdens had about double the odds of transitioning into poverty (Model 4), 150% greater odds of transitioning within 150% of the poverty threshold (Model 5), and about 60% greater odds of transitioning within 200% of the poverty threshold (Model 6). The impact of prior energy burdens on concurrent poverty status again accounts for whether a household experienced a substantial loss in income, which is obviously the single largest driver of the outcome across all models.

As with Models 1–3, Models 4–6 control for a variety of other variables commonly associated with transitions into economic poverty. Both married and divorced heads of household were less likely to transition into poverty relative to single household heads. Likewise, owning a home or graduating from college were positive predictors of economic wellbeing.

Although a full discussion of the role of health is beyond the scope of this paper, it is worthy to note the impact of health on economic wellbeing. In Model 4, for example, household heads rating their subjective health as fair or poor had about 20% greater odds of entering poverty two years later, compared to their counterparts rating their health as good, very good, or excellent. Concurrently having private health insurance predicts economic wellbeing. This is consistent with other research suggesting that access to health insurance through the Affordable Care Act marketplace may lower home mortgage delinquency rates (Gallagher et al. 2017), and is aligned with research linking maternal health with entrance into material hardship in the forms of food insufficiency, utility disconnections, unmet medical needs, and housing problems (Heflin 2013).

Discussion

These results clearly point to the economic disadvantage faced by energy-burdened households. As policymakers and activists continue to address energy consumption as part of climate change mitigation, it is important to recognize how increased energy prices could affect economically vulnerable households. Impacts from increased energy costs can be immediate, for instance if a household reduces expenditure on other necessities in order to heat the home (Bhattacharya et al. 2003), or when a household falls behind on their utility bills and consequently harms their credit rating (see Fourcade and Healy 2013 on the stratifying effect of credit ratings in the United States). Activists and policymakers should keep in mind that too many households lack a proper safety net to secure them from policies that increase energy costs. For researchers and theorists, this analysis highlights how energy burdens may act as triggering events for poverty entry and draws attention to the inadequacy of welfare state programs addressing this. We hope this analysis points to how energy consumption, the welfare state, and social stratification are intertwined.

Environmental activists, program implementers, and policymakers should keep these energy equity issues in mind when confronting potential

transitions to cleaner energy. For example, programs offering energy efficiency or clean energy services for low-income households can simultaneously work toward economic equity (by ensuring access to affordable energy) and environmental mitigation (by ensuring cleaner and/or more efficient energy consumption), social concerns historically brought up by [Lutzenhiser and Hackett \(1993\)](#). Ideally, renewable energy and energy efficiency programs would be accessible to low-income households, with funding assistance if necessary, since utility hardships are linked with other forms of hardship and assistance may reduce risks in other areas ([Finnigan and Meagher 2019](#)). In reality, activists and policymakers need to consider energy burdens in three policy areas: energy assistance, energy efficiency programs, and clean or renewable energy programs.

These results demonstrate that the benefits of energy efficiency and weatherization could extend beyond energy use to include reduced risk of economic poverty. For example, home insulation can last 80 years or more, effectively serving the duration of residency for a given household. Direct energy assistance may offer similar benefits in the short term, although future research should confirm that direct and weatherization assistance can mitigate the results found in this analysis. In terms of program design, high-quality and well-funded low-income energy programs may help reduce the risk of economic poverty while supporting environmental, climate, and other goals. We suspect, however, that current funding levels for LIHEAP and weatherization programs insufficiently mitigate inadequate energy access, at least at the federal level. Historically, LIHEAP and federal weatherization assistance funding has served only a fraction of eligible households ([Higgins and Lutzenhiser 1995](#)), although it can be a critical form of assistance for those who receive it ([Murray and Mills 2014](#)), and federal weatherization assistance programs have reduced energy bills by 12% on average ([U.S. DOE 2015](#)). Nonetheless, policy or activist efforts to address climate change mitigation could consider energy consumption as a site of intersection that simultaneously addresses social and environmental concerns ([Hernández 2015](#)).

To maximize the benefits of energy efficiency programs, these programs must be accessible to low-income households. This potentially requires greater funding for direct assistance or to address building health and safety issues that must be fixed before a retrofit can safely proceed ([Scheu et al. 2018](#)). Furthermore, to the extent that low-income households engage in energy rationing, low-income efficiency programs may see smaller energy savings but greater benefits in terms of healthy home temperatures and other non-energy benefits. For energy efficiency programs to be accessible to renters, these programs need to target multifamily building owners. Landlords remain key to the reform of energy consumption. [Bird and Hernández \(2012\)](#) suggest incentivizing landlords to take on energy efficiency upgrades for their units by covering the cost of loan financing in exchange for committing their property to low-income renting for the period of the loan. Future research could help to encourage multifamily energy efficiency by evaluating the benefits for landlords who do not pay utility

bills, for instance more comfortable housing units that reduce tenant turnover and increase net operating income for the building (Philbrick, Scheu, and Brand 2016). Energy efficiency programs targeting multifamily buildings can offer services to a significant share of low-income renters. For example, in Chicago, 59% of multifamily housing units are in low-cost, low-income neighborhoods, or are subsidized (Corso, Garascia, and Scheu 2017), and programs targeting these buildings may reduce energy burdens among low-income tenants. Research in the UK, however, indicates that income poverty spells typically last longer than fuel poverty (consistent with data used here), although rates of long-term fuel poverty exit vary across rural/urban settings, indicating that policies targeting housing stock may see inconsistent results (Roberts, Vera-Toscano, and Phimister 2015). Nonetheless, improving the efficiency of low-income housing will likely produce environmental benefits while potentially reducing the risk of energy burdens triggering poverty entry.

In addition to implications for activists, policymakers, and program implementers, these results also point to several fruitful directions for further research. We suspect the relationship between energy burden and economic poverty reflects multiple points of vulnerability and resource constraints relating to physical housing structure, neighborhood context, and consequences for social networks, physical health, or mental health. Energy burdens are understudied and need much more attention from social researchers to refine the mechanisms that connect this experience with poverty, and to understand the myriad coping strategies households employ. Comparative research could illuminate the effectiveness of policies and programs in mitigating these problems.

Other research areas could benefit from considering energy burdens as possible mechanisms, moderators, or complicating factors for other relationships. As one example, these results could hold implications for research on environmental risk perceptions and support for clean energy. Overall, lower-income individuals perceive greater long-term environmental risks than higher-income individuals (Trumbo et al. 2011; Lo 2014). Researchers could inquire how energy insecurity affects support for clean energy or climate change mitigation policy, particularly when those policies may result in slightly higher energy prices or inequitable impacts on consumers. Although renewable energy costs have fallen dramatically and are near parity with the cost of other fuels (Lazard 2016), carbon taxes or related instruments may nonetheless contribute to higher energy costs for some consumers, or the perception of higher costs. Additionally, tax credits and rebates for clean energy technologies can exacerbate inequity because upfront costs or credit requirements make them accessible primarily to the rich: 60% of US clean energy tax credits have gone to the top income quintile (Borenstein and Davis 2016). It is thus important to understand how perceptions of energy burdens or inequities affect support for social and environmental change. Energy justice could be crucial for working toward the goals held by mainstream environmentalists and clean energy movements.

Along this line of thought, several topics are proposed for future research to extend insights into energy burdens in the United States:

1. Does the experience of energy burden erode support for clean energy (assuming clean energy options are perceived as more expensive than conventional energy options)?
2. To what extent does energy consumption constitute a barrier to social mobility if basic needs exceed energy burden thresholds? How does energy burden compare to equivalent concepts of food and housing cost burden in terms of volatility and temporal patterns, and interrelationships? What are the relative impacts on poverty and social mobility of these and other independent causes of poverty?
3. In what ways does experiencing an energy burden contribute to poverty, and do the mechanisms vary in meaningful ways? What are the roles of housing (physical structure as well as affordability), health, financial constraints, cognitive capacity (Mani et al. 2013), utility rates and disconnection policies, and other factors?
4. What is the role of utility assistance, low-income weatherization assistance, LIHEAP, or other energy programs in moderating the relationship between energy burden and poverty? Do the programs that have the largest and longest-lasting impact on reducing energy use (e.g., weatherization) also have a large impact on reducing energy burden?

The first question brings a concern from social stratification (financial hardship) into the realm of environmental sociology and related social science by suggesting an analysis of support for clean energy development. The second question brings a concern from environmental sociology (energy consumption) into the realm of social stratification and material hardship and ties energy policy to broader poverty alleviation efforts, while the third question delves deeper into the processes that link energy and financial hardships. The fourth question addresses a potential moderating factor in that relationship and may have implications for program design and our theoretical understanding of the welfare state.

When analyzing energy consumption in the United States, sociologists typically focus on excessive use. But household energy scarcity could constitute an important topic for environmental sociology and social science more broadly, particularly in contexts where natural resource consumption to meet basic needs results in financial hardship. Sociological research in general would benefit from greater attention to energy burden and energy insecurity, in terms of financial hardships as well as variation in utility rates⁸, the impact of utility disconnection, the intersection of housing and energy, and other topics. This presents an opportunity for social scientists to engage in a larger discourse about social inequality that will be crucial to future conversations about energy and climate policy.

Notes

1. The models predicting income of 150% and 200% of poverty thresholds are included to address concerns in the literature that the 100% threshold is too low and reflects outdated modes of consumption. A full discussion of this issue is beyond the scope of this paper, but see [Ruggles \(1990, 1992\)](#) and [Blank \(2008\)](#) for examples. Additionally, since many states use 150% and 200% thresholds to determine qualification for energy assistance, it makes sense to extend analysis to these levels.
2. Although the supplemental poverty measure could account for differences in cost of living, it was not published by the US Census until 2011 and thus not available for many of the PSID waves analyzed here.
3. Another common threshold is 60% of the state median income, which is often higher than 150% of the federal poverty guideline, and some states extend the threshold to 200% of the poverty level. The LIHEAP Clearinghouse provides eligibility details for each state: <https://liheapch.acf.hhs.gov/snapshots.htm>.
4. Before 2011, this question asked about “gas or other types of heating fuel,” and was revised in 2011 to “gas or other types of fuel.” There are other small changes in PSID question wording over time, which we do not believe are likely to influence results. Models restricted to 1999–2009 produce results consistent with the models presented here.
5. There still may be a seasonal aspect to these data because respondents provide different estimates of typical monthly costs depending on when you ask them (e.g., average gas costs among respondents interviewed in March–May is \$164, versus \$157 in June–August). We ran basic one-way ANOVA tests for the influence of interview season, defining winter as December through February and summer as June through August, which is aligned with heating and cooling months for most of the United States. These models found a statistically significant effect of interview season on heating costs and electricity costs (both $p < .001$), and a marginally significant effect of interview season on combined heating and electricity costs ($p < .1$). We therefore ran additional sensitivity checks controlling for interview season, and the results are consistent with the models presented here.
6. We also explored the reverse relationship—different thresholds of economic poverty leading to energy burdens in a fixed effects logistic regression model. Results are available upon request, and indicate that lagged economic poverty is positively correlated with future energy burden status (controlling for factors described in the Data section).
7. Heating subsidies are not included in the main model due to potential double-counting (if respondents track subsidies as reduced expenditure, then they are incorporated into the energy burden metric), and a potential spurious correlation due to eligibility criteria. LIHEAP “crisis” assistance is only available to households at risk of disconnection (i.e., who are behind on their utility bills), and many states use higher income eligibility thresholds and/or provide larger subsidies for crisis assistance. These characteristics would

select for households at risk of poverty entry or extension. Historically, LIHEAP participation was strongly predicted by households receiving other forms of social welfare (SSI, e.g., Higgins and Lutzenhiser 1995).

8. State-level average residential prices for electricity in the contiguous United States in May 2018 ranged from 9.53 cents/kWh in Louisiana to 21.69 cents/kWh in Massachusetts (U.S. EIA 2018). Rates and rate structures also vary within states, for example, flat rates, time-of-use rates, inclining or declining block rates, flat customer charges versus volumetric charges, etc.

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References

- Allison, Paul 2009. *Fixed Effects Regression Models*. Thousand Oaks, CA: SAGE Publications.
- Applied Public Policy Research Institute for Study and Evaluation (APPRISE). 2005. *LIHEAP Energy Burden Evaluation Study*. Accessed August 2018. https://www.energy.gov/sites/prod/files/2018/03/f49/HHS_LIHEAP%20study_july_2005.pdf
- Arellano, Manuel, and Stephen, Bond. 1991. “Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations.” *Review of Economic Studies* 58:277–97.
- Bane, Mary Jo, and David T. Ellwood. 1986. “Slipping Into and Out of Poverty: The Dynamics of Spells.” *The Journal of Human Resources* 21(1):1–23.
- Bednar, Dominic J., Tony, Gerard Reames, and Gregory, A. Keoleian. 2017. “The Intersection of Energy and Justice: Modeling the Spatial, Racial/Ethnic and Socioeconomic Patterns of Urban Residential Heating Consumption and Efficiency in Detroit, Michigan.” *Energy and Buildings* 143:25–34.
- Bhattacharya, Jayanta, Thomas DeLeire, Steven Haider, and Janet Currie. 2003. “Heat or Eat? Cold-Weather Shocks and Nutrition in Poor American Families.” *American Journal of Public Health* 93(7):1149–54.
- Bird, Stephen, and Hernández, Diana. 2012. “Policy Options for the Split Incentive: Increasing Energy Efficiency for Low-Income Renters.” *Energy Policy* 48:506–514.
- Blank, Rebecca M. 2008. “How to Improve Poverty Measurement in the United States.” *Journal of Policy Analysis and Management* 27(2):233–254.

- Boardman, Brenda. 1991. *Fuel Poverty: From Cold Homes to Affordable Warmth*. London: Belhaven Press.
- . 2010. *Fixing Fuel Poverty: Challenges and Solutions*. London: Earthscan.
- . 2012. "Fuel Poverty Synthesis: Lessons Learnt, Actions Needed." *Energy Policy* 49:143–148.
- Borenstein, Severin, and Davis, Lucas W.. 2016. "The Distributional Effects of U.S. Clean Energy Tax Credits." *Tax Policy and the Economy* 30:191–234.
- Brady, David, Ryan M. Finnigan, and Sabine Hübgen. 2017. "Rethinking the Risks of Poverty: A Framework for Analyzing Prevalences and Penalties." *American Journal of Sociology* 123(3):740–786.
- Büchs, Milena, AbuBakr Bahaj, Luke Blunden, Leonidas Bourikas, Jane Falkingham, Patrick James, Mamusu Kamanda, and Yue Wu. 2018. "Sick and Stuck at Home—How Poor Health Increases Electricity Consumption and Reduces Opportunities for Environmentally-Friendly Travel in the United Kingdom." *Energy Research & Social Science* 44 (2018):250–9.
- Cellini, Stephanie Riegg, Signe-Mary McKernan, and Caroline Ratcliffe. 2008. "The Dynamics of Poverty in the United States: A Review of Data, Methods, and Findings." *Journal of Policy Analysis and Management* 27(3):577–605.
- Center for Education Policy Analysis 2006. *Colorado Statewide Homeless Count*. Denver, CO: Graduate School of Public Affairs, University of Colorado Denver.
- Cook, John T., Deborah A. Frank, Patrick H. Casey, Ruth Rose-Jacobs, Maureen M. Black, Mariana Chilton, Stephanie Ettinger de Cuba et al. 2008. "A Brief Indicator of Household Energy Security: Associations with Food Security, Child Health, and Child Development in US Infants and Toddlers." *Pediatrics* 122(4):e867–e875.
- Corso, Abigail, Garascia, Margaret, and Scheu, Rachel. 2017. *Segmenting Chicago Multifamily Housing to Improve Energy Efficiency Programs*. Chicago, IL: Elevate Energy.
- Desmond, Matthew. 2016. *Evicted: Poverty and Profit in the American City*. New York, NY: Penguin Random House.
- DiPrete, Thomas A., and Patricia, A. McManus. 2000. "Family Change, Employment Transitions, and the Welfare State: Household Income Dynamics in the United States and Germany." *American Sociological Review* 65:343–370.
- Drehobl, Ariel, and Lauren Ross. 2016. *Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low Income and Underserved Communities*. Washington, DC: ACEEE. Accessed January 2017. <http://aceee.org/research-report/u1602>.
- Engel, Ernst. 1857. "Die produktions-und konsumptionsverhältnisse des königreichs Sachsen." *Zeitschrift des Statistischen Bureau des Königlich Sächsischen Ministeriums des Innern* 8:1–54.
- Evens, Anne. 2015. "The Utility of the Future and Low-Income Households." *The Electricity Journal* 28(10):43–52.
- Finkel, Steven E.. 1995. *Causal Analysis with Panel Data*. Thousand Oaks, CA: SAGE Publications.
- Finnigan, Ryan, and Meagher, Kelsey D.. 2019. "Past Due: Combinations of Utility and Housing Hardship in the United States." *Sociological Perspectives* 62(1):96–119.
- Fourcade, Marion, and Healy, Kieran. 2013. "Classification Situations: Life-Chances in the Neoliberal Era." *Accounting, Organizations and Society* 38:559–572.
- Frees, Edward W.. 2004. *Longitudinal and Panel Data: Analysis and Applications in the Social Sciences*. Cambridge, UK: Cambridge University Press.
- Gallagher, Emily A., Gopalan, Radhakrishnan, Grinstein-Weiss, Michal, Roll, Stephen P., and Davison, Genevieve. 2017. *Home Delinquency Rates are Lower Among ACA Marketplace Households: Evidence from a Natural Experiment*. St. Louis, MO: Washington University in St. Louis Center for Social Development, CSD Research Brief, pp. 17–01.

- Gillingham, Kenneth, Richard G. Newell, and Karen Palmer. 2009. "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics* 1(1):597–620.
- , Matthew Harding, and David Rapson. 2012. "Split Incentives in Residential Energy Consumption." *The Energy Journal* 33(2):37–62.
- Hacker, Jacob S.. 2002. *The Divided Welfare State: The Battle Over Public and Private Social Benefits in the United States*. Cambridge, UK: Cambridge University Press.
- . 2004. "Privatizing Risk Without Privatizing the Welfare State: The Hidden Politics of Social Policy Retrenchment in the United States." *American Political Science Review* 98(2):243–260.
- Harrison, Conor, and Jeff Popke. 2011. "'Because You Got to Have Heat': The Networked Assemblage of Energy Poverty in Eastern North Carolina." *Annals of the Association of American Geographers* 101(4):949–961.
- Heflin, Colleen. 2006. "Dynamics of Material Hardship in the Women's Employment Study." *Social Service Review* 80(3):377–397.
- . 2013. "Why do Women Enter and Exit from Material Hardship?" *Journal of Family Issues* 34(5):631–660.
- . 2016. "Family Instability and Material Hardship: Results from the 2008 Survey of Income and Program Participation." *Journal of Family and Economic Issues* 37(3):359–372.
- Heflin, Colleen., and J. S. Butler. 2012. "Why do Women Enter and Exit from Material Hardship?" *Journal of Family Issues* 34(5):631–660.
- Heflin, Colleen, Andrew S. London, and Ellen K. Scott. 2011. "Mitigating Material Hardship: The Strategies Low-Income Families Employ to Reduce the Consequences of Poverty." *Sociological Inquiry* 81(2):223–246.
- Hernández, Diana. 2013. "Energy Insecurity: A Framework for Understanding Energy, the Built Environment, and Health among Vulnerable Populations in the Context of Climate Change." *American Journal of Public Health* 103(4):e32–e34.
- . 2015. "Sacrifice Along the Energy Continuum: A Call for Energy Justice." *Environmental Justice* 8(4):151–156.
- . 2016. "Understanding 'Energy Insecurity' and Why it Matters to Health." *Social Science & Medicine* 167:1–10.
- Hernández, Diana, and Stephen Bird. 2010. "Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy." *Poverty & Public Policy* 2(4):5–25.
- Higgins, Lorie, and Loren Lutzenhiser. 1995. "Ceremonial Equity: Low-Income Energy Assistance and the Failure of Socio-Environmental Policy." *Social Problems* 42(4):468–492.
- Hills, John. 2011. "Fuel Poverty—The Problem and its Measurement." In *Interim Report of the Fuel Poverty Review*. CASE. London: LSE.
- Himmelstein, David U., Deborah Thorne, Elizabeth Warren, and Steffie Woolhandler. 2009. "Medical Bankruptcy in the United States, 2007: Results of a National Study." *The American Journal of Medicine* 122(8):741–746.
- Jenkins, Stephen P.. 2000. "Modelling Household Income Dynamics." *Journal of Population Economics* 13:529–567.
- Kaiser, Mark J., and Allan G. Pulsipher. 2006. "Concerns Over the Allocation Methods Employed in the US Low-Income Home Energy Assistance Program." *Interfaces* 36(4):344–358.
- Klinenberg, Eric. 2002. *Heat Wave: A Social Autopsy of Disaster in Chicago*. Chicago, IL: University of Chicago Press.
- Lazard. 2016. *Lazard's Levelized Cost of Energy Analysis – Version 10.0*. Accessed November 2017. <https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf>.

- Lo, Alex Y.. 2014. "Negative Income Effect on Perception of Long-Term Environmental Risk." *Ecological Economics* 107:51–58.
- Lutzenhiser, Loren, and Bruce Hackett. 1993. "Social Stratification and Environmental Degradation: Understanding Household CO₂ Production." *Social Problems* 40(1):50–73
- Mani, Anandi, Sendhil Mullainathan, Eldar Shafir, and Jiaying Zhao. 2013. "Poverty Impedes Cognitive Function." *Science* 341(6149):976–980.
- Maroto, Michelle Lee. 2015. "Pathways to Bankruptcy: Accumulating Disadvantage and the Consequences of Adverse Life Events." *Sociological Inquiry* 85(2):183–216.
- McKernan, Signe-Mary, and Ratcliffe, Caroline. 2005. "Events that Trigger Poverty Entries and Exits." *Social Science Quarterly* 86:1146–1169.
- Mendenhall, Ruby, Karen Z. Kramer, and Illana R. Akresh. 2014. "Asset Accumulation and Housing Cost Burden: Pathways to (Not) Saving." *Housing Policy Debate* 24(2):387–414.
- Mettler, Suzanne. 2011. *The Submerged State: How Invisible Government Policies Undermine American Democracy*. Chicago, IL: University of Chicago Press.
- Middlemiss, Lucie, and Gillard, Ross. 2015. "Fuel Poverty from the Bottom-Up: Characterising Household Energy Vulnerability Through the Lived Experience of the Fuel Poor." *Energy Research and Social Science* 6:146–154.
- Moore, Richard. 2012. "Definitions of Fuel Poverty: Implications for Policy." *Energy Policy* 49:19–26.
- Moser, Caroline O.N.. 1998. "The Asset Vulnerability Framework: Reassessing Urban Poverty Reduction Strategies." *World Development* 26(1):1–19.
- Murkowski, Lisa, and Tim Scott. 2014. "Plenty at Stake: Indicators of American Energy Insecurity." *Energy 20/20 White Paper 113th United States Congress*. Accessed February 2019. https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=075f393e-3789-4ffe-ab76-025976ef4954.
- Murray, Anthony G., and Bradford F. Mills. 2014. "The Impact of Low-Income Home Energy Assistance Program Participation on Household Energy Insecurity." *Contemporary Economic Policy* 32(4):811–825.
- Newman, Sandra J., and Holupka, C. Scott. 2014. "Housing Affordability and Investments in Children." *Journal of Housing Economics* 24:89–100.
- Philbrick, D., Scheu, R., and Brand, L.. 2016. *Quantifying the Financial Benefits of Multifamily Retrofits*. Golden, CO: National Renewable Energy Laboratory (NREL). Contract No. DE-AC36-08G028308.
- Pollack, Craig Evan, Beth Ann Griffin, and Julia Lynch. 2010. "Housing Affordability and Health Among Homeowners and Renters." *American Journal of Preventive Medicine* 39(6):515–521.
- Prasad, Monica. 2011. "Tax 'Expenditures' and Welfare States: A Critique." *Journal of Policy History* 23(2):251–266.
- . 2012. *The Land of Too Much: American Abundance and the Paradox of Poverty*. Cambridge, MA: Harvard University Press.
- Price, Catherine Waddams, Brazier, Karl, and Wang, Wenjia. 2012. "Objective and Subjective Measures of Fuel Poverty." *Energy Policy* 49:33–39.
- Pudney, Stephen. 2008. "Institute for Social and Economic Research, University of Essex." *Heaping and Leaping: Survey Response Behaviour and the Dynamics of Self-Reported Consumption Expenditure. No. 2008–09. ISER Working Paper Series*.
- Reames, Tony Gerard. 2016. "Targeting Energy Justice: Exploring Spatial, Racial/Ethnic and Socioeconomic Disparities in Urban Residential Heating Energy Efficiency." *Energy Policy* 97:549–558.
- Roberts, Deborah, Vera-Toscano, Esperanza, and Phimister, Euan. 2015. "Fuel Poverty in the UK: Is There a Difference Between Rural and Urban Areas?" *Energy Policy* 87:216–223.
- Ruggles, Patricia, and Williams, Robertson C.. 1987. *Transitions In and Out of Poverty: New Data from the Survey of Income and Program Participation*. Washington, DC: Census Bureau.

- Ruggles, Patricia. 1990. *Drawing the Line: Alternative Poverty Measures and Their Implications for Public Policy*. Washington, DC: Urban Institute Press.
- . 1992. "Measuring Poverty." *Focus* 14(1):1–9.
- Scheu, Rachel, Parham Azimi, Mary Ellen Guest, Amanda Gramigna, and Brent Stephens. 2018. "Why Equity Matters: Energy Use and Health Disparities by Neighborhood: Stories (and Data) from Families Living in Chicago's Bungalow Belt." *Proceedings from the ACEEE Summer Study on Energy Efficiency in Buildings*. Pacific Grove, CA: ACEEE.
- Smith, James P. 2004. "Unraveling the SES—Health Connection." *Population and Development Review* 30:108–132.
- Sovacool, Benjamin K., Sidortsov, Roman V., and Jones, Benjamin R.. 2014. *Energy Security, Equality, and Justice*. New York: Routledge.
- Stewart, Mark B., and Joanna K. Swaffield. 1999. "Low Pay Dynamics and Transition Probabilities." *Economica* 66(261):23–42.
- Tach, Laura M., and Eads, Alicia. 2015. "Trends in the Economic Consequences of Marital and Cohabitation Dissolution in the United States." *Demography* 52:401–432.
- Trumbo, Craig, Michelle Lueck, Holly Marlatt, and Lori Peek. 2011. "The Effect of Proximity to Hurricanes Katrina and Rita on Subsequent Hurricane Outlook and Optimistic Bias." *Risk Analysis* 31(12):1907–1918.
- U.S. Department of Energy (DOE). 2015. *Weatherization Assistance Program National Evaluations: Summary of Results*. Accessed June 2019. <https://weatherization.ornl.gov/wp-content/uploads/2018/06/WAPNationalEvaluationWxWorks14blue8515.pdf>.
- U.S. Energy Information Administration (EIA). 2015a. *Residential Energy Consumption Survey, "One in Three U.S. Households Faced Challenges in Paying Energy Bills in 2015."* Accessed February 2019. <https://www.eia.gov/consumption/residential/reports/2015/energybills/>.
- . 2015b. *Residential Energy Consumption Survey, Household Demographics Table HC9.2.* Accessed February 2019. <https://www.eia.gov/consumption/residential/data/2015/>.
- . 2018. *"Electric Power Monthly with Data for May 2018, Table 5.6.A, Average Price of Electricity to Ultimate Customers by End-Use Sector, by State, May 2018 and 2017 (Cents per Kilowatthour)."* Accessed August 2018. https://www.eia.gov/electricity/monthly/current_month/epm.pdf.
- Verclas, Kirsten, and Eric Hsieh. 2018. "From Utility Disconnection to Universal Access." *The Electricity Journal* 31(6):1–8.
- Weir, Margaret, Orloff, Ann Shola, and Skocpol, Theda (eds.) 1988. In *The Politics of Social Policy in the United States*. Princeton, NJ: Princeton University Press.
- Western, Bruce, Bloome, Deirdre, Sosnaud, Benjamin, and Tach, Laura. 2012. "Economic Insecurity and Social Stratification." *Annual Review of Sociology* 38:341–359.
- Wilson, Jonathan, Jacobs, David, Reddy, Amanda, Tohn, Ellen, Cohen, Jonathan, and Jacobsohn, Ely. 2016. *Home Rx: The Health Benefits of Home Performance – A Review of the Current Evidence*. Washington, DC: U.S. Department of Energy.



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ORIGINAL ARTICLE | LIFE EXPECTANCY

Marked Disparities in Life Expectancy by Education, Poverty Level, Occupation, and Housing Tenure in the United States, 1997-2014

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ABSTRACT

Objectives: Socioeconomic disparities in life expectancy in the United States (US) are marked and have widened over time. However, there is limited research using individual-level socioeconomic variables as such information is generally lacking or unreliable in vital records used for life table construction. Using longitudinal cohort data, we computed life expectancy for US adults by social determinants such as education, income/poverty level, occupation, and housing tenure.

Methods: We analyzed the 1997-2014 National Health Interview Survey prospectively linked to mortality records in the National Death Index (N=1,146,271). Standard life table methodologies were used to compute life expectancy and other life table functions at various ages according to socioeconomic variables stratified by sex and race/ethnicity.

Results: Adults with at least a Master's degree had 14.7 years higher life expectancy at age 18 than those with less than a high school education and 8.3 years higher life expectancy than those with a high school education. Poverty was inversely related to life expectancy. Individuals living in poverty had 10.5 years lower life expectancy at age 18 than those with incomes $\geq 400\%$ of the poverty threshold. Laborers and those employed in craft and repair occupations had, respectively, 10.9 years and 8.6 years lower life expectancy at age 18 than those with professional and managerial occupations. Male and female renters had, respectively, 4.0 years and 4.6 years lower life expectancy at age 18 than homeowners. Women in the most advantaged socioeconomic group outlived men in the most disadvantaged group by 23.5 years at age 18.

Conclusions and Global Health Implications: Marked socioeconomic gradients in US life expectancy were found across all sex and racial/ethnic groups. Adults with lower education, higher poverty levels, in manual occupations, and with rental housing had substantially lower life expectancy compared to their counterparts with higher socioeconomic position.

Key words: • Life expectancy • Education • Poverty • Occupation • Housing Tenure • Social determinants • Longitudinal

1. Introduction

Life expectancy has long been considered an important indicator of a nation's health and well-being and human development.^{1,3} For over three decades, reducing health inequalities and increasing life expectancy among Americans have been the two most important health policy goals for the United States (US).^{1,4} Although life expectancy estimates for the US are routinely reported by sex, race/ethnicity, rural-urban residence, and geographic area,⁵⁻⁸ they are not readily available by individual measures of socioeconomic status (SES). A number of studies have shown persistent or widening socioeconomic disparities in life expectancy over time both in the US and other Western nations such as Canada, the United Kingdom, Australia, and New Zealand.^{1,9-14} Life expectancy disparities have widened as people in higher SES groups or in more affluent communities have experienced larger gains in life expectancy than their disadvantaged counterparts.⁹⁻¹¹

Many of these studies have used area-based socioeconomic deprivation measures to study disparities in life expectancy in the absence of patient-level socioeconomic data in administrative databases, including the vital statistics-based national mortality database in the US.^{1,6,9,10} Few studies have analyzed variations in life expectancy according to individual SES measures, using longitudinal cohort data for the US.¹⁵⁻¹⁸ Efforts have been made to estimate life expectancy using educational attainment data on the death certificate, but the quality of education data, especially for decedents aged 65 years and older, remains poor and unreliable.^{5,19} Prospective linkages of population surveys and census cohorts with disease registries and mortality records have enabled recent studies to examine differentials in life expectancy by individual or household income, education, and occupation,¹⁵⁻¹⁷ but none have tackled the issue of life expectancy disparities using a wide range of individual-level social determinants.

To address the continuing gap in research on life expectancy disparities by individual-level SES, we examine variations in life expectancy among US adults with different levels of education, income/poverty status, occupations, and housing tenure (home

ownership vs. renting house) across gender and racial/ethnic groups, using a nationally representative longitudinal dataset containing 18-years of mortality follow-up. Assessing inequalities in life expectancy according to key social determinants such as education, poverty, employment, and housing status is important in that it provides information on the extent to which life expectancy can be improved among various socioeconomic and demographic groups in a given population. Monitoring social inequalities in leading health indicators, such as life expectancy, is important for policy formulation and to set and support targets for reducing health disparities and achieving health equity.^{6,11,12}

Life expectancy is a summary measure of mortality that can be used to document both absolute and relative inequalities in survival between social groups and populations with low, medium, and high levels of socioeconomic position.^{1,8,9} It shows the effects of excess mortality risks during childhood, youth, working ages, and old age as well as those from major communicable and non-communicable diseases and injuries. The aim of our study is to estimate SES disparities in life expectancy across gender and major racial/ethnic groups in the United States during 1997-2014.

2. Methods

The data source for this study was the 1997-2014 National Health Interview Survey (NHIS) prospectively linked to the National Death Index (NDI).²⁰ NHIS is a nationally representative, cross-sectional household interview survey that provides socio-economic, demographic, and health characteristics of the US civilian, non-institutionalized population. We used the public-use linked NHIS-NDI mortality file, developed by the National Center for Health Statistics, that contains 18 years of mortality follow-up data from the date of survey participation through December 31, 2014.²¹

The study sample was restricted to adults aged 18 years and older in the database as the public-use linked file did not include deaths among those aged under 18 at baseline. The sample ineligible for mortality follow-up was eliminated from the analysis. The final pooled sample size was 1,146,271. Each of the four SES variables selected for life table construction had missing

data: education (1.56%), poverty status (20.07%), occupation (the category for unemployed and those outside the labor force (62.49%)), and housing tenure (1.16%). We computed life expectancy estimates only for the known categories of the SES variables.

Follow-up time for individuals who died during the study period was defined by the number of months from the month/year of interview to the month/year of death. Since the NHIS-NDI file provides only the quarter of death, we assumed that death occurred in the middle month of the quarter; February, May, August, or November.²² The mean follow-up time for the sample was 8.2 years.

The four SES variables were measured as follows. Educational attainment consisted of five categories: less than high school diploma, high school diploma, some college, Bachelor's degree, and Master's degree or higher. Poverty status, defined as the ratio of family income to poverty threshold consisted of 5 categories: <100%, 100-199%, 200-299%, 300-399%, and ≥400%. Housing tenure included two categories: homeowners and renters. Detailed occupation categories were collapsed into 5 broad occupational groups: professional and managerial, sales/ clerical and technical support, service, craft and repair, and laborers. These broad occupational groups, derived from the major occupational groups defined by the Census Bureau, are consistent with previously defined social class positions of upper white collar, lower white collar, upper blue collar, and lower blue collar jobs.²³

We used the standard life table methodology to calculate life expectancy at age 18 and subsequent ages along with standard errors.^{24,25} Specifically, life expectancy was estimated by converting age-specific mortality rates (for 14 age groups: 18-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, 75-79, 80-84, and ≥85 years) into life-table probabilities of dying, allowing computation of various life-table functions. Age-specific mortality rates were computed based on person-years of exposure for each SES category. In computing person-years for age-specific mortality rates, deaths were assumed to occur uniformly throughout the follow-up period rather than being clustered in the first part of the period. We tested for differences in

life expectancy estimates by SES levels across gender, race/ethnicity, and age.

3. Results

3.1. Educational Disparities in Life Expectancy

Table 1 presents life expectancy by educational attainment for the total population, males, females, and three racial/ethnic groups. Educational attainment was positively and consistently related to life expectancy for all groups except Hispanics. Adults with at least a Master's degree had a life expectancy of 61.4 years at age 18, 14.7 years higher life expectancy than those with less than a high school education (46.7 years), and 8.3 years higher life expectancy than those with a high school education (53.1 years). Persons with a Master's degree or higher had one year higher life expectancy at age 18 than those with a bachelor's degree. Similar educational patterns in life expectancy can be noted at ages 45 and 65. Educational differentials in life expectancy were larger for men than for women (Figure 1).

Educational differentials in life expectancy were larger for non-Hispanic Blacks than for non-Hispanics Whites and Hispanics. The difference in life expectancy at age 18 between persons with at least a Master's degree and those with less than a high school education was 17.7 years for non-Hispanic Blacks, 16.2 years for non-Hispanic Whites, and 10.1 years for Hispanics. For educational categories from less than high school to bachelor's degree, blacks had significantly lower life expectancy than non-Hispanic Whites and Hispanics. However, at age 18, non-Hispanic Blacks with at least a Master's degree had a life expectancy of 62.5 years, significantly higher than the life expectancy of 60.1 and 61.8 years for Hispanics and Non-Hispanic Whites with similar educational attainment.

3.2. Disparities in Life Expectancy by Income/ Poverty Level

Higher poverty levels were associated with lower life expectancy for each age, gender, and racial/ethnic group (Table 2). Compared to those with incomes ≥400% of the poverty threshold, individuals living in poverty and those with family incomes at 100-199% of the poverty level had, respectively, 10.5 years and

Table 1: Estimated life expectancies at selected ages at baseline by education, United States, 1997-2014

	Both Sexes		Male		Female	
	LE	SE	LE	SE	LE	SE
Sample size	1,128,409		531,943		596,466	
Age 18						
Less than high school	46.70	0.11	44.03	0.15	49.51	0.15
High school diploma	53.13	0.08	50.31	0.12	55.77	0.11
Some college	56.20	0.09	53.09	0.13	58.94	0.12
Bachelor's degree	60.40	0.12	58.23	0.17	62.80	0.18
Master's degree or higher	61.39	0.25	59.89	0.36	63.59	0.35
Age 45						
Less than high school	25.55	0.08	23.79	0.11	27.24	0.12
High school diploma	30.32	0.07	28.25	0.10	31.99	0.09
Some college	32.40	0.08	29.91	0.11	34.54	0.11
Bachelor's degree	35.22	0.11	33.40	0.15	37.33	0.17
Master's degree or higher	36.26	0.14	34.84	0.18	38.38	0.22
Age 65						
Less than high school	13.34	0.06	12.16	0.09	14.32	0.08
High school diploma	16.28	0.06	14.93	0.09	17.18	0.08
Some college	17.38	0.08	15.59	0.11	18.80	0.11
Bachelor's degree	18.81	0.11	17.54	0.15	20.29	0.16
Master's degree or higher	19.51	0.13	18.64	0.17	21.00	0.22
	NHW		NHB		Hispanics	
Sample size	686,533		151,729		224,222	
Age 18						
Less than high school	45.55	0.18	44.82	0.30	49.93	0.18
High school diploma	53.34	0.10	52.64	0.22	56.10	0.27
Some college	56.46	0.10	55.99	0.29	58.12	0.36
Bachelor's degree	60.42	0.14	59.57	0.49	60.64	0.55
Master's degree or higher	61.76	0.26	62.53	0.60	60.05	0.82
Age 45						
Less than high school	23.17	0.13	23.57	0.21	29.94	0.16
High school diploma	29.97	0.08	30.06	0.20	34.45	0.27
Some college	32.12	0.09	32.67	0.28	35.58	0.37
Bachelor's degree	34.92	0.12	34.66	0.47	36.29	0.53
Master's degree or higher	36.11	0.15	36.91	0.58	35.74	0.61
Age 65						
Less than high school	11.94	0.08	13.20	0.15	16.61	0.14
High school diploma	15.71	0.06	17.43	0.20	20.36	0.28
Some college	16.93	0.08	18.66	0.30	20.55	0.39
Bachelor's degree	18.26	0.12	19.56	0.49	19.85	0.54
Master's degree or higher	19.14	0.14	21.49	0.59	18.84	0.60

LE=Life expectancy, SE=standard error, NHW=non-Hispanic Whites, NHB=non-Hispanic Blacks

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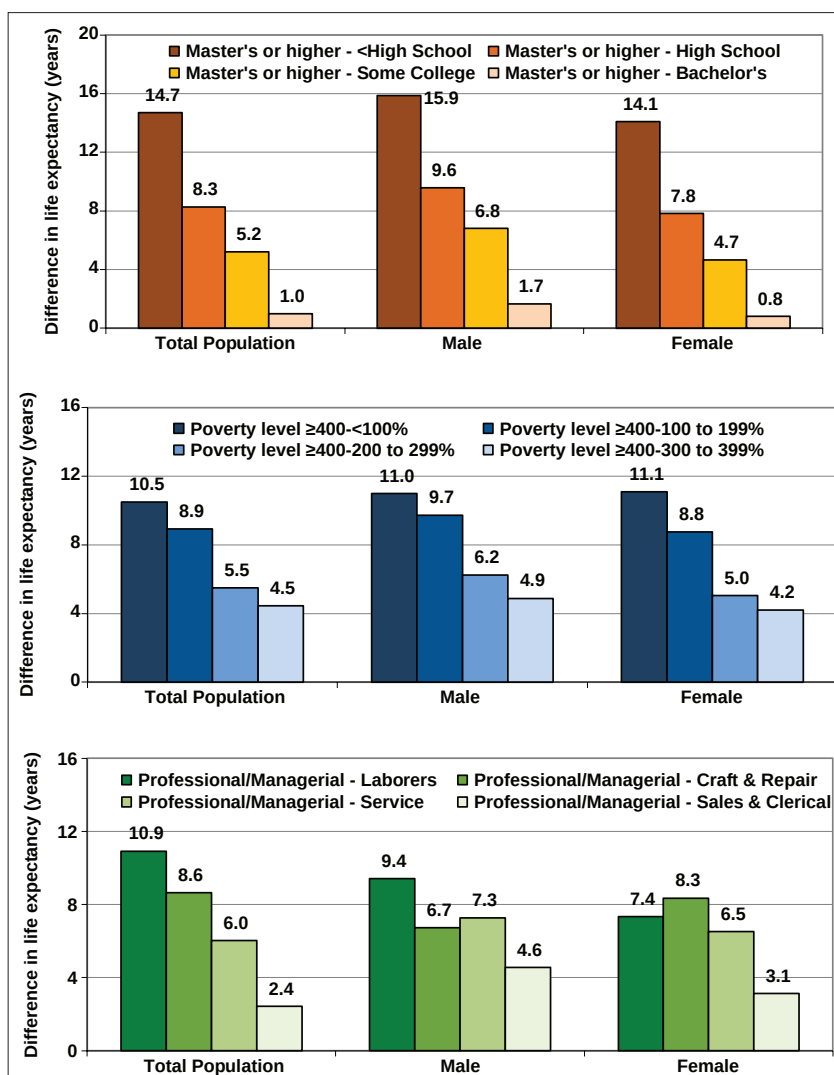


Figure 1: Differences in Life Expectancy at Age 18 Across Education, Poverty, and Occupation Groups, United States, 1997-2014
Gradients in life expectancy by education, poverty level, and occupation were statistically significant at $p < 0.001$. All life expectancy differences between the highest socioeconomic category and other categories were statistically significant at $p < 0.01$, except for the difference between Master's degree or higher and bachelor's degree for women ($p < 0.05$)

8.9 years lower life expectancy at age 18. Income/poverty differentials in life expectancy were similar for men and women (Figure 1). At age 65, men with incomes $\geq 400\%$ of the poverty threshold had a life expectancy of 18.0 years, 3.9 years longer than that for men living in poverty (14.1 years). At age 65, women with incomes $\geq 400\%$ of the poverty threshold

had a life expectancy of 20.5 years, 5.1 years longer than that for women living in poverty (15.4 years). At each age and income/poverty level, women had significantly higher life expectancy than men.

Income/poverty differentials in life expectancy were larger for non-Hispanic Blacks and non-

Table 2: Estimated life expectancies at selected ages at baseline by poverty status¹, United States, 1997-2014

	Both Sexes		Male		Female	
	LE	SE	LE	SE	LE	SE
Sample size	916,190		434,443		481,747	
Age 18						
<100%	49.20	0.13	46.30	0.21	51.35	0.17
100-199%	50.78	0.11	47.57	0.16	53.69	0.15
200-299%	54.20	0.12	51.06	0.17	57.40	0.16
300-399%	55.24	0.14	52.41	0.19	58.23	0.19
≥400%	59.70	0.10	57.29	0.13	62.44	0.14
Age 45						
<100%	26.82	0.12	25.03	0.19	28.10	0.16
100-199%	27.88	0.10	25.60	0.14	29.80	0.13
200-299%	30.69	0.10	28.33	0.14	33.00	0.15
300-399%	31.28	0.12	29.07	0.17	33.57	0.17
≥400%	35.20	0.08	33.37	0.11	37.26	0.12
Age 65						
<100%	14.91	0.11	14.07	0.18	15.39	0.14
100-199%	14.76	0.08	13.26	0.11	15.84	0.10
200-299%	16.42	0.09	14.79	0.12	17.97	0.13
300-399%	16.42	0.11	15.01	0.15	17.85	0.16
≥400%	19.17	0.09	18.01	0.11	20.47	0.13
	NHW		NHB		Hispanics	
Sample size	557,459		121,717		182,780	
Age 18						
<100%	48.14	0.21	47.95	0.27	52.00	0.27
100-199%	50.41	0.15	50.76	0.27	52.98	0.24
200-299%	54.13	0.14	55.11	0.35	55.75	0.34
300-399%	55.30	0.16	55.36	0.45	57.28	0.56
≥400%	59.76	0.10	59.63	0.41	59.13	0.39
Age 45						
<100%	25.12	0.18	25.34	0.24	30.58	0.26
100-199%	26.58	0.13	27.63	0.24	31.45	0.23
200-299%	29.98	0.12	31.60	0.32	33.85	0.32
300-399%	30.91	0.14	31.60	0.42	35.09	0.57
≥400%	34.93	0.09	35.66	0.38	35.83	0.37
Age 65						
<100%	13.51	0.16	14.37	0.22	17.13	0.25
100-199%	13.91	0.09	15.16	0.20	17.33	0.21
200-299%	15.78	0.10	17.80	0.31	19.28	0.33
300-399%	15.92	0.12	17.35	0.44	20.76	0.62
≥400%	18.71	0.09	20.93	0.42	20.34	0.39

LE=Life expectancy, SE=standard error, NHW=non-Hispanic Whites, NHB=non-Hispanic Blacks.¹Poverty status is the ratio of family income to poverty threshold (%)

Hispanics Whites than for Hispanics. However, within each income/poverty stratum except for the most affluent category, Hispanics had higher life expectancy at age 18 than Non-Hispanic Whites and Non-Hispanic Blacks. For the highest-income category, the three racial/ethnic groups had similar life expectancies at age 18 (Table 2).

3.3. Occupational Disparities in Life Expectancy

Life expectancy at age 18 was highest among adults employed in professional and managerial occupations (64.0 years), followed by those in sales/clerical/technical support occupations (61.6 years), service occupations (58.0 years), craft and repair occupations (55.4 years), and laborers (53.1 years) [Table 3]. Occupational differentials in life expectancy were larger for men than for women (Figure 1), and within each occupational category, women had substantially higher life expectancy than men. Occupational disparities in life expectancy were larger for non-Hispanic Blacks than for non-Hispanic Whites and Hispanics. Non-Hispanic Blacks in professional and managerial occupations had the highest life expectancy at age 18 (66.1 years), at least two years longer than their non-Hispanic White counterparts (63.9 years) and Hispanic counterparts (64.1 years) [Table 3].

3.4. Disparities in Life Expectancy by Housing Tenure (Homeownership vs. Renting)

At age 18, life expectancy of homeowners was 4.1 years longer than that for renters (55.2 vs. 51.1 years) [Table 4]. The life expectancy gap by housing tenure was greater for women than for men, and for non-Hispanic Whites than for non-Hispanic Blacks and Hispanics. At age 18, female homeowners had a life expectancy of 57.9 years, 5.4 years longer than the life expectancy of 52.5 years for male homeowners. Female renters had a life expectancy of 53.3 years, compared with the life expectancy of 48.6 years for male renters.

3.5. Disparities in Life Expectancy by Socioeconomic Advantage/Disadvantage

At age 18, adults in the most-advantaged socioeconomic group had a life expectancy of 63.7 years, 17.5 years longer than the life expectancy

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Table 3: Estimated life expectancies at selected ages at baseline by occupation¹, United States, 1997-2014

	Both Sexes		Male		Female	
	LE	SE	LE	SE	LE	SE
Sample size	418,332		195,585		222,747	
Age 18						
Professional and managerial	64.01	0.16	60.97	0.22	67.00	0.22
Sales/clerical and tech support	61.58	0.16	56.41	0.28	63.86	0.20
Service	57.98	0.20	53.70	0.32	60.49	0.25
Craft and repair	55.37	0.21	54.23	0.23	58.66	0.42
Laborer	53.09	0.32	51.55	0.35	59.65	0.73
Age 45						
Professional and managerial	39.16	0.14	36.37	0.20	41.95	0.20
Sales/clerical and tech support	37.63	0.15	33.08	0.26	39.54	0.18
Service	34.83	0.18	31.39	0.29	36.68	0.23
Craft and repair	33.07	0.17	32.08	0.20	35.42	0.33
Laborer	30.95	0.27	29.79	0.30	35.72	0.66
Age 65						
Professional and managerial	23.28	0.14	21.05	0.19	25.58	0.20
Sales/clerical and tech support	22.78	0.14	19.25	0.25	24.05	0.16
Service	20.85	0.17	18.12	0.29	22.11	0.21
Craft and repair	19.68	0.16	18.81	0.19	21.24	0.27
Laborer	18.16	0.26	17.26	0.28	21.62	0.62
	NHW		NHB		Hispanics	
Sample size	268,551		59,810		68,486	
Age 18						
Professional and managerial	63.90	0.17	66.12	0.60	64.07	0.71
Sales/clerical and tech support	61.71	0.19	62.24	0.59	64.01	0.73
Service	57.43	0.26	57.00	0.43	62.53	0.58
Craft and repair	55.58	0.25	55.95	0.59	56.82	0.54
Laborer	53.40	0.40	52.92	0.71	54.86	0.81
Age 45						
Professional and managerial	38.77	0.15	42.12	0.57	40.19	0.69
Sales/clerical and tech support	37.29	0.16	38.76	0.58	41.46	0.75
Service	33.63	0.24	33.77	0.39	40.89	0.58
Craft and repair	32.48	0.20	33.11	0.48	36.43	0.51
Laborer	30.31	0.34	30.05	0.61	35.28	0.76
Age 65						
Professional and managerial	22.67	0.15	27.98	0.56	24.92	0.70
Sales/clerical and tech support	22.29	0.15	24.95	0.61	27.01	0.78
Service	19.75	0.22	20.68	0.37	26.29	0.60
Craft and repair	18.91	0.18	20.83	0.46	23.13	0.50
Laborer	17.43	0.32	18.19	0.62	21.84	0.73

LE=Life expectancy; SE=standard error; NHW=non-Hispanic Whites; NHB=non-Hispanic Blacks. ¹Occupation was recoded based on a modified variable of the 1995 revised Standard Occupational Classification-based codes, offering a consistent long-term classification of occupations

Table 4: Estimated life expectancies at selected ages at baseline by housing tenure, United States, 1997-2014

	Both Sexes		Male		Female	
	LE	SE	LE	SE	LE	SE
Sample size	1,132,919		534,577		598,342	
Age 18						
Renter	51.10	0.08	48.57	0.12	53.32	0.11
Owner	55.21	0.05	52.53	0.08	57.87	0.07
Age 45						
Renter	28.06	0.08	26.28	0.12	29.50	0.11
Owner	31.58	0.04	29.70	0.06	33.37	0.06
Age 65						
Renter	14.84	0.08	13.79	0.12	15.52	0.10
Owner	16.41	0.04	15.16	0.05	17.51	0.05
	NHW		NHB		Hispanics	
Sample size	687,456		152,534		226,793	
Age 18						
Renter	50.65	0.12	50.34	0.18	53.18	0.19
Owner	55.91	0.06	53.45	0.17	54.13	0.16
Age 45						
Renter	26.72	0.11	27.07	0.17	31.71	0.20
Owner	31.50	0.05	30.41	0.14	32.48	0.14
Age 65						
Renter	13.70	0.10	14.62	0.17	17.66	0.20
Owner	16.01	0.04	16.50	0.12	18.04	0.14

LE=Life expectancy, SE=standard error

of 46.2 years for the most-disadvantaged group (Figure 2). The corresponding group difference was 18.5 years for men and 18.2 years for women. Women in the most-advantaged socioeconomic group outlived men in the most-disadvantaged group by 23.5 years at age 18. Large life expectancy differences between the most-advantaged and most-disadvantaged socioeconomic groups can also be noted at ages 45 and 65.

4. Discussion

In this large prospective study of 1,146,271 US adults using a mortality follow-up of 18 years, we found that adults with lower SES levels had substantially lower life expectancy, with a life expectancy gap of almost 18 years between the lowest and highest SES groups. Strikingly large socioeconomic

disparities in life expectancy existed for both men and women and for non-Hispanics Whites, non-Hispanic Blacks, and Hispanics. A particularly novel feature of our study is that it provides recent life expectancy estimates for Americans according to four different individual-level SES measures of education, income, occupation, and housing tenure. Such a comprehensive range of socioeconomic inequalities in life expectancy has not been previously reported in the same study, to the best of our knowledge.

The findings of our study are consistent with those from previous studies of individual-level socioeconomic differentials in life expectancy.^{12, 15, 17, 18, 26, 27} Rogot and colleagues found a difference in life expectancy at age 25 of 6 years for white men and 5 years for white women between the highest (master's degree or higher) and lowest (less than high school) education levels, much smaller than the education differentials shown in our study.¹⁵ Consistent with our study, higher income was associated with higher life expectancy in the Rogot et al. study; however, the corresponding income/poverty differential in life expectancy in our study (11 years) was substantially greater than the difference of 5 years reported in their study.¹⁵ Although SES groups were slightly different, education and income/poverty differences (the highest SES group – the lowest SES group) in male and female life expectancy were much smaller in Canada (5 to 8 years)¹² compared with 11 to 16 years noted in our US study. In a German study,²⁶ differences in life expectancy at age 40 between the highest and lowest educated men and women were 6.3 and 2.3 years respectively, considerably smaller than the corresponding difference of 11 years for men and women in our study. Income differences in life expectancy were also smaller for Germany than for the US.²⁶

Occupational differences in life expectancy in Germany were similar to those found in our study, with life expectancy of German men at age 40 ranging from 30 years for manual, unskilled workers to 39 years for those in professional and technical occupations.²⁶ In England and Wales, the difference in life expectancy at birth between professional/managerial occupations and routine manual

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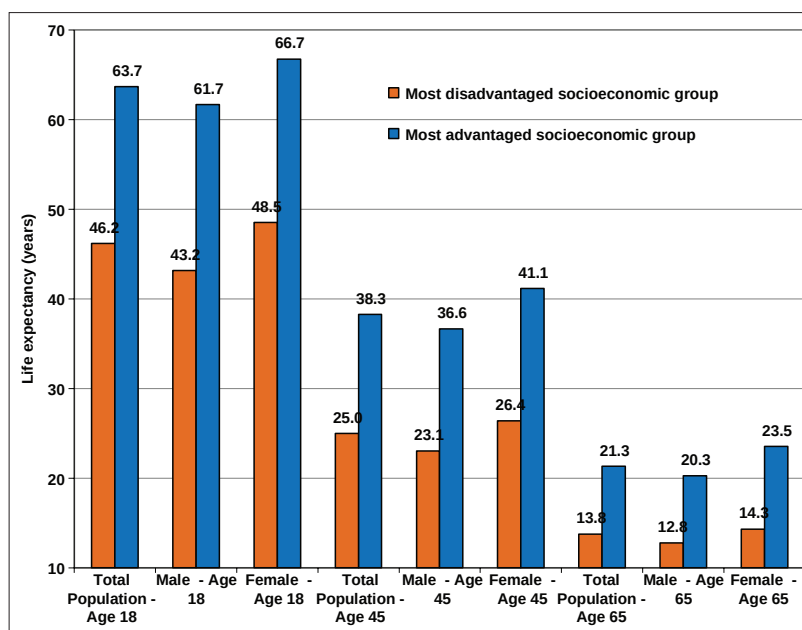


Figure 2: Life Expectancy of the Most Disadvantaged and Most Advantaged Socioeconomic Groups by Age and Sex, United States, 1997-2014

The most disadvantaged socioeconomic group consisted of adults with less than a high school education and family income below the poverty level. The most advantaged socioeconomic group consisted of adults with a master's or higher degree and family income at or above 400% of the poverty threshold. Differences in life expectancy between the most advantaged and most disadvantaged socioeconomic groups across all sex and age groups were statistically significant at $p < 0.001$.

occupations (laborers, lorry drivers, and bar staff) was 6 years for men and 4 years for women.²⁷ This is substantially smaller than the occupational difference in life expectancy noted for the US in our study. In the 1979-2011 US National Longitudinal Mortality Study, homeowners at age 20 had a life expectancy of 54.8 years, 3.4 years longer than the life expectancy of 51.4 years for renters.¹⁶ In our study, the difference in life expectancy at age 18 between homeowners and renters was 4.1 years.

Our study shows large socioeconomic differences in life expectancy among US men and women, which appeared to have increased over time in both absolute and relative terms when compared with similar estimates for comparative US populations in earlier time periods. Differences in material, psychosocial (stress, low control at work, home, or over life circumstances, social support, and social integration), lifestyle, and healthcare (health insurance, access to preventive health services,

stage of disease at diagnosis, and treatment) factors may partly account for SES differences in life expectancy.^{1,9,28} Lower levels of education, income, occupational social class, and homeownership have been associated with higher prevalence of smoking, obesity, physical inactivity, heavy alcohol consumption, poor diet, and lower access to health services.^{1,6,29,30} Smoking rates have decreased more rapidly among those in higher SES groups, which has partly contributed to the widening disparities in life expectancy, all-cause mortality, and mortality from major causes of death such as cardiovascular disease (CVD) and cancer in the US.^{1,29,31} Indeed, smoking and obesity-related causes such as CVD, cancer, COPD, and diabetes and injuries may account for 50% to 75% of the life expectancy disparities between socioeconomic groups.^{1,9,29} However, a formal cause-of-death decomposition analysis is needed to better explain SES disparities in life expectancy shown here.

4.1. Limitations

This study has limitations. First, our study only contains NHIS samples eligible for linkage to the NDI. Excluding samples ineligible for linkage or unmatched records in the two databases may have affected life expectancy estimates. Second, our study did not conduct a life table decomposition analysis, which would have allowed us to partition socioeconomic disparities in life expectancy due to excess mortality in specific age groups and causes of death. Third, although our analysis of life expectancy does stratify by gender and race/ethnicity, it does not account for differences in other demographic characteristics such as marital status, nativity/immigrant status, geographic mobility, and place of residence. In our study, housing tenure was defined as a dichotomous variable, which does not distinguish renters who live in public or social housing or receive rental or housing assistance from a government program from those who do not receive any rental assistance. Renters receiving housing assistance or those living in public/social housing experience much higher risks of morbidity and mortality than homeowners and other renters.^{16,32,33} Fourth, since the NHIS excludes the institutionalized population, who may have higher levels of socioeconomic disadvantage, morbidity, and mortality, life expectancy for those at lower SES levels may have been overestimated, leading to possible underestimation of SES inequalities in life expectancy reported here. Fifth, all SES variables in the NHIS-NDI database were time-fixed at the baseline as of the survey date. Although education is fairly stable after age 25 for most adults over the life course, other measures of SES such as income/poverty status, occupation and employment status, and housing tenure may have changed over the long mortality follow-up of 18 years, potentially influencing the magnitude and patterns in life expectancy associated with these measures. Further studies are needed to evaluate the temporal robustness of socioeconomic patterns in life expectancy using longitudinal datasets with time-varying covariates and/or shorter mortality follow-ups.

5. Conclusions and Global Health Implications

Marked socioeconomic gradients in US life expectancy were found across all sex and racial/ethnic groups. Adults with lower education, higher poverty level, in manual occupations, and with rental housing had substantially lower life expectancy compared to their counterparts with higher socioeconomic position. Socioeconomic inequalities in life expectancy most likely reflect inequalities in material and social conditions as well as those in behavioral and healthcare factors.^{1,9,28} As life expectancy has improved around the globe, persistent or growing social inequalities in life expectancy are not only characteristic of high-income countries but also of the developing world.³⁴ Social policies aimed at reducing disparities in the broader, more fundamental social determinants such as education, poverty, affordable housing, employment, work environment, labor market opportunities, and transportation, along with public health measures that target reductions in smoking, obesity, inadequate access to healthy foods, and improvements in access to health services have the potential to reduce health and life expectancy inequalities between high and low SES groups.^{1,9,10}

Compliance with Ethical Standards

Conflicts of Interest: None. **Financial Disclosure:** None to report. **Funding/Support:** Hyunjung Lee was supported in part by an appointment to the Research Participation Program at the Health Resources & Services Administration - Office of Health Equity (HRSA-OHE), administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the US Department of Energy and HRSA. **Ethical approval:** The study was exempt from Institutional Review Board approval as it utilized a de-identified public use dataset. **Disclaimer:** The views expressed in this article are those of the author and do not necessarily reflect the official policies of the US Department of Health and Human Services or the Health Resources and Services Administration.

References

1. Singh GK, Siahpush M. Inequalities in US life expectancy by area unemployment level. *Scientifica*. 2016; 8290435. DOI: 10.1155/2016/8290435.
2. Singh GK, Kogan MD, Slifkin RT. Widening disparities in

Key Messages

- ▶ This study estimated life expectancy of 1,146,271 American adults according to their education and income levels, occupation, and housing tenure.
- ▶ Americans with an advanced degree (Master's degree or higher) had 14.7 years higher life expectancy at age 18 than those with less than a high school education.
- ▶ Poor Americans had 10.5 years lower life expectancy at age 18 than those with incomes at or above 400% of the poverty threshold. Laborers and those employed in craft and repair occupations had, respectively, 10.9 years and 8.6 years lower life expectancy at age 18 than those in professional and managerial occupations.
- ▶ Among Americans with an advanced degree, non-Hispanic Blacks (62.5 years) had a higher life expectancy at age 18 than Hispanics (60.1) and Non-Hispanic Whites (61.8).
- ▶ Male and female renters had, respectively, 4.0 years and 4.6 years lower life expectancy at age 18 than homeowners. Women in the most advantaged socioeconomic group outlived men in the most disadvantaged socioeconomic group by 23.5 years at age 18.

infant mortality and life expectancy between Appalachia and the rest of the United States, 1990-2013. *Health Aff.* 2017;36(8):1423-1432.

3. United Nations Development Programme. *Human Development Report 2015*. New York: United Nations; 2015.
4. US Department of Health and Human Services. *Healthy People 2020*. <http://www.healthypeople.gov/2020/default.aspx>. Accessed October 15, 2020.
5. Kochanek KD, Murphy SL, Xu JQ, Arias E. Deaths: final data for 2017. *Natl Vital Stat Rep.* 2019;68(9):1-77.
6. Singh GK, Daus GP, Allender M, et al. Social determinants of health in the United States: addressing major health inequality trends for the nation, 1935-2016. *Int J MCH AIDS.* 2017;6(2):139-164.
7. Singh GK, De Los Reyes A, Allender M, et al. (authors/editors). *Health Equity Report 2017*. Health Resources and Services Administration, Office of Health Equity. Rockville, Maryland: US Department of Health and Human Services; 2018.
8. Singh GK, Siahpush M. Widening rural-urban disparities in life expectancy, U.S., 1969-2009. *Am J Prev Med.* 2014; 46(2):e19-e29.
9. Singh GK, Siahpush M. Widening socioeconomic inequalities in US life expectancy, 1980-2000. *Int J Epidemiol.* 2006;35(4):969-979.
10. Singh GK, Lin CC. Area deprivation and inequalities in health and health care outcomes. *Ann Intern Med.* 2019; 171(2):131-132.
11. Department of Health. *Tackling Health Inequalities: 10 Years On*. London, UK: Health Inequalities Unit, Department of Health; 2009.
12. Bushnik T, Tjepkema M, Martel L. Socioeconomic disparities in life and health expectancy among the household population in Canada. *Health Rep.* 2020;31(1):3-14.
13. Stephens AS, Gupta AL, Thackway S, Broome RA. Socioeconomic, Remoteness and Sex Differences in Life Expectancy in New South Wales, Australia, 2001-2012: A Population-Based Study. *BMJ Open.* 2017;7(1):e013227. doi: 10.1136/bmjopen-2016-013227.
14. Tobias MI, Cheung J. Monitoring health inequalities: life expectancy and small area deprivation in New Zealand. *Popul Health Metr.* 2003;1:2. doi: 10.1186/1478-7954-1-2.
15. Rogot E, Sorlie PD, Johnson NJ. Life expectancy by employment status, income, and education in the National Longitudinal Mortality Study. *Public Health Rep.* 1992; 107(4):457-461.
16. Health Resources and Services Administration, Office of Health Equity. *Health Equity Report 2019-2020: Special Feature on Housing and Health Inequalities*. Health Resources and Services Administration, Office of Health Equity. Rockville, Maryland: US Department of Health and Human Services; 2020. <https://www.hrsa.gov/sites/default/files/hrsa/health-equity/HRSA-health-equity-report.pdf>. Accessed October 15, 2020.
17. Meara ER, Richards S, Cutler DM. The gap gets bigger: changes in mortality and life expectancy, by education, 1981-2000. *Health Aff.* 2008;27(2):350-360.
18. Olshansky SJ, Antonucci T, Berkman L, et al. Differences in life expectancy due to race and educational differences are widening, and many may not catch up. *Health Aff.* 2012; 31(8):1803-1813.
19. Rostron BL, Boies JL, Arias E. Education reporting and classification on death certificates in the United States. National Center for Health Statistics. *Vital Health Stat.* 2010;2(151):1-14.
20. Blewett LA, Rivera Drew JA, King ML, Williams KCW. IPUMS Health Surveys: National Health Interview Survey, Version 6.4 [dataset]; 2019. doi:<https://doi.org/10.18128/D070.V6.4>.
21. National Center for Health Statistics (NCHS). Office of

- Analysis and Epidemiology. *Public-Use Linked Mortality File*; 2015.
22. Siahpush M, Singh GK, Tibbits M, Pinard CA, Shaikh RA, Yaroch A. It is better to be a fat ex-smoker than a thin smoker: findings from the 1997–2004 National Health Interview Survey– National Death Index linkage study. *Tob Control*. 2014;23(5):395–402.
 23. Singh GK, Siahpush M, Hiatt RA, Timsina. Dramatic increases in obesity and overweight prevalence and body mass index among ethnic-immigrant and social class groups in the United States, 1976–2008. *J Community Health*. 2011;36(1):94–110.
 24. Namboodiri K, Suchindran CM. *Life Table Techniques and Their Applications*. Orlando, Fla:Academic Press; 1987.
 25. Preston SH, Heuveline P, Guillot M. *Demography: Measuring and Modeling Population Processes*. Oxford, UK: Blackwell Publishers Ltd; 2001.
 26. Luy M, Wegner-Siegmundt C, Wiedemann A, Spijker J. Life Expectancy by education, income and occupation in Germany: estimations using the longitudinal survival method. *Comparative Population Studies*. 2015;40(4):399–436.
 27. Office for National Statistics (ONS). Trend in life expectancy at birth and at age 65 by socio-economic position based on the National Statistics Socio-economic Classification, England and Wales: 1982–1986 to 2007–2011. *Statistical Bulletin*. United Kingdom; 2015. <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/bulletins/trendinlifeexpectancyatbirthandage65bysocioeconomicpositionbasedonthenationalstatistics socioeconomicclassificationenglandandwales> /2015-10-21. Accessed June 25, 2020.
 28. Kawachi I, Subramanian SV, Almeida-Filho N. A glossary of health inequalities. *J Epidemiol Community Health*. 2006;56(9):647–652.
 29. Singh GK, Jemal A. Socioeconomic and racial/ethnic disparities in cancer mortality, incidence, and survival in the United States, 1950–2014: over six decades of changing patterns and widening Inequalities. *J Environ Public Health*; 2017;2819372. doi: 10.1155/2017/2819372.
 30. National Center for Health Statistics. *Health, United States, 2018*. Hyattsville, MD: US Department of Health and Human Services; 2019.
 31. Singh GK, Siahpush M, Azuine RE, Williams SD. Widening socioeconomic and racial disparities in cardiovascular disease mortality in the United States, 1969–2013. *Int J MCH AIDS*. 2015;3(2):106–118.
 32. Shaw M. Housing and public health. *Annu Rev Public Health*. 2004; 25:397–418.
 33. Filakti H, Fox J. Differences in mortality by housing tenure and by car access from the OPCS Longitudinal Study. *Population Trends*. 1995;81:27–30.
 34. Permanyer I, Scholl N. Global trends in lifespan inequality: 1950–2015. *PLoS One*. 2019;14(5): e0215742. doi: 10.1371/journal.pone.0215742.



Housing Table 2. Household Energy Use and Spending in the last 12 Months, by Select Characteristics: United States

Source: U.S. Census Bureau Household Pulse Survey, Cycle 02.

Note: These data are experimental. Users should take caution using estimates based on subpopulations of the data – sample sizes may be small and the standard errors may be large.**

Total Population 18 Years and Older

Select characteristics	Total*	Household reduced or forwent expenses for basic household necessities, such as medicine or food, in order to pay an energy bill					Almost every month
		Almost every month	Some months	1 or two months	Never	Did not report	
Total	256,311,560	21,544,100	28,585,565	21,640,334	137,486,848	47,054,712	14,019,730
Age							
18 - 24	18,754,825	1,360,569	1,986,804	1,949,122	8,237,720	5,220,611	975,437
25 - 39	74,241,688	7,317,086	9,134,718	7,384,668	36,238,383	14,166,834	3,810,815
40 - 54	65,251,738	6,889,019	8,462,701	5,891,716	32,244,465	11,763,837	3,282,106
55 - 64	42,184,846	3,359,927	4,891,657	3,430,991	23,220,877	7,281,394	2,857,753
65 and above	54,648,593	2,570,896	4,085,816	2,969,237	37,027,758	7,994,886	2,999,151
Sex at birth							
Male	124,903,432	9,863,593	12,941,950	10,261,712	68,631,929	23,204,247	6,812,077
Female	131,408,128	11,680,507	15,643,615	11,378,622	68,854,919	23,850,465	7,207,654
Gender							
Cisgender male	58,974,265	4,559,683	6,602,677	5,109,175	32,528,109	10,174,621	3,253,854
Cisgender female	61,182,038	5,470,813	7,004,174	5,070,765	33,217,951	10,418,336	3,187,327
Transgender	1,434,631	142,533	194,333	116,184	607,948	373,634	143,799
None of these	2,007,132	238,359	149,722	107,369	957,725	553,957	219,545
Did not report	132,713,493	11,132,712	14,634,660	11,236,842	70,175,116	25,534,164	7,215,205
Sexual orientation							
Gay or lesbian	8,166,640	830,656	909,442	615,138	4,449,391	1,362,013	455,219
Straight	221,226,062	18,156,828	23,956,991	18,495,584	120,920,165	39,696,494	11,800,817
Bisexual	12,455,885	1,161,706	1,881,881	1,465,504	6,264,603	1,682,190	791,443
Something else	5,798,579	625,129	815,593	687,467	2,726,019	944,371	437,627
I don't know	4,865,091	510,736	685,071	191,102	2,024,187	1,453,995	401,396
Did not report	3,799,303	259,044	336,587	185,540	1,102,483	1,915,650	133,229
Lesbian, Gay, Bisexual and Transgender							
Yes	21,339,967	2,088,254	2,862,068	2,160,368	10,906,349	3,322,927	1,334,023
No	105,505,410	8,648,217	11,452,629	8,726,637	58,410,123	18,267,803	5,480,839
Other	5,771,793	497,856	807,430	499,613	2,643,926	1,322,969	492,550
Did not report	123,694,390	10,309,773	13,463,438	10,253,716	65,526,450	24,141,014	6,712,318
Hispanic origin and Race							
Hispanic or Latino (may be of any race)	46,076,504	5,322,310	6,906,809	5,178,909	18,045,838	10,622,638	2,744,739
White alone, not Hispanic	155,908,031	10,772,991	14,870,909	11,922,506	93,944,638	24,396,986	8,348,946
Black alone, not Hispanic	29,940,051	3,114,868	4,039,823	2,487,857	12,686,595	7,610,908	1,539,136
Asian alone, not Hispanic	12,789,635	809,139	1,250,959	645,622	7,730,634	2,353,281	546,016
Two or more races + Other races, not Hispanic	11,597,338	1,524,791	1,517,064	1,405,441	5,079,143	2,070,898	840,893
Education							
Less than high school	21,702,760	3,023,834	2,980,559	2,286,576	7,736,339	5,675,451	1,681,247
High school or GED	74,506,380	7,736,882	10,193,071	6,839,836	32,650,351	17,086,239	4,375,511
Some college/associate's degree	74,764,183	7,416,525	9,745,387	7,092,577	36,379,617	14,130,077	4,330,772
Bachelor's degree or higher	85,338,237	3,366,859	5,666,548	5,421,345	60,720,541	10,162,945	3,632,201
Marital status							
Married	140,139,921	9,491,947	13,566,952	11,153,171	83,198,835	22,729,015	6,793,266
Widowed	11,879,836	877,484	1,429,449	870,229	6,665,969	2,036,705	819,136
Divorced/separated	35,640,367	4,628,789	4,796,222	3,060,277	16,356,365	6,798,714	2,752,022
Never married	66,810,785	6,453,374	8,685,494	6,515,055	30,785,055	14,371,806	3,623,727
Did not report	1,840,651	92,506	107,447	41,602	480,624	1,118,472	31,579
Household size							
1 person in the household	24,908,789	2,023,180	2,715,307	1,803,942	14,891,583	3,474,776	1,695,479
2 people in the household	82,091,296	5,340,074	7,117,068	5,813,082	51,480,834	12,340,238	4,437,885
3 people in the household	48,885,919	4,268,504	6,048,239	4,130,343	25,688,462	8,750,371	2,779,331
4 people in the household	46,240,580	3,696,294	5,187,265	3,694,998	23,965,567	9,696,457	1,938,248

5 people in the household	27,627,608	2,613,363	4,038,870	3,249,064	12,116,437	5,609,874	1,479,942
6 people in the household	13,188,173	1,513,542	2,050,055	1,282,110	5,090,193	3,252,273	755,564
7 or more people in the household	13,369,195	2,089,144	1,428,761	1,666,795	4,253,772	3,930,723	933,281
Presence of children under 18 years old							
Children in household	95,626,653	9,361,123	11,553,727	9,655,268	43,162,075	21,894,460	4,701,094
No children	160,684,907	12,182,977	17,031,838	11,985,067	94,324,774	25,160,252	9,318,636
Respondent or household member experienced loss of employment income in last 4 weeks							
Yes	34,062,641	6,651,019	6,536,923	4,053,824	10,676,342	6,144,533	3,113,998
No	214,606,198	14,816,505	21,955,021	17,541,560	126,620,602	33,672,510	10,829,588
Did not report	7,642,721	76,576	93,621	44,950	189,903	7,237,669	76,144
Respondent employed in the last 7 days							
Yes	151,330,365	12,228,874	17,544,001	14,067,664	84,970,825	22,519,001	7,999,690
No	96,257,836	9,215,620	10,874,301	7,456,986	51,881,111	16,829,818	5,932,095
Did not report	8,723,359	99,606	167,263	115,684	634,912	7,705,893	87,945
Household income							
Less than \$25,000	28,463,161	5,941,286	6,127,554	3,523,842	12,786,656	83,822	3,303,557
\$25,000 - \$34,999	20,610,402	3,267,360	4,443,130	2,763,989	10,042,060	93,863	1,672,298
\$35,000 - \$49,999	24,778,958	4,191,155	4,536,276	3,404,605	12,611,242	35,680	2,008,511
\$50,000 - \$74,999	32,536,021	3,363,244	5,122,721	4,234,075	19,774,620	41,361	2,423,342
\$75,000 - \$99,999	24,916,617	1,719,648	3,094,175	2,606,836	17,479,370	16,588	1,263,982
\$100,000 - \$149,999	32,169,468	1,538,128	2,811,123	2,538,617	25,213,910	67,690	1,419,962
\$150,000 - \$199,999	15,804,441	411,328	751,708	995,576	13,612,854	32,975	628,259
\$200,000 and above	19,643,805	323,301	407,289	561,481	18,338,647	13,087	725,944
Did not report	57,388,687	788,650	1,291,590	1,011,313	7,627,489	46,669,645	573,874
Active duty military*							
Serving on active duty	1,080,140	100,403	44,925	44,824	633,926	256,062	68,603
Serving in Reserve or National Guard	760,930	65,155	60,698	68,589	426,552	139,937	46,213
Spouse serving on active duty	745,342	77,556	69,568	33,863	438,350	126,005	44,706
Spouse serving in Reserve or National Guard	766,857	66,763	54,080	55,294	330,196	260,524	62,976
No active duty service (self or spouse)	248,112,228	21,188,446	28,338,272	21,373,534	135,520,497	41,691,480	13,745,756
Did not report	5,049,539	73,070	23,970	65,165	256,652	4,630,683	63,392
Previous military service*							
No	204,701,521	18,393,144	24,224,770	17,874,115	109,553,619	34,655,873	11,296,115
Served on active duty	16,599,908	936,452	1,493,446	1,350,939	10,546,224	2,272,847	1,018,818
Served in the Reserve or National Guard	4,637,047	307,849	449,416	430,981	2,950,931	497,869	210,164
Spouse served on active duty	12,391,704	704,372	1,189,461	868,584	7,801,490	1,827,798	653,556
Spouse served in the Reserve or National Guard	2,737,007	182,704	324,104	237,527	1,651,079	341,592	176,288
Did not report	19,257,368	1,238,873	1,180,717	1,225,581	7,633,929	7,978,268	882,356
Difficulty seeing							
No difficulty	166,836,712	11,322,404	16,621,207	14,018,398	104,916,633	19,958,069	8,150,169
Some difficulty	63,717,650	8,545,071	10,386,475	7,007,705	29,840,911	7,937,487	4,854,641
A lot of difficulty	6,629,350	1,473,579	1,510,232	586,443	2,148,599	910,497	852,279
Cannot do at all	649,632	173,624	58,049	14,990	256,028	146,942	126,328
Did not report	18,478,216	29,422	9,603	12,798	324,676	18,101,718	36,312
Difficulty hearing							
No difficulty	198,255,226	16,400,714	23,412,618	17,693,412	116,597,994	24,150,489	10,603,693
Some difficulty	33,482,953	3,852,097	4,394,053	3,321,060	18,234,626	3,681,118	2,556,327
A lot of difficulty	4,336,746	958,848	574,064	431,930	1,701,039	670,864	544,227
Cannot do at all	786,955	196,205	89,426	64,809	301,721	134,794	137,973
Did not report	19,449,680	136,237	115,403	129,123	651,469	18,417,447	177,510
Difficulty remembering or concentrating							
No difficulty	162,818,371	11,628,573	16,728,678	12,994,761	101,829,579	19,636,779	8,376,463
Some difficulty	64,963,712	7,945,635	10,034,943	7,256,374	32,109,524	7,617,236	4,254,316
A lot of difficulty	8,955,974	1,739,735	1,719,996	1,290,269	2,952,027	1,253,946	1,161,497
Cannot do at all	545,531	185,046	38,029	6,043	201,272	115,141	92,004
Did not report	19,027,973	45,111	63,918	92,887	394,445	18,431,611	135,449

Difficulty walking or climbing stairs							
No difficulty	181,818,308	13,735,609	19,749,213	16,092,411	109,905,391	22,335,684	9,205,218
Some difficulty	43,803,658	5,821,630	6,928,762	4,054,168	21,983,848	5,015,250	3,435,581
A lot of difficulty	10,556,429	1,670,548	1,770,059	1,291,626	4,586,910	1,237,287	1,074,871
Cannot do at all	1,172,014	254,481	72,650	97,105	590,477	157,302	144,008
Did not report	18,961,151	61,832	64,881	105,026	420,223	18,309,190	160,053
Difficulty with self-care							
No difficulty	217,883,683	17,918,431	24,985,901	19,174,110	129,476,568	26,328,674	11,848,890
Some difficulty	16,272,858	2,838,157	2,964,837	1,849,380	6,730,292	1,890,193	1,579,187
A lot of difficulty	2,557,770	574,453	470,508	460,654	660,011	392,144	348,104
Cannot do at all	633,448	146,870	99,233	55,565	240,334	91,446	85,237
Did not report	18,963,801	66,191	65,086	100,626	379,643	18,352,255	158,313
Difficulty understanding or being understood							
No difficulty	220,534,561	18,429,189	25,745,648	19,929,255	130,278,002	26,152,467	12,159,423
Some difficulty	14,894,781	2,384,134	2,440,342	1,511,460	6,251,348	2,307,497	1,449,955
A lot of difficulty	1,535,603	486,544	314,029	86,280	423,281	225,469	190,468
Cannot do at all	495,028	113,274	25,494	49,396	214,992	91,872	78,809
Did not report	18,851,587	130,959	60,053	63,944	319,224	18,277,406	141,074

* Totals may not sum to 100% as the question allowed for multiple categories to be marked.

** The Census Bureau considers estimated coefficients of variation (standard error divided by the estimate times 100) over 30 percent to indicate potentially serious data quality issues related to sampling error.

Household kept home at a temperature that felt unsafe or unhealthy				Household was unable to pay an energy bill or unable to pay the full bill amount				
Some months	1 or two months	Never	Did not report	Almost every month	Some months	1 or two months	Never	Did not report
19,940,648	13,960,750	161,179,124	47,211,308	11,694,847	18,906,271	18,634,722	160,105,730	46,969,990
1,636,753	1,215,473	9,684,177	5,242,984	779,994	916,181	1,744,547	10,084,315	5,229,788
5,148,676	4,985,940	46,057,006	14,239,251	4,192,942	6,453,726	6,369,323	43,046,987	14,178,710
5,713,645	3,354,281	41,063,579	11,838,126	3,866,157	6,148,136	5,504,068	37,952,475	11,780,901
3,530,015	2,337,563	26,109,975	7,349,540	1,628,961	3,013,723	2,970,295	27,287,422	7,284,445
3,878,495	2,047,831	37,803,744	7,919,372	1,198,657	2,357,915	2,021,602	41,196,306	7,874,112
8,985,138	6,701,592	79,083,751	23,320,875	4,741,373	7,479,943	8,876,536	80,639,002	23,166,578
10,955,510	7,259,158	82,095,373	23,890,433	6,953,474	11,426,328	9,758,186	79,466,728	23,803,413
4,150,895	3,344,927	37,969,996	10,254,592	2,341,051	3,603,687	4,340,412	38,503,833	10,185,282
5,237,294	3,203,358	39,083,995	10,470,064	3,080,872	5,209,605	4,491,486	37,944,398	10,455,678
160,771	124,234	637,089	368,739	118,142	86,561	126,308	734,882	368,739
199,320	163,002	869,781	555,483	176,473	144,408	138,282	992,594	555,374
10,192,367	7,125,228	82,618,263	25,562,430	5,978,309	9,862,010	9,538,234	81,930,023	25,404,918
693,442	413,219	5,250,275	1,354,485	491,041	440,952	582,870	5,300,486	1,351,292
16,840,775	11,352,443	141,432,272	39,799,755	9,485,180	16,179,517	15,737,067	140,265,628	39,558,670
1,142,988	1,124,633	7,697,659	1,699,162	765,406	1,317,405	1,124,495	7,564,389	1,684,190
659,747	622,881	3,126,623	951,702	435,979	443,293	801,483	3,161,794	956,030
347,544	335,373	2,324,844	1,455,934	422,511	334,767	230,427	2,400,410	1,476,976
256,150	112,201	1,347,452	1,950,271	94,730	190,337	158,380	1,413,023	1,942,833
1,911,197	1,575,930	13,191,342	3,327,476	1,322,973	1,805,450	1,757,972	13,144,262	3,309,311
8,096,285	5,455,958	68,113,553	18,358,775	4,638,277	7,424,092	7,547,212	67,624,610	18,271,219
464,187	523,473	2,966,453	1,325,131	398,854	533,764	584,272	2,917,379	1,337,523
9,468,979	6,405,389	76,907,776	24,199,928	5,334,743	9,142,965	8,745,266	76,419,479	24,051,938
4,691,999	3,318,865	24,634,520	10,686,380	3,074,464	4,227,423	4,884,343	23,268,306	10,621,969
10,676,966	7,732,163	104,727,571	24,422,386	5,125,774	8,923,314	9,519,782	108,021,407	24,317,755
2,227,150	1,323,720	17,220,187	7,629,858	2,196,616	3,926,821	2,790,077	13,415,164	7,611,373
997,525	741,828	8,136,631	2,367,636	321,758	667,988	450,342	9,034,597	2,314,950
1,347,008	844,174	6,460,215	2,105,048	976,235	1,160,725	990,178	6,366,257	2,103,944
2,439,193	1,259,360	10,629,580	5,693,380	1,834,543	2,159,668	2,232,480	9,844,059	5,632,010
6,541,004	4,004,127	42,461,695	17,124,042	4,223,694	6,903,665	6,554,439	39,742,488	17,082,094
6,715,101	4,752,691	44,800,232	14,165,388	3,891,817	6,696,981	6,238,415	43,882,297	14,054,673
4,245,349	3,944,572	63,287,617	10,228,498	1,744,793	3,145,957	3,609,388	66,636,886	10,201,213
8,685,420	6,224,824	95,492,802	22,943,609	4,759,630	8,581,858	9,015,415	94,993,304	22,789,713
1,300,627	519,229	7,304,240	1,936,605	495,914	1,024,226	762,865	7,673,078	1,923,753
3,804,537	2,074,765	20,190,851	6,818,192	2,657,333	3,725,394	2,737,586	19,692,042	6,828,012
6,072,487	5,109,788	37,612,494	14,392,289	3,757,250	5,532,805	6,071,556	37,137,637	14,311,537
77,576	32,144	578,738	1,120,614	24,719	41,988	47,301	609,669	1,116,974
2,336,510	1,424,367	15,948,025	3,504,409	1,010,565	1,650,686	1,331,022	17,403,230	3,513,286
5,976,693	4,026,046	55,345,181	12,305,492	2,137,817	4,310,225	4,273,816	59,159,390	12,210,048
3,760,718	2,662,866	30,902,871	8,780,134	1,927,590	3,830,844	3,596,682	30,790,128	8,740,674
3,166,081	2,414,906	28,940,945	9,780,399	2,153,228	3,745,447	3,668,049	26,975,950	9,697,906

2,201,063	1,567,284	16,793,189	5,586,131	1,824,072	2,748,587	2,745,629	14,766,972	5,542,348
1,175,726	1,006,706	6,983,851	3,266,325	1,049,294	1,232,219	1,649,220	5,983,632	3,273,807
1,323,857	858,576	6,265,062	3,988,419	1,592,281	1,388,262	1,370,303	5,026,428	3,991,921
6,457,296	5,165,077	57,327,368	21,975,818	6,166,645	9,143,739	9,128,260	49,310,011	21,877,998
13,483,352	8,795,673	103,851,756	25,235,490	5,528,202	9,762,532	9,506,461	110,795,719	25,091,993
4,434,313	3,219,095	17,111,945	6,183,290	3,906,424	4,852,279	4,307,508	14,861,744	6,134,686
15,453,481	10,695,150	143,834,391	33,793,589	7,735,816	13,984,933	14,296,373	144,991,431	33,597,645
52,853	46,505	232,788	7,234,430	52,608	69,059	30,840	252,555	7,237,659
11,662,967	8,961,046	100,067,059	22,639,604	6,483,697	11,617,421	11,635,761	99,095,883	22,497,603
8,217,142	4,941,409	60,322,822	16,844,368	5,140,067	7,205,798	6,943,501	60,217,811	16,750,659
60,539	58,295	789,243	7,727,337	71,082	83,052	55,460	792,037	7,721,728
4,984,999	2,598,280	17,375,505	200,820	3,735,063	4,613,232	3,856,283	16,149,457	109,126
3,138,806	2,006,626	13,712,556	80,117	1,676,891	3,146,633	2,377,886	13,359,245	49,748
3,314,114	1,936,902	17,478,855	40,575	2,246,800	3,369,548	3,164,948	15,963,309	34,353
3,055,962	2,338,702	24,649,338	68,677	1,689,649	3,429,927	3,454,414	23,906,215	55,816
2,015,192	1,605,393	19,964,577	67,473	733,252	1,669,384	1,967,266	20,482,804	63,911
1,545,173	1,706,542	27,415,747	82,042	697,609	1,420,120	2,069,827	27,940,284	41,627
567,437	559,643	14,025,729	23,373	202,635	362,398	540,680	14,682,858	15,870
398,817	477,320	18,012,986	28,738	204,720	156,313	322,862	18,944,858	15,052
920,146	731,341	8,543,831	46,619,495	508,227	738,716	880,557	8,676,700	46,584,487
56,327	75,289	625,669	254,251	58,182	34,365	48,468	687,878	251,246
61,286	58,944	454,550	139,937	53,489	26,920	86,249	454,336	139,937
54,866	91,164	434,977	119,629	24,983	38,145	42,477	523,113	116,624
18,402	12,620	380,040	292,820	28,899	46,270	37,285	361,582	292,820
19,707,829	13,699,615	159,154,478	41,804,550	11,501,626	18,726,038	18,407,367	157,882,853	41,594,345
47,139	28,585	260,324	4,650,100	54,959	37,536	17,142	317,911	4,621,991
16,366,067	11,516,340	130,807,405	34,715,595	10,055,998	15,905,650	15,889,014	128,316,937	34,533,923
993,586	839,330	11,458,252	2,289,921	445,968	995,168	753,935	12,152,950	2,251,887
407,416	265,322	3,260,473	493,672	152,915	384,492	183,211	3,420,212	496,216
929,058	660,733	8,399,695	1,748,662	420,282	724,058	706,846	8,781,777	1,758,742
332,062	164,750	1,724,596	339,310	164,812	163,196	229,431	1,841,473	338,096
1,145,818	786,485	8,303,113	8,139,596	614,890	934,998	1,065,662	8,532,220	8,109,598
10,325,503	8,553,440	119,712,573	20,095,027	6,140,579	10,558,794	11,393,459	118,767,598	19,976,281
8,279,887	4,725,223	37,917,091	7,940,807	4,352,847	7,377,137	6,257,346	37,893,731	7,836,588
1,303,299	660,294	2,888,002	925,476	1,007,333	927,622	832,321	2,950,021	912,053
16,828	15,074	342,359	149,043	169,529	33,047	47,724	252,389	146,942
15,131	6,719	319,098	18,100,955	24,558	9,671	103,871	241,990	18,098,126
14,660,383	11,161,349	137,580,061	24,249,740	8,742,578	15,487,427	15,393,934	134,573,698	24,057,589
4,355,870	2,346,183	20,496,916	3,727,656	2,177,617	2,818,156	2,834,316	21,963,531	3,689,332
769,996	324,012	2,096,756	601,755	515,776	448,317	342,376	2,438,835	591,441
95,023	47,070	372,095	134,794	192,153	79,993	29,491	350,525	134,794
59,375	82,137	633,295	18,497,363	66,722	72,378	34,605	779,141	18,496,835
10,420,636	7,805,964	116,511,621	19,703,687	5,961,683	10,854,469	10,703,990	115,754,424	19,543,804
8,016,544	5,230,546	39,768,743	7,693,563	4,505,741	6,754,318	6,612,069	39,472,846	7,618,737
1,416,636	882,227	4,318,210	1,177,403	1,049,614	1,181,844	1,238,264	4,311,275	1,174,976
66,698	32,085	240,941	113,802	143,744	97,225	37,259	153,501	113,802
20,134	9,927	339,609	18,522,853	34,065	18,414	43,139	413,683	18,518,671

12,563,482	9,924,360	127,700,648	22,424,600	7,111,610	12,681,870	13,180,226	126,589,338	22,255,263
5,677,908	3,033,355	26,662,187	4,994,626	3,403,386	4,717,219	4,188,319	26,542,019	4,952,715
1,574,844	902,629	5,761,101	1,242,984	977,384	1,346,044	1,141,695	5,874,595	1,216,710
93,464	57,477	719,764	157,302	157,116	119,864	62,304	675,428	157,302
30,949	42,929	335,425	18,391,796	45,351	41,274	62,178	424,349	18,388,000
16,611,392	12,085,099	151,009,546	26,328,756	9,418,154	16,173,679	16,489,515	149,664,805	26,137,531
2,746,463	1,532,466	8,467,473	1,947,270	1,796,723	2,122,512	1,733,766	8,704,020	1,915,837
482,201	295,124	1,036,544	395,796	306,708	482,323	315,071	1,060,122	393,546
76,219	43,892	336,654	91,446	118,863	91,655	58,964	272,519	91,446
24,373	4,168	328,907	18,448,040	54,399	36,101	37,406	404,264	18,431,630
17,075,215	12,625,931	152,390,253	26,283,740	9,923,119	16,882,850	16,794,132	150,892,095	26,042,366
2,422,575	1,165,857	7,617,036	2,239,357	1,340,958	1,809,602	1,561,907	7,930,079	2,252,235
366,294	155,344	587,275	236,222	272,537	148,776	193,499	694,055	226,736
58,505	5,722	260,119	91,872	114,841	39,633	73,045	175,636	91,872
18,058	7,896	324,440	18,360,118	43,393	25,410	12,138	413,865	18,356,781

Housing Table 4. Household Energy Use and Spending in the last 12 Months, by Select Characteristics: Michigan

Source: U.S. Census Bureau Household Pulse Survey, Cycle 02.

Note: These data are experimental. Users should take caution using estimates based on subpopulations of the data – sample sizes may be small and the standard errors may be large.**

Total Population 18 Years and Older

Select characteristics	Total*	Household reduced or forwent expenses for basic household necessities, such as medicine or food, in order to pay an energy bill							Almost every month
		Almost every month	Some months	1 or two months	Never	Did not report			
Total	7,741,821	2,135,348	657,173	800,636	677,539	4,297,218	1,309,254	1,276,804	458,393
Age		33%						20%	
18 - 24	490,338		38,644	-	175,431	141,043	135,221		31,054
25 - 39	2,267,692		274,063	313,986	145,428	1,127,722	406,493		172,709
40 - 54	1,861,471		188,498	251,508	190,216	931,587	299,663		102,447
55 - 64	1,332,901		105,492	128,107	83,054	776,901	239,346		77,276
65 and above	1,768,921	240,923	50,477	107,035	83,411	1,299,467	228,531	241,224	74,907
		16%						16%	
Sex at birth									
Male	3,781,559		299,989	325,321	294,648	2,212,953	648,648		252,899
Female	3,960,262		357,184	475,315	382,892	2,084,265	660,606		205,494
Gender									
Cisgender male	1,721,167		93,956	150,189	161,958	1,021,319	293,747		117,097
Cisgender female	1,802,363		137,605	289,045	159,166	962,281	254,267		74,227
Transgender	32,733		-	-	-	30,893	1,841		-
None of these	67,962	21,841	1,850	15,284	4,707	43,686	2,435	25,546	3,620
		33%						40%	
Did not report	4,117,595		423,763	346,119	351,708	2,239,040	756,966		263,448
Sexual orientation									
Gay or lesbian	205,117	41,263	9,150	9,393	22,720	112,398	51,455	44,625	12,777
		27%						29%	
Straight	6,916,922		566,546	733,083	590,946	3,902,733	1,123,615		373,076
Bisexual	261,479	72,841	33,511	26,324	13,006	129,864	58,774	49,290	25,659
		36%						25%	
Something else	141,149	61,251	12,830	19,577	28,844	63,348	16,550	#VALUE!	10,411
		49%						#VALUE!	
I don't know	88,478		12,826	7,476	2,353	51,314	14,509		12,421
Did not report	128,676		22,310	4,784	19,670	37,561	44,351		24,050
Lesbian, Gay, Bisexual and Transgender									
Yes	474,297	114,104	42,661	35,717	35,726	248,124	112,069	96,679	38,435
		32%						27%	
No	3,205,531		182,310	423,060	279,013	1,830,168	490,981		148,572
Other	137,465		9,885	19,770	5,109	80,914	21,787		16,159
Did not report	3,924,527		422,317	322,089	357,692	2,138,012	684,417		255,226
Hispanic origin and Race									
Hispanic or Latino (may be of any race)	411,817	151,099	44,299	81,230	25,570	157,224	103,494	28,202	7,734
		49%						10%	
White alone, not Hispanic	5,870,413	1,441,571	397,216	497,188	547,167	3,491,132	937,709	875,211	287,737
		29%						18%	
Black alone, not Hispanic	988,268	372,949	142,007	148,938	82,004	426,448	188,871	249,747	116,247
		47%						32%	
Asian alone, not Hispanic	173,764	34,676	13,945	7,395	13,336	102,538	36,549	#VALUE!	-
		25%						#VALUE!	
Two or more races + Other races, not Hispanic	297,559	135,052	59,705	65,885	9,462	119,877	42,630	97,616	46,675
		53%						39%	
Education									
Less than high school	512,268	233,280	91,749	113,280	28,251	186,764	92,223	146,976	75,593
		56%						36%	
High school or GED	2,394,911		265,706	274,325	241,940	1,139,028	473,912		180,548
Some college/associate's degree	2,515,468		230,793	299,404	213,839	1,372,929	398,504		128,566
Bachelor's degree or higher	2,319,174	376,062	68,925	113,628	193,509	1,598,496	344,616	227,687	73,686
		19%						12%	
Marital status									
Married	4,095,544		248,937	292,201	292,975	2,612,139	649,294		184,774

Widowed	400,425		18,866	63,874	28,582	229,954	59,148		24,666
Divorced/separated	1,122,703		138,407	128,526	85,615	565,349	204,806		102,127
Never married	2,075,984		250,963	316,035	270,367	861,470	377,147		146,826
Did not report	47,165		-	-	-	28,306	18,859		-
Household size									
1 person in the household	852,453	260,910	79,859	99,139	81,912	472,704	118,839	182,233	65,849
		36%						25%	
2 people in the household	2,767,149		228,569	178,852	169,944	1,762,166	427,619		181,318
3 people in the household	1,547,217		149,289	209,519	163,567	780,935	243,908		111,988
4 people in the household	1,316,464		93,689	149,340	82,189	675,777	315,469		69,986
5 people in the household	666,168		28,255	102,099	100,260	335,375	100,179		13,030
6 people in the household	265,417		43,756	23,976	4,282	114,030	79,373		9,835
7 or more people in the household	326,952		33,756	37,712	75,385	156,231	23,867		6,386
Presence of children under 18 years old									
Children in household	2,608,552	837,899	260,519	333,343	244,037	1,257,129	513,524	339,062	123,320
		40%						16%	
No children	5,133,269	1,297,450	396,655	467,293	433,502	3,040,089	795,731	937,741	335,072
		30%						22%	
Respondent or household member experienced loss of employment income in last 4 weeks									
Yes	838,003		144,629	159,630	131,950	287,571	114,223		99,799
No	6,713,966		490,234	641,006	543,972	4,001,361	1,037,393		335,450
Did not report	189,852		22,310	-	1,617	8,286	157,638		23,144
Respondent employed in the last 7 days									
Yes	4,507,976		338,902	497,119	415,551	2,596,840	659,564		251,607
No	2,998,779		295,055	297,597	260,371	1,674,570	471,187		183,569
Did not report	235,066		23,216	5,921	1,617	25,808	178,504		23,216
Household income									
Less than \$25,000	998,850	588,517	254,037	215,149	119,331	410,332	-	443,225	161,399
		59%						45%	
\$25,000 - \$34,999	597,734	271,239	150,099	93,498	27,642	315,811	10,683	206,658	91,411
		46%						35%	
\$35,000 - \$49,999	868,360	427,723	89,319	177,473	160,931	439,768	870	187,984	39,337
		49%						22%	
\$50,000 - \$74,999	1,093,592		370,118	68,972	167,413	133,733	723,475		-
		34%							
\$75,000 - \$99,999	764,849		27,868	47,363	84,275	605,344	-		28,773
\$100,000 - \$149,999	967,001		42,866	58,939	91,127	767,555	6,514		23,598
\$150,000 - \$199,999	453,404		2,404	18,143	10,442	422,415	-		9,131
\$200,000 and above	366,068		-	4,445	723	360,900	-		14,790
Did not report	1,631,962		21,608	18,212	49,336	251,619	1,291,187		18,447
Active duty military*									
Serving on active duty	21,885		-	-	11,582	2,103	8,199		-
Serving in Reserve or National Guard	3,932		-	-	-	3,932	-		-
Spouse serving on active duty	915		-	-	-	915	-		-
Spouse serving in Reserve or National Guard	369		-	-	-	369	-		-
No active duty service (self or spouse)	7,587,740		617,827	800,636	665,957	4,286,969	1,216,350		433,115
Did not report	126,981		39,346	-	-	2,930	84,705		25,277
Previous military service*									
No	6,368,039		536,224	696,017	539,915	3,547,305	1,048,577		331,920
Served on active duty	493,345	119,226	23,318	41,282	54,626	325,278	48,840	68,580	35,651
		27%						15%	
Served in the Reserve or National Guard	98,362	#VALUE!	-	14,128	10,054	64,290	9,891	#VALUE!	5,530
		#VALUE!						#VALUE!	
Spouse served on active duty	361,397	77,430	32,927	24,936	19,567	224,866	59,101	#VALUE!	43,215
		26%						#VALUE!	
Spouse served in the Reserve or National Guard	81,789	27,991	9,465	6,780	11,746	44,399	9,399	#VALUE!	-
		39%						#VALUE!	
Did not report	458,071		55,239	19,276	60,140	175,575	147,841		47,606
Difficulty seeing									
No difficulty	5,126,267		310,758	464,937	445,376	3,236,126	669,069		209,528

Some difficulty	1,965,159		282,656	298,730	207,797	1,005,041	170,936		208,430
A lot of difficulty	153,466		32,686	35,664	19,658	47,518	17,941		14,996
Cannot do at all	17,302		13,810	-	-	-	3,493		6,870
Did not report	479,626		17,264	1,305	4,707	8,533	447,816		18,569
Difficulty hearing									
No difficulty	5,954,068		455,047	673,927	586,891	3,560,310	677,894		326,381
Some difficulty	1,101,303		114,545	119,857	75,056	618,981	172,865		91,915
A lot of difficulty	159,868		70,318	4,413	13,705	64,245	7,187		19,640
Cannot do at all	5,380		-	-	1,887	-	3,493		1,887
Did not report	521,202		17,264	2,440	-	53,682	447,816		18,569
Difficulty remembering or concentrating									
No difficulty	4,962,053		345,598	558,023	402,640	3,092,069	563,723		300,174
Some difficulty	1,970,941		256,972	205,060	241,494	1,048,232	219,183		126,522
A lot of difficulty	337,377		54,603	36,248	33,406	138,082	75,039		30,391
Cannot do at all	3,493		-	-	-	-	3,493		-
Did not report	467,957		-	1,305	-	18,835	447,816		1,305
Difficulty walking or climbing stairs									
No difficulty	5,380,016		362,254	581,742	506,262	3,282,211	647,547		276,598
Some difficulty	1,588,433		237,872	192,509	142,428	839,067	176,557		120,503
A lot of difficulty	298,061		57,047	25,080	27,147	161,203	27,584		59,986
Cannot do at all	8,944		-	-	-	4,581	4,363		-
Did not report	466,368		-	1,305	1,701	10,156	453,205		1,305
Difficulty with self-care									
No difficulty	6,580,465		489,291	752,158	568,021	4,004,268	766,728		376,082
Some difficulty	605,143		150,899	46,673	100,824	255,589	51,157		79,241
A lot of difficulty	81,682		4,764	500	8,694	28,828	38,897		1,763
Cannot do at all	4,657		-	-	-	-	4,657		-
Did not report	469,874		12,219	1,305	-	8,533	447,816		1,305
Difficulty understanding or being understood									
No difficulty	6,853,207		525,551	763,072	618,364	4,137,497	808,724		384,799
Some difficulty	368,767		98,507	32,582	56,435	134,046	47,198		57,808
A lot of difficulty	54,588		30,070	3,677	2,740	15,206	2,894		12,543
Cannot do at all	5,429		-	-	-	1,937	3,493		1,937
Did not report	459,830		3,045	1,305	-	8,533	446,946		1,305

* Totals may not sum to 100% as the question allowed for multiple categories to be marked.

** The Census Bureau considers estimated coefficients of variation (standard error divided by the estimate times 100) over 30 percent to indicate potentially serious data quality issues related to sampling error.

Household kept home at a temperature that felt unsafe or unhealthy					Household was unable to pay an energy bill or unable to pay the full bill amount				
Some months	1 or two months	Never	Did not report		Almost every month	Some months	1 or two months	Never	Did not report
462,913	355,498	5,126,950	1,338,067	1,653,911	386,014	734,945	532,952	4,754,646	1,333,264
				26%					
34,270	-	289,794	135,221		6,218	74,773	41,824	232,303	135,221
106,623	169,984	1,410,340	408,035		132,521	352,548	148,327	1,226,280	408,016
132,866	56,886	1,251,028	318,244		164,761	156,425	199,040	1,032,676	308,569
99,332	52,133	854,214	249,946		55,127	75,352	110,575	840,167	251,680
89,822	76,495	1,301,076	226,621	136,421	27,387	75,848	33,186	1,402,722	229,779
				9%					
185,525	146,538	2,522,159	674,438		178,166	277,888	178,148	2,481,071	666,285
277,388	208,960	2,604,791	663,629		207,848	457,057	354,804	2,273,574	666,979
73,791	45,473	1,184,530	300,276		76,770	91,392	68,335	1,181,850	302,821
92,497	129,110	1,252,307	254,222		90,289	242,353	134,400	1,074,682	260,639
5,185	-	25,708	1,841		-	-	-	30,893	1,841
20,076	1,850	38,455	3,960	38,775	1,850	7,777	29,148	26,752	2,435
				59%					
271,364	179,066	2,625,950	777,768		217,106	393,422	301,069	2,440,469	765,529
18,610	13,238	109,038	51,455	29,282	5,519	7,302	16,461	124,380	51,455
				19%					
394,901	323,188	4,676,397	1,149,361		325,520	637,994	509,302	4,298,003	1,146,103
4,559	19,072	151,889	60,300	69,179	21,055	42,152	5,972	133,525	58,774
				34%					
26,513	-	87,675	16,550	#VALUE!	-	22,968	-	101,631	16,550
				#VALUE!					
10,532	-	49,475	16,051		11,609	7,325	1,217	53,818	14,509
7,799	-	52,475	44,351		22,310	17,204	-	43,289	45,873
25,934	32,310	264,023	113,595	98,462	26,575	49,454	22,433	263,767	112,069
				27%					
155,267	167,156	2,237,071	497,466		133,431	283,746	199,534	2,082,394	506,427
18,799	1,850	78,870	21,787		8,903	18,897	15,323	72,554	21,787
262,913	154,183	2,546,986	705,219		217,106	382,848	295,662	2,335,931	692,980
13,407	7,061	267,901	115,713	132,176	26,863	66,645	38,668	176,146	103,494
				43%					
362,899	224,575	4,050,963	944,239	958,788	196,222	385,273	377,293	3,960,161	951,464
				19%					
67,240	66,260	541,452	197,070	419,549	116,568	217,612	85,369	371,457	197,261
				53%					
6,038	19,990	111,187	36,549	22,583	13,945	6,450	2,188	114,632	36,549
				16%					
13,329	37,612	155,447	44,496	120,813	32,415	58,964	29,434	132,250	44,496
				48%					
28,095	43,288	256,954	108,338	173,732	72,721	50,329	50,682	230,197	108,338
				43%					
185,886	107,248	1,435,098	486,131		157,900	304,450	233,661	1,221,729	477,171
161,892	138,002	1,689,569	397,440		109,036	311,672	174,096	1,522,205	398,459
87,040	66,961	1,745,330	346,158	189,364	46,357	68,493	74,514	1,780,515	349,296
				10%					
167,157	138,023	2,942,726	662,864		144,501	245,979	290,391	2,741,325	673,348

28,656	14,792	273,163	59,148		16,319	37,889	53,715	233,354	59,148
74,249	64,593	677,313	204,421		94,401	108,171	74,329	642,907	202,896
192,851	138,090	1,205,442	392,774		130,793	342,906	114,517	1,108,754	379,013
-	-	28,306	18,859		-	-	-	28,306	18,859
67,302	49,082	543,184	127,037	179,455	45,375	86,455	47,625	549,028	123,969
				25%					
174,565	104,760	1,855,728	450,779		107,934	191,149	102,295	1,924,054	441,717
103,231	49,925	1,038,165	243,908		103,447	158,363	161,528	879,971	243,908
40,880	108,092	784,581	312,925		56,378	141,786	114,603	686,706	316,991
33,065	23,886	496,008	100,179		16,292	64,601	58,410	426,685	100,179
-	1,594	174,615	79,373		28,638	13,740	31,518	108,890	82,633
43,869	18,160	234,669	23,867		27,949	78,851	16,973	179,312	23,867
125,576	90,166	1,758,510	510,979	843,295	181,433	406,713	255,149	1,246,952	518,305
				40%					
337,337	265,332	3,368,440	827,088	810,616	204,581	328,232	277,803	3,507,694	814,959
				19%					
54,160	55,291	517,074	111,679		98,288	178,543	113,541	333,408	114,223
408,753	300,207	4,600,806	1,068,750		265,416	556,402	419,411	4,411,335	1,061,403
-	-	9,070	157,638		22,310	-	-	9,903	157,638
270,827	198,623	3,111,728	675,191		176,964	494,237	297,707	2,876,115	662,952
186,166	156,875	1,987,796	484,373		186,739	239,802	235,245	1,845,185	491,808
5,921	-	27,425	178,504		22,310	906	-	33,346	178,504
117,803	164,023	534,839	20,786	490,956	174,689	184,422	131,845	500,854	7,041
				50%					
75,476	39,771	382,303	8,773	243,320	71,365	141,863	30,092	345,641	8,773
				41%					
92,817	55,830	670,432	9,944	290,554	53,325	122,612	114,617	564,602	13,203
				34%					
71,506	47,296	24,916	949,873		-	30,873	158,080	96,968	807,671
44,140	41,740	648,655	1,542		7,150	40,163	59,066	655,313	3,158
50,863	12,697	873,329	6,514		34,583	53,132	51,132	821,640	6,514
15,657	12,038	416,577	-		-	11,399	24,389	417,615	-
1,522	1,650	348,107	-		-	-	-	366,068	-
17,339	2,833	302,835	1,290,508		14,030	23,273	24,843	275,241	1,294,575
9,993	-	3,692	8,199		-	9,993	-	3,692	8,199
-	-	3,932	-		-	-	-	3,932	-
-	-	915	-		-	-	-	915	-
-	-	369	-		-	-	-	369	-
452,920	353,649	5,115,112	1,232,944		349,635	721,984	532,952	4,742,808	1,240,360
-	1,850	2,930	96,924		36,379	2,967	-	2,930	84,705
401,462	322,033	4,263,523	1,049,100		307,311	649,132	457,291	3,897,788	1,056,517
20,245	12,684	377,834	46,930	57,373	12,737	22,928	21,708	389,043	46,930
				13%					
-	3,681	79,260	9,891	#VALUE!	-	15,717	2,340	70,415	9,891
				#VALUE!					
20,634	-	238,447	59,101	64,045	25,562	10,517	27,966	238,251	59,101
				21%					
12,216	2,404	57,770	9,399	#VALUE!	-	17,012	13,570	41,808	9,399
				#VALUE!					
14,290	14,696	203,438	178,041		40,404	27,356	24,285	200,204	165,822
235,620	194,421	3,797,383	689,315		184,867	417,579	307,445	3,530,338	686,038

201,741	142,146	1,234,867	177,977		157,106	269,100	193,928	1,167,048	177,977
25,552	18,932	74,520	19,467		12,967	43,558	31,579	47,422	17,941
-	-	6,940	3,493		13,810	-	-	-	3,493
-	-	13,240	447,816		17,264	4,707	-	9,838	447,816
376,161	282,365	4,276,200	692,962		281,599	591,835	412,827	3,969,061	698,746
80,841	47,470	708,212	172,865		51,070	131,443	96,492	649,434	172,865
5,911	25,663	87,721	20,932		36,081	10,533	23,633	79,276	10,345
-	-	-	3,493		-	-	-	1,887	3,493
-	-	54,816	447,816		17,264	1,134	-	54,987	447,816
245,006	208,407	3,627,904	580,562		193,322	384,376	342,585	3,466,101	575,668
183,565	123,115	1,313,622	224,117		163,401	300,813	178,010	1,104,510	224,207
31,080	23,977	176,891	75,039		29,291	49,756	12,357	170,934	75,039
-	-	-	3,493		-	-	-	-	3,493
3,261	-	8,533	454,857		-	-	-	13,100	454,857
259,237	213,872	3,972,192	658,118		180,330	516,147	379,310	3,639,714	664,515
174,706	117,237	980,170	195,817		153,277	181,818	132,772	936,969	183,597
27,269	24,390	159,850	26,565		52,408	36,979	19,168	161,921	27,584
-	-	4,581	4,363		-	-	-	4,581	4,363
1,701	-	10,156	453,205		-	-	1,701	11,462	453,205
385,992	289,402	4,746,515	782,474		272,032	646,578	506,798	4,366,185	788,872
66,242	64,126	345,395	50,138		98,865	88,367	24,184	342,570	51,157
10,680	1,970	26,507	40,762		2,898	-	1,970	36,052	40,762
-	-	-	4,657		-	-	-	-	4,657
-	-	8,533	460,035		12,219	-	-	9,838	447,816
410,679	308,267	4,927,537	821,926		291,560	681,249	503,257	4,546,273	830,868
46,926	45,080	169,889	49,063		66,647	48,388	28,169	176,500	49,063
5,308	2,152	17,946	16,639		24,762	5,308	1,526	20,098	2,894
-	-	-	3,493		-	-	-	1,937	3,493
-	-	11,578	446,946		3,045	-	-	9,838	446,946

Housing Table 4. Household Energy Use and Spending in the last 12 Months, by Select Characteristics: Detroit-Warren-Dearborn, MI Metro Area

Source: U.S. Census Bureau Household Pulse Survey, Cycle 02.

Note: These data are experimental. Users should take caution using estimates based on subpopulations of the data – sample sizes may be small and the standard errors may be large.**

Total Population 18 Years and Older

Select characteristics	Total*	Household reduced or forwent expenses for basic household necessities, such as medicine or food, in order to pay an energy bill					Almost every month
		Almost every month	Some months	1 or two months	Never	Did not report	
Total	3,355,816	267,567	334,326	314,216	1,805,872	633,834	211,934
Age							
18 - 24	291,698	24,836	-	93,191	72,025	101,645	31,054
25 - 39	948,846	101,478	130,997	64,490	479,210	172,671	54,646
40 - 54	795,211	85,393	90,496	98,757	388,654	131,910	60,901
55 - 64	550,380	30,788	58,801	34,416	290,628	135,746	24,011
65 and above	749,182	25,072	54,032	23,361	554,856	91,862	41,323
Sex at birth							
Male	1,647,698	107,718	140,975	140,222	929,681	329,101	97,183
Female	1,708,118	159,849	193,351	173,994	876,191	304,734	114,751
Gender							
Cisgender male	790,520	39,839	64,559	68,778	450,344	167,000	69,473
Cisgender female	838,870	85,842	119,497	74,744	433,902	124,886	41,956
Transgender	21,072	-	-	-	21,072	-	-
None of these	28,861	-	-	4,707	21,719	2,435	-
Did not report	1,676,491	141,886	150,271	165,986	878,834	339,514	100,505
Sexual orientation							
Gay or lesbian	83,849	9,150	3,595	1,522	67,548	2,034	9,114
Straight	2,944,804	223,630	308,373	259,264	1,623,728	529,809	180,138
Bisexual	170,343	22,196	17,767	9,102	65,338	55,940	9,333
Something else	60,107	982	2,919	28,844	19,822	7,540	-
I don't know	29,395	11,609	151	1,542	8,152	7,941	11,609
Did not report	67,319	-	1,522	13,942	21,285	30,570	1,740
Lesbian, Gay, Bisexual and Transgender							
Yes	254,191	31,346	21,362	10,624	132,885	57,974	18,447
No	1,470,387	87,746	178,549	122,844	822,513	258,735	90,246
Other	36,945	8,035	1,937	5,109	15,655	6,209	7,053
Did not report	1,594,292	140,440	132,478	175,639	834,818	310,916	96,187
Hispanic origin and Race							
Hispanic or Latino (may be of any race)	157,796	22,857	9,126	20,747	48,242	56,823	6,353
White alone, not Hispanic	2,302,410	131,275	189,800	224,683	1,343,799	412,852	117,557
Black alone, not Hispanic	645,605	78,048	102,923	55,929	298,501	110,203	88,024
Asian alone, not Hispanic	130,052	13,945	7,395	7,298	67,471	33,943	-
Two or more races + Other races, not Hispanic	119,952	21,441	25,081	5,558	47,859	20,013	-
Education							
Less than high school	195,883	25,717	25,428	19,177	70,310	55,252	22,570
High school or GED	1,056,191	131,817	142,308	94,230	471,062	216,774	88,876
Some college/associate's degree	1,120,249	89,216	122,163	103,145	585,262	220,464	75,479
Bachelor's degree or higher	983,492	20,817	44,428	97,665	679,238	141,344	25,010
Marital status							
Married	1,635,825	96,769	139,845	86,183	1,013,606	299,423	92,327
Widowed	184,758	5,387	22,312	5,934	117,848	33,276	7,007
Divorced/separated	402,362	32,785	43,596	38,469	208,310	79,202	17,890
Never married	1,110,782	132,626	128,573	183,630	455,593	210,359	94,710
Did not report	22,089	-	-	-	10,514	11,574	-
Household size							
1 person in the household	426,652	33,398	47,036	45,522	245,609	55,087	21,414
2 people in the household	1,092,469	91,514	67,251	63,892	676,755	193,058	108,204
3 people in the household	659,179	54,146	78,497	72,064	332,702	121,771	34,347
4 people in the household	586,024	41,138	71,966	33,126	285,112	154,683	34,100

5 people in the household	278,645	20,909	33,378	43,982	126,371	54,006	1,268
6 people in the household	122,845	4,750	13,740	2,688	70,306	31,362	6,214
7 or more people in the household	190,000	21,712	22,460	52,943	69,019	23,867	6,386
Presence of children under 18 years old							
Children in household	1,150,326	99,416	155,572	105,593	542,435	247,310	52,963
No children	2,205,490	168,151	178,754	208,623	1,263,437	386,524	158,971
Respondent or household member experienced loss of employment income in last 4 weeks							
Yes	423,347	90,729	82,380	44,536	145,662	60,041	83,843
No	2,838,275	176,838	251,947	269,680	1,659,377	480,433	127,258
Did not report	94,194	-	-	-	833	93,361	833
Respondent employed in the last 7 days							
Yes	1,973,709	150,531	225,410	227,519	1,091,498	278,751	115,393
No	1,273,408	116,130	108,916	86,697	708,221	253,443	95,635
Did not report	108,699	906	-	-	6,153	101,640	906
Household income							
Less than \$25,000	386,757	96,958	81,333	62,887	145,579	-	52,308
\$25,000 - \$34,999	298,461	77,013	50,810	26,928	143,710	-	60,698
\$35,000 - \$49,999	298,639	23,302	32,039	69,799	172,629	870	19,159
\$50,000 - \$74,999	471,186	30,207	98,753	33,602	308,623	-	20,442
\$75,000 - \$99,999	373,159	12,560	25,827	49,964	284,809	-	22,854
\$100,000 - \$149,999	388,422	12,749	26,868	36,046	306,245	6,514	13,207
\$150,000 - \$199,999	198,827	-	4,340	6,367	188,120	-	3,365
\$200,000 and above	163,237	-	1,839	723	160,675	-	4,384
Did not report	777,127	14,778	12,517	27,901	95,482	626,450	15,517
Active duty military*							
Serving on active duty	10,302	-	-	-	2,103	8,199	-
Serving in Reserve or National Guard	3,622	-	-	-	3,622	-	-
Spouse serving on active duty	915	-	-	-	915	-	-
Spouse serving in Reserve or National Guard	-	-	-	-	-	-	-
No active duty service (self or spouse)	3,285,687	252,380	334,326	314,216	1,799,232	585,532	208,967
Did not report	55,289	15,186	-	-	-	40,103	2,967
Previous military service*							
No	2,831,739	238,110	295,324	280,697	1,492,029	525,579	175,737
Served on active duty	153,842	1,792	21,352	8,812	109,537	12,349	968
Served in the Reserve or National Guard	26,241	-	1,783	-	22,189	2,269	-
Spouse served on active duty	140,126	2,646	3,905	11,757	100,065	21,753	19,955
Spouse served in the Reserve or National Guard	43,388	7,061	1,613	5,934	24,485	4,295	-
Did not report	207,665	17,958	12,132	12,950	94,615	70,009	15,274
Difficulty seeing							
No difficulty	2,233,189	148,217	212,833	201,876	1,362,280	307,982	97,068
Some difficulty	800,353	101,839	109,525	100,368	409,367	79,254	94,763
A lot of difficulty	79,576	10,641	11,967	7,265	31,762	17,941	13,233
Cannot do at all	10,363	6,870	-	-	-	3,493	6,870
Did not report	232,335	-	-	4,707	2,463	225,165	-
Difficulty hearing							
No difficulty	2,587,131	165,317	288,822	284,914	1,539,211	308,867	139,566
Some difficulty	440,651	74,071	44,370	23,361	206,466	92,384	54,521
A lot of difficulty	48,743	28,179	-	4,055	12,584	3,926	15,959
Cannot do at all	5,380	-	-	1,887	-	3,493	1,887
Did not report	273,911	-	1,134	-	47,612	225,165	-
Difficulty remembering or concentrating							
No difficulty	2,122,711	123,652	239,342	195,824	1,317,787	246,107	138,212
Some difficulty	829,998	133,569	78,919	100,546	421,183	95,781	63,154
A lot of difficulty	171,986	10,346	16,065	17,847	64,439	63,289	10,568
Cannot do at all	3,493	-	-	-	-	3,493	-
Did not report	227,628	-	-	-	2,463	225,165	-

Difficulty walking or climbing stairs							
No difficulty	2,263,319	159,162	217,835	221,832	1,379,518	284,972	136,660
Some difficulty	704,147	86,332	96,618	78,566	346,275	96,355	34,315
A lot of difficulty	144,766	22,072	19,873	13,819	71,411	17,591	40,959
Cannot do at all	8,944	-	-	-	4,581	4,363	-
Did not report	234,639	-	-	-	4,086	230,553	-
Difficulty with self-care							
No difficulty	2,808,512	207,610	303,612	266,292	1,696,552	334,446	185,062
Some difficulty	259,265	44,737	30,714	47,924	105,218	30,671	26,872
A lot of difficulty	43,535	3,000	-	-	1,639	38,897	-
Cannot do at all	4,657	-	-	-	-	4,657	-
Did not report	239,847	12,219	-	-	2,463	225,165	-
Difficulty understanding or being understood							
No difficulty	2,882,924	209,103	318,517	275,165	1,721,443	358,695	187,292
Some difficulty	201,764	33,701	13,658	39,051	70,897	44,457	10,162
A lot of difficulty	38,940	24,762	2,152	-	9,132	2,894	12,543
Cannot do at all	5,429	-	-	-	1,937	3,493	1,937
Did not report	226,758	-	-	-	2,463	224,295	-

* Totals may not sum to 100% as the question allowed for multiple categories to be marked.

** The Census Bureau considers estimated coefficients of variation (standard error divided by the estimate times 100) over 30 percent to indicate potentially serious data quality issues related to sampling error.

Household kept home at a temperature that felt unsafe or unhealthy				Household was unable to pay an energy bill or unable to pay the full bill amount				
Some months	1 or two months	Never	Did not report	Almost every month	Some months	1 or two months	Never	Did not report
203,904	183,107	2,109,954	646,917	155,693	440,039	214,406	1,905,196	640,482
20,462	-	138,537	101,645	6,218	60,966	-	122,869	101,645
33,735	85,844	600,409	174,213	43,604	199,758	69,096	462,195	174,193
76,819	28,480	485,560	143,451	59,076	107,065	64,697	430,597	133,776
34,505	24,828	331,289	135,746	19,409	36,174	59,723	296,069	139,005
38,382	43,955	533,661	91,862	27,387	36,077	20,890	572,967	91,862
86,348	90,763	1,034,628	338,775	80,064	163,210	78,833	994,968	330,623
117,555	92,344	1,075,327	308,141	75,628	276,830	135,573	910,228	309,859
50,014	20,697	485,880	164,456	43,642	63,273	44,483	472,122	167,000
42,384	59,599	568,180	126,751	37,233	163,050	66,213	442,364	130,011
2,419	-	18,653	-	-	-	-	21,072	-
12,299	-	14,128	2,435	-	-	12,299	14,128	2,435
96,787	102,812	1,023,113	353,275	74,818	213,716	91,411	955,510	341,036
15,894	1,522	55,285	2,034	5,519	7,302	13,745	55,249	2,034
173,017	164,917	1,885,383	541,349	129,931	372,002	197,075	1,710,862	534,934
3,357	16,668	85,044	55,940	8,633	39,748	3,586	62,435	55,940
5,109	-	47,458	7,540	-	7,045	-	45,521	7,540
1,989	-	6,313	9,483	11,609	-	-	9,845	7,941
4,538	-	30,471	30,570	-	13,942	-	21,285	32,092
19,251	18,190	140,329	57,974	14,153	47,050	17,331	117,684	57,974
85,451	75,272	961,362	258,056	59,669	182,802	108,355	855,702	263,860
6,947	-	16,735	6,209	7,053	7,045	-	16,637	6,209
92,255	89,644	991,529	324,677	74,818	203,142	88,721	915,174	312,438
2,997	1,245	78,159	69,042	19,923	20,261	3,589	57,200	56,823
164,975	65,324	1,544,246	410,308	56,789	212,593	148,858	1,469,795	414,374
32,198	58,936	354,702	111,745	65,036	155,287	53,209	258,610	113,463
-	19,990	76,119	33,943	13,945	6,450	2,188	73,527	33,943
3,733	37,612	56,727	21,879	-	45,448	6,562	46,063	21,879
15,832	25,742	76,488	55,252	19,465	28,813	20,173	72,180	55,252
80,333	89,128	568,860	228,994	70,990	236,857	71,270	457,040	220,034
61,845	40,273	722,866	219,785	56,574	141,239	95,665	604,442	222,330
45,893	27,964	741,740	142,886	8,664	33,129	27,298	771,534	142,867
68,972	66,968	1,110,681	296,878	58,426	144,208	92,621	1,036,366	304,204
13,198	10,399	120,878	33,276	2,967	18,017	24,376	106,120	33,276
26,740	45,965	232,565	79,202	15,374	53,816	26,552	227,418	79,202
94,994	59,776	635,316	225,986	78,926	223,998	70,857	524,776	212,225
-	-	10,514	11,574	-	-	-	10,514	11,574
29,843	28,256	290,510	56,629	15,658	49,420	31,621	274,866	55,087
41,817	50,714	684,591	207,143	60,082	81,731	67,915	687,817	194,924
53,788	29,836	419,436	121,771	22,862	110,295	47,324	356,927	121,771
16,160	32,256	351,370	152,138	32,649	99,093	19,173	278,904	156,205

25,751	23,886	173,735	54,006	14,529	22,161	22,880	165,069	54,006
-	-	85,268	31,362	3,527	13,740	13,625	57,332	34,621
36,544	18,160	105,043	23,867	6,386	63,599	11,869	84,280	23,867
47,499	75,151	729,947	244,766	49,205	270,316	65,710	513,004	252,092
156,405	107,956	1,380,007	402,151	106,488	169,723	148,696	1,392,192	388,390
38,241	49,581	194,186	57,496	54,147	124,863	41,859	142,437	60,041
165,662	133,526	1,915,768	496,060	101,546	315,176	172,547	1,761,925	487,080
-	-	-	93,361	-	-	-	833	93,361
131,008	86,791	1,346,139	294,378	56,145	311,153	116,645	1,207,627	282,139
72,896	96,316	757,662	250,899	99,548	127,980	97,761	691,416	256,703
-	-	6,153	101,640	-	906	-	6,153	101,640
61,723	72,409	188,098	12,219	61,148	105,124	67,553	152,933	-
38,702	21,618	177,444	-	24,888	97,689	13,508	162,375	-
34,566	37,888	206,157	870	27,959	49,622	31,373	185,555	4,129
16,513	21,293	412,938	-	25,710	106,354	24,843	314,278	-
22,328	16,856	309,578	1,542	1,957	28,193	37,922	305,087	-
17,044	3,733	347,923	6,514	-	32,962	21,663	327,284	6,514
4,258	6,476	184,727	-	-	-	3,796	195,031	-
1,522	-	157,331	-	-	-	-	163,237	-
7,247	2,833	125,759	625,771	14,030	20,095	13,748	99,417	629,838
-	-	2,103	8,199	-	-	-	2,103	8,199
-	-	3,622	-	-	-	-	3,622	-
-	-	915	-	-	-	-	915	-
-	-	-	-	-	-	-	-	-
203,904	183,107	2,103,314	586,395	143,474	437,072	214,406	1,898,556	592,180
-	-	-	52,322	12,219	2,967	-	-	40,103
181,560	166,166	1,783,700	524,577	138,346	401,328	172,087	1,589,617	530,361
6,350	7,715	126,460	12,349	-	9,873	9,589	122,031	12,349
-	-	23,972	2,269	-	1,783	-	22,189	2,269
10,295	-	88,122	21,753	2,486	10,517	19,459	85,911	21,753
10,514	-	28,579	4,295	-	14,608	11,869	12,617	4,295
1,119	9,226	97,952	84,094	14,862	9,647	13,271	98,010	71,875
112,213	126,472	1,576,371	321,064	97,801	265,159	119,172	1,436,428	314,629
89,509	39,673	497,154	79,254	42,863	146,897	88,673	442,666	79,254
2,182	16,962	29,259	17,941	8,158	23,276	6,562	23,639	17,941
-	-	-	3,493	6,870	-	-	-	3,493
-	-	7,170	225,165	-	4,707	-	2,463	225,165
175,503	146,759	1,815,573	309,731	109,762	353,781	167,449	1,640,626	315,515
25,376	36,348	232,021	92,384	22,103	80,774	43,990	201,400	92,384
3,024	-	13,614	16,145	23,829	4,350	2,967	13,671	3,926
-	-	-	3,493	-	-	-	1,887	3,493
-	-	48,746	225,165	-	1,134	-	47,612	225,165
129,019	84,739	1,514,959	255,781	74,464	258,156	116,625	1,422,579	250,888
71,287	74,391	521,977	99,189	72,908	158,185	90,189	411,069	97,647
3,598	23,977	70,555	63,289	8,320	23,699	7,592	69,085	63,289
-	-	-	3,493	-	-	-	-	3,493
-	-	2,463	225,165	-	-	-	2,463	225,165

107,330	104,196	1,626,753	288,380	82,162	308,621	132,026	1,448,892	291,620
82,734	62,021	416,502	108,575	54,338	101,416	69,441	382,597	96,355
13,839	16,889	58,032	15,046	19,193	30,003	12,939	65,040	17,591
-	-	4,581	4,363	-	-	-	4,581	4,363
-	-	4,086	230,553	-	-	-	4,086	230,553
176,945	139,202	1,971,315	335,987	129,027	383,564	191,748	1,764,946	339,227
25,824	43,905	134,537	28,126	13,312	56,475	22,658	136,148	30,671
1,134	-	1,639	40,762	1,134	-	-	1,639	40,762
-	-	-	4,657	-	-	-	-	4,657
-	-	2,463	237,384	12,219	-	-	2,463	225,165
190,794	145,759	2,001,385	357,693	108,557	413,869	191,234	1,805,788	363,477
13,109	35,196	96,974	46,323	22,374	26,170	23,172	83,724	46,323
-	2,152	9,132	15,114	24,762	-	-	11,284	2,894
-	-	-	3,493	-	-	-	1,937	3,493
-	-	2,463	224,295	-	-	-	2,463	224,295

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Lifting the High Energy Burden in America's Largest Cities:

How Energy Efficiency Can Improve Low Income and Underserved Communities

Ariel Dreihobl and Lauren Ross



About the Authors

Ariel Dreihobl joined ACEEE in 2015. She conducts research and analysis on local-level energy efficiency policies and initiatives, with an emphasis on low-income energy efficiency. Ariel earned her master of science in environmental science, policy, and management from a joint-degree program at Central European University, Lund University, and the University of Manchester. She earned her bachelor of arts from Northwestern University.

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Executive Summary



This report provides a snapshot of energy burdens in cities across the US. We focus on the high home energy burdens faced by select groups in major metropolitan areas.¹ Years of analysis by the firm of Fisher Sheehan & Colton determined that low-income households pay proportionally more than the average household for energy costs.² Our analysis builds on this research as we take a closer look at energy burden in specific household groups. In the first half of this report, we analyze data from the US Census Bureau's 2011 and 2013 American Housing Survey to determine energy burden values for 48 of the largest US cities and specific households within each city. In the second half of the report, we discuss strategies for alleviating high energy burdens, with a focus on policies and programs to increase the impact of energy efficiency initiatives in these communities.

Families who face higher energy burdens experience many negative long-term effects on their health and well-being. These families are at greater risk for respiratory diseases and increased stress, and they can experience increased economic hardship and difficulty in moving out of poverty. Our research determined that the overwhelming majority of single-family and multifamily low-income households (those

with income at or below 80% of area median income), minority households, low-income households residing in multifamily buildings, and renting households experienced higher energy burdens than the average household in the same city.³ For example, the median US energy burden across all cities in our sample was 3.5%. The median low-income household's energy burden was more than twice as high at 7.2%, and

three times greater than higher income households (2.3%). Overall, low-income households experienced the highest median energy burden (7.2%), followed by African-American households (5.4%), low-income households living in multifamily buildings (5.0%), Latino households (4.1%), and renting households (4.0%).⁴ We also examined the results by region and found that these groups faced the highest average energy burdens in the Southeast and Midwest regions.

Research Results: US Energy Burden Landscape

The efficiency of housing stock is an important factor that influences a household's energy burden. Low-income households, renters, African-American households, and Latino households paid more for utilities per square foot than the average household, indicating that they reside in less efficient housing (see table ES1).

When we compared each group's expenditures on energy per square foot with the median household expenditure, we were able to determine the extent to which home inefficiency contributed to energy burden as compared with lower incomes. We found that for low-income households and for multifamily low-income households, bringing housing stock up to the efficiency of the median household would eliminate 35% of excess energy burden, reducing energy burden from 7.2% to 5.9%. For African-American, Latino, and renting households, 42%, 68%, and 97% of their excess energy burdens, respectively, could be eliminated by raising household efficiency to the median.

By examining these specific groups within cities, we found that many households experienced energy burdens that greatly exceeded both the overall median of 3.5% and their city medians. Median energy burdens were as high as 13% for some groups.

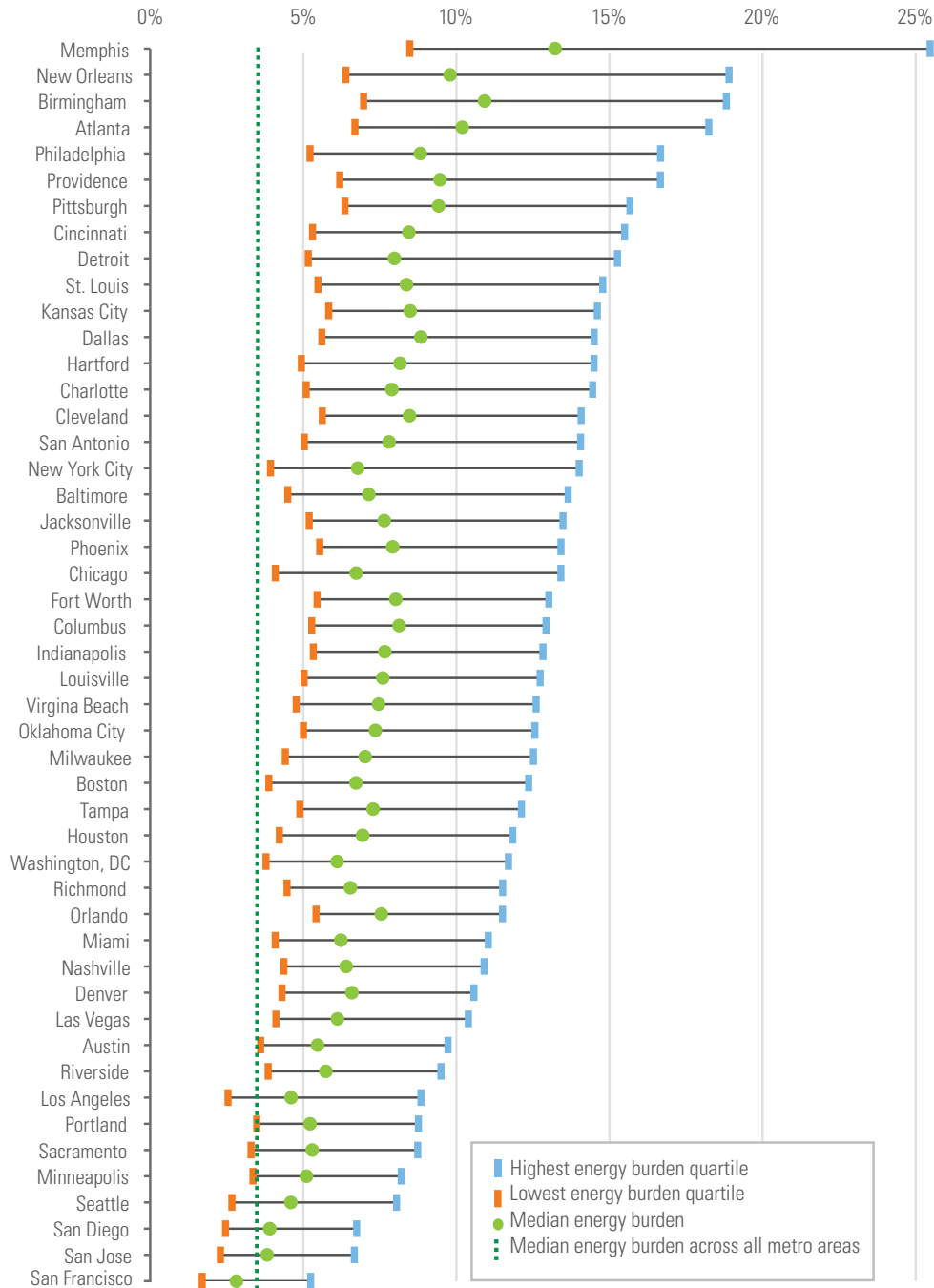
TABLE ES1. Median income, utility bill, energy burden, and unit size for households based on income type, building type, building ownership, and household race for groups across all metro areas

	Household type	Median annual income	Median size of unit (square feet)	Median annual utility spending	Median annual utility costs per square foot	Median energy burden ¹
Income type	Low-income ² (≤80% AMI) ³	\$24,998	1,200	\$1,692	\$1.41	7.2%
	Non-low-income	\$90,000	1,800	\$2,112	\$1.17	2.3%
	Low-income multifamily (≤80% AMI)	\$21,996	800	\$1,032	\$1.29	5.0%
	Non-low-income multifamily	\$71,982	950	\$1,104	\$1.16	1.5%
Building ownership	Renters	\$34,972	1,000	\$1,404	\$1.40	4.0%
	Owners	\$68,000	1,850	\$2,172	\$1.17	3.3%
Head of household race	White	\$58,000	1,600	\$1,956	\$1.22	3.3%
	African-American	\$34,494	1,290	\$1,920	\$1.49	5.4%
	Latino	\$39,994	1,200	\$1,704	\$1.42	4.1%
All households	N/A	\$53,988	1,573	\$1,932	\$1.23	3.5%

¹ Energy burden is the percentage of household income that is spent on energy bills. To calculate median energy burden, we calculated energy burden for all households and then took the median. This value differs from the median energy burden that is calculated using median annual utility spending and income.
² Low-income includes both single- and multifamily households. ³ Area median income (AMI) is the median dollar amount that divides the population into two equal parts.
Source: American Housing Survey (Census Bureau 2011 and 2013a).

FIGURE ES1. Low-income ($\leq 80\%$ AMI) household energy burden for the median, highest energy burden quartile, and lowest energy burden quartile households. The orange bars represent the beginning of the quartile of low-income households with the lowest energy burden. The blue bars represent the beginning of the quartile of low-income households with the highest energy burden. These data include both single- and multifamily low-income households.

Low-income energy burden



For low-income households, we found that energy burden varied substantially. Figure ES1 presents energy burden data for low-income households in each city at the lowest, median, and highest energy burden quartiles. In 17 cities—which is more than one-third of the cities studied—a quarter of low-income households experienced an energy burden greater than 14%, substantially higher than the 3.5% average for all households.

Strategies for Improving Energy Efficiency in Low-Income Communities

Reducing high energy burden on low-income households is a well-established policy objective at the federal, state, and local levels. To help meet this objective, many state utility regulators require that utilities provide bill assistance programs that complement federal programs, such as the Weatherization Assistance Program (WAP) and the Low Income Home Energy Assistance Program (LIHEAP). In addition, many utility regulators require utilities with energy efficiency programs to target low-income customers.

Participants in energy efficiency programs, utilities, and whole communities experience multiple benefits from increased investments in energy efficiency. These benefits include improved health and safety, reduced risk of utility rate increases, reduced costs associated with arrearages and shutoffs, investment in the local economy, and local job creation, among others.⁵ While energy efficiency programs provide benefits beyond energy savings, we find they are an underutilized strategy that could complement bill assistance and weatherization programs to reduce high energy burdens in low-income communities.

We propose the following strategies for improving energy efficiency in low-income communities: (1) Improve and expand low-income utility programs. (2) Collect, track, and report demographic data on program participation. (3) Strengthen policy levers and leverage existing programs. (4) Utilize the Clean Power Plan to prioritize investment in low-income energy efficiency.

Improve and Expand Low-Income Utility Programs

To increase program impact in low-income single- and multifamily housing, energy efficiency program managers should design programs to meet the needs

While energy efficiency programs provide benefits beyond energy savings, we find they are an underutilized strategy that could complement bill assistance and weatherization programs to reduce high energy burdens in low-income communities.

of diverse low-income communities, include a range of eligible measures and services, coordinate delivery with other services, align and add on to existing weatherization efforts, address health and safety, and incorporate energy efficiency education into program design.⁶

Low-income programs should also target multifamily customers, who are often underserved by energy efficiency programs. More than two-thirds of the multifamily rental market consists of households that have an annual household income of less than \$50,000 (NMHC 2015). Yet residential energy efficiency programs administered by states and utilities have historically focused on single-family, owner-occupied housing. Efficiency measures are far less likely to be installed in multifamily rentals than in any other type of housing, leaving significant energy savings unrealized. Examples of best practices in multifamily programs include integrating direct installation and rebate programs, streamlining rebates and incentives, offering multiple pathways to participation, and incorporating on-bill repayment or low-cost financing, among others.⁷

Access to up-front capital is one of the many barriers to energy efficiency for low-income single- and multifamily households and property owners. Financing programs—provided by several utilities and public and community-based entities—can serve as a complement to energy efficiency programs for low-income customers. With strong consumer protections in place, energy efficiency loans can be beneficial for some households and allow the financing of cost-saving measures. Financing options can also benefit multifamily building owners who lack the up-front capital to invest in energy efficiency retrofits.

Collect, Track, and Report Demographic Data on Program Participation

By collecting and making demographic data on program participation public, utilities can assess the extent to which their programs are serving different segments of the population, especially those customers known to experience high energy burdens. Demographic information can inform program design and marketing and outreach strategies. Examples of demographic data that should be incorporated into program evaluation include income level, renter versus owner, multifamily versus single family, and race/ethnicity.

Strengthen Policy Levers and Leverage Existing Programs

Utility regulators and boards of publicly owned utilities should aid utilities in developing, promoting, and executing strong low-income programs by approving and setting goals and guidelines for spending, savings, cost recovery, and cost-effectiveness testing. Additionally, state and local governments can set policy directives that support low-income energy efficiency, including disclosure and benchmarking policies for multifamily buildings, workforce development initiatives, state-level requirements for utility-delivered energy efficiency that include low-income goals, and other special efforts. Some public utility commissions (PUCs) also set low-income energy savings goals and spending requirements in order to increase investment in low-income energy efficiency. Many community-based organizations, city governments, and local utilities can petition PUCs to advance stronger low-income savings goals.

Few utilities include the nonenergy benefits of energy efficiency in their cost-benefit testing.⁸ Both PUCs and

local governments can encourage or require that cost-effectiveness testing take into account the multiple benefits of low-income energy efficiency programs.

Utilize the Clean Power Plan to Prioritize Investment in Low-Income Energy Efficiency

The Clean Power Plan—the first rulemaking to set limits on carbon pollution from power plants—offers another incentive for investment in low-income energy efficiency. States have several choices in developing their compliance plans, and they have the opportunity to prioritize low-income energy efficiency programs in this process. States can also opt into the Clean Energy Incentive Program, which offers early credit for energy efficiency projects in low-income communities during the two years before the start of the compliance period. These new regulations can make investment in low-income energy efficiency more attractive at the state and local levels.

Conclusion

We determined that low-income households and other groups experience higher energy burdens than households on average. Low-income families often live in less efficient housing and pay more per square foot on energy costs. Current utility-led energy efficiency programs could better complement bill assistance and weatherization programs to reduce high energy burdens in low-income communities. Our research identified several strategies to ramp up energy efficiency in these communities. While these represent important steps, we still have much work to do to increase energy affordability among vulnerable communities across the country.

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- 1 Energy burden refers to the percentage of gross household income spent on energy bills.
 - 2 For more information on Fisher Sheehan & Colton's previous work on the Home Energy Affordability Gap, see www.homeenergyaffordabilitygap.com.
 - 3 Area median income (AMI) is the median dollar amount that divides the population into two equal parts. HUD uses AMI to determine eligibility for low-income programs based on metropolitan area and household size.
 - 4 Single-family low-income households experienced the highest average energy burden of 7.8%. We did not specifically analyze these households in this study.
 - 5 For more information, see C. Russell et al., *Recognizing the Value of Energy Efficiency's Multiple Benefits* (Washington, DC: ACEEE, 2015).
 - 6 For a more comprehensive discussion on successful low-income utility programs, see R. Cluett, J. Amann, and S. Ou, *Building Better Energy Efficiency Programs for Low-Income Households* (Washington, DC: ACEEE, 2016).
 - 7 For a more comprehensive discussion of best practices in multifamily energy efficiency programs, see K. Johnson, *Apartment Hunters: Programs Searching for Energy Savings in Multifamily Buildings* (Washington, DC: ACEEE, 2013).
 - 8 See M. Kushler, S. Nowak, and P. Witte, *A National Survey of State Policies and Practices for Evaluation of Ratepayer Funded Energy Efficiency Programs* (Washington, DC: ACEEE, 2012).

Introduction



This report analyzes energy affordability in cities across the United States, focusing on the high home energy burdens faced by select groups in major metropolitan areas. As defined in this study, a household's energy burden is its total annual utility spending (electric, gas, and/or other heating fuel) as a percentage of total annual gross household income. We focus on households in select cities due to the high concentration of poverty in cities, as well as the availability of city-level data.⁹ However households in rural areas also suffer from high energy burdens (McCormick 2015). Our focus on cities does not imply that high energy burdens are not a serious issue in rural communities.

Years of analyzing home energy burdens by the firm of Fisher Sheehan & Colton have determined that low-income households pay proportionally more than the average household for energy (Fisher Sheehan & Colton 2013). Our analysis builds on this research as we look more closely at the energy burden of specific household groups. For low-income families, the majority of household income goes toward rent, transportation, and energy, in that order (CNT 2016).¹⁰ In this study, we measure only home energy burden,

which includes all spending on a home's energy utility bills. Spending on rent, water, and transportation is outside the scope of this analysis.

Annual energy bills may be affordable for one family but not for another due to differences in income. For example, a low-income family and middle-income family may pay the same \$1,800 per year on utilities (\$150 monthly average), but for the low-income family, this will be a larger burden on the household.

The data we examine show that the median energy burden for low-income households is more than two times that of the median household (7.2% and 3.5%, respectively), and three times greater than higher income households (2.3%).

This utility bill may represent 8% of annual household income for the low-income family and only 3% for the middle-income family, indicating that the low-income household faces a disproportionate energy burden. The data we examine show that the median energy burden for low-income households is more than two times that of the median household (7.2% and 3.5%, respectively), and three times greater than higher income households (2.3%). Low-income households also pay more per square foot for energy than the average household. These families experience higher



energy burdens not only because of lower incomes but also because of inefficiencies in the home. This causes families to face trade-offs between energy and other basic necessities, such as food and medical care.

In the first half of this report, our analysis uses data from the US Census Bureau's *American Housing Survey* (AHS), a national sample of households, to systematically measure energy burdens in metro areas. In the second half of the report, we highlight several policies and programs that can reduce the high energy burden of many households, with a particular focus on programs to improve the energy efficiency of low-income housing. We conclude with an overview of recommended strategies for increasing investments in low-income energy efficiency.

While high energy costs are an important social and economic issue, few have systematically analyzed how energy burdens vary across the country and among specific groups. By developing a clearer understanding of the intersection of energy costs and household demographics, stakeholders can better target investments in energy efficiency to create more economically viable and healthy communities.

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- 9 According to the Brookings Institute's 2013 study, poverty is concentrated in metropolitan areas. Of the families at or below the federal poverty level, 7.3 million live in rural areas as compared to 13.4 million in large cities and a growing 16.4 million in suburbs (Ross 2013).
- 10 See the Center for Neighborhood Technology's Housing + Transportation Index for more information on housing and transportation affordability: www.cnt.org/tools/housing-and-transportation-affordability-index.

Causes and Effects of High Home Energy Burden

What Is a High Home Energy Burden, and Why Is It Important?

There is no widely accepted value or threshold that establishes whether a household faces a high or unaffordable energy burden. Some researchers suggest home energy bills are unaffordable when they represent more than 6% of a household's annual gross income; others suggest a threshold of at least 10 or 11% of a household's annual gross income (Fisher Sheehan & Colton 2015; Heindl 2015; Hernández and Bird 2010).¹¹ Fisher Sheehan & Colton recommends using an affordability standard of 6% of gross household income based on the idea that a household can afford to spend about 30% of income on shelter costs and that about 20% of shelter costs are used for energy bills. Meanwhile, the Applied Public Policy Research Institute for Study and Evaluation (APPRISE) uses a model that identifies a severe shelter burden as 50% or more of income, and energy costs as about 22% of shelter costs.¹² Using this approach, APPRISE

suggests that analysts use 11% of income as an indicator of high energy burden (APPRISE 2007). Other researchers and policymakers use the area median energy burden as the threshold for affordable energy. For example, the Nevada Percentage of Income program indicates that low-income home energy burden should be no higher than that of a median-income household (Nevada 2013). Others suggest that high energy burden should be defined as twice the median (Liddell et al. 2012; Moor 2012). When we discuss high energy burden in this report, we refer to households with an energy burden greater than the city's median energy burden.

As in the case of housing and transportation costs, low-income households spend a greater proportion of their income on energy costs compared with the average household.

The families who are the worst off—such as those with extremely low incomes or who face sudden economic



hardship—often suffer from high rates of arrearages and potential utility shutoffs due to unpaid energy bills. These families often live in older, less efficient housing stock, which means that their homes require more energy for heating and cooling than newer, more efficient housing (Penney and Kloer 2015). Due to lack of savings, disposable income, and access to credit, low-income households also have fewer choices in regard to housing options, with many low-income families living in units with structural deficiencies that can make energy retrofits not viable. These families also experience greater barriers to upgrading housing stock with traditional efficiency measures, especially in multifamily buildings where the majority of low-income residents are renters (EPC 2013a).

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physical, economic, policy, and behavioral factors that cause high energy burden.

Causes of High Home Energy Burden

Numerous factors contribute to a high household energy burden. Commonly reported causes of high utility expenses are inefficiencies in housing, such as poor insulation or air leaks; inefficient heating systems and appliances; lack of control over systems and appliances (e.g., in rental households); lack of access to or information about relevant energy efficiency programs; and lack of knowledge about energy conservation measures. High energy burden can also be caused by income reductions, such as loss of employment or support, or an increase in utility bills, such as with additional children or adult household members. In table 1, we list a range of possible

Even though they spend a larger proportion of their income on energy than the average home, low-income households typically spend less on energy overall. According to the US Energy Information Administration's 2009 *Residential Energy Consumption Survey*, low-income households spend on average \$1,690 annually on energy bills, while the average non-low-income household spends \$2,134 per year (EIA 2009).¹³ However low-income utility bills are lower not because low-income households are more efficient, but often because they live in smaller spaces.

At the same time, low-income households spend much more per square foot on utilities, with an average cost of \$1.23 per square foot for low-income households

TABLE 1. Drivers of household energy burden

Type of driver	Examples
Physical	Inefficient and/or poorly maintained HVAC systems
	Heating system and fuel type
	Poor insulation, leaky roofs, and inadequate air sealing
	Inefficient large-scale appliances (e.g., refrigerators, dishwashers) and lighting sources
	Weather extremes that raise the need for heating and cooling
Economic	Chronic economic hardship due to persistent low income (see text box "Income Inequality and Energy Affordability")
	Sudden economic hardship (e.g., severe health event or unemployment)
	Inability or difficulty affording the up-front costs of energy efficiency investments
Policy	Insufficient or inaccessible policies and programs for bill assistance, weatherization, and energy efficiency for low-income households
	Certain utility rate design practices, such as high customer fixed charges, that limit the ability of customers to respond to high bills through energy efficiency or conservation
Behavioral	Lack of access to information about bill assistance or energy efficiency programs
	Lack of knowledge about energy conservation measures
	Increased energy use due to age or disability

versus \$0.98 for non-low-income households (EIA 2009). The higher energy cost per square foot in low-income households appears to be, at least in part, a function of energy use, household/appliance efficiency, and unit size. Low-income households make up the majority of multifamily rentals, and families who rent tend to use more energy on average than owner-occupied homes, due in part to the difficulties renters face in regard to energy efficiency investments (Carliner 2013). In addition, the structure and appliances are less efficient in low-income housing (Penney and Kloer 2015). For example, low-income households are more likely to have older and less efficient appliances such as refrigerators and washing machines (EIA 2013). Finally, energy consumption is typically spread over a smaller area in low-income households, which are on average smaller than the average home (Census Bureau 2013a).

Investing in energy efficiency upgrades is often more challenging for low-income households than for higher-income households. For renters, of which the majority are low-income, landlords who do not pay for utilities may not be motivated to invest in efficiency upgrades, and renters may not want to invest, unsure if their

tenure will be sufficient to recoup the investment. In many cases, low-income home and building owners are not able to afford the up-front investment needed to upgrade housing stock and equipment. The type of heating system installed in a building will also influence energy burden, as certain heating technologies are more expensive than others. Later in this report, we discuss strategies for overcoming the up-front barriers to energy efficiency investments for low-income households.

Customers who have difficulty paying their bills may ultimately contribute to additional utility costs that can increase utility bills for all customers. For example, the utility's costs for covering arrearages, bill payment accommodations, and shutoffs are distributed to all ratepayers. Therefore, customers' inability to meet monthly utility payments may lead to higher costs for the utility, which can lead to even higher home energy burdens for all households.

A recent trend toward raising fixed monthly charges on customer utility bills also threatens energy affordability, especially for low-income customers (Kind 2015). Fixed charges are generally applied to all bills equally, or based on peak demand, and are not related to the volume of energy usage. Shifting costs to fixed charges and away from the amount of energy use itself acts as a disincentive for energy efficiency and reduces the ability of the customer to save money by conserving energy (Whited, Woolf, and Daniel 2016). Increases in energy bills due to higher fixed charges pose a real threat to already overburdened households, negating their efforts to avoid high energy bills by reducing consumption. Strategies aimed at improving energy affordability must also address the issue of rising fixed charges and their impacts on low-income customers.

Therefore, customers' inability to meet monthly utility payments may lead to higher costs for the utility, which can lead to even higher home energy burdens for all households.

INCOME INEQUALITY AND ENERGY AFFORDABILITY

If income does not increase for all households on par with changes in energy costs, household energy burden for low-income and disadvantaged households will increase in future years. In the largest US cities, income inequality continues to rise and consistently remains higher than the national average (Stone et al. 2015). Between 1979 and 2007, the average income of the bottom 99% of households grew by 18.9%, while the average income of the top 1% of households grew by 200.5% (Sommeiller and Price 2015; Desilver 2015). According to a 2016 Brookings report, declining incomes are an influential factor in present-day inequality, as most households in cities experience growing income inequality between the top 5% and bottom 20% of households (Berube and Holmes 2015). Slow income growth—or even real income decline at the lowest levels—can lead to more extensive economic hardship and unaffordable energy costs. From 2004 to 2014, average US residential electricity prices increased from 9 cents/kWh to 12.5 cents/kWh, an increase of 39% (EIA 2016a). In contrast, average adjusted income grew from \$29,900 in 2004 to \$30,180 in 2014, an increase of 0.9% (Census Bureau 2014). If energy prices continue to increase more rapidly than income, energy burden will continue to grow for vulnerable households.

Families suffering from high energy burdens also tend to experience stress from living in constant fear of losing necessary electricity and gas service due to inability to pay their bills.

Effects of High Energy Burden

Addressing energy affordability can help to break the cycle of poverty and improve economic development, educational achievement, and public health. High energy burden can cause very real mental and physical health problems for household members due to thermal discomfort, inadequate lighting, unsafe housing conditions, and constant financial and social stress. Individuals who experience high energy burdens may cut back on necessary energy use and inadequately heat, cool, and light their homes, which can result in many negative health consequences.

Studies have found that living in homes that are not properly heated or cooled increases cases of asthma, respiratory problems, heart disease, arthritis, and rheumatism (Heyman 2011; Hernández and Bird 2010; Liddell and Morris 2010; Wright 2004). Children and the elderly are more susceptible to these health impacts. Families suffering from high energy burdens also tend to experience stress from living in constant fear of losing necessary electricity and gas service due to inability to pay their bills.

For many low-income families, this compounds with other stresses, such as difficulty accessing health care, fear of losing their housing, and living in potentially unsafe buildings and neighborhoods. These constant stresses cause serious health problems.

Researchers have also found that high energy burdens affect mental health by creating more stressful environments, increasing social isolation, and negatively impacting educational achievement and emotional resiliency (Li et al. 2014; Dear and McMichael 2011; Liddell and Morris 2010). Families that have trouble paying their energy bills may sacrifice nutrition, medicine, and other necessities in order to avoid shutoffs. These effects are especially detrimental to the physical and mental development of children. Living in underheated homes puts adolescents at double

the risk of respiratory problems and five times the risk of mental health problems (Dear and McMichael 2011). Families may also cope with high energy burdens by heating fewer rooms in their home and reducing lighting use (Bruner Spitzer, and Christanell 2012). These stresses can hinder the ability of adolescents to study and complete school assignments, which negatively affects their academic success.

High energy burdens can also cause societal problems extending well beyond the household. For example, 5.5% of low-income customers in California experienced disconnections for nonpayment in 2011 as compared with 2.9% of non-low-income customers. Half of the disconnected households owed less than \$315, and 6% of those disconnected did not reconnect within the year. Because of the disconnections, some of these families improvised hazardous methods to light and heat their homes (Watts-Zagha 2011). Additionally, researchers conducted studies in northern Kentucky, St. Paul, and Philadelphia and found utility shutoffs to be one of the primary factors that led to homelessness (Vick and Norton 2008).

Ultimately, the drivers and effects of high energy burden create a negative feedback loop that can become a trap that is hard to escape. Various factors associated with low income contribute to a high energy burden. In turn, higher utility bills require more of a family's income and make them more likely to remain in poverty.

The troubling reality is that many households resort to high-cost payday lending in order to pay their utility bills, which can further exacerbate the cycle of poverty. A 2012 study found that paying utility bills was the most common reason why individuals took out a payday loan (Levy and Sledge 2012). These loans are small, short-term loans with high interest rates that can make repayment difficult and costly. By addressing energy affordability, policymakers can help to break the cycle of poverty and increase economic development, educational achievement, and public health.

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- 11 For more information on defining the energy affordability gap, see Fisher Sheehan & Colton's Home Energy Affordability Gap research at www.homeenergyaffordabilitygap.com. They provide a model that calculates the monetary gap between actual and affordable home energy bills at the county level for segments of the low-income population. Their model includes factors left out of this research, such as household size, fuel mix, and heating and cooling degree days.
- 12 In this context, shelter costs include all expenses relating to housing, such as rent or mortgage payments, condominium fees, utilities, and property taxes.
- 13 In 2009, the US Energy Information Administration's Residential Energy Consumption Survey defined "low-income" as less than or equal to 150% of the federal poverty line (FPL). This survey compiles data from a household survey and energy supplier survey and uses estimates of consumption and expenditures.

The US Home Energy Burden Landscape



We took a snapshot of energy burdens across the largest US metropolitan areas, with a focus on select groups. These data have helped us understand the disproportionate impact of energy burden on vulnerable households and the extent to which this experience varies regionally.

Methodology

Research shows that low-income households, especially renters and minority households, face disproportionate energy cost burdens (Hernández 2015). As part of this analysis, we focus on the energy burdens experienced by four groups of households:

- *Low-income households*: those who report an annual gross household income at or below 80% of the area median income, including both single- and multifamily households¹⁴
- *Low-income multifamily households*: those who report an annual gross household income at or below 80% of the area median income and reside in a building with five or more units

- *Minority households*: African-American and Latino families¹⁵
- *Renting households*

We analyzed data from the US Census Bureau and US Department of Housing and Urban Development's (HUD) *American Housing Survey* (AHS) in 2011 and 2013. This survey samples households across the US to gather information on housing stock characteristics, housing and energy costs, occupant characteristics, and other related information (Census Bureau 2011 and 2013a). The survey is conducted every two years in 25 to 30 metro areas; the 2011 and 2013 surveys contain the most recent city data available. The survey's unit of analysis is the household, and interviewees self-report

TABLE 2. Metropolitan statistical areas (MSAs) included in analysis, by region

Northeast	Southeast	Midwest	South Central	Southwest	Northwest	California
Baltimore	Atlanta	Chicago	Austin	Denver	Portland	Los Angeles
Boston	Birmingham	Cincinnati	Dallas	Las Vegas	Seattle	Riverside
Hartford	Charlotte	Cleveland	Fort Worth	Phoenix		Sacramento
New York City	Jacksonville	Columbus	Houston			San Diego
Philadelphia	Louisville	Detroit	Oklahoma City			San Francisco
Pittsburgh	Memphis	Indianapolis	San Antonio			San Jose
Providence	Miami	Kansas City				
Washington, DC	Nashville	Milwaukee				
	New Orleans	Minneapolis				
	Orlando	St. Louis				
	Richmond					
	Tampa					
	Virginia Beach					

all collected information. For this study, we analyzed individual household-level data to measure energy burden in 48 of the largest US metropolitan statistical areas (MSAs), as detailed in table 2.¹⁶

Data Limitations

We experienced a few limitations in our analysis that should be considered when examining the results. While city samples are representative, these data represent only a snapshot in time (2011 and 2013). Therefore, the results may not reflect future energy burdens. Volatile gas or oil prices, stagnant wages, and rising electricity prices in past and future years could also significantly impact home energy burden. We did not adjust energy bills to reflect the difference in energy prices between 2011 and 2013 (EIA 2016b).

These data are also self-reported. Every household in the sample provided self-reported estimates of average monthly electricity and heating fuel bills, as well as estimated household income and household size. Even so, our findings are comparable to EIA's 2009 *Residential Energy Consumption Survey* (EIA 2009). EIA found that the average household spent \$2,134 and low-income household spent \$1,690 annually on energy bills, which is similar to our findings of \$1,932 and \$1,692 median annual bills for the average household and low-income household.

We also limited our sample to include only those households that reported positive income, paid their electricity bill directly, and also directly paid for their main heating fuel (electricity, gas, fuel oil, wood, coal, kerosene, or other).¹⁷ Due to a lack of data necessary to calculate energy burden, our analysis necessarily excludes two categories of low-income homes that often have a high energy burden: households without any reported income and households in master-metered apartment buildings where energy costs are paid by the landlord and incorporated into monthly rent. Before we limited the sample sizes, the average city sample size was 4,190 households. This was reduced to 2,700 households after controlling for the above factors.

Measuring Home Energy Burden

We calculated energy burden as follows:

$$\text{HOME ENERGY BURDEN} = \frac{\text{TOTAL ENERGY UTILITY SPENDING}^{18}}{\text{TOTAL GROSS HOUSEHOLD INCOME}}$$

We first determined the energy burden for each household in our data set, and then calculated the median burden for each of the four household groups in each metro area (see Appendix B).¹⁹

We also examined the households at the highest energy burden quartile in each group. (Simply put, 25% of households have an energy burden equal to or greater than the highest energy burden quartile value.) Appendix C shows the highest energy burden quartile value alongside the median. This additional analysis of the highest quartile gives a better sense of the burden placed on the most vulnerable households in each metro area, without the median burden masking the extremes.

Because different cities have different median energy burdens, comparing vulnerable groups between cities becomes difficult and potentially misleading. To provide a way to compare groups between cities, we created a metric that measures the proportion of each group that experiences an energy burden greater than or equal to twice the metropolitan area's median energy burden. We report these results in Appendix D.

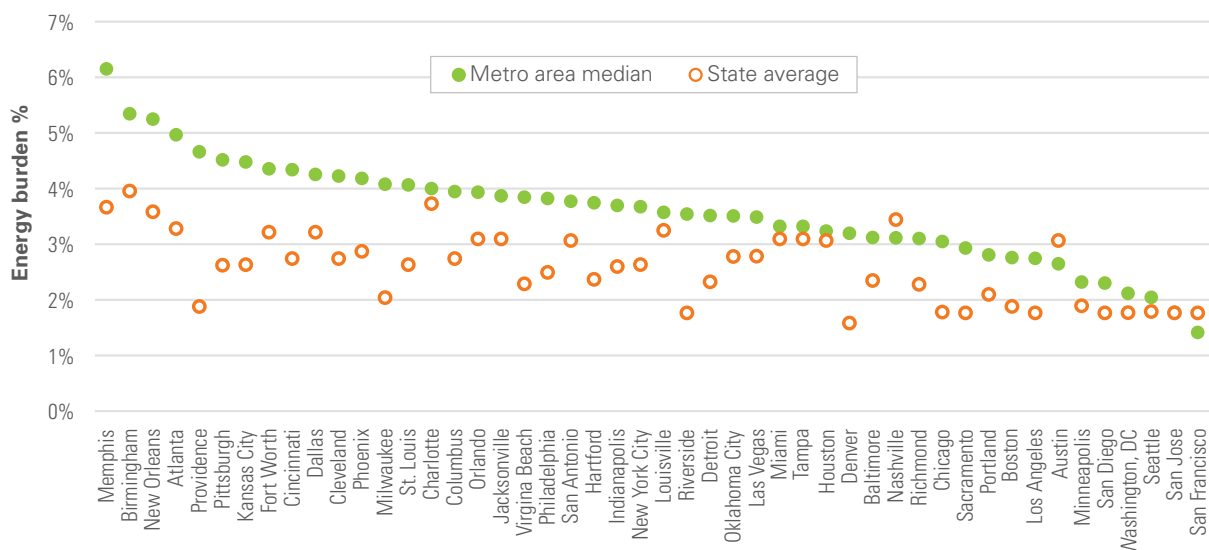


Results: Energy Burdens in US Cities

Figure 1 compares the median energy burden in each metro area with the average for its state. Because we could not calculate state energy burdens using the AHS data set, we used EIA and US Census Bureau data to make these calculations. Most cities have higher energy burdens than the state average.²⁰ The five cities

with the greatest difference between the city and state energy burden were Providence, Memphis, Milwaukee, Pittsburgh, and Kansas City. In these cities, the median metro-area energy burden ranged from 1.9 to 2.8 percentage points greater than the overall burden for the state.

FIGURE 1. Median energy burden for metro area and average energy burden for state households. Metro areas are ranked by their median energy burden. We used American Housing Survey (AHS) data from 2011 and 2013 to calculate the median energy burden for the metro areas (Census Bureau 2011 and 2013a). We also used data from the 2011 and 2013 US Energy Information Administration (Annual Electric Power Industry Report, EIA-861) and average historical income from 2011 and 2013 (Census Bureau 2013b) to calculate the average energy burden for the states.



Metro areas also varied by their median energy burden, ranging from more than 6% to less than 1.5%. The cities with the highest median energy burdens were Memphis (6.2%), Birmingham (5.3%), New Orleans (5.3%), Atlanta (5.0%), and Providence (4.7%). These metro areas—and others with higher median energy burdens—differ from one another in terms of typical energy costs. Overall, metro areas in the Southeast and Midwest regions faced the highest median energy burdens.

It is noteworthy that many of the metro areas in the Southeast—a region with relatively low electricity prices and lower average incomes—faced the highest energy burdens compared with cities nationally. As we describe further in the text box “The Relationship between Energy Burden and Energy Prices,” low electricity prices do not equate to low bills. Figure 2 provides a visual

FIGURE 2. Median metro-area energy burden for all households

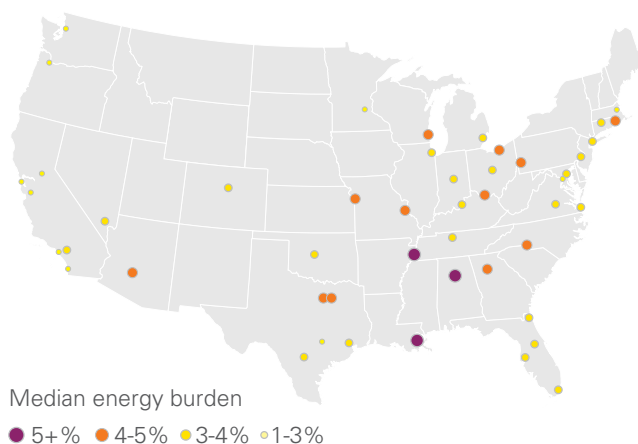


TABLE 3. Median income, utility bill, energy burden, and unit size for households based on income type, building type, building ownership, and household race for groups across all metro areas

	Household type	Median annual income	Median size of unit (square feet)	Median annual utility spending	Median annual utility costs per square foot	Median energy burden ¹
Income type	Low-income ² (≤80% AMI ³)	\$24,998	1,200	\$1,692	\$1.41	7.2%
	Non-low-income	\$90,000	1,800	\$2,112	\$1.17	2.3%
Building ownership	Low-income multifamily (≤80% AMI)	\$21,996	800	\$1,032	\$1.29	5.0%
	Non-low-income multifamily	\$71,982	950	\$1,104	\$1.16	1.5%
	Renters	\$34,972	1,000	\$1,404	\$1.40	4.0%
	Owners	\$68,000	1,850	\$2,172	\$1.17	3.3%
Head-of-household race	White	\$58,000	1,600	\$1,956	\$1.22	3.3%
	African-American	\$34,494	1,290	\$1,920	\$1.49	5.4%
	Latino	\$39,994	1,200	\$1,704	\$1.42	4.1%
All households	N/A	\$53,988	1,573	\$1,932	\$1.23	3.5%

¹ Energy burden is the percentage of household income that is spent on energy bills. To calculate median energy burden, we calculated energy burden for each household, then took the median. This value differs from the median energy burden that is calculated using median annual utility spending and income.

² Low-income includes both single- and multifamily households.

³ Area median income (AMI) is the median dollar amount that divides the population into two equal parts.

Source: American Housing Survey (Census Bureau 2011 and 2013a).

representation of the median energy burdens in metro regions across the country. See Appendix B for the median energy burden values for each city.

The five cities with the lowest median energy burdens were San Francisco (1.4%), San Jose (1.8%), Seattle (2.1%), Washington, DC (2.1%), and San Diego (2.3%). In these cities, households spent less of their overall income on utility bills, which could be due to a combination of lower energy bills and higher household income throughout the metro areas, and/or more efficient buildings and energy use.

Currently, we cannot make causal arguments about why a city has either a high or low energy burden. Factors such as the efficiency of housing stock and the effectiveness and reach of energy efficiency investments, among other factors, may play a role. More research is needed to understand the drivers of energy burdens in specific geographical areas.

Results: Energy Burden Trends by Household Group

We compared various household groups in our sample to identify overall energy burden trends. Table 3 includes median income, housing unit size, annual utility bills, annual utility spending per square foot, and energy burden for these groups across all metro areas.

Median energy burdens in low-income households were more than three times higher than in non-low-income households (7.2% and 2.3%, respectively). Higher energy burdens result in part from lower income. The data also show these households have

higher energy cost per square foot than the average household, which could indicate lower efficiency of the housing unit itself. We discuss this point in greater detail below. The situation for multifamily households was similar. The median low-income multifamily household experienced an energy burden more than three times higher than that of the median non-low-income multifamily household (5.0% and 1.5%, respectively) and had higher utility cost per square foot.²¹ Renters were also disproportionately impacted. The median renter experienced an energy burden greater than that of the median owner (4.0% and 3.3%, respectively).

We also found that energy burdens were related to the race of householders. On average, African-American and white households paid similar utility bills, but African-American households experienced a median energy burden 64% greater than white households (5.4% and 3.3%, respectively). Latino households paid lower utility bills, on average, than African-American and white households did, yet they experienced a median energy burden 24% greater than white households (4.1% and 3.3%, respectively).

Looking at how inefficient housing contributes to this issue, we calculated what the energy burdens for various categories would be if their housing stock were as efficient as the median—i.e., if their energy expenditures per square foot were the same as the median for all households. Then, for each category, we calculated the proportion of the excess energy burden (the difference between category median burdens and the all-household median burden) that would be eliminated if their housing stock were brought up to the efficiency standard of the all-household median.

THE RELATIONSHIP BETWEEN ENERGY BURDEN AND ENERGY PRICES

Many people confuse their high energy bills with high electricity and gas prices. However our findings show that low prices do not necessarily mean low bills. Consider that, in 2014, three of the five states with the highest average monthly utility bills for households—Alabama, South Carolina, and Mississippi—were states with average (not high) electricity prices and a wide range of gas prices. Our study found that the Southeast and Midwest regions, while having among the lowest average prices, also had the highest average metropolitan energy burdens. In 2014, New Orleans and Memphis were among the five cities in our sample with the lowest average electricity prices (both \$0.10/kWh) and average gas prices (\$10.9 and \$10.1/1,000 ft³). Even with these low prices, these two cities are in the top three for highest average energy burden for all households, at 5.27% and 6.18%, respectively. Therefore, it is important to recognize that factors beyond prices—such as lower incomes and inefficient housing stock—contribute to high energy bills.

We found that for all low-income households and for multifamily low-income households, bringing their housing stock up to the efficiency level of the median household would eliminate 35% of their excess energy burden. As one might expect, the energy burdens of low-income households are driven in large part by their low-income status. However more than one-third of their excess energy burden was caused by inefficient housing stock. Bringing their homes up to median efficiency would lower their energy burden from 7.2% to 5.9%. For African-American and Latino households, 42% and 68% of the excess energy burden, respectively, was due to inefficient homes. For renters that number was 97%, meaning that almost all of their excess energy burden could be eliminated by making their homes as efficient as the median.

Far from being an intractable problem related to persistent income disparity, the excess energy burdens they face are directly related to the inefficiency of their homes. This is important not only for understanding how best to address the problem for various populations, but also to correct any misconceptions that the energy burden problem is a

We found that for all low-income households and for multifamily low-income households, bringing their housing stock up to the efficiency level of the median household would eliminate 35% of their excess energy burden.

driven purely by income, a perception that might be reinforced by the stark differences in incomes shown in table 3.

Results: Energy Burdens by City and Household Groups

When we examined specific demographic groups across different cities, we found that many of these groups experienced energy burdens greatly exceeding

TABLE 4. Energy burdens for demographic groups in the 10 cities with the highest energy burdens

	All households	Low-income households*	Low-income multifamily households	African-American households	Latino households	Renting households
1	Memphis (6.2%)	Memphis (13.2%)	Memphis (10.9%)	Memphis (9.7%)	Memphis (8.3%)	Memphis (8.6%)
2	Birmingham (5.3%)	Birmingham (10.9%)	Birmingham (8.7%)	Pittsburgh (8.3%)	Providence (7.3%)	Birmingham (7.3%)
3	New Orleans (5.3%)	Atlanta (10.2%)	Atlanta (8.3%)	New Orleans (8.1%)	Philadelphia (7.3%)	Atlanta (6.8%)
4	Atlanta (5.0%)	New Orleans (9.8%)	Providence (7.1%)	Kansas City (7.9%)	Kansas City (6.6%)	New Orleans (6.3%)
5	Providence (4.7%)	Providence (9.5%)	Pittsburgh (7.1%)	Birmingham (7.7%)	Atlanta (6.6%)	Providence (6.2%)
6	Pittsburgh (4.5%)	Pittsburgh (9.4%)	New Orleans (6.9%)	Milwaukee (7.4%)	Birmingham (6.6%)	Kansas City (6.1%)
7	Kansas City (4.5%)	Dallas (8.8%)	Columbus (6.5%)	St. Louis (7.4%)	Phoenix (6.0%)	Pittsburgh (6.0%)
8	Fort Worth (4.4%)	Philadelphia (8.8%)	Dallas (6.5%)	Cleveland (7.0%)	Dallas (6.0%)	Cincinnati (6.0%)
9	Cincinnati (4.3%)	Kansas City (8.5%)	Indianapolis (6.5%)	Cincinnati (6.9%)	Fort Worth (5.7%)	St. Louis (5.9%)
10	Dallas (4.3%)	Cleveland (8.5%)	Kansas City (6.3%)	Atlanta (6.6%)	Detroit (5.7%)	Cleveland (5.5%)

* Low-income includes both single- and multifamily households.

the city median, ranging as high as 13% for some groups (see Appendix B). Table 4 gives details for the 10 cities with the highest overall median energy burdens, as per figure 1. For example, low-income households face the greatest energy burden in Memphis (13.2%), Birmingham (10.9%), and Atlanta (10.2%), and African-American households face the greatest energy burden in Memphis (9.7%), Pittsburgh (8.3%), and New Orleans (8.1%).

For example, the median low-income energy burden in Atlanta was 10.2%, meaning that half of the city's low-income households experienced an energy burden greater than 10.2%. Looking at the highest energy burden quartile in Atlanta, we can see that 25% of the low-income population experienced an energy burden greater than or equal to 18.2%. This is more than three times the city median of 5.0%. Results for the 10 cities with the highest energy burdens are detailed in table 5.

Results by Energy Burden Quartile

We also calculated energy burden for the highest energy burden quartile households in each group (see Appendix C). Simply looking at the median does not provide insight into the distribution across the group and does not properly represent the range of experiences of those who are the worst off within these groups. We can better understand this by comparing the energy burden of the household at the median and the highest quartile of energy burdens.

In Atlanta, we can see that 25% of the low-income population experienced an energy burden greater than or equal to 18.2%. This is more than three times the city median of 5.0%.

TABLE 5. Highest energy burden quartiles in the 10 cities with the highest energy burdens

	All households	Low-income households*	Low-income multifamily households	African-American households	Latino households	Renting households
1	Memphis (12.8%)	Memphis (25.5%)	Memphis (21.8%)	Memphis (19.4%)	Memphis (15.9%)	Memphis (18.5%)
2	Birmingham (10.8%)	New Orleans (18.9%)	Birmingham (16.2%)	New Orleans (16.4%)	Philadelphia (15.7%)	Birmingham (15.1%)
3	New Orleans (10.0%)	Birmingham (18.8%)	Atlanta (15.7%)	Kansas City (16.2%)	Pittsburgh (12.4%)	Atlanta (13.3%)
4	Atlanta (9.7%)	Atlanta (18.2%)	Pittsburgh (15.7%)	Pittsburgh (16.1%)	Kansas City (12.0%)	St. Louis (12.9%)
5	Providence (8.7%)	Philadelphia (16.7%)	Chicago (14.6%)	Cincinnati (15.6%)	Providence (11.7%)	New Orleans (12.6%)
6	Pittsburgh (8.6%)	Providence (16.7%)	Cincinnati (13.0%)	Milwaukee (15.5%)	Atlanta (11.5%)	Cincinnati (12.1%)
7	Cincinnati (8.5%)	Pittsburgh (15.7%)	St. Louis (12.9%)	Birmingham (15.4%)	Hartford (11.1%)	Cleveland (11.9%)
8	Kansas City (8.4%)	Cincinnati (15.5%)	Cleveland (12.3%)	Chicago (15.3%)	Phoenix (10.7%)	Pittsburgh (11.9%)
9	Philadelphia (8.3%)	Detroit (15.3%)	Hartford (11.8%)	Detroit (14.8%)	Birmingham (10.4%)	Providence (11.7%)
10	Dallas (8.2%)	St. Louis (14.8%)	Fort Worth (11.4%)	St. Louis (14.4%)	Detroit (10.2%)	Kansas City (11.7%)

* Low-income includes both single- and multifamily households.

FIGURE 4. Low-income ($\leq 80\%$ AMI) household energy burdens for the median, highest energy burden quartile, and lowest energy burden quartile households for each metro area. The orange bars represent the beginning of the quartile of low-income households with the lowest energy burden. The blue bars represent the beginning of the quartile of low-income households with the highest energy burden. These data include both single- and multifamily low-income households.

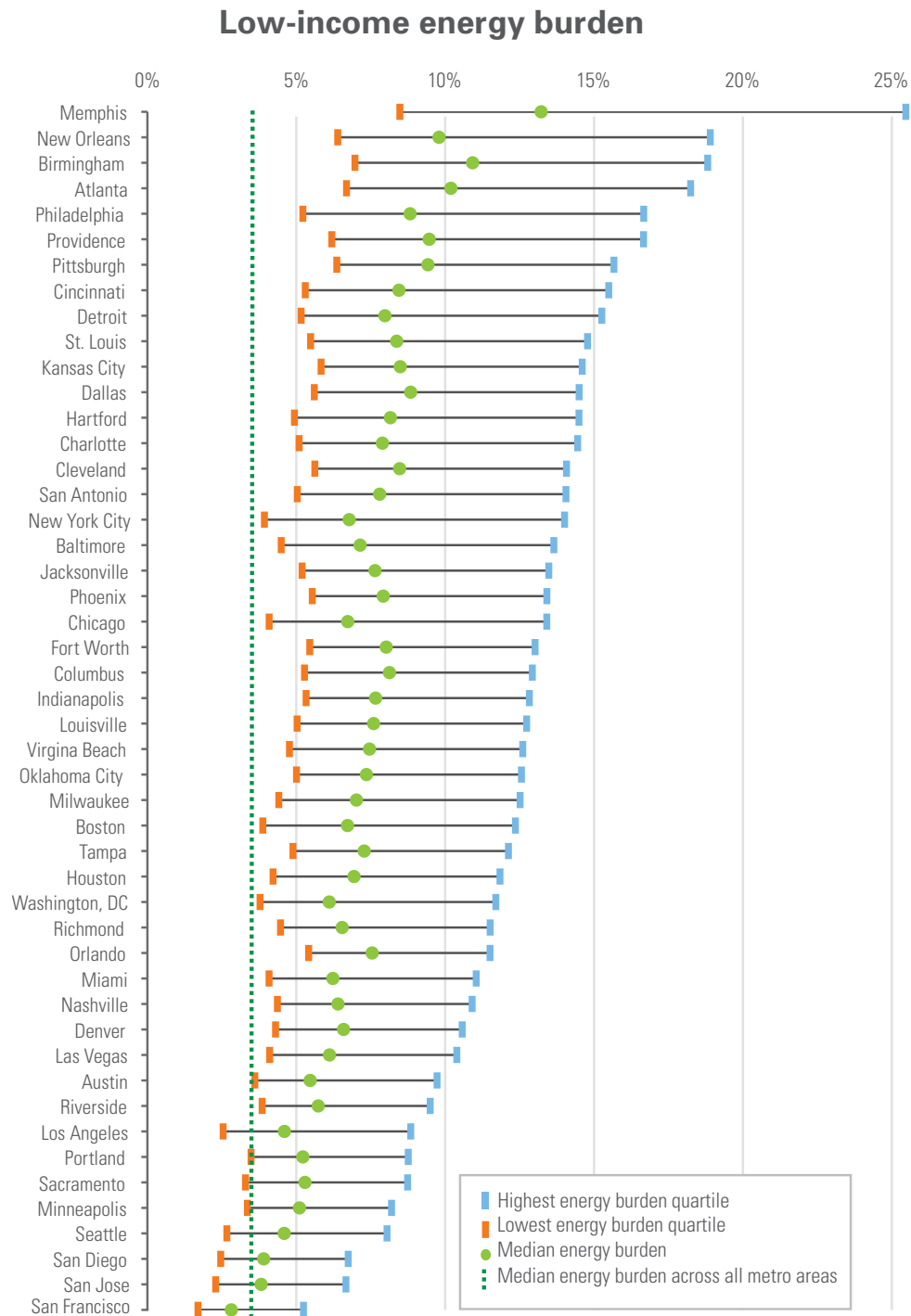


Figure 4 provides a more detailed representation of the energy burden faced by low-income households in each metro area. Across the metro areas in our sample, based on our definition of “low-income” ($\leq 80\%$ of AML), low-income households made up 44% of all households included in our analysis (see Appendix A). Figure 4 highlights the household energy burdens for the highest and lowest quartiles, as well as the median energy burden for all low-income households. For comparison, the figure also includes a line indicating the median energy burden for all households across all metro areas in the sample.

For low-income households, the range of energy burdens varies greatly across and within cities. For example, one-fourth of low-income households in Nashville had an energy burden below 4.4%, one-fourth had an energy burden between 4.4% and the median of 6.4%, one-fourth had an energy burden between 6.4% and 10.9%, and one-fourth had a burden greater than 10.9%. The data, presented in this way, are useful for understanding the depth of the low-income energy burden in cities. In 17 cities, a quarter of low-income households experienced an energy burden greater than 14%.

In 17 cities, a quarter of low-income households experienced an energy burden greater than 14%.



Additionally, we assessed the energy burden for certain households and examined the proportion of residents that experienced an energy burden greater than or equal to twice the city median. We include this analysis in Appendix D. For all the cities in the sample, at least 38% of low-income households experienced an energy burden that was twice the city median.

Results: Regional Energy Burden Trends

In this section, we examine regional energy burden data for our select groups in more detail. Figure 5

shows the regional median energy burden for each group and for all households. In Appendix E, we include similar graphs for each region.

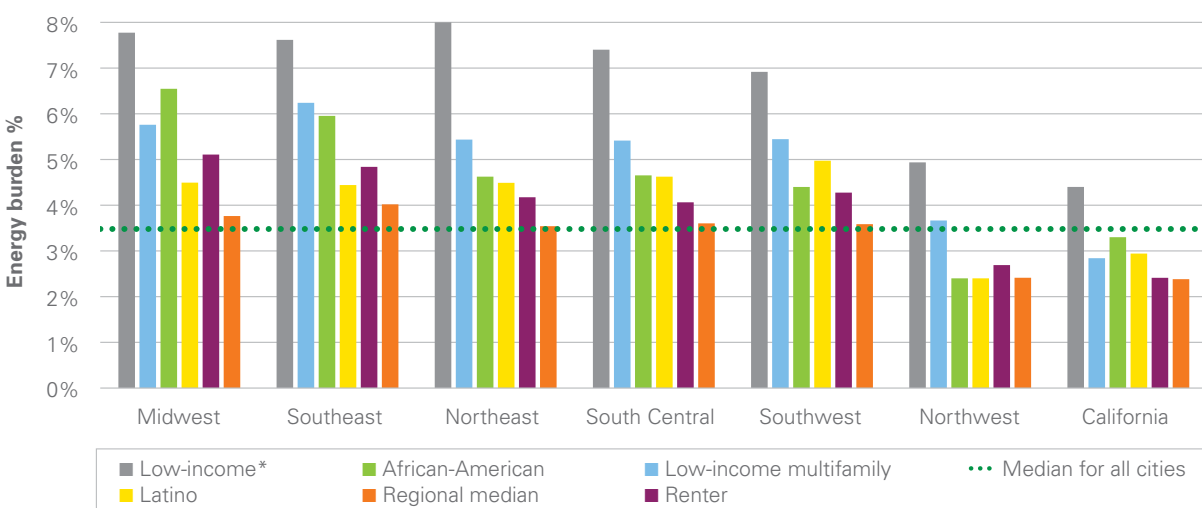
Metro areas in the Midwest and Southeast had the highest median energy burdens across all groups, with African-American and low-income multifamily households the worst-off in these regions.

Low-income households—including both single- and multifamily—had the highest energy burden in each region and were the worst-off across Northeastern metro areas. While we cannot attribute with certainty

REGIONAL TRENDS IN UTILITY ENERGY EFFICIENCY INVESTMENTS

We found that many cities with little to no investment in utility energy efficiency programs also experienced higher average energy burdens. Programs that help households save energy are often administered by the local utility. Utilities taking the lead on energy efficiency provide an array of programs for commercial and residential customers. Some localities and states will adopt energy savings targets or requirements to encourage and guide utility program spending and design. According to the rankings in *The 2015 City Energy Efficiency Scorecard* issued by ACEEE, the utilities with the least spending on energy efficiency programs were those serving southeastern cities. All of the southeastern cities in the *Scorecard* fell within the bottom 40% of the ranking (Ribeiro et al. 2015b). The cities with the most energy efficiency investment in 2015 were Boston, Minneapolis, Portland (Oregon), Chicago, and San Francisco. However, even when cities do have strong utility programs, there is no guarantee that low-income households will benefit. Information on what types of households are currently being served by energy efficiency programs is crucial to ensuring that these programs reach a diverse set of households.

FIGURE 5. Energy burden of select groups by region, ordered from highest to lowest based on the average of the median energy burdens across all groups.



the drivers of high energy burden within specific regions and cities, we know that numerous factors are at play. Southeastern households have the lowest median incomes in the country, which likely contributes to higher energy burdens. In terms of energy prices, the Southeast, Midwest, and Northwest regions have the lowest average electricity prices, but at the same time, they also have the highest average energy burdens. This indicates that low electricity and gas prices do not necessarily lead to low bills or affordable

energy (see earlier text box “The Relationship between Energy Burden and Energy Prices”). Although we do not know the relative efficiency of housing stock in the Southeast, we do know that the southeastern utilities serving major cities currently have the lowest investment in energy efficiency programs as compared with other regions (see text box “Regional Trends in Utility Energy Efficiency Investments”). Low energy prices therefore do not compensate for the lack of energy efficiency investment or low incomes.

Metro areas in the Midwest and Southeast had the highest median energy burdens across all groups, with African-American and low-income multifamily households the worst-off in these regions.

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- 14 Area median income (AMI) is the median dollar amount that divides the population into two equal parts. HUD uses AMI to determine eligibility for low-income programs based on metropolitan area and household size.
- 15 Sample sizes in some cities for Latino households (Birmingham, Cincinnati, Detroit, Louisville, Pittsburgh, and St. Louis) and African-American households (Portland) were small. See Appendix A for sample sizes for each group by city.
- 16 A metropolitan statistical area (MSA) is a geographical region typically made up of several counties, with a core urban area having a population of 50,000 or more. MSAs, therefore, include a central city and surrounding suburbs. Raleigh and Salt Lake City, two of the top 50 MSAs, were not included in the AHS 2011 and 2013 and therefore were not included in this analysis. See Appendix A for the corresponding year of data for each MSA—either 2011 or 2013.
- 17 See Appendix A for sample sizes for each group studied after filtering for these variables.
- 18 Total utility spending includes average annual spending on electricity and heating fuels, as reported. Total gross household income includes all annual income reported by all household members, including all government assistance.
- 19 By using medians for both income and energy costs, we were able to arrive at a truer median, as the data distributions for income and energy costs differed greatly.
- 20 We should note that we are comparing a median energy burden in metro areas with an average energy burden statewide. By using an average, the data may be skewed toward higher values because there is a zero lower bound on energy burden and no upper bound.
- 21 Single-family low-income households experienced the highest average energy burden of 7.8%. We did not specifically analyze these households in this study.

Policies and Programs to Address High Energy Burdens



In the following sections of this report, we discuss policies and programs that address high energy burdens, with a focus on energy efficiency. Reducing the impact of high energy burden has been a long-standing policy goal at the local, state, and national levels. Policy has focused on three main intervention programs: bill payment assistance, weatherization, and utility-funded efficiency programs (see table 6).

These efforts aim to address the two factors that impact energy burden: low income and high energy bills. Federal, state, local, and utility funding supports these programs as well as other, related programs that focus on health and safety, behavior, and education.²²

Policymakers and program administrators design these programs to address high utility bills, inefficiencies in housing units, and lack of awareness in regard to energy efficiency programs and actions that customers can take.

TABLE 6. Policies and programs for addressing high energy burden

Program type	Program	Funding source
Bill assistance	Low Income Home Energy Assistance Program (LIHEAP)	Federal and state taxpayers
	Other low-income bill assistance programs	Utility ratepayers; private contributions
	Modified rate design, rate discounts or waivers, and modified billing methods	Utility ratepayers
Weatherization	Weatherization Assistance Program (WAP)	Federal and state taxpayers
Energy efficiency	Low-income energy efficiency programs ¹	Utility ratepayers ²

¹ Customer benefit surcharges are collected through customer utility bills. Public utility commissions or city councils set these charges, and the utility uses this money to fund energy efficiency and energy education programs. ² Non-utility entities can also fund low-income energy efficiency programs, such as the Regional Greenhouse Gas Initiative (RGGI), Qualified Energy Conservation Bonds (QECBs), state treasury funding, and general obligation bonds (EPC 2013b; RGGI 2015; Brown 2008).

Funding for low-income programs varies by program type. Figure 6 illustrates the allocation of funding from ratepayer-funded bill assistance and energy efficiency programs, the Weatherization Assistance Program (WAP), and the Low Income Home Energy Assistance Program (LIHEAP). As indicated in the chart, the overwhelming majority of program support—about 81%, or \$6.31 billion—goes toward helping customers pay their utility bills. Energy efficiency programs receive about 14% of program support (\$1.17 billion), and the remaining 5% of program support (\$38 million) is unspecified (LIHEAP Clearinghouse 2016). While bill assistance programs provide important, immediate relief to distressed households, energy efficiency investment appears to be an underutilized strategy for addressing energy affordability. Increased investment, expanded reach, and improved design of energy efficiency programs could better complement bill assistance and weatherization programs.

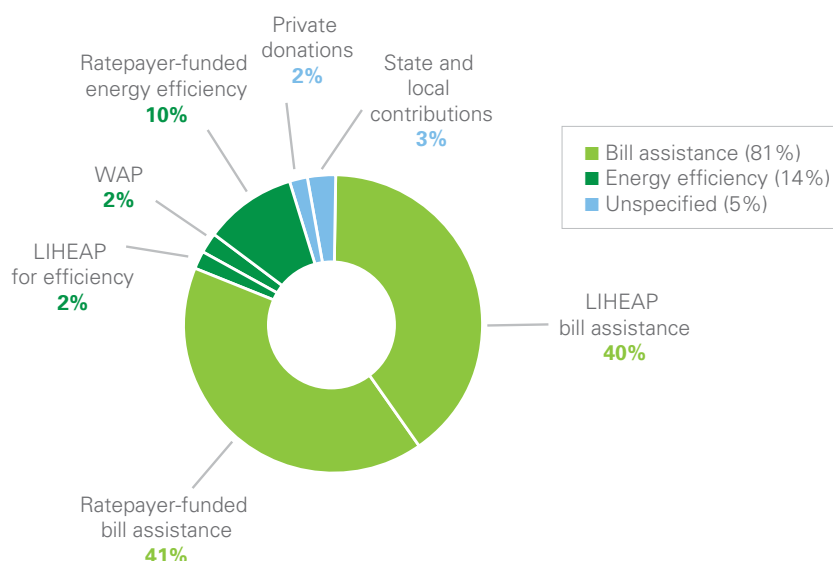
Increased investment, expanded reach, and improved design of energy efficiency programs could better complement bill assistance and weatherization programs.

Assistance Program (LIHEAP) is the primary vehicle for bill assistance. LIHEAP provides funding to states, based on a formula, and then states allocate this funding to qualified households according to established federal parameters. Funds can take the form of direct bill assistance, crisis assistance, support for weatherization programs, or other aid to reduce household energy needs (Perl 2012). The bulk of funding, however, goes toward energy bill assistance and ends up with utilities. States typically determine household eligibility for bill assistance as between 150% and 110% of the federal poverty line, or 60% of the state median income.

Bill Assistance Programs

Bill assistance programs provide financial assistance to help families pay their immediate home energy bills. The federally funded Low Income Home Energy

FIGURE 6. Support for low-income energy needs. Data on ratepayer-funded bill assistance, ratepayer-funded energy efficiency, WAP, and LIHEAP assistance are from 2013. LIHEAP spending on efficiency is approximated based on 6% of LIHEAP funds spent on efficiency in 2006. Data on state and local contributions and private donations are from 2010. Data collected from the LIHEAP Clearinghouse in 2016. Source: Cluett, Amann, and Ou 2016.



LIHEAP serves between 20 and 25% of eligible households, about 7.6 million in 2009 and 8.3 million in 2010 (Jackson 2011). Other bill assistance programs help to meet the overwhelming need, such as voluntary utility customer contributions to cold weather funds and other forms of bill assistance, programs supported by charitable groups, and, in some cases, structured payment programs offered by utilities. Agencies that provide weatherization services may also deliver LIHEAP assistance. In these cases, LIHEAP eligibility can act as a gateway for weatherization and low-income energy efficiency programs. Bill assistance programs remain critical for alleviating the *immediate* energy burden that many households face, but they could be better coordinated with weatherization and other energy efficiency programs to provide upgrades that can reduce energy burden over the long term.

Weatherization Programs

Weatherization programs address the longer-term energy needs of households by making home repairs that reduce high energy bills. By upgrading the efficiency of homes, programs can then reach more customers who need immediate assistance with more persistent intervention. Weatherization programs consist of energy efficiency measures aimed at improving the building envelope, such as weather-stripping doors and windows, air sealing, and installing insulation. In some cases, weatherization includes upgrades or repairs to heating and cooling systems and the reduction of electric baseload consumption through energy efficiency measures such as lighting and appliances, but these measures are less common among typical weatherization programs.

The federal government, state governments, and utilities all fund and sponsor weatherization programs. The US Department of Energy's Weatherization Assistance Program (WAP) historically has been the largest funder of these programs. Because states can choose to allocate funding from LIHEAP toward weatherization programs, LIHEAP funding (as well as state and local funding) supplements WAP in many states. Households with income up to 200% of the

federal poverty line qualify for WAP funding. WAP estimates that 38 million households qualify for the program and that of these, approximately 15 million are good candidates for cost-effective weatherization (WAPTAC 2016). Over the history of the program, WAP has served about 7 million households (Benefits.gov 2015). Numerous factors limit the reach of the federal program, such as funding, capacity of implementing agencies, and the necessity of making health and safety improvements before weatherization can begin.²³

The most effective weatherization programs address the largest household energy uses with the longest sustained savings (e.g., heating and cooling systems), which often have the greatest impact on reducing energy burdens. Low-income housing units can also require substantial structural improvements before energy efficiency measures can be implemented; these can be costly and require large up-front investment. However many researchers have proved these programs to be cost effective in the long run. The Department of Energy determined that, on average, the value of efficiency upgrades is 2.2 times greater than their cost (DOE 2015). This value does not come from energy savings alone, as WAP also aims to improve health, safety, and security for participating households. When program evaluators include all of these multiple benefits into cost-benefit analyses, WAP proves to be a cost-effective solution to improving energy affordability.

Utility Energy Efficiency Programs

Many utilities provide energy efficiency programs that target low-income households. These programs are funded through customers (or "ratepayers"). Such programs generally have a very good record of delivering cost-effective energy savings as a resource to the entire utility system. Unlike bill assistance and most weatherization programs, utility energy efficiency programs can include a variety of program strategies.²⁴ Some utility energy efficiency programs operate in tandem with local or statewide weatherization efforts, using similar channels to reach customers.

When program evaluators include all of these multiple benefits into cost-benefit analyses, WAP proves to be a cost-effective solution to improving energy affordability.

Typical low-income programs focus on single-family whole-house retrofits (Cluett, Amann, and Ou 2016; Hoffman et al. 2015). These programs can mirror other residential energy efficiency programs offered by utilities or weatherization implementers; they often focus on specific measures and provide higher incentives. The most common low-income energy efficiency approaches are of two types: comprehensive weatherization, and the direct installation of low-cost energy efficiency measures (e.g., efficient lighting, high-efficiency showerheads and faucet aerators, and air infiltration reductions). Some utilities operate direct-install programs targeting multifamily rental buildings as part of their low-income program offerings. Other, less common low-income programs include conservation kits, product rebates, appliance recycling, and programs that promote behavioral change or provide information on home energy use (Cluett, Amann, and Ou 2016).

Low-income households in multifamily buildings can also be reached through whole-building programs that target these buildings and typically require the participation of only the building owner. In most cases, energy efficiency retrofits and measures provide energy bill reduction for both owner and residents. There are three types of program models that utilities typically use to serve their multifamily customers: direct install services, equipment and product rebates, and comprehensive energy retrofits for existing buildings and new construction (Johnson and Mackres 2013). In some cases, these programs

Despite the existence of such programs, low-income households remain a hard-to-reach group with many barriers to participation.

are adapted to meet the needs of properties that house low-income residents by offering higher incentives or additional measures.

Despite the existence of such programs, low-income households remain a hard-to-reach group with many barriers to participation. Most utilities have found that their energy efficiency program strategies do not adequately reach these households (Rasmussen et al. 2014). Low-income households and owners of multifamily buildings that provide affordable housing may find it challenging to participate in residential low-income energy efficiency programs that require a copay. These households may also lack the time, resources, and up-front capital to register and participate. As a result, many low-income programs offer free or discounted direct-install measures, such as efficient lighting, low-flow showerheads, smart thermostats, and/or smart power strips in order to facilitate program participation.

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- 22 At times, low-income programs that address health and safety issues are implemented in conjunction with weatherization programs to provide the most comprehensive offering. These programs make sure the house is fit from a health and safety perspective before it undergoes weatherization (Wilson and Katz 2010). Behavior and education programs can also supplement low-income assistance and energy efficiency programs. These programs typically provide educational material on energy saving behaviors, feedback on customer energy use, or games and other interactive measures to encourage energy savings (Mazur-Stommen and Farley 2013).
- 23 Spending on WAP is historically low. However, as a part of the American Recovery and Reinvestment Act of 2009, WAP received \$5 billion over the course of 2009, 2010, and 2011, which is about 25 times the funding the program has received in each year since (LIHEAP Clearinghouse 2016).
- 24 For more information on best practices for low-income utility programs, see Cluett, Amann, and Ou 2016.

Benefits of Investing in Energy Efficiency in Low-Income Communities



Low-income energy efficiency programs provide benefits that go beyond reduced utility bills and beyond benefits experienced by direct participants. In table 7, we categorize these benefits as those received by participating low-income households, by utilities and ratepayers, and by the wider community. These values can justify policy decisions to increase such investments.

Low-income households participating in energy efficiency programs report direct benefits that improve their quality of life. For example, energy efficiency investments lower energy bills, which reduces energy burden, eases economic and social stresses, and provides families with more disposable income that can be spent on other necessities beyond energy (e.g., medicine, food, transportation) (Tonn et al. 2014). Building efficiency upgrades also increase property value and the reliability of appliances and HVAC equipment, which reduces maintenance costs and stress (Cluett and Amann 2015). Multiple case studies by the New York State Energy Research and Development Authority (NYSERDA) found that energy efficiency programs also increase tenant comfort

and provide tenants with more control over their surroundings (NYSERDA 2013a; NYSEDA 2013b). These benefits occur as a result of both single- and multifamily energy efficiency projects, though some benefits—such as increased property value—accrue only to the building owner in cases where the household rents the unit (Russell et al. 2015).

In affordable multifamily housing, the cost of energy is typically the highest controllable operating expense. Reducing operating expenses allows affordable housing providers to maintain reasonable rents, invest in resident services, and make necessary building improvements. Energy efficiency can also help low-income households manage bills in the event of utility

TABLE 7. Energy efficiency benefits for low-income households, utilities, and communities

Benefit recipient	Energy efficiency outcome	Resulting benefit
Low-income program participants	Lower monthly utility bills	Lower household energy burden and greater disposable income
		Reduced stress and fewer trade-offs between energy and other necessities
		Reduced exposure to risk from utility rate increases
	Improvements in the efficiency of the housing stock	Improved health and safety and greater household comfort
		Increased property value, more reliable equipment, and lower maintenance costs
		Greater satisfaction with the building/unit and improved household and neighborhood stability
Utilities and ratepayers	Demand-side management (both gas and electric)	Avoided excess costs of increased generation, capacity, and transmission investments
		Contribution toward compliance with energy efficiency portfolio standards and other environmental legislation
	Cost savings to utilities and ratepayers	Reduced arrearages and cost of shutoffs, which lowers utility operating costs
		Improved customer service
Communities	Lower electric and gas demand	Reduced environmental pollutants and improved public health
	Lower monthly utility bills due to avoided utility costs	More money spent in the local economy due to greater household disposable income, with higher local multiplier effect
		Poverty alleviation and increased standard of living
	Improvements in the efficiency of the housing stock	Local job creation through weatherization programs and energy efficiency providers and trade allies
		Improved quality of life
		Increased property values and preservation of housing stock

price increases and variable seasons. In 2014, residential electricity prices rose to the highest level in six years, with average electric price increasing by 3.1% annually between 2008 and 2014 (EIA 2015). By improving household efficiency, individuals and communities can be more resilient in times of price increases.

Utilities operate energy efficiency programs because of the benefits that accrue not only to customers but also to the utility system. Investing in low-income energy efficiency can mean avoiding the excess costs of increased energy generation, capacity, and transmission due to reduced demand. The reduction in energy production due to efficiency also reduces environmental pollutants, which helps utilities comply with environmental legislation that limits emissions (Baatz 2015; Brockway, Kallay, and Malone 2014). Energy

By improving household efficiency, individuals and communities can be more resilient in times of price increases.

efficiency investments in low-income communities also reduce the risk of arrearages and the costs of shutoffs for families who have difficulty paying their bills. By lowering these costs, utilities can reduce overall tariffs and charges for their entire ratepayer base.

Although not all low-income customers have the opportunity to participate in their utility's energy efficiency programs, research shows that energy efficiency benefits

the whole community and can be used as a core strategy for increasing energy affordability and community resilience (Ribeiro et al. 2015a). Energy efficiency programs benefit the entire population by reducing environmental pollutants, which tend to impact low-income communities disproportionately (NAACP 2015; EPA 2012). Investments in energy efficiency also stimulate the local economy by providing individuals and families with greater disposable income, alleviating poverty, increasing purchasing power, and creating more local jobs (Bell 2014; IEA 2014).

Last, investing in energy efficiency allows communities to increase their percentage of renewable energy sources. Numerous state and local governments have invested in solar energy projects for low-income

multifamily households; these include the Colorado Energy Office, the District of Columbia Department of Energy and Environment, and the Baltimore Office of Sustainability (Collins 2015; Shahan 2015). By using energy efficiency to lower a building's energy demand, utilities and local governments can maximize the percentage of a building's energy needs that can be met by renewables. Also, because energy efficiency is relatively inexpensive, it can help reduce the total cost per kWh of a combined renewable energy and energy efficiency project. As more states and local governments seek to advance renewable projects in low-income communities—and especially in multifamily housing—energy efficiency can and should play a crucial role in these efforts.

Energy efficiency programs benefit the entire population by reducing environmental pollutants, which tend to impact low-income communities disproportionately.

Strategies for Improving Energy Efficiency in Low-Income Communities



When developing energy efficiency policies and programs, policymakers and other stakeholders must consider the extent to which these investments will reach the target populations, especially those experiencing persistent and high energy burdens. Individuals or families experiencing high energy burdens vary in important ways relevant to program design: by ownership, income, building type, race/ethnicity, energy use per square foot, and languages spoken (Berelson 2014). Therefore, programs and policies should be designed, targeted, and implemented with the goal of reaching a wide variety of households facing high energy burdens.

Based on research, experience, and findings in other reports, we suggest the following strategies for improving energy efficiency in low-income communities:

- Improve and expand low-income utility programs
- Collect, track, and report demographic data on program participation
- Strengthen policy levers and more effectively leverage existing programs
- Utilize the Clean Power Plan to prioritize investment in low-income energy efficiency

Utilities and state and local governments can utilize these strategies to create more effective low-income energy efficiency programs. These strategies should

be used in combination, and they should be prioritized according to the needs of the community.

Improve and Expand Low-Income Utility Programs

Take advantage of best practices in low-income energy efficiency program design and delivery

Utilities and other program administrators can increase the impact of their low-income programs by taking advantage of best practices in low-income energy efficiency program design and delivery. In doing so, they must recognize the diversity of the low-income housing stock, including renter- and owner-occupied housing as well as single- and multifamily units.

In regard to single-family housing, successful low-income energy efficiency programs have been found to

- offer a range of measures and services
- coordinate delivery with other organizations
- align and add on to existing weatherization efforts
- address health and safety issues when implementing efficiency measures
- incorporate strategies for customer energy efficiency education

Some programs may also coordinate efficiency with bill assistance programs and develop dual-fuel and fuel-blind programs to make program delivery seamless. Examples of utilities and other program administrators that run strong low-income energy efficiency programs include Southern California Edison, Efficiency Vermont, National Grid, and Pacific Power. For a more comprehensive discussion of successful low-income utility programs, see ACEEE's 2016 report *Building Better Energy Efficiency Programs for Low-Income Households* (Cluett, Amann, and Ou 2016).

To achieve greater savings within this sector, utilities can offer more comprehensive programs that meet the needs of a diverse low-income customer base. These programs could include direct-install and weatherization measures, as well as appliance, equipment, and electronics upgrades. Currently, the majority of low-income energy efficiency programs offered by utilities focus on the weatherization model and direct-install measures, with the most common ones including insulation, air sealing, and heating and cooling measures (Cluett, Amann, Ou 2016). Some utility programs go beyond weatherization and incorporate additional offerings, such as energy efficiency equipment upgrades and initiatives that encourage behavioral change.

Utilities are well positioned to serve low-income customers with energy efficiency programs. They already have built-in communication channels and relationships with households and building owners who receive their energy bills. Some utilities have also built strong partnerships with trusted community organizations to disseminate information and run programs. For example, utilities can expand low-income energy efficiency programs alongside WAP implementation in order to best leverage delivery channels and program strengths and resources (Cluett, Amann, and Ou 2016). In order to better inform the design and delivery of low-income energy efficiency

programs, state and local governments can partner with utilities and local organizations that already work on outreach to low-income communities. Local governments can also assist with joint delivery of energy efficiency programs with other low-income services in order to streamline program delivery and maximize participation.

Develop Programs Targeted to Affordable Multifamily Housing

In many states the majority of low-income households are renters. Yet residential energy efficiency programs administered by states and utilities have historically focused on single-family, owner-occupied housing. Efficiency measures are far less likely to be installed in multifamily rentals than in any other type of housing, leaving significant unrealized energy savings (Pivo 2014). A recent study issued by Energy Efficiency for All estimates that energy efficiency in multifamily affordable housing could realistically cut the sector's electricity usage by as much as 26%, based on data from a sample of states (Mosenthal and Socks 2015).

Utilities and other program administrators should develop programs to target multifamily customers. In 2013, ACEEE completed a review of leading multifamily programs and identified 10 best practices among these programs (Johnson 2013):

- provide a one-stop shop for program services
- incorporate on-bill repayment or low-cost financing
- integrate direct installation and rebate programs
- streamline rebates and incentivize in-unit measures to overcome split incentives
- coordinate programs across electric, natural gas, and water utilities
- provide escalating incentives for achieving greater savings levels
- serve both low-income and market-rate multifamily households
- align utility and housing finance programs
- partner with the local multifamily housing industry
- offer multiple pathways for participation to reach more buildings

Program administrators designed these programs specifically to serve multifamily customers, often targeting building owners who have a budget for repairs and improvements. As a result, these programs often address the specific needs identified for this market.

Work with Utility Regulators and Utilities to Document and Recognize the Nonenergy Benefits of Low-Income Energy Efficiency Programs

Program administrators do not often include nonenergy benefits in their pre- and post-program cost-benefit analyses, even though programs often have purposes beyond energy savings, such as addressing health and safety measures and increasing energy affordability (Cluett, Amann, and Ou 2016). A 2012 ACEEE study found that less than one-third of sampled utilities included the multiple and nonenergy benefits of energy efficiency in their cost-benefit testing, although three-fourths did include all participant costs. Of the utilities that included multiple benefits, few included comprehensive nonenergy benefits, with utilities in Massachusetts and Rhode Island performing best in this regard (Kushler, Nowak, and Witte 2012).

Both public utility commissions and local governments can encourage or require cost-effectiveness screening and testing to take into account the multiple benefits of low-income energy efficiency programs.

When program administrators include the nonenergy benefits of energy efficiency alongside energy savings, the benefit-cost ratio can improve to up to 1.5 times the initial investment for single-family households and up to 3.5 times for multifamily households (Russell et al. 2015; Mosenthal and Socks 2015). Program managers and researchers have not yet come to an agreement on values for nonenergy benefits of energy efficiency, but studies show that these benefits, especially health-related ones, greatly increase the benefit-cost ratio (Skumatz 2014; Oppenheim and MacGregor 2014). Some utilities have found ways

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to account for these benefits, such as by using an adder in the cost-benefit calculation. An adder is a factor that adjusts the calculated benefit of an energy efficiency measure on the basis of its perceived value, including nonenergy benefits. In other words, while certain benefits may be difficult to measure, it is more accurate to use an approximation than to use zero.

By including costs and excluding some benefits, the evaluation of low-income programs might not reflect their full value. If tests measure only energy-related benefits, then costs not associated with energy—such as health- and safety-related home repairs and job training—should not be included. In order to produce more accurate results, benefit-cost tests should include only costs and benefits related to energy savings or include all energy and nonenergy costs and benefits.

Some states—including Connecticut, California, and New Hampshire—acknowledge that low-income programs provide benefits beyond energy savings (Berelson 2014; Woolf et al. 2013). These states do not apply the same cost-effectiveness standards to low-income programs that they apply to the other energy efficiency programs throughout the state. They recognize difficult-to-measure nonenergy benefits, as well as the fact that the portfolio must include programs that reach low-income households even if those particular programs incur higher costs. Program administrators may set a lower cost-effectiveness threshold for low-income programs, or they may use adders to account for the non-monetized benefits (Cluett and Amann 2015). For example, cost-benefit testing of low-income programs in Colorado assumes an increase in benefits of 25%, and Vermont similarly increases benefits by 15% for low-income programs (Malmgren and Skumatz 2014).

Provide Financing Options to Households and Building Owners

Access to up-front capital is one of the many barriers to energy efficiency for low-income households and low-income multifamily property owners. Several utilities and public and community-based entities have developed financing programs to help these customers access credit to make cost-effective energy efficiency improvements. These programs have the potential to serve as a complement to energy efficiency programs for low-income customers. In the Southeast, electric cooperative utilities are increasingly offering financing

programs that enable households to pay for energy efficiency upgrades via their utility bills. The bill reductions due to energy savings help cover the cost of upgrades (Marsh-Robinson 2016; Lundin 2016). While these programs are typically open to all customers, many low-income households participate.

On-bill financing programs, like most loan products, should include program terms with strong consumer protections. They should also strive to achieve bill neutrality, which means that energy savings from efficiency investments cover the monthly loan payments so the post-investment bill does not exceed the pre-investment amount.²⁵ With strong consumer protections in place, energy efficiency loans can prove beneficial for some households by providing a way to finance efficient and cost-saving measures.

Financing can also be critical to furthering energy efficiency investments in multifamily housing. Multifamily building owners, especially low-income housing providers, face increasing operational costs as their buildings age. Maintenance and improvement priorities often compete with energy efficiency upgrades for limited financial capital, and as a result, building owners often lack the up-front capital needed for energy efficiency retrofits. Low-interest financing or on-bill financing can limit or eliminate up-front costs, allowing building owners to undertake more substantial energy efficiency projects and repay loans with a portion of the energy savings.

Additionally, state housing finance agencies can support energy efficiency in both new and existing affordable multifamily buildings. Their financing programs can require energy efficiency standards in all new construction and rehabilitation that they support in this sector. They can also work with utilities that provide ratepayer-funded programs for multifamily building owners. Utility incentives can be applied to refinance or redevelopment loans to buy down some up-front costs and yield deeper, more comprehensive energy efficiency improvements throughout the affordable building stock.²⁶

Collect, Track, and Report Demographic Data on Program Participation

By collecting demographic data on program participation, utilities can assess the extent to which their programs are serving different segments of the

population, especially those customers known to experience high energy burdens. For example, many utilities do not track the percentage of multifamily customers that they serve relative to the eligible customer base, leaving themselves unaware of the extent to which they are adequately serving these customers. Utilities can rely on this information to inform program design and marketing and outreach strategies. Our research indicates that some of the household demographics that should be incorporated into program evaluation for these purposes include: income level, renter versus owner, multifamily versus single family, and race/ethnicity. These data points and/or evaluations should also be made available to the public for stakeholder review (Kallay et al. 2015).

Even though some utilities do collect demographic data on program participation, few utilities use this information during program evaluation. In a sample of California utility programs, the majority did collect demographic data and published these data in their evaluation reports, but only half of these utilities used the data to make program design recommendations, and even fewer used the data in the analysis of program impact (Frank and Nowak 2016 forthcoming). According to this study, utility program managers most commonly collected data on income and education, with data on home ownership, age, language spoken, and race/ethnicity collected less often.

While some utilities use segmentation to identify customers for specific programs using factors such as geography, income, and energy use per square foot to determine who should be targeted for certain programs, the majority of programs do not use demographic information for evaluation purposes. For many, collecting these data would be a first step toward better program design and measurement. To ensure that energy efficiency programs reach all types of households—especially those experiencing high energy burdens—program administrators should examine demographically identifiable participation gaps in past programs, adjust their program design to target these populations, and continue to collect and analyze these data to measure program success.

Strengthen Policy Levers and Leverage Existing Programs

Utility regulators and boards of publicly owned utilities should help utilities develop, promote, and execute strong low-income programs by approving and

setting goals and guidelines for spending, savings, cost recovery, and cost-effectiveness testing. For municipally owned utilities, city boards and councils can require strong goals and targets for low-income energy efficiency savings and also incorporate cost-effectiveness testing into program evaluation. Even though public utility commissions (PUCs) set goals for investor-owned utilities (IOUs), state and local governments can still encourage PUCs to set low-income program goals and evaluation criteria and can advocate for improved program design and implementation.

Additionally, state and local governments can set policy directives that support low-income energy efficiency, disclosure and benchmarking policies for multifamily buildings, workforce development initiatives, state-level requirements for utility-delivered energy efficiency (e.g., energy efficiency resource standards [EERSs]), and other, related efforts.²⁷

States can also set EERSs that include targets for the low-income sector. Currently, 25 states have an EERS in place, and some of these also have low-income energy-saving goals. Utilities in states that do not have an EERS could also create quantifiable performance indicators (QPIs) that include low-income efficiency programs as a measurement of success.²⁸ For example, Efficiency Vermont includes a minimum acceptable threshold for low-income household participation in programs as one of its QPIs, aiming for \$7.5 million in spending on low-income single- and multifamily programs (Efficiency Vermont 2013). Local governments can support the development of low-income goals and performance indicators by advocating to their PUC, petitioning the utility itself for QPIs, or establishing targets for municipally owned utilities.

Some PUCs also set low-income energy savings goals and spending requirements. For example, the Maine Public Utilities Commission allocates 10% of energy efficiency funds to support low-income programs. Some stakeholders advocate for PUCs to adopt more-stringent goals. Massachusetts's Green Communities Act requires that energy efficiency program funds be allocated in proportion to the customer class from which the funds are contributed but also stipulates that at least 10% for electric and 20% for gas energy efficiency programs be spent on comprehensive low-income programs (Commonwealth of Massachusetts 2008). In Pennsylvania, many community-based organizations, city governments, and local utilities petitioned the PUC to raise its low-income goal. In

June 2015, their efforts succeeded: the PUC increased its low-income target from 4.5% to 5.5% of energy efficiency savings by 2021 (Pennsylvania Public Utility Commission 2016).

Use the Clean Power Plan to Prioritize Investment in Low-Income Energy Efficiency

The Clean Power Plan, announced by President Obama on August 3, 2015, sets the first-ever limits on carbon pollution from power plants—the nation's largest source of the pollution driving dangerous climate

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change. The US Environmental Protection Agency (EPA) projects that by 2030, the Clean Power Plan will cut the electric sector's carbon pollution by 32% nationally, relative to 2005 levels (EPA 2016). Under the Clean Power Plan, states have the opportunity to develop state plans that apply emissions limits to their power plants. They face several choices in developing these plans, and they can, if they wish, prioritize low-income energy efficiency programs in this process.

To do so, states would first choose a plan approach that incentivizes low-income energy efficiency programs. One way to do this would be to adopt a mass-based plan, which limits the total amount of carbon pollution from the state's power plants. Under this system, the state issues a permit—called an allowance—for each ton of carbon pollution that its power plants are allowed to emit. These allowances have an economic value because they represent the right to emit one ton of a capped pollutant.

Next, states would distribute these allowances in a manner that allowed their value to be captured for public policy purposes, including low-income energy efficiency programs. There are three main ways states can do this. First, they can auction allowances and take in revenue, and then use some of this revenue to fund low-income energy efficiency programs. This is the approach used in the northeastern and mid-Atlantic states in the Regional Greenhouse Gas Initiative, which invested \$1 billion of allowance auction revenue in energy efficiency programs between 2008 and 2013

(RGGI 2015). Second, in states where distribution utilities operate separately from power plant owners (known as deregulated states), allowances can be distributed to the distribution utility, which operates under public utility commission oversight. The distribution utility then sells these allowances and uses the revenue for regulator-approved activities, such as funding low-income energy efficiency programs. Third, states can allocate allowances directly to low-income energy efficiency programs, which can then sell them to generate revenue. All three strategies can be used to fund programs.

States can also opt in to the Clean Energy Incentive Program, which offers early credit for energy efficiency projects in low-income communities during the two years prior to the start of the compliance period. Without this program, projects could not receive credit until the start of the compliance period, currently slated for 2022. For each megawatt-hour of electricity that programs save in 2020 and 2021, eligible low-income energy efficiency programs will get two emission rate credits, or an equivalent number of allowances. Project developers can sell credits to power plant owners, gaining revenue to offset program costs.

Low-income energy efficiency providers should engage with state air agencies to help shape state plans. The Clean Power Plan provides a unique opportunity to drive investment in low-income energy efficiency programs and gives states additional incentive to act.

25 For more information on consumer protections for on-bill financing programs, particularly for low-income households, see Burcat and Power 2013.

26 For properties financed through Low Income Housing Tax Credits (LIHTC), recapitalization windows present approximately every 15 years.

27 Disclosure and benchmarking policies refer to local laws that require owners of commercial and multifamily residential buildings to annually disclose their buildings' energy use and benchmark it relative to other buildings. An energy efficiency resource standard (EERS) establishes specific, long-term targets for energy savings that utilities or non-utility program administrators must meet through customer energy efficiency programs. For more information on EERSs, see aceee.org/topics/energy-efficiency-resource-standard-eers.

28 Quantifiable performance indicator (QPI) targets are set by the utility in order to measure how well its performance meets planned strategic goals and objectives. Low-income participation can be included as a QPI in order to make sure that attention to low-income households remains a priority for the utility.

Conclusion



Based on our analysis results, we determined that certain households—namely low-income, low-income multifamily, African-American, Latino, and renters—devote a disproportionate share of their income to energy expenses. Low-income households typically live in less efficient housing and are often more difficult to reach with information about energy efficiency programs.

Many of these households, due to lack of disposable income to invest in energy efficiency measures, have less ability to participate in their utility's energy efficiency programs. In order to overcome the barriers to participation that low-income customers face, governments and utilities should enhance their low-income program offerings, improve program design and implementation for low-income households, and better utilize existing channels and programs that target low-income households. Programs that address high energy burden also help alleviate poverty and provide other benefits to society beyond energy savings, such as economic development, employment, education, and public health.

Utility-led energy efficiency is an underutilized strategy that could complement bill assistance and weatherization programs to alleviate high household energy burdens in low-income communities. Energy efficiency programs in low-income communities need improved design and targeting in order to address long-term energy affordability needs. Local governments and utilities can work together to improve energy efficiency in these communities. We identified several strategies to ramp up energy efficiency, including improving current low-income program offerings, incorporating demographic data into program goals and evaluation, exploring financing options, and using additional policy levers.

This report has focused on improving low-income energy efficiency as a strategy for addressing high energy burdens. While this is an important strategy for reducing household energy use, it will not break cycles of poverty or completely eradicate high utility costs for all households. We estimate that energy efficiency investments (i.e., whole-home retrofits) for low-income households can make homes 25% more efficient than the average home, which means these investments have the potential to reduce the energy burden of a low-income household by nearly 30%.²⁹ Energy efficiency is a big part of the solution, but we still have a long way to go to ensure an equitable distribution of energy costs for all American families.

Due to changing regulatory policies, cities and states have additional urgency to ramp up efforts to increase low-income energy efficiency. In addition to the Clean Power Plan, the EPA has numerous potential rulemakings to limit the emissions of nitrogen oxides, sulfur dioxide, and carbon dioxide, which will increase states' obligations to reduce emissions. Energy efficiency remains a least-cost strategy for states to reduce multipollutant emissions. Under this approach, greater investment in low-income energy efficiency can cut emissions while improving energy affordability for those most in need.

Next Steps and Future Research

We encourage cities and other stakeholder groups to use this report's energy burden data and principles in

their efforts to design and deliver energy efficiency policies and programs targeted toward the alleviation of high energy burdens. Cities can compare their median energy burden with the burdens of the groups in the study (Appendix B) and determine how their city or metro area stacks up regionally and nationally for each group studied (Appendix E). The energy burden data in this report is a snapshot of the current energy burden landscape, and stakeholders should use the data as a baseline for improvement.

While this report focuses on energy burdens in cities, rural communities experience acute energy burdens as well, and the severity of these burdens may differ from those experienced in cities. Although the strategies presented in this report can be applied to rural communities, future research should explore the landscape of rural energy burden and determine the specific policy needs of rural families that experience high energy burdens.

We hope that this report's findings and recommendations will act as conversation starters for cities and states that want to consider new energy affordability measures and determine how best to help their citizens obtain affordable and equitable access to energy. We have found that high energy bills, low household income, inefficient housing stock, and lack of access to efficiency programs contribute to energy burden. Cities and states should explore these drivers to determine why energy burden is higher in some regions and communities than in others.

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²⁹ We assume 25% savings from energy efficiency upgrades based on the US Department of Energy's estimate (DOE 2014), and use the values in table 3 to calculate the 30% energy savings. A 30% savings for low-income households would reduce energy costs per square foot to \$1.06, which reduces annual utility spending to \$1,269 and energy burden to 5.1%. This is a reduction of 29.2% from the original energy burden of 7.2%. This savings estimate does not include the net costs for energy efficiency improvements.

References

- APPRISE (Applied Public Policy Research Institute for Study and Evaluation). 2007. *Ratepayer-Funded Low-Income Energy Programs: Performance and Possibilities*. Princeton: APPRISE. www.appriseinc.org/reports/NLIEC%20Multi-Sponsor%20Study.pdf.
- Baatz, B. 2015. *Everyone Benefits: Practices and Recommendations for Utility System Benefits of Energy Efficiency*. Washington, DC: American Council for an Energy-Efficient Economy. aceee.org/everyone-benefits-practices-and-recommendations.
- Bell, C. 2014. "Understanding the True Benefits of Both Energy Efficiency and Job Creation." *Community Development Investment Review* 10 (1): 109–16. www.frbsf.org/community-development/publications/community-development-investment-review/2014/march/benefits-energy-efficiency-job-creation/.
- Benefits.gov. 2015. "Weatherization Assistance Program for Low-Income Persons." Accessed December 4. www.benefits.gov/benefits/benefit-details/580.
- Berelson, S. 2014. "Myths of Low-Income Energy Efficiency Programs: Implications for Outreach." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings 7*: 32–43. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/7-287.pdf.
- Berube, A., and H. Holmes. 2015. *Some Cities Are Still More Unequal than Others—An Update*. Washington, DC: Brookings Institution. www.brookings.edu/research/reports/2015/03/city-inequality-berube-holmes.
- Brockway, N., J. Kallay, and E. Malone. 2014. *Low-Income Assistance Strategy Review: Options for the Design and Implementation of Ratepayer-Funded Assistance Programs for Low-Income Electricity Customers*. Cambridge, MA: Synapse Energy Economics, Inc. www.synapse-energy.com/sites/default/files/Low-Income-Assistance-Strategy-Review-14-111.pdf.
- Brown, M. 2008. *State Energy Efficiency Policies: Options and Lessons Learned*. Washington, DC: Alliance to Save Energy. www.ase.org/sites/ase.org/files/file_Brief_1v3.pdf.
- Bruner, K., M. Spitzer, and A. Christanell. 2012. "Experiencing Fuel Poverty: Coping Strategies of Low-Income Households in Vienna/Austria." *Energy Policy* 49: 53–59.
- Burcat, L., and M. Power. 2013. *On-Bill Repayment for Home Energy Efficiency: The Benefits and the Risks*. Washington, DC: Economic Opportunity Studies. cleanenergycoops.org/downloads/OBR_Final_Report.pdf.
- Carliner, M. 2013. *Reducing Energy Costs in Rental Housing: The Need and the Potential*. Cambridge, MA: Center for Housing Studies of Harvard University. www.jchs.harvard.edu/sites/jchs.harvard.edu/files/carliner_research_brief_0.pdf.
- Census Bureau. 2011. "American Housing Survey 2011 Public Use File." Accessed November 2015. www.census.gov/programs-surveys/ahs/data/2011/ahs-national-and-metropolitan-puf-microdata.html.
- . 2013a. "American Housing Survey 2013 Metropolitan Public Use File." Accessed November 2015. www.census.gov/programs-surveys/ahs/data/2013/ahs-2013-public-use-file-puf/2013-ahs-metropolitan-puf-microdata.html.
- . 2013b. "Table H-8B: Historical Income Tables: Households." www.census.gov/hhes/www/income/data/historical/household/.
- . 2014. "Table P-1: Total CPS Population and Per Capita Income: All Races." www.census.gov/hhes/www/income/data/historical/people/.
- Cluett, R., and J. Amann. 2015. *Multiple Benefits of Multifamily Energy Efficiency for Cost-Effectiveness Screening*. Washington, DC: ACEEE. aceee.org/multiple-benefits-multifamily-energy-efficiency.
- Cluett, R., J. Amann, and S. Ou. 2016. *Building Better Energy Efficiency Programs for Low-Income Households*. Washington, DC: ACEEE. <http://aceee.org/research-report/a1601>.

- CNT (Center for Neighborhood Technology). 2016. "Transportation and Community Development." Accessed January 26. www.cnt.org/transportation-and-community-development.
- Collins, M. 2015. "Pilot Project Provides C.A.R.E. Community with Solar Electric Systems." *The Baltimore Sun*, June 22. www.baltimoresun.com/news/maryland/baltimore-city/bs-md-ci-solar-power-20150622-story.html.
- Commonwealth of Massachusetts. 2008. *An Act Relative to Green Communities*. Chapter 169. malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter169.
- Dear, K., and A. McMichael. 2011. "The Health Impacts of Cold Homes and Fuel Poverty." *BMJ* 342. [dx.doi.org/10.1136/bmj.d2807](https://doi.org/10.1136/bmj.d2807)
- DeSilver, D. 2015. "The Many Ways to Measure Economic Inequality." *Fact Tank* blog, September 22. www.pewresearch.org/fact-tank/2015/09/22/the-many-ways-to-measure-economic-inequality/.
- DOE (Department of Energy). 2014. *Better Buildings Neighborhood Program Summary of Reported Data from July 1, 2010–September 30, 2013*. Washington, DC: DOE. energy.gov/sites/prod/files/2014/09/f18/bbnp_summary_reported_data_9-15-2014.pdf.
- . 2015. "What is Weatherization." Accessed December 4. energy.gov/eere/wipo/what-weatherization.
- Efficiency Vermont. 2013. *Annual Report 2012*. Burlington: Efficiency Vermont. www.efficiencyvermont.com/docs/about_efficiency_vermont/annual_reports/Efficiency-Vermont-Annual-Report-2012.pdf.
- EIA (Energy Information Administration). 2009. "Residential Energy Consumption Survey." Accessed November 2015. www.eia.gov/consumption/residential/index.cfm.
- . 2013. "Heating and Cooling No Longer Majority of US Home Energy Use." *Today in Energy*, March 7. www.eia.gov/todayinenergy/detail.cfm?id=10271&src=Consumption Residential Energy Consumption Survey (RECS)-b1.
- . 2015. "Growth in Residential Electricity Prices Highest in 6 Years, but Expected to Slow in 2015." *Today in Energy*, March 16. www.eia.gov/todayinenergy/detail.cfm?id=20372.
- . 2016a. *Short-Term Energy Outlook February 2016*. Washington, DC: EIA. www.eia.gov/forecasts/steo/archives/Feb16.pdf.
- . 2016b. "Average Price of Electricity to Ultimate Customers, Table 5.3." *Electric Power Monthly*. Accessed February 10. www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3.
- EPA (Environmental Protection Agency). 2012. *President's Task Force on Environmental Health Risks and Safety Risks to Children: Coordinated Federal Action Plan to Reduce Racial and Ethnic Asthma Disparities*. Washington, DC: EPA. www.epa.gov/sites/production/files/2014-08/documents/federal_asthma_disparities_action_plan.pdf.
- . 2016. *Overview of the Clean Power Plan: Cutting Carbon Pollution from Power Plants*. Washington, DC: EPA. www.epa.gov/sites/production/files/2015-08/documents/fs-cpp-overview.pdf.
- EPC (Energy Programs Consortium). 2013a. *Multifamily Energy: What We Know and What's Next*. Washington, DC: Energy Programs Consortium. www.naseo.org/data/sites/1/documents/publications/EPC-Report-Multi-Family-Housing.pdf.
- . 2013b. *Qualified Energy Conservation Bonds (QECCBs)*. Washington, DC: Energy Programs Consortium. energy.gov/sites/prod/files/2014/06/f16/QECB_memo_12-13-13.pdf.
- Fisher Sheehan & Colton. 2013. "Home Energy Affordability Gap." www.homeenergyaffordabilitygap.com/.
- Frank, M., and S. Nowak. 2016 (forthcoming). "Mining Participant Demographics to Yield New Opportunities from Old Measures." In *Proceedings of the ACEEE 2016 Summer Study on Energy Efficiency in Buildings*. Washington, DC: ACEEE.
- Heindl, P. 2015. "Dynamic Properties of Energy Affordability Measures." *Energy Policy* 86: 123–32.

- Hernández, D. 2015. "Sacrifice Along the Energy Continuum: A Call for Energy Justice." *Environmental Justice* 8 (4): 151–6.
- Hernández, D., and S. Bird. 2010. "Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy." *Poverty and Public Policy* 2 (4): 5–25.
- Heyman, B., B. Harrington, and A. Heyman. 2011. "A Randomized Controlled Trial of an Energy Efficiency Intervention for Families Living in Fuel Poverty." *Housing Studies* 26 (1): 117–32.
- Hoffman, I., G. Rybka, G. Leventis, C. Goldman, L. Schwartz, M. Billingsley, and S. Schiller. 2015. *The Total Cost of Saving Electricity through Utility Customer-Funded Energy Efficiency Programs: Estimates at the National, State, Sector, and Program Level*. Berkeley: Lawrence Berkeley National Laboratory. emp.lbl.gov/sites/all/files/total-cost-of-saved-energy_0.pdf.
- IEA (International Energy Agency). 2014. *Capturing the Multiple Benefits of Energy Efficiency*. Paris: IEA. www.iea.org/publications/freepublications/publication/Captur_the_MultiplBenef_ofEnergyEfficiency.pdf.
- Jackson, A. 2011. *Fact Sheet: The Low Income Home Energy Assistance Program: A Critical Resource for Low-Income Households*. Washington, DC: AARP (American Association of Retired Persons) Public Policy Institute. assets.aarp.org/rgcenter/consume/fs138_liheap.pdf.
- Johnson, K. 2013. *Apartment Hunters: Programs Searching for Energy Savings in Multifamily Buildings*. Washington, DC: ACEEE. aceee.org/research-report/e13n.
- Johnson, K., and E. Mackres. 2013. *Scaling up Multifamily Energy Efficiency Programs: A Metropolitan Area Assessment*. Washington, DC: ACEEE. aceee.org/research-report/e135.
- Kallay, J., K. Takahashi, A. Napoleon, and T. Woolf. 2015. *Fair, Abundant, and Low Cost: A Handbook for Using Energy Efficiency in Clean Power Plan Compliance*. Cambridge, MA: Synapse Energy Economics, Inc. synapse-energy.com/sites/default/files/EE-Handbook.pdf.
- Kind, P. 2015. *Pathway to a 21st Century Electric Utility*. Boston: Ceres. www.ceres.org/resources/reports/pathway-to-a-21st-century-electric-utility/view.
- Kushler, M., S. Nowak, and P. Witte. 2012. *A National Survey of State Policies and Practices for Evaluation of Ratepayer Funded Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/u122.
- Levy, R., and J. Sledge. 2012. *A Complex Portrait: An Examination of Small-Dollar Credit Consumers*. Chicago: Center for Financial Services Innovation. www.fdic.gov/news/conferences/consumersymposium/2012/A%20Complex%20Portrait.pdf.
- Li, K., B. Lloyd, X-J. Liang, and Y-M Wei. 2014. "Energy Poor or Fuel Poor: What Are the Differences?" *Energy Policy* 68: 476–81.
- Liddell, C., and C. Morris. 2010. "Fuel Poverty and Human Health: A Review of Recent Evidence." *Energy Policy* 38 (6): 2987–97.
- Liddell, C., C. Morris, S. McKenzie, and G. Rae. 2012. "Measuring and Monitoring Fuel Poverty in the UK: National and Regional Perspectives." *Energy Policy* 49: 27–32.
- LIHEAP Clearinghouse 2016. "Low-Income Energy Programs Funding History 1977–2015." Accessed February 2. www.liheapch.acf.hhs.gov/Funding/lhemhist.htm.
- Lundin, B. 2016. "Tariff Really PAYS for Arkansas Co-ops." *Smart Grid News*, February 16. www.smartgridnews.com/story/tariff-really-pays-arkansas-co-ops/2016-02-16.
- Malmgren, I., and L. Skumatz. 2014. "Lessons from the Field: Practical Applications for Incorporating Non-Energy Benefits into Cost-Effectiveness Screening." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*, 8: 186–200. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/8-357.pdf.
- Marsh-Robinson, M. 2016. "Rural Electric Cooperatives Improve Energy Efficiency with On-Bill Financing." *The Environmental Defense Fund* blog, March 9. blogs.edf.org/energyexchange/2016/03/09/rural-electric-cooperatives-improve-energy-efficiency-with-on-bill-financing/.

- Mazur-Stommen, S., and K. Farley. 2013. *ACEEE Field Guide to Utility-Run Behavior Programs*. Washington, DC: ACEEE. aceee.org/research-report/b132.
- McCormick, K. 2015. *Bridging the Clean Energy Divide: Affordable Clean Energy Solutions for Today and Tomorrow*. New York: Natural Resources Defense Council. www.nrdc.org/energy/files/clean-energy-benefits-vulnerable-comms-report.pdf.
- Moor, R. 2012. "Definitions of Fuel Poverty: Implications for Policy." *Energy Policy* 49: 19–26.
- Mosenthal, P., and M. Socks. 2015. *The Potential for Energy Savings in Affordable Multifamily Housing*. Hinesburg, VT: Optimal Energy. www.energyefficiencyforall.org/sites/default/files/EEFA%20Potential%20Study%20EXECSUM.pdf.
- NAACP (National Association for the Advancement of Colored People). 2015. "NAACP Statement on President Obama's Clean Power Plan." August 4. www.naacp.org/press/entry/naacp-statement-on-president-obamas-clean-power-plan.
- Nevada. 2013. *Nevada Fund for Energy Assistance and Conservation State Plan FY 2013*. Carson City: State of Nevada.
- NMHC (National Multifamily Housing Council). 2015. "Apartment Household Incomes in the Previous Year." nmhc.org/Content.aspx?id=4708.
- NYSERDA (New York State Energy Research and Development Authority). 2013a. *Aging Systems Open the Door for Major Energy Savings: Carnegie House, Manhattan*. Albany: NYSERDA. www.nyserda.ny.gov/-/media/Files/Publications/Case-Studies/MEPP/carnegie-building-cs.pdf.
- . 2013b. *A Dramatic Turnaround—and Major Energy Savings to Go with It: Rose May Manor Apartments, Pulaski, NY*. Albany: NYSERDA. www.nyserda.ny.gov/-/media/Files/Publications/Case-Studies/MEPP/rose-may-manor-cs.pdf.
- Oppenheim, J., and T. MacGregor. 2014. "Accounting for Health Benefits." In *Proceedings of the 2014 International Energy Policy and Programmes Evaluation Conference, Berlin*. democracyandregulation.com/attachments/146/Accounting_for_Health_Benefits..pdf.
- Penney, B., and P. Kloer. 2015. *Shelter Report 2015—Less Is More: Transforming Low-Income Communities Through Energy Efficiency*. Atlanta: Habitat for Humanity. www.habitat.org/sites/default/files/2015-habitat-for-humanity-shelter-report.pdf.
- Pennsylvania Public Utility Commission. 2016. "Energy Efficiency and Conservation (EE&C) Program." No. M-2012-2289411. Accessed March 27. www.puc.pa.gov/filing_resources/issues_laws_regulations/act_129_information/energy_efficiency_and_conservation_ee_c_program.aspx.
- Perl, L. 2012. *The LIHEAP Formula: Legislative History and Current Law*. Washington, DC: Congressional Research Service. neada.org/wp-content/uploads/2013/03/RL332751.pdf.
- Pivo, G. 2014. "Unequal Access to Energy Efficiency in US Multifamily Rental Housing: Opportunities to Improve." *Building Research & Information* 42 (5): 551–73.
- Rasmussen, T., C. Edwards, B. Getting, M. O'Drain, and A. Tran. 2014. "Understanding the Needs of Low Income Customers: Comprehensive, Robust Results form a Needs Assessment Study." In *Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings 2*: 293–304. Washington, DC: ACEEE. aceee.org/files/proceedings/2014/data/papers/2-1088.pdf.
- RGGI (Regional Greenhouse Gas Initiative). 2015. *Investment of RGGI Proceeds through 2013*. New York: RGGI. www.rggi.org/docs/ProceedsReport/Investment-RGGI-Proceeds-Through-2013.pdf.
- Ribeiro, D., E. Mackres, B. Battz, R. Cluett, M. Jarrett, M. Kelly, and S. Vaidyanathan. 2015a. *Enhancing Community Resilience through Energy Efficiency*. Washington, DC: ACEEE. aceee.org/research-report/u1508.
- Ribeiro, D., V. Hewitt, E. Mackres, R. Cluett, L. Ross, S. Vaidyanathan, and S. Zerbonne. 2015b. *The 2015 City Energy Efficiency Scorecard*. Washington, DC: ACEEE. aceee.org/research-report/u1502.
- Ross, T. 2013. "Addressing Urban Poverty in American Must Remain a Priority." June 5. www.americanprogress.org/issues/poverty/news/2013/06/05/65268/addressing-urban-poverty-in-america-must-remain-a-priority/.

- Russell, C., B. Baatz, R. Cluett, and J. Amann. 2015. *Recognizing the Value of Energy Efficiency's Multiple Benefits*. Washington, DC: ACEEE. aceee.org/research-report/ie1502.
- Shahan, Z. 2015. "Solar Power for Low- & Moderate-Income Americans—Obama's New Solar Initiative." *Clean Technica*, July 11. cleantechnica.com/2015/07/11/solar-power-for-low-moderate-income-americans-obamas-new-solar-initiative/.
- Skumatz, L. 2014. *Non-Energy Benefits/Non-Energy Impacts (NEBs/NEIs) and their Role & Values in Cost-Effectiveness Tests: State of Maryland*. Superior, CO: Skumatz Economic Research Associates, Inc. energyefficiencyforall.org/sites/default/files/2014_%20NEBs%20report%20for%20Maryland.pdf.
- Sommeiller, E., and M. Price. 2015. *The Increasingly Unequal States of America: Income Inequality by State, 1917 to 2012*. Washington, DC: Economic Policy Institute. www.epi.org/files/2014/IncreasinglyUnequalStatesofAmerica1917to2012.pdf.
- Stone, C., D. Trisi, A. Sherman, and B. Debot. 2015. *A Guide to Statistics on Historical Trends in Income Inequality*. Washington, DC: Center on Budget and Policy Priorities. www.cbpp.org/sites/default/files/atoms/files/11-28-11pov_0.pdf.
- Tonn, B., Rose, E., Hawkins, B., and Conlon, B. 2014. *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program*. Oak Ridge, TN: Oak Ridge National Laboratory. weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_345.pdf.
- Vick, J., and C. Norton. 2008. *State of Metropolitan Housing Report 2008*. Louisville, KY: Metropolitan Housing Coalition. www.metropolitanhousing.org/wp-content/uploads/member_docs/2008_State_of_Metropolitan_Housing_Report.pdf.
- WAPTAC (Weatherization Assistance Program Technical Assistance Center). 2016. "Questions and Answers: Frequently Asked Questions." Accessed March 23. <http://www.waptac.org/WAP-Basics/Briefing-Book.aspx>.
- Watts-Zagha, C. 2011. *Status of Energy Utility Service Disconnections in California*. San Francisco: California Public Utilities Commission, Division of Ratepayer Advocates. www.dra.ca.gov/WorkArea/DownloadAsset.aspx?id=634.
- Whited, M., T. Woolf, and J. Daniel. 2016. *Caught in a Fix: The Problem with Fixed Charges for Electricity*. Cambridge, MA: Synapse Energy Economics, Inc. www.synapse-energy.com/sites/default/files/Caught-in-a-Fix.pdf.
- Wilson, J., and A. Katz. 2010. *Integrating Energy Efficiency and Healthy Housing*. Washington, DC: National Center for Healthy Housing and Advanced Energy. www.nchh.org/Portals/0/Contents/Coalition_briefing_paper_energy.pdf.
- Woolf, T., E. Malone, J. Kallay, and K. Takahashi. 2013. *Energy Efficiency Cost-Effectiveness Screening in the Northeast and Mid-Atlantic States*. Cambridge, MA: Synapse Energy Economics, Inc. www.neep.org/sites/default/files/resources/EMV_Forum_C-E-Testing_Report_Synapse_2013%2010%2002%20Final.pdf.
- Wright, F. 2004. "Old and Cold: Older People and Policies Failing to Address Fuel Poverty." *Social Policy & Administration* 38 (5): 488–503.

Appendix A. Sample Sizes

Table A1. Sample sizes used in energy burden calculations

City	Data year	All households	Low-income households	Low-income multifamily households	African-American households	Latino households	Renting households
Atlanta	2011	2,564	1,170	291	878	202	835
Austin	2013	2,794	1,178	326	206	692	1,145
Baltimore	2013	2,786	1,084	213	742	126	756
Birmingham	2011	2,876	1,397	212	809	91	717
Boston	2013	2,373	829	183	199	172	732
Charlotte	2011	2,816	1,326	263	716	214	888
Chicago	2013	766	388	128	176	128	288
Cincinnati	2011	2,401	1,141	246	271	66	683
Cleveland	2011	2,708	1,204	168	485	132	679
Columbus	2011	3,009	1,317	243	431	105	1,030
Dallas	2011	2,887	1,280	353	491	669	1,064
Denver	2011	2,714	1,171	354	144	482	884
Detroit	2013	2,530	1,063	186	445	77	628
Fort Worth	2011	3,095	1,435	309	426	671	1,052
Hartford	2013	2,817	1,105	210	252	303	659
Houston	2013	2,527	1,096	319	471	705	910
Indianapolis	2011	3,013	1,314	246	429	176	900
Jacksonville	2013	2,996	1,358	208	606	175	972
Kansas City	2011	2,974	1,430	216	356	164	876
Las Vegas	2013	2,496	1,186	294	284	564	1,112
Los Angeles	2011	3,001	1,773	635	290	1,161	1,591
Louisville	2013	2,916	1,218	204	370	98	822
Memphis	2011	2,870	1,348	220	1,280	119	900
Miami	2013	2,351	1,154	444	445	971	865
Milwaukee	2011	1,911	1,005	309	284	137	785
Minneapolis	2013	2,624	914	170	118	100	517
Nashville	2013	2,919	1,233	238	416	155	921
New Orleans	2011	2,800	1,407	191	901	210	911
New York City	2013	677	353	155	147	131	333
Oklahoma City	2013	3,304	1,310	214	354	319	1,034
Orlando	2013	3,031	1,284	276	444	719	1,101
Philadelphia	2013	2,893	1,322	163	602	215	730
Phoenix	2011	2,569	1,137	264	147	555	873
Pittsburgh	2011	2,758	1,203	128	210	50	642
Portland	2011	2,916	1,256	347	60	209	1,022
Providence	2011	2,666	1,143	110	105	195	672
Richmond	2013	2,916	1,193	189	791	134	868
Riverside	2011	2,816	1,400	216	232	1,105	1,063
Sacramento	2011	2,954	1,422	334	219	472	1,154
San Antonio	2013	3,357	1,499	273	212	1,659	1,142
San Diego	2011	3,123	1,497	498	169	732	1,404
San Francisco	2011	2,878	1,220	469	115	410	1,343
San Jose	2011	3,292	1,374	392	113	658	1,337
Seattle	2013	2,765	1,017	361	142	179	976
St. Louis	2011	2,663	1,224	201	541	71	748
Tampa	2013	2,225	883	211	234	293	680
Virginia Beach	2011	3,018	1,335	278	873	136	1,002
Washington, DC	2013	2,307	670	207	556	226	611
Total	N/A	129,662	57,266	12,665	19,187	17,333	42,857

Appendix B. City Median Energy Burdens

Table B1. Median gross household income and energy burdens for the median household in each group

City	Data year	Median household	Median low-income household	Median low-income multifamily	Median African-American household	Median Latino household	Median renter household
Atlanta	2011	4.97%	10.19%	8.31%	6.60%	6.60%	6.75%
Austin	2013	2.65%	5.47%	4.09%	3.47%	3.72%	3.14%
Baltimore	2013	3.12%	7.14%	4.80%	4.41%	3.29%	3.64%
Birmingham	2011	5.34%	10.92%	8.71%	7.68%	6.55%	7.30%
Boston	2013	2.76%	6.72%	4.40%	3.89%	3.28%	2.86%
Charlotte	2011	4.00%	7.89%	5.50%	5.14%	4.91%	4.78%
Chicago	2013	3.05%	6.73%	5.57%	6.56%	3.64%	4.12%
Cincinnati	2011	4.34%	8.45%	6.19%	6.86%	3.87%	5.96%
Cleveland	2011	4.22%	8.47%	5.36%	7.00%	4.64%	5.47%
Columbus	2011	3.95%	8.13%	6.52%	6.19%	5.00%	5.17%
Dallas	2011	4.25%	8.84%	6.51%	5.45%	5.97%	4.73%
Denver	2011	3.20%	6.59%	5.43%	4.81%	4.54%	4.18%
Detroit	2013	3.52%	7.98%	5.26%	5.78%	5.72%	4.56%
Fort Worth	2011	4.36%	8.02%	6.12%	5.24%	5.72%	5.04%
Hartford	2013	3.74%	8.16%	5.90%	6.03%	5.20%	4.92%
Houston	2013	3.24%	6.94%	5.22%	3.96%	3.81%	3.49%
Indianapolis	2011	3.70%	7.66%	6.51%	5.40%	4.13%	5.00%
Jacksonville	2013	3.87%	7.64%	5.56%	5.30%	4.33%	4.41%
Kansas City	2011	4.48%	8.49%	6.36%	7.91%	6.64%	6.11%
Las Vegas	2013	3.49%	6.11%	4.51%	4.08%	4.42%	3.71%
Los Angeles	2011	2.75%	4.60%	3.48%	3.72%	3.27%	2.73%
Louisville	2013	3.57%	7.60%	6.10%	4.66%	4.16%	4.77%
Memphis	2011	6.15%	13.22%	10.88%	9.65%	8.26%	8.64%
Miami	2013	3.32%	6.23%	4.80%	4.10%	3.73%	3.80%
Milwaukee	2011	4.08%	7.02%	5.54%	7.40%	4.46%	4.93%
Minneapolis	2013	2.32%	5.11%	3.05%	4.14%	3.14%	2.57%
Nashville	2013	3.11%	6.40%	5.18%	4.21%	4.45%	3.76%
New Orleans	2011	5.25%	9.79%	6.93%	8.06%	5.07%	6.31%
New York City	2013	3.67%	6.78%	5.68%	4.37%	4.87%	3.75%
Oklahoma City	2013	3.51%	7.36%	5.21%	4.98%	4.26%	4.27%
Orlando	2013	3.93%	7.55%	6.24%	5.27%	4.85%	4.14%
Philadelphia	2013	3.82%	8.82%	5.12%	6.46%	7.30%	4.70%
Phoenix	2011	4.18%	7.92%	6.09%	4.93%	6.00%	5.30%
Pittsburgh	2011	4.52%	9.42%	7.08%	8.31%	4.95%	6.00%
Portland	2011	2.81%	5.22%	4.16%	3.99%	3.53%	3.34%
Providence	2011	4.66%	9.46%	7.10%	6.03%	7.33%	6.18%
Richmond	2013	3.10%	6.54%	5.17%	4.24%	3.49%	3.97%
Riverside	2011	3.54%	5.74%	4.22%	3.81%	3.77%	4.14%
Sacramento	2011	2.93%	5.29%	3.60%	4.49%	3.45%	3.41%
San Antonio	2013	3.77%	7.80%	5.00%	3.99%	4.50%	3.95%
San Diego	2011	2.30%	3.90%	2.66%	2.24%	2.54%	2.27%
San Francisco	2011	1.41%	2.82%	1.89%	2.27%	1.83%	1.27%
San Jose	2011	1.78%	3.82%	2.28%	1.86%	2.35%	1.73%
Seattle	2013	2.05%	4.59%	3.08%	2.84%	2.22%	2.18%
St. Louis	2011	4.07%	8.37%	6.25%	7.40%	4.21%	5.90%
Tampa	2013	3.32%	7.28%	5.95%	3.97%	3.91%	3.64%
Virginia Beach	2011	3.85%	7.46%	5.39%	4.98%	3.75%	4.54%
Washington, DC	2013	2.12%	6.11%	4.28%	2.88%	2.67%	2.44%

Appendix C. Energy Burdens at the Median and Highest Energy Burden Quartile, by City

Table C1. Energy burdens for low-income and multifamily low-income households

City	Data year	Median household	Median low-income household	Highest energy burden quartile for low-income households	Median low-income multifamily household	Highest energy burden quartile for low-income multifamily households
Atlanta	2011	4.97%	10.19%	18.24%	8.31%	15.72%
Austin	2013	2.65%	5.47%	9.73%	4.09%	7.29%
Baltimore	2013	3.12%	7.14%	13.65%	4.80%	9.54%
Birmingham	2011	5.34%	10.92%	18.82%	8.71%	16.17%
Boston	2013	2.76%	6.72%	12.36%	4.40%	8.94%
Charlotte	2011	4.00%	7.89%	14.45%	5.50%	10.22%
Chicago	2013	3.05%	6.73%	13.41%	5.57%	14.59%
Cincinnati	2011	4.34%	8.45%	15.49%	6.19%	12.95%
Cleveland	2011	4.22%	8.47%	14.07%	5.36%	12.31%
Columbus	2011	3.95%	8.13%	12.93%	6.52%	11.17%
Dallas	2011	4.25%	8.84%	14.50%	6.51%	11.28%
Denver	2011	3.20%	6.59%	10.57%	5.43%	8.79%
Detroit	2013	3.52%	7.98%	15.26%	5.26%	9.76%
Fort Worth	2011	4.36%	8.02%	13.02%	6.12%	11.35%
Hartford	2013	3.74%	8.16%	14.49%	5.90%	11.75%
Houston	2013	3.24%	6.94%	11.84%	5.22%	9.18%
Indianapolis	2011	3.70%	7.66%	12.83%	6.51%	9.91%
Jacksonville	2013	3.87%	7.64%	13.48%	5.56%	9.06%
Kansas City	2011	4.48%	8.49%	14.60%	6.36%	11.08%
Las Vegas	2013	3.49%	6.11%	10.39%	4.51%	7.55%
Los Angeles	2011	2.75%	4.60%	8.84%	3.48%	6.67%
Louisville	2013	3.57%	7.60%	12.74%	6.10%	10.42%
Memphis	2011	6.15%	13.22%	25.47%	10.88%	21.73%
Miami	2013	3.32%	6.23%	11.04%	4.80%	7.99%
Milwaukee	2011	4.08%	7.02%	12.52%	5.54%	9.65%
Minneapolis	2013	2.32%	5.11%	8.20%	3.05%	5.77%
Nashville	2013	3.11%	6.40%	10.91%	5.18%	9.40%
New Orleans	2011	5.25%	9.79%	18.90%	6.93%	10.43%
New York City	2013	3.67%	6.78%	14.01%	5.68%	9.97%
Oklahoma City	2013	3.51%	7.36%	12.56%	5.21%	9.03%
Orlando	2013	3.93%	7.55%	11.51%	6.24%	9.39%
Philadelphia	2013	3.82%	8.82%	16.67%	5.12%	9.07%
Phoenix	2011	4.18%	7.92%	13.42%	6.09%	9.79%
Pittsburgh	2011	4.52%	9.42%	15.67%	7.08%	15.72%
Portland	2011	2.81%	5.22%	8.76%	4.16%	6.53%
Providence	2011	4.66%	9.46%	16.66%	7.10%	11.07%
Richmond	2013	3.10%	6.54%	11.51%	5.17%	9.26%
Riverside	2011	3.54%	5.74%	9.50%	4.22%	7.19%
Sacramento	2011	2.93%	5.29%	8.74%	3.60%	6.35%
San Antonio	2013	3.77%	7.80%	14.06%	5.00%	9.16%
San Diego	2011	2.30%	3.90%	6.74%	2.66%	4.80%
San Francisco	2011	1.41%	2.82%	5.24%	1.89%	3.26%
San Jose	2011	1.78%	3.82%	6.67%	2.28%	4.05%
Seattle	2013	2.05%	4.59%	8.05%	3.08%	5.61%
St. Louis	2011	4.07%	8.37%	14.78%	6.25%	12.87%
Tampa	2013	3.32%	7.28%	12.13%	5.95%	9.54%
Virginia Beach	2011	3.85%	7.46%	12.61%	5.39%	9.67%
Washington, DC	2013	2.12%	6.11%	11.70%	4.28%	7.68%

Table C2. Energy burdens for African-American and Latino households

City	Data year	Median household	Median African-American household	Highest energy burden quartile for African-American households	Median Latino household	Highest energy burden quartile for Latino households
Atlanta	2011	4.97%	6.60%	12.32%	6.60%	11.53%
Austin	2013	2.65%	3.47%	6.11%	3.72%	6.75%
Baltimore	2013	3.12%	4.41%	8.92%	3.29%	5.66%
Birmingham	2011	5.34%	7.68%	15.44%	6.55%	10.44%
Boston	2013	2.76%	3.89%	6.38%	3.28%	6.22%
Charlotte	2011	4.00%	5.14%	10.85%	4.91%	8.90%
Chicago	2013	3.05%	6.56%	15.27%	3.64%	7.14%
Cincinnati	2011	4.34%	6.86%	15.64%	3.87%	7.26%
Cleveland	2011	4.22%	7.00%	13.14%	4.64%	9.77%
Columbus	2011	3.95%	6.19%	10.93%	5.00%	9.56%
Dallas	2011	4.25%	5.45%	10.61%	5.97%	10.06%
Denver	2011	3.20%	4.81%	9.39%	4.54%	8.70%
Detroit	2013	3.52%	5.78%	14.78%	5.72%	10.19%
Fort Worth	2011	4.36%	5.24%	10.27%	5.72%	9.07%
Hartford	2013	3.74%	6.03%	12.47%	5.20%	11.10%
Houston	2013	3.24%	3.96%	8.56%	3.81%	6.87%
Indianapolis	2011	3.70%	5.40%	10.07%	4.13%	7.57%
Jacksonville	2013	3.87%	5.30%	10.06%	4.33%	6.68%
Kansas City	2011	4.48%	7.91%	16.22%	6.64%	11.96%
Las Vegas	2013	3.49%	4.08%	8.04%	4.42%	7.09%
Los Angeles	2011	2.75%	3.72%	9.47%	3.27%	6.38%
Louisville	2013	3.57%	4.66%	8.59%	4.16%	9.10%
Memphis	2011	6.15%	9.65%	19.36%	8.26%	15.93%
Miami	2013	3.32%	4.10%	8.63%	3.73%	6.36%
Milwaukee	2011	4.08%	7.40%	15.48%	4.46%	7.92%
Minneapolis	2013	2.32%	4.14%	7.90%	3.14%	6.10%
Nashville	2013	3.11%	4.21%	9.21%	4.45%	7.81%
New Orleans	2011	5.25%	8.06%	16.38%	5.07%	8.23%
New York City	2013	3.67%	4.37%	9.00%	4.87%	8.90%
Oklahoma City	2013	3.51%	4.98%	9.14%	4.26%	7.40%
Orlando	2013	3.93%	5.27%	8.53%	4.85%	7.55%
Philadelphia	2013	3.82%	6.46%	14.23%	7.30%	15.74%
Phoenix	2011	4.18%	4.93%	8.61%	6.00%	10.74%
Pittsburgh	2011	4.52%	8.31%	16.14%	4.95%	12.44%
Portland	2011	2.81%	3.99%	10.61%	3.53%	6.87%
Providence	2011	4.66%	6.03%	12.90%	7.33%	11.66%
Richmond	2013	3.10%	4.24%	7.99%	3.49%	6.28%
Riverside	2011	3.54%	3.81%	7.30%	3.77%	6.01%
Sacramento	2011	2.93%	4.49%	8.14%	3.45%	5.98%
San Antonio	2013	3.77%	3.99%	7.96%	4.50%	8.60%
San Diego	2011	2.30%	2.24%	4.29%	2.54%	4.40%
San Francisco	2011	1.41%	2.27%	4.22%	1.83%	3.33%
San Jose	2011	1.78%	1.86%	3.93%	2.35%	4.33%
Seattle	2013	2.05%	2.84%	6.08%	2.22%	4.65%
St. Louis	2011	4.07%	7.40%	14.41%	4.21%	7.32%
Tampa	2013	3.32%	3.97%	8.05%	3.91%	6.44%
Virginia Beach	2011	3.85%	4.98%	9.64%	3.75%	6.08%
Washington, DC	2013	2.12%	2.88%	5.78%	2.67%	4.57%

Table C3. Energy burdens for renting households

City	Data year	Median household	Median renting household	Highest energy burden quartile for renting households
Atlanta	2011	4.97%	6.75%	13.25%
Austin	2013	2.65%	3.14%	5.65%
Baltimore	2013	3.12%	3.64%	7.41%
Birmingham	2011	5.34%	7.30%	15.06%
Boston	2013	2.76%	2.86%	5.76%
Charlotte	2011	4.00%	4.78%	9.65%
Chicago	2013	3.05%	4.12%	10.01%
Cincinnati	2011	4.34%	5.96%	12.12%
Cleveland	2011	4.22%	5.47%	11.93%
Columbus	2011	3.95%	5.17%	9.82%
Dallas	2011	4.25%	4.73%	9.07%
Denver	2011	3.20%	4.18%	7.77%
Detroit	2013	3.52%	4.56%	10.20%
Fort Worth	2011	4.36%	5.04%	8.70%
Hartford	2013	3.74%	4.92%	10.24%
Houston	2013	3.24%	3.49%	6.83%
Indianapolis	2011	3.70%	5.00%	9.43%
Jacksonville	2013	3.87%	4.41%	8.21%
Kansas City	2011	4.48%	6.11%	11.68%
Las Vegas	2013	3.49%	3.71%	6.82%
Los Angeles	2011	2.75%	2.73%	5.97%
Louisville	2013	3.57%	4.77%	9.25%
Memphis	2011	6.15%	8.64%	18.48%
Miami	2013	3.32%	3.80%	6.62%
Milwaukee	2011	4.08%	4.93%	9.85%
Minneapolis	2013	2.32%	2.57%	5.52%
Nashville	2013	3.11%	3.76%	6.99%
New Orleans	2011	5.25%	6.31%	12.61%
New York City	2013	3.67%	3.75%	7.19%
Oklahoma City	2013	3.51%	4.27%	7.97%
Orlando	2013	3.93%	4.14%	7.90%
Philadelphia	2013	3.82%	4.70%	11.18%
Phoenix	2011	4.18%	5.30%	9.11%
Pittsburgh	2011	4.52%	6.00%	11.87%
Portland	2011	2.81%	3.34%	5.85%
Providence	2011	4.66%	6.18%	11.74%
Richmond	2013	3.10%	3.97%	7.03%
Riverside	2011	3.54%	4.14%	7.30%
Sacramento	2011	2.93%	3.41%	6.39%
San Antonio	2013	3.77%	3.95%	7.52%
San Diego	2011	2.30%	2.27%	4.03%
San Francisco	2011	1.41%	1.27%	2.50%
San Jose	2011	1.78%	1.73%	3.45%
Seattle	2013	2.05%	2.18%	4.25%
St. Louis	2011	4.07%	5.90%	12.93%
Tampa	2013	3.32%	3.64%	6.77%
Virginia Beach	2011	3.85%	4.54%	8.52%
Washington, DC	2013	2.12%	2.44%	5.22%

Appendix D. Households with Energy Burden At Least Twice the City Median

Table D1. Percentage of households in each group with energy burdens over two times the city median energy burden

City	Data year	All households	Low-income households	Low-income multifamily households	African-American households	Latino households	Renting households
Atlanta	2011	24.18%	51.45%	41.24%	32.57%	34.65%	33.77%
Austin	2013	23.55%	53.14%	36.81%	33.01%	34.68%	28.82%
Baltimore	2013	23.80%	56.83%	37.09%	36.12%	19.84%	28.84%
Birmingham	2011	25.31%	51.32%	41.51%	38.32%	23.08%	36.82%
Boston	2013	23.98%	50.54%	42.62%	30.65%	26.16%	25.82%
Charlotte	2011	23.76%	49.47%	32.70%	32.40%	29.44%	30.41%
Chicago	2013	29.11%	56.44%	48.44%	52.84%	28.13%	37.85%
Cincinnati	2011	24.32%	48.29%	36.99%	41.70%	22.73%	35.43%
Cleveland	2011	22.97%	50.08%	34.52%	41.03%	28.79%	36.38%
Columbus	2011	23.20%	51.40%	39.51%	40.37%	30.48%	32.43%
Dallas	2011	23.93%	52.19%	39.38%	33.60%	33.18%	27.16%
Denver	2011	23.25%	51.84%	40.40%	40.28%	35.27%	32.13%
Detroit	2013	25.26%	57.10%	36.02%	44.49%	38.96%	34.71%
Fort Worth	2011	21.55%	45.30%	33.33%	30.75%	27.57%	24.90%
Hartford	2013	22.97%	54.30%	38.57%	40.48%	37.29%	34.90%
Houston	2013	24.10%	53.28%	38.87%	34.39%	26.24%	26.37%
Indianapolis	2011	23.76%	52.82%	41.46%	34.97%	26.70%	34.00%
Jacksonville	2013	22.53%	48.97%	30.29%	33.50%	20.57%	26.54%
Kansas City	2011	22.66%	46.50%	34.72%	44.66%	34.15%	33.79%
Las Vegas	2013	20.95%	42.50%	27.89%	30.99%	25.71%	24.64%
Los Angeles	2011	26.22%	42.92%	32.44%	40.34%	30.15%	27.72%
Louisville	2013	22.98%	53.28%	41.67%	31.89%	30.61%	33.33%
Memphis	2011	26.10%	54.15%	43.64%	40.00%	32.77%	37.67%
Miami	2013	23.05%	46.10%	31.08%	32.36%	22.76%	24.74%
Milwaukee	2011	23.81%	43.08%	30.74%	46.13%	24.09%	30.19%
Minneapolis	2013	20.54%	56.46%	31.76%	46.61%	34.00%	29.01%
Nashville	2013	22.82%	52.23%	41.18%	34.38%	34.84%	29.21%
New Orleans	2011	23.71%	45.84%	24.08%	39.62%	17.14%	29.20%
New York City	2013	27.03%	47.03%	36.13%	29.25%	28.24%	24.62%
Oklahoma City	2013	22.19%	52.90%	36.92%	33.62%	26.96%	29.21%
Orlando	2013	20.59%	47.12%	34.42%	29.28%	22.95%	25.25%
Philadelphia	2013	27.03%	56.88%	31.29%	43.52%	47.44%	35.07%
Phoenix	2011	21.37%	46.53%	31.82%	25.85%	34.77%	28.29%
Pittsburgh	2011	23.57%	52.45%	40.63%	45.24%	34.00%	33.18%
Portland	2011	20.71%	45.86%	32.28%	40.00%	31.58%	26.91%
Providence	2011	22.66%	50.83%	34.55%	30.48%	38.46%	33.04%
Richmond	2013	22.53%	53.39%	39.68%	32.24%	25.37%	29.84%
Riverside	2011	20.10%	38.57%	25.93%	25.86%	20.45%	26.06%
Sacramento	2011	22.58%	43.74%	28.74%	36.53%	26.06%	29.12%
San Antonio	2013	24.13%	51.97%	31.14%	26.42%	29.42%	24.78%
San Diego	2011	21.07%	40.88%	26.10%	21.89%	23.91%	20.73%
San Francisco	2011	23.45%	49.92%	30.70%	40.00%	29.27%	21.67%
San Jose	2011	24.30%	53.78%	31.38%	28.32%	32.67%	24.61%
Seattle	2013	23.33%	55.36%	38.23%	38.03%	28.49%	26.33%
St. Louis	2011	24.30%	51.80%	38.81%	46.03%	19.72%	38.77%
Tampa	2013	22.47%	54.47%	41.23%	29.06%	23.55%	25.44%
Virginia Beach	2011	22.27%	48.39%	32.73%	32.42%	19.85%	28.34%
Washington, DC	2013	22.71%	68.06%	50.24%	32.91%	28.32%	29.30%

Appendix E. Regional Energy Burden

FIGURE E1. Energy burden for median household from select groups in Southeast cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

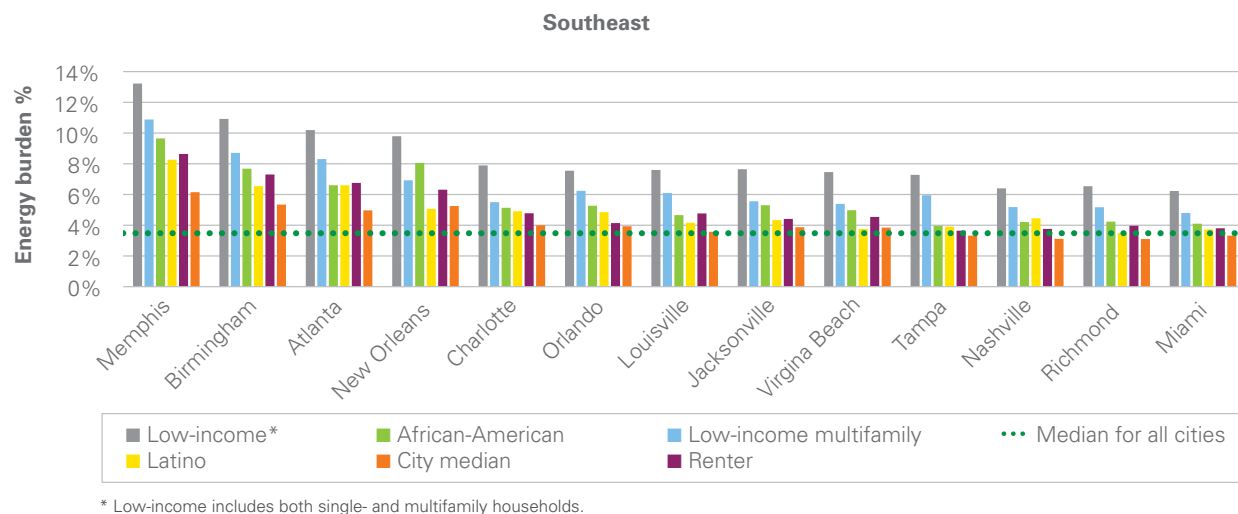


Figure E2. Energy burden for median household from select groups in Midwest cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

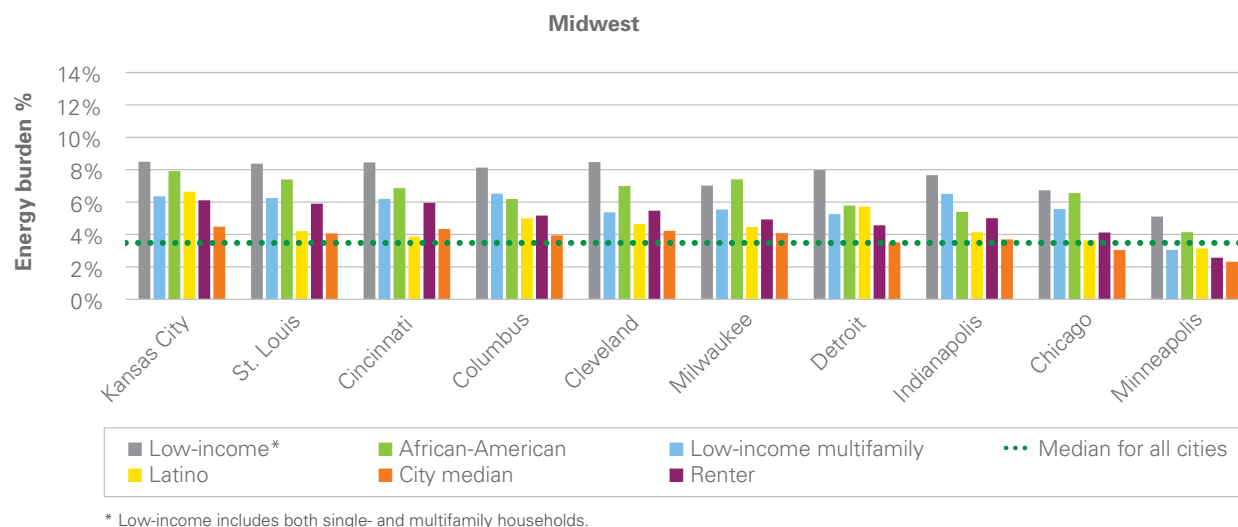


FIGURE E3. Energy burden for median household from select groups in Northeast cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

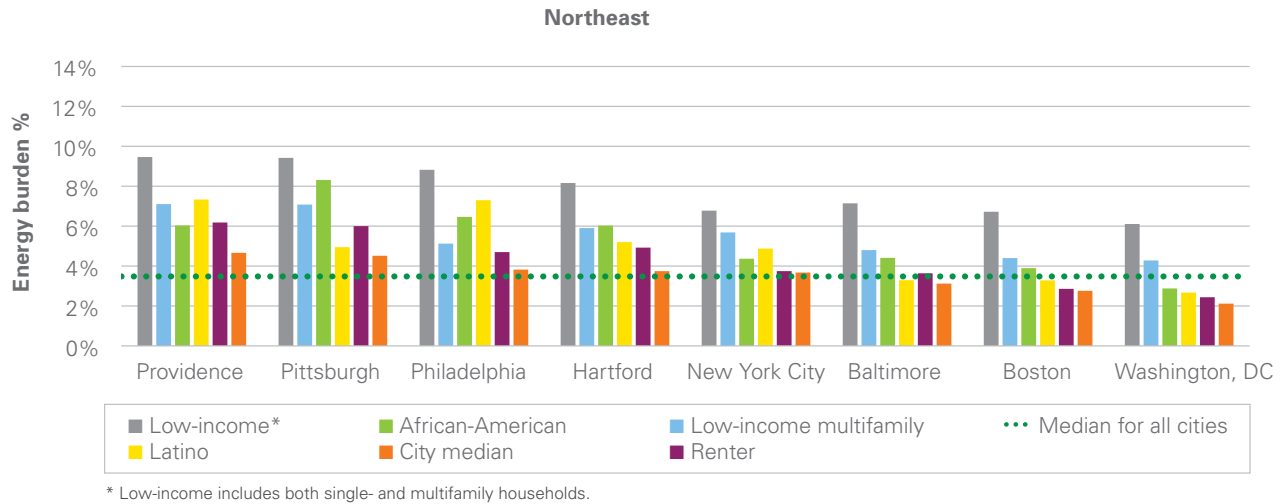


Figure E4. Energy burden for median household from select groups in South Central cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

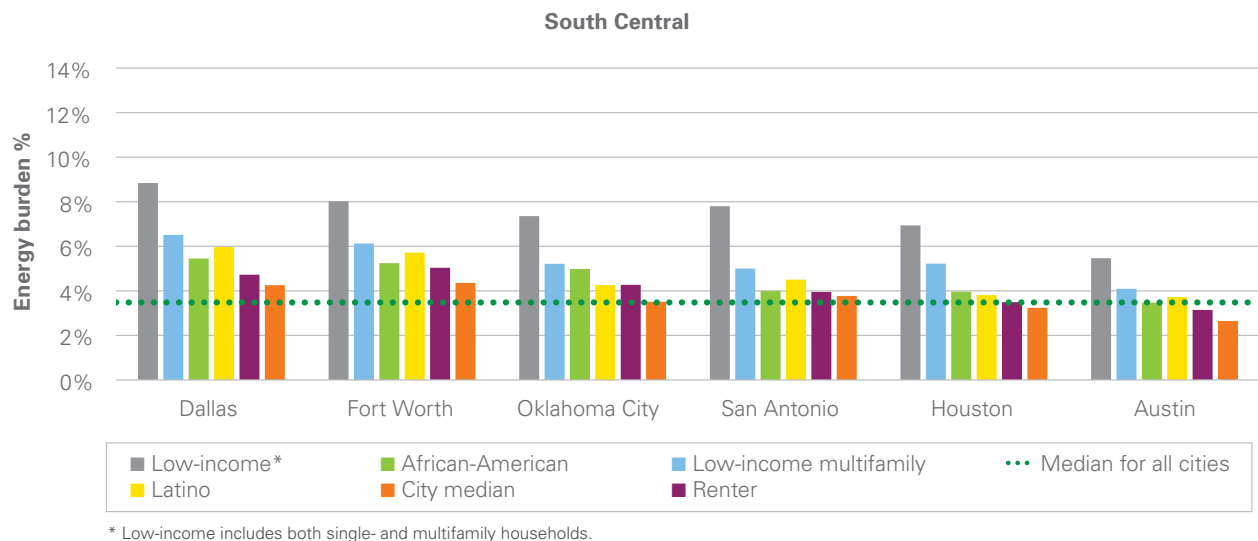


FIGURE E5. Energy burden for median household from select groups in Southwest cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

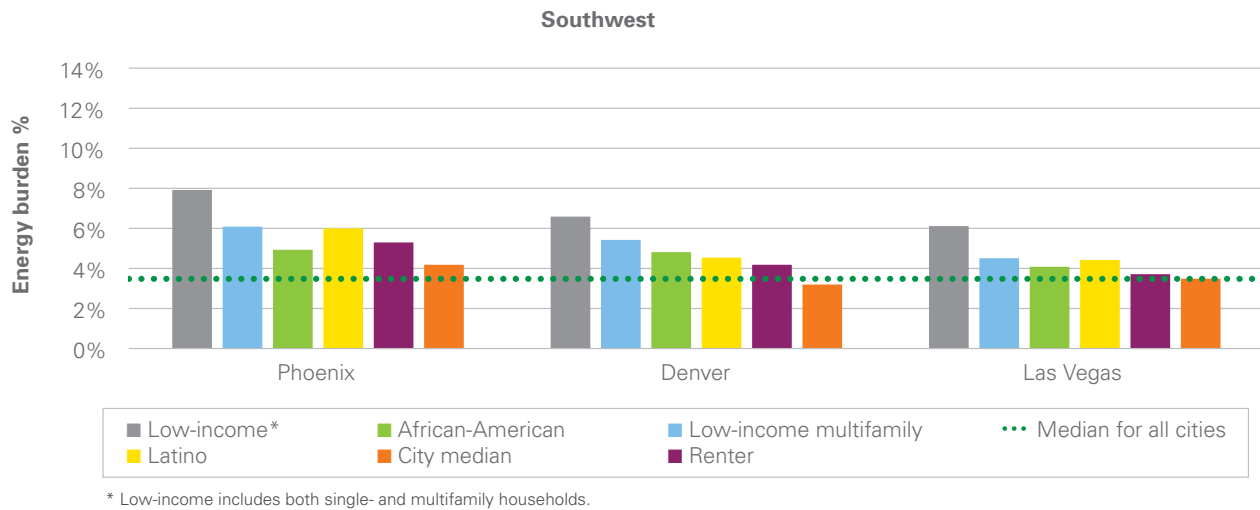


FIGURE E6. Energy burden for median household from select groups in Northwest cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.

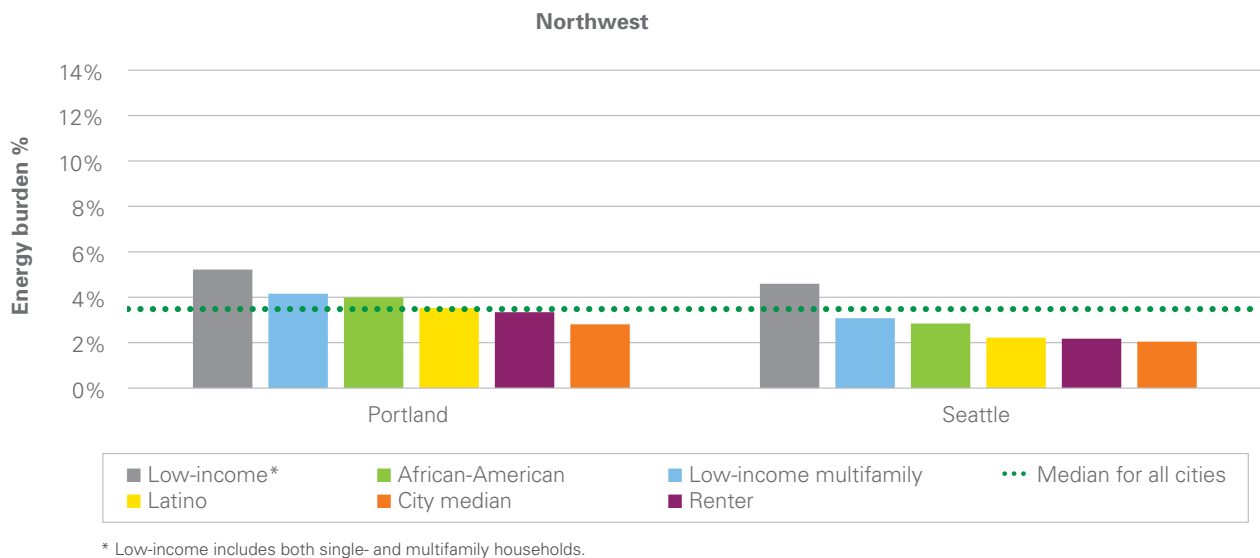
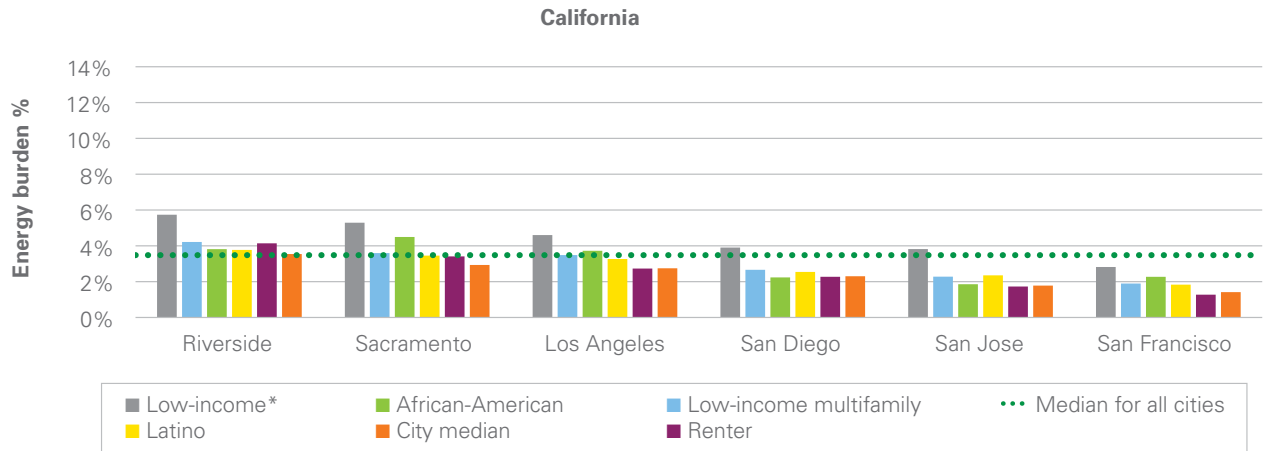


FIGURE E7. Energy burden for median household from select groups in California cities, ordered from highest to lowest based on the average of the median energy burdens across all groups.



* Low-income includes both single- and multifamily households.



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Energy & Transportation Science Division

**LOW-INCOME ENERGY AFFORDABILITY:
CONCLUSIONS FROM A LITERATURE REVIEW**

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ACRONYMS

AMI	Area Median Income
ARRA	American Recovery and Reinvestment Act
CDC	Center for Disease Control
DOE	U.S. Department of Energy
EECLP	Energy Efficiency and Conservation Loan Program
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicles
FERC	Federal Energy Regulatory Commission
FPL	Federal Poverty Level
HHS	U.S. Department of Health and Human Services
HUD	U.S. Department of Housing and Urban Development
IRP	Integrated Resource Plan
LIHEAP	Low Income Home Energy Assistance Program
LIHTA	Low-Income Housing Tax Credit Program
MSA	Metropolitan Statistical Area
MOU	Memorandum of Understanding
NASCSP	National Association of State Community Services Programs
NGO	Non-governmental organization
NCHH	National Center for Healthy Housing
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
RECS	Residential Energy Consumption Survey
RGGI	Regional Greenhouse Gas Initiative
SDG	Sustainable Cities and Communities
SEP	State Energy Program
SMI	State Median Income
SPM	Supplemental Poverty Measure
UNDP	U.S. Development Program
USDA	U.S. Department of Agriculture
TVA	Tennessee Valley Authority
WAP	Weatherization Assistance Program

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ABSTRACT

This paper examines the persistent problem of high energy burdens among low-income households, based on a review of more than 180 publications that pointed to several promising opportunities to address energy affordability including inclusive solar programs, leveraged health care benefits, and behavioral economics. using an equity and affordability lens. Even after decades of weatherization and bill-payment programs, low-income households, on average, continue to spend a higher share of their income on electricity and natural gas bills than any other income group. Energy burden for low-income households is not declining, and it remains persistently high, particularly in the South, in rural America, among minority households, and those with children and elderly residents. On a per household basis, utility companies spend less on energy-efficiency programs for low-income households than for other income groups. In addition, government and utility programs that promote rooftop solar power, electric vehicles, and home energy storage are largely inaccessible to low-income households. Our review identifies promising opportunities to address energy affordability including inclusive solar programs, leveraged health care benefits, behavioral economics, data analytics, advanced information and communication technologies, and grid resiliency. Scalable approaches require linking implementing agencies, programs and policies to tackle the complex web of causes and impacts on low-income households with high energy burdens.

1. INTRODUCTION: GOALS, SCOPE, AND STRUCTURE OF LITERATURE REVIEW

1.1 GOALS OF THE LITERATURE REVIEW

Energy drives the U.S. economy and impacts nearly every dimension of modern society; it is an imperative of daily existence. When access to energy becomes difficult, the burden is felt in every facet of life – housing, mobility, health, work, education, and much more.

Since the 1970's introduction of major low-income energy programs in the U.S., the nature of household energy consumption has evolved. For decades, the energy consumed by a typical household increased as suburbanization and sprawl enabled homes to grow, and affluence and innovation made central heating and cooling systems almost universal. Appliances multiplied, and “plug loads” proliferated with the creation of new low-voltage AC devices: computers, telephones, hi-fi's and more (Nordman and Sanchez, 2006). In contrast, low-income households continued to occupy much of the energy inefficient housing stock in the older core of American cities.

Over time, these trends have evolved. Increasingly congested urban areas have motivated moves back to inner cities, re-densifying and gentrifying older neighbourhoods, sometimes at the expense of affordable housing. This has created a new geography of suburban poverty with issues of energy affordability that have not yet been documented. At the same time, many low-income households in rural communities have chosen to maintain their social networks and ways of life, and have not moved to urban areas where jobs and property values have been growing more rapidly. In rural areas where the economy has been stagnant and the housing stock is older, low-income energy burdens are worsening.

Nationwide, innovations continued to transform home energy use, with more efficient appliances (furnaces and heat pumps, refrigerators, etc.), smart thermostats, solid state lighting, low-emissivity windows, and foam insulation – reducing the energy consumed by individual households. Rooftop solar panels have reached “grid parity” in some parts of the U.S.¹, and soon home energy storage systems and electric vehicles (EVs) will enable households to arbitrage their energy assets.

In the midst of these transformations, it is time to review what we know about the energy burden of low-income households:

- How have low-income energy burdens changed over the past decade?
- How have they been affected by energy programs, policies, and technology trends?
- What opportunities offer the greatest promise to reduce the energy burden of low-income households, as the U.S. continues its transition to a more efficient and renewable energy system?

To answer these questions, we summarize the knowledge embodied in the last decade of literature focused on low-income energy burdens in the U.S. Many entities across the U.S. – chiefly utilities and federal and state agencies, but also nonprofits and religious organizations, as well as cities and community organizations – work to save energy and reduce the energy costs of

¹ <https://www.greentechmedia.com/articles/read/gtm-research-20-us-states-at-grid-parity-for-residential-solar#gs.7enug2>

low-income households. As a result, a substantial body of literature has examined the design and impacts of these programs and policies. Other research has produced energy-focused case studies of low-income communities, surveys of the energy behavior of low-income households, and accounts of energy bills in the overall expenditures of low-income households. With the proliferation of information on the internet, this decade of literature is immense. Our literature search methodology is described in Section 1.3.

This paper begins by characterizing the magnitude, causes, and impacts of the energy burden currently experienced by low-income households in the U.S. It then describes the multiplicity of energy programs and policies that impact low-income energy burdens. Program design, implementation, participation rates, and investment levels are described in Section 3. This is followed by a summary of the cost-effectiveness and impacts of the programs, which enables estimates of the remaining potential in Section 4. Attention then turns to identifying major gaps and opportunities that energy programs and policies could address in the future (Section 5), and we end with conclusions about opportunities to scale up these impacts.

1.2 THE ENERGY EQUITY LENS

Increasingly energy scholars are focusing on the importance of equity in the transition to a smarter and greener energy economy. The rapid uptake of new technologies has the potential to benefit some and harm others, to the extent that resources, jobs, and capital are redistributed. Depending on the sources and distribution of financing, the design of policies and programs, and the location of infrastructure and facility investments, low-income households may benefit or lose going forward. And if low-income households “lose,” all households lose, because there will be negative effects for all Americans if segments of society are left behind. Overall, the U.S. is experiencing a growing wealth disparity between low-income households and more affluent Americans (Curti, Andersen, and Wright, 2018). Living in communities of color, indigenous populations, and immigrants typically means more limited access to resources. This intersection of race, ethnicity, and class needs to be considered when designing effective low-income energy programs and policies (Reames, 2016; Sunter, Castellanos, and Kammen, 2019).

The environmental justice community has highlighted equity issues in the debate about environmental externalities from the consumption of energy. Due to their lower per capita energy consumption, low-income households contribute proportionately less to local and global air pollution. At the same time, they tend to suffer disproportionately more from the impacts of poor air quality (National Research Council, 2010a, b). These past trends highlight the possibility that the transition to increasing use of renewable energy underway for many states and communities could cause energy justice to unfold in similarly inequitable ways because of long-standing and uneven power dynamics (Healy and Barry, 2017). Equity is increasingly being considered in discussions of energy program design (Curti et al., 2018; Massetti et al., 2017). The literature on environmental equity concerns have enumerated energy policy linkages to health outcomes, access to cleaner air, transportation and other public services which contribute to households’ overall well-being (Jenkins et al., 2016; Massetti et al., 2017). In addition, researchers also recognize that policies to decarbonize the energy sector, can, in fact, worsen disparities due to their disproportionate effects on economically weaker segments of society (Monyei et al., 2019).

Formal discussions of equity typically distinguish between procedural equity that deals with “inclusion” and distributive equity that deals with “access” (Curti et al., 2018). In addition, this

paper also considers intergenerational equity as an important dimension of energy affordability. Each of these dimensions is discussed below in the context of low-income energy programs. Additional dimensions often refer to redistributive equity (fairness in the punishment of wrongs), structural equity (prevention of the chronic, cumulative disadvantage experienced by subordinated groups), and transgenerational equity (avoidance of unfair burdens on future generations) (Franklin and Osborne, 2017).

1.2.1 Procedural Equity (Inclusion)

Procedural equity is the idea of fairness and transparency of the processes that allocate resources and adjudicate disputes. Connected to the desire for due process, one aspect of procedural equity is related to administrative and legal proceedings. In some instances, courts of law have demanded an equitable distribution of resources. As one example, a court settlement of an EPA case against the Tennessee Valley Authority involving air pollution violations involved the creation of an energy-efficiency program for low-income customers.² The idea of procedural equity can also be applied to non-legal contexts in which some process is employed to resolve conflict or divide benefits or burdens. Others emphasize “inclusion” as a key component of procedural equity: “inclusive, accessible, authentic engagement and representation in the process to develop or implement programs or policies” (Curti et al., 2018, p. 9).

Economically disadvantaged communities across the country are amplifying their voices to ensure that the transition to increasing use of energy efficiency and renewable energy considers their needs. For example, Goldberg and McKibbin (2018) describe how the Future Energy Jobs Act in Illinois materialized with the help of a coalition of interest groups, increasing investment in energy efficiency and targeting economically disadvantaged communities. Similarly, advocates from the environmental, affordable housing, energy, and low-income communities in Pennsylvania organized a collaborative advocacy that drove improvements to low-income energy-efficiency policy across the State. Their work drew on the skills, expertise, and resources of multiple disciplines, and prioritized the multiple benefits that energy efficiency provides for low-income households (Grevatt et al., 2018).

1.2.2 Distributive Equity (Access)

Distributive equity refers to fairness in the distribution of rights or resources. In his *Theory of Justice*, John Rawls (1971) claims that one's place of birth, social status, and family influences are matters of luck that should not unduly influence the amount of benefits we receive in life. The goal of distributive equity is to limit the influence of luck so that goods are distributed more fairly and to everyone's advantage. This line of reasoning has been extended by many to argue that distributive equity is achieved when programs and policies result in fair distributions of benefits and burdens across all segments of a community, prioritizing those with highest need (Curti et al., 2018, p. 9).

Across the country, energy-efficiency programs, special rates for electric vehicles, and net metering of solar rooftop installations are paid for in part with low-income ratepayer funds, but do not provide commensurate benefits to low-income ratepayers who do not have the resources to take advantage of these programs. If the energy industry, government agencies, NGOs and

²https://www.tva.gov/file_source/TVA/Site%20Content/Environment/Environmental%20Stewardship/Air%20Quality/EPA%20Mitigation%20Projects/Smart%20Communities%20-%20Extreme%20Energy%20Makeovers%20FAQ.pdf

nonprofits do not address these unintentional consequences, low-income households will continue to suffer disproportionately from high energy burdens, failing most tests of distributive equity (Chant and Huessey, 2018). Carley et al. (2018) also draw the same conclusion based on their assessment of disparities in vulnerability across U.S. counties using the renewable portfolio standard.

1.2.3 Intergenerational Equity

Intergenerational equity adds a time dimension to the equity discussion by considering community obligations to future generations. Actions that serve to increase rather than limit the development options of future generations can be said to improve intergenerational equity (Norton, 2005). In the field of clean energy, intergenerational equity frequently involves deliberating which aspects of the present should be maintained or changed for future generations. Most energy efficiency and renewable energy programs reduce CO₂ emissions and, as a result, contribute positively to intergenerational equity in some ways. How these programs may impact the social and economic contours of communities across generations has received much less emphasis.

1.3 THE CONTEXT: MULTIPLE STAKEHOLDERS IN THE LOW-INCOME HOUSING MARKET

Numerous decision-makers and stakeholders influence the energy efficiency and renewable energy consumption of low-income housing (Figure 1.1). This highly fragmented affordable housing market challenges efforts to improve low-income energy affordability. Government agencies have administrative and regulatory roles that influence each of these stakeholders to varying degrees. In terms of word counts, energy utilities are mentioned most often in the abstracts of the 183 publications examined in this review. Local non-governmental organizations (NGOs) and community-based groups are also key stakeholders based on this tally. At the other extreme, the terms “building manager” and “property manager” do not appear in the 183 abstracts, and “landlord” and “property owner” are mentioned only 10 times, indicating that these stakeholders have received limited analysis in this body of literature. While the literature describes the landlord/tenant split incentive and the difference between renter and homeowner investments in energy-efficiency, there is little analysis of the nature of landlords operating in the low-income housing market, despite our assessment of the influential roles they play. Figure 1.1 provides a framework for understanding how current programs and policies operate and how they can be leveraged to provide a more effective and coordinated system of assistance.

1.4 SCOPE AND STRUCTURE OF LITERATURE REVIEW

A search of the peer reviewed published literature was conducted along with a search of the grey literature of more informal materials. For the peer reviewed literature, the Web of Science bibliography was searched. The Web of Science is a service provided by Thomson Reuters and Clarivate Analytics. The service curates and compiles databases on citations for several academic disciplines. The aggregate citation and publication data can then be used in performing comprehensive literature searches and analyzing the search outcomes.

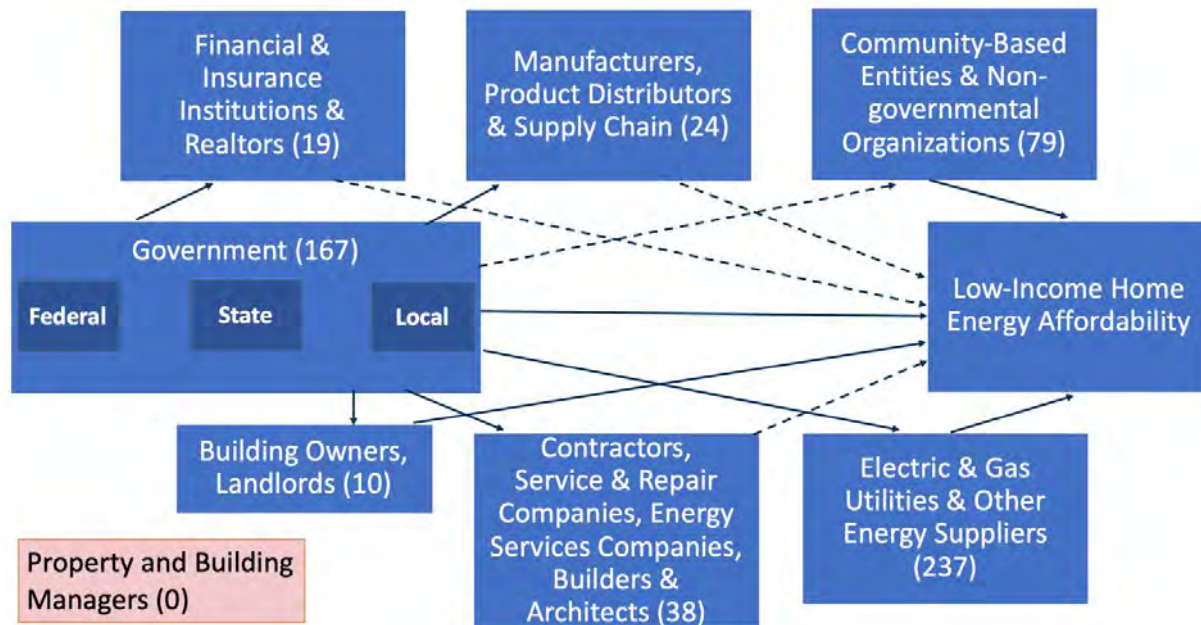


Figure 1.1. The array of stakeholders in the fragmented low-income housing market.
(Source: Authors)

Note: Numbers in parentheses are the frequency that stakeholders are mentioned in the abstracts of 183 publications examined for this review. Solid and dashed lines represent strong and weak connections, respectively.

A search protocol was established using a syntax of keywords that included synonyms of three attributes: (1) poverty and low-income households, (2) energy efficiency and solar energy, and (3) evaluation and data analysis. All three dimensions were required. In addition, at least one author had to be from the U.S., and the papers had to be published in the 2010-2019 timeframe. The resulting 270 peer-reviewed publications were “culled” for out-of-scope citations and also “mined” for additional references as the citations embedded in the original 270 publications were examined. This process produced a curated set of 171 publications. Several seminal references published earlier than 2010 are also cited in this report.

A Delphi approach to ensure consideration of the associated grey literature – including conference proceedings, trade association documents, and workshop presentations. In some instances, for instance, technology, program implementation, and policy innovations are so recent that the published literature has not yet addressed them.

The technology scope of this review is broad. Energy efficiency is a core technology of interest, referring to technologies, materials, and practices that require less energy to deliver a given service, such as heat, light, and warm water (Brown and Wang, 2015). Solar photovoltaic systems are also included in the technology scope, as well as electric vehicles, home storage, and microgrids because they too, can help to reduce energy burdens.

To manage and archive this vast information resource, an annotated bibliography of the literature reviewed in this paper is also available (Lapsa, Brown, and Soni, 2020).

While the scope is national, the review also highlights how geography, race, ethnicity, culture, health, and age create unique circumstances. Cities, suburbs, rural areas, island territories, and Indian reservations all offer different challenges and solutions. Low-income families with children and the elderly and disabled have different needs for energy and face different challenges to reduce their utility bills. Nevertheless, principles associated with successful programs and policies do emerge. In each section, we also summarize the key findings based on the dominant view in the literature that we examine. These findings are then summarized and organized into conclusions in Section 6, based on common themes and the preponderance of evidence from the literature review.

2. ENERGY BURDEN OF LOW-INCOME HOUSEHOLDS

Low-income households in the U.S. are diverse, as are their patterns of energy consumption. In this section, we describe alternative measures of energy burden, the energy consumption patterns of low-income households, how these patterns have changed over the past decade, and the causes and effects of high energy burden among low-income households.

2.1 MEASURING THE EXTENT OF THE BURDEN

To understand low-income energy burdens, it is important to examine the metrics used by analysts to characterize the energy consumption patterns of low-income households.

2.1.1 Variable and Inconsistent Definitions

Finding: Variable and inconsistent definitions and metrics are used to describe the energy consumption patterns of low-income households. The extent and nature of energy burden, and the estimated impact and value of solutions, depend upon the metrics used.

The term “household energy burden” has become a dominant construct used by analysts working on low-income energy issues in the U.S. Early and subsequent research conducted for DOE by Oak Ridge National Laboratory (ORNL) (Eisenberg, 2014) and Economic Opportunity Studies, Inc (Power, 2008) used energy burden as a means to characterize the U.S. population in need and to inform program and policy. The term is generally defined as the share of a household’s income that is spent on energy utilities (Drehobl and Ross, 2016). There are two parts to this definition – the numerator provides a measure of energy expenditure by the households, reflecting energy consumption and rates; the denominator is a measure of household income or budget.

Household energy expenditure is usually measured by looking at the total spending on household utility bills for heating, cooling, and other home energy services (Berry, Hronis, and Woodward, 2018). Most energy burden studies do not analyze household spending on transportation energy.

Household income or budget is also measured in a variety of ways, using different benchmarks. These include, the Federal Poverty Level (FPL), State Median Income (SMI), Area Median Income (AMI), and household budgets. The Supplemental Poverty Measure (SPM)³ conducted by the Census Bureau measures household income after including different sources of financial support. Accounting for households that receive different support payments and reducing them from the household income levels increases the level of poverty across most categories. The income benchmarks used to qualify households for different energy assistance programs can influence the program’s energy savings (Hoffman, 2017).

In fiscal year (FY) 2014 (October 1, 2013-September 30, 2014), the average annual weather-normalized expenditure for low-income households (at or below 200% of the federal poverty level) was estimated to be \$1,851 (Eisenberg, 2014, p. 10). About 39% of this (\$721) was estimated to be for primary heating and cooling expenses. Based on the same source, non-low-income households spent \$2,284 on residential energy in FY 2014, with \$906 (40%) spent for primary heating and cooling. Based on the 2009 Residential Energy Consumption Survey

³ <https://www.census.gov/prod/2012pubs/p60-244.pdf>

(RECS) and inflation adjustments, the average income of low-income households in FY 2014, was estimated to be \$18,773 compared to \$71,755 for non-low-income households. The resulting household energy burdens were estimated to be 16.3% for low-income households compared to 3.5% for non-low-income households (Eisenberg, 2014, p. 10).

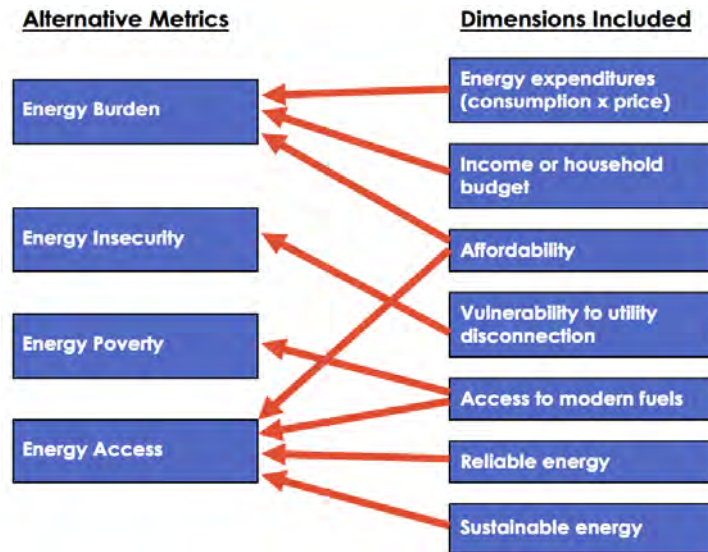


Figure 2.1. Scope of energy burden and related definitions.
(Source: Authors)

Based on household energy burden, Colton (2011) defines “energy poor households” as those spending more than 6% of their income on meeting energy costs. The premise for this benchmark is that a household should not spend more than 30% of its income on housing expenses, and the utility costs should not exceed 20% of these expenses. This threshold is often used for comparison purposes and to estimate the “affordability gap” (Fisher, Sheehan, and Colton, 2013). A range of thresholds has also been developed. In a study for the State of Colorado, Cook and Shah (2018a) distinguished between “energy stressed” households with energy burdens of 4-7%, “energy burdened” households with 7-10% energy burdens, and “energy impoverished” households with energy burdens greater than 10%.

A second construct – “energy insecurity” – refers to the uncertainty that a household might face in being able to make utility bill payments (Berry et al., 2018), which can ultimately result in being disconnected from energy services either permanently or temporarily (Verclas and Hsieh, 2018). Elnakat, Gomez, and Booth (2016) and Ross, Jarrett, and York (2016) document that the incidence of energy security varies by region with the highest rates in the South.

In contrast, the term “energy poverty” generally refers to living in a home that does not have access to enough energy to meet their essential needs. More functionally, it is described by the U.N. Development Program (UNDP, 2005) as the “inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset.” Modern energy services are crucial to human well-being. About half a million Americans live without access to basic electricity services, and a majority of these households reside in U.S. territories or on American Indian reservations (Begay, 2018b; EIA, 2000).

In the international literature, “energy access” is a common term, and is recognized in the Sustainable Development Goals adopted by the United Nations in 2015. Further, the first target of the Sustainable Cities and Communities Goal (SDG 11) is access to adequate and affordable housing with basic services, which includes affordable utilities. SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy to all by 2030. Affordability and reliability are both critical components of energy burden analysis in the U.S. context, where high levels of access to energy exist as compared to other countries, but many groups face high energy burdens. SDGs were adopted in 2015 at the U.N. Sustainable Development Summit in New York. The SDGs are a continuation of the global pursuit of sustainable development which was first recognized in the 1992 Earth Summit in Rio de Janeiro through the Adoption of Agenda 21.⁴

In sum, multiple definitions are used to discuss low-income energy burdens, to qualify households for assistance in different programs, and to estimate the potential for future energy bill reductions (Hoffman, 2017). This is problematic because the extent and nature of the energy burden problem depends on the definition used (Figure 2.1).

- The problem of energy burden and vulnerability is more widespread when measured by a combination of indicators (Lin, 2018b), such as income poverty combined with hardship making bill payments (Berry et al., 2018).
- GIS mapping documents that using different definitions can lead to higher or lower estimates of energy burden in different types of regions; while income and energy poverty are highly correlated, the problem of high energy burden among the income poor is more pronounced for those living in rural areas (Lin, 2018b).
- Using a range of definitions of income and spatial densities to provide estimates of potential savings, Hoffman (2017) demonstrates that total savings and their distribution can vary greatly based on the definition of low-income households and communities.

2.1.2 Magnitudes, Distributions, and Trends

Finding: Energy burden is higher among low-income households than other income groups. The average energy burden of low-income households is not declining, and it continues to be high in particular geographies and socio-economic groups. Low-income households spend a higher proportion of their income on energy bills than any other income group (Eisenberg, 2014; Berry et al., 2018), spending on average three times more of their income on energy bills than higher income households (Drehobl and Ross, 2016). This is true, even though low-income households consume less energy per capita than other households. Evidence indicates that participants in the Weatherization Assistance Program (WAP) managed by the U.S. Department of Energy (DOE) have even higher energy burdens (Eisenberg, 2014). These high burdens were strong motivators to apply for services: 43% of respondents in one study reported this as a motivating factor (Rose et al., 2015, p. 22). This is consistent with the finding by Tonn, Rose, and Hawkins (2015, p. 5) that prior to weatherization, 65% of survey respondents reported that it was hard or very hard to pay for energy bills, while post-weatherization, the percentage dropped to 49%.

⁴ <https://sustainabledevelopment.un.org/outcomedocuments/agenda21>

High energy burdens produce energy insecurity. Residential Energy Consumption Survey (RECS) data for 2015 indicate that 31% of all U.S. households experienced some form of energy insecurity – often foregoing food and medicine in order to pay an energy bill. These rates were particularly high in mobile homes (58%) and in apartments in buildings with 2-4 units (46%) (Berry et al., 2018). In 2015, nearly seven million households had their access to heat interrupted at least once, and six million lost access to air conditioning at least once (Verclas and Hsieh, 2018).

Energy security is significantly more problematic for low-income households. Based on a national survey in 2015, 40% of households with income below \$50,000 find it difficult to pay their energy bills at least “once in a while”.⁵ In 2017, one-third of consumers with household incomes of less than \$50,000 had trouble paying their electric or heating bills at least sometimes, 7% more than in 2016, despite the stronger economy (Treadway, 2018). Utility disconnections are difficult to track because most states do not require utilities to record these numbers. However, there is an exception in some states where utilities file these numbers with the Public Utility Commissions (Verclas and Hsieh, 2018). The number of disconnections appears to be increasing in at least two states. In Texas, the number of recorded disconnections increased by 64% between 2010 and 2016, and in California, the numbers tripled between 2006 and 2016 (Verclas and Hsieh, 2018). The authors further note that low-income households (with incomes less than \$20,000) were almost three times as likely to face energy insecurity as households with income greater than \$60,000. A simple but nonetheless meaningful definition of energy access is the ability to get utility service, which is impacted by the disconnection practices and policies of utilities.

Just as energy security is not improving, the average energy burden of low-income households is also not declining. To assess trends and geographic variations in energy burden, Fisher, Sheehan and Colton define the home energy affordability gap as the difference between actual home energy bills and affordable home energy bills.⁶ The actual bills are calculated as a function of energy usage, housing, and weather characteristics. As noted earlier, the affordable burden is set at 6% of the household’s income. The gap is calculated at a county-by-county and state-by-state level, for different segments of the low-income populations starting at 50% and going up to 200% of the household federal poverty level. Based on updated national estimates, the home energy affordability gap index for the U.S. in 2018 was 134.4 (compared to the indexed value of 100 in 2011).^{7 8} In monetary terms, this is equivalent to \$51.8 billion. The report also provides a summary of this distribution across census regions. The Mountain region had the highest Home Energy Affordability Gap Index at 284.6. This translates to \$3.7 billion in 2018, compared to \$1.3 billion in the base year, 2011.

At the same time that these indicators show that neither energy affordability nor energy security are improving, program evaluations document clearly that the energy affordability for the millions of homes that have received weatherization and energy-efficiency services has, in aggregate, improved (see Section 4). The average burden of low-income households overall has

⁵ <http://defgllc.com/news/article/how-well-are-you-reading-your-low-income-customers/#!/>

⁶ http://www.homeenergyaffordabilitygap.com/01_whatIsHEAG2.html

⁷ http://www.homeenergyaffordabilitygap.com/03a_affordabilityData.html

⁸

http://www.homeenergyaffordabilitygap.com/downloads/2018_Released_Apr19/HEAG2018%20Regional%20Fact%20Sheets.pdf

not declined largely because only a fraction of the total eligible population has received such services.

The energy consumption patterns of low-income households vary with gender, age, race, education, health and disability status, as well as cultural attributes and occupations of members (Tonn et al. 2015, 2015b). Elnakat et al. (2016) found that households in zip code areas where the median age of the household head was less than 30 years, used significantly less energy per capita than zip code areas with median ages above 40 years. Zip codes with a higher percentage of high school graduates also had higher levels of energy consumption.

Geography is also important: household energy patterns vary widely across highly urbanized areas (Porse et al., 2016), suburbs (Verclas, 2018), rural and remote locations (Souba and Mendelson, 2018; Lin, 2018b; Ross, Drehobl, and Stickles, 2018; Begay, 2018a, b) and climate regions (Ross, Jarrett & York, 2016). Many low-income households have experienced generations of the poverty cycle, especially the chronically unemployed including disabled individuals who are dependent on public assistance or charitable support for survival. Others have recently experienced income declines, due to shifting job opportunities and retirement from the workforce. Some have chosen a low-paying profession such as artists, writers, and community activists. Still others are unskilled or semi-skilled, working in low-wage jobs in retail, hospitality, and health services. Energy decision making varies across all of these groups (Schwartz, 2014).

The problems of high energy burden and insecurity are more severe in minority households and those with children and older residents (Berry et al., 2018). Hernandez, Aratani, and Jiang (2014) found that black households with children were more likely than any other group to experience energy insecurity, after controlling for income. Kontokosta, Reina, and Bonczak (2019) examined an extensive database describing 3,122 census block groups (CBGs) in five U.S. cities. Of these CBGs, 42% were classified as predominantly minority neighborhoods, and the remainder were predominantly non-hispanic white neighborhoods. For the three lowest income groups ($\leq 50\%$, 51%–80%, and 81%–120% AMI), energy burdens in the two types of neighborhoods were statistically distinct. Very-low-income residents ($\leq 50\%$ AMI) in minority neighborhoods had energy burdens that were 1.56% higher than households of the same income category living in predominantly non-hispanic white communities. A similar difference was identified in the two other low-income groups (51%–80% AMI and 81%–120% AMI), although the gap in energy burden was smaller (Kontokosta, Reina, and Bonczak, 2019).

Energy burden also tends to be concentrated in rural areas, and states in the East South Central, New England and Mid-Atlantic regions have the highest rural energy burdens (Ross, Drehobl, and Stickles, 2018). Hoffman (2017) cautions against using aggregate national or regional indicators of energy burden, arguing that they can significantly underestimate the number of eligible households because the extremes in the distribution disappear when averages are examined.

2.2 CAUSES OF HIGH ENERGY BURDEN

The underlying causes of high energy burden identified in literature can be divided into five main categories – location and geography, housing characteristics, socio-economic situation, energy prices and policies, and behavioral factors (Table 2.1).

The first category of causes and correlates is geographic location, which is a strong predictor of energy burden. Low-income residents of rural communities and island territories pay higher-than-average bills for both electricity and heating fuels (Shoemaker, Gilleo, and Ferguson, 2018). With high energy costs, the benefits of energy efficiency could be significant, but rural residents face numerous other barriers such as a generally older housing stock that has produced a “rural energy-efficiency gap” (Winner et al., 2018).

Similarly, low-income households in the nation’s largest cities face higher-than-average energy burdens (Drehobl and Ross, 2016). Fox (2016) and Brown⁹ document the problem of low-income burdens in Southeastern states,¹⁰ where poverty rates are high, and households consume significant amounts of energy for both heating and cooling to keep their aging and poorly built homes livable. There is a correlation between the types of fuels used for heating and cooling and their impacts on the household bills. HVAC systems in the South tend to be electric whereas heating in most other regions is dominated by natural gas, which is more affordable. In summer months and in hotter climates, households with electric space conditioning have greater opportunities to save energy (Bradshaw, Bou-Zeid, and Harris, 2016) whereas in the winter months, there is more potential to save energy in the colder regions (Bradshaw et al., 2014; 2016).

Finally, low-income neighborhoods can lack access to efficient appliances. For example, Reams, Reiner, and Stacey (2018) found that energy-efficient bulbs are less available in low-income areas, based on in-store surveys conducted in Wayne County, Michigan.

Second, housing characteristics are a major determinant of energy consumption and intensity (consumption per square foot). Older homes, public housing, and multifamily units also correlate with high energy intensity (Berkland, Pande, and Moezzi, 2018; Langevin, Gurian and Wen, 2013). Variation in maintenance and housing quality also manifests in the form of different levels of gas and electricity consumption (Scheu et al., 2018). Typically, low-income houses are older and undergo fewer repairs and upgrades over time. As a result, these housing units usually have inefficient insulation and older appliances, further adding to the energy burden (Cabeza et al., 2014). Bradshaw et al. (2014) also conclude that the overall savings potentials ultimately depend on the housing stock and the space conditioning equipment in use. In sum, much of the affordable housing/low-income housing in the U.S. remains energy inefficient despite advancements in building technologies and science.

Third, socio-economic characteristics determine a household’s ability to afford energy-efficiency retrofits and more energy-efficient appliances (Thorve et al., 2018). Based on 2015 data from the Residential Energy Consumption Survey, low-income households use less energy than any other income group. However, they have the highest energy burdens, particularly households with incomes less than \$20,000, whose energy burdens are more than twice as high as households who earn \$20,000-\$40,000.¹¹ While high-income households consume more energy, their EUI (that is, energy use per square foot of housing) is lower (Bednar et al., 2017).

⁹ https://cepl.gatech.edu/sites/default/files/attachments/SCEN_PPT_Energy_Equity_05-30-18-Final_0.pdf

¹⁰ https://www.energy.gov/sites/prod/files/2019/01/f58/WIP-Energy-Burden_final.pdf

¹¹ https://www.nclc.org/images/pdf/special_projects/climate_change/report-reversing-energy-system-inequity.pdf

Table 2.1. Causes and Correlates of High Energy Burden

Location and Geography	Housing Characteristics	Socio-economic Situation	Energy Prices and Policies	Behavioral Factors
• Rural, urban, Native American, remote community, island territory • Climate • Population density • Urban morphology (affecting access to jobs and efficient appliances)	• Thermal integrity of building • Type, age and size: single-family, manufactured, multifamily) • Owner-occupied vs rental and public housing • Age and type of appliances • Type of thermostat: WiFi, smart, programmable, touch screen	• Income • Ethnicity/Racial background • Immigrant vs native-born • Number of occupants, children, elderly, and handicapped	• Energy prices • Energy rate designs • Energy mix and access to natural gas • Availability and effectiveness of low-income energy programs and appliances	• Lack of knowledge • Misplaced incentives/principal-agent problems (especially in multifamily homes) • Lifestyle cultural factors • Lack of control over energy bills • High non-monetary costs

Race and ethnicity also correlate with overall energy use, level of energy burden, and household energy consumption patterns. Hernandez et al (2016) and Bednar et al. (2017) find that African Americans have higher utility costs and higher Energy Use Intensity (EUI), as do Hispanic households. The underlying causes of these patterns are complex, but likely include impacts from historical housing injustices such as Jim Crow laws that enforced racial segregation. In addition, the size and composition of a household are key determinants of household energy consumption. Some of the same patterns are emerging in studies of other advanced energy technologies. For instance, Sunter et al. (2019) analyze rooftop solar adoption across the country and find that census tracts with larger shares of racial and ethnic minority groups have lower rates of adoption compared to white-majority census tracts.

Understanding the relationship between social demographics, load shapes and energy burden is only now emerging as a research focus (Jaske, 2016), which is particularly promising because it could help to guide efforts to manage consumption during the hours when it matters most.

The fourth category of causes and correlates of high energy burden is prices and policies. For example, high fixed components in power bills or reconnection fees are important barriers to reducing energy bills. These are discussed further in Section 3.

The fifth category covers behavioral determinants of energy consumption. Lack of knowledge and split incentives can be major hurdles to well-functioning housing markets, undermining investments in home retrofits and participation in energy efficiency programs. Building owners and managers know more about the energy performance and efficiency of their buildings than do prospective buyers and tenants, leading to the well documented situation of “lemons”, when consumers buy energy-inefficient appliances and homes because of imperfect marketplace

information (Brown and Wang, 2015). Split incentives are especially evident in rental apartments where tenants do not have control over appliance choices and energy conservation measures, but they have to pay the bills (Brown, 2001). Tenants are often beholden to building owners and managers to make smart energy decisions based on their understanding of the energy integrity of the units. Tenants that are not provided information on behavior solutions or provided technical improvements, are likely to remain in situations of high energy use and burden (Berkland et al, 2018). In addition, residents of rental housing do not always have control over their energy bills; for example, building management may control the heating and cooling settings, resulting in thermal discomfort. This asymmetry of information and lack of control renders tenants vulnerable to high bills and the possibility of eviction.

Despite the stated willingness of most households to conserve energy and invest in energy-efficient appliances, there is often inconsistency between these values and their actual purchase behavior. These inconsistencies are sometimes based on various personal and contextual constraints including lack of available capital and nearby vendors (Brown and Sovacool, 2018).

Some energy programs have long waitlists of eligible program participants, while others face difficulty meeting their outreach and participation goals (Hirshfield and Iyer, 2012). From the utility's perspective, the small scale and dispersed nature of energy-efficiency projects challenges the aggregation of this resource, increasing its transaction costs. Effort is required to fill the "pipeline" with energy-efficiency projects that are investment-ready and creditworthy (Brown and Wang, 2015).

Such transaction costs suggest the case for utility partnerships with local community agencies that offer human services and already have people with completed income qualification paperwork for other programs (food, housing, medical care, etc.). This is particularly valuable for a program like WAP because its administrative costs are generally capped at 10%. (10 CFR 440). To take advantage of shared resources, WAP tends to be delivered alongside other social service programs so that transaction costs can be shared under the larger umbrella program (Community Action Agency). These types of transaction cost savings also motivated the MOU between DOE and HUD, which provided lists of income eligible "properties".

2.3 EFFECTS OF HIGH ENERGY BURDEN

High energy burdens have far-reaching and enduring consequences. Broadly defined, high energy burdens for low-income households have two types of inter-locking effects related to household economics and health.

Adverse economic and financial consequences often occur when low-income households with high utility bills have to make trade-offs between meeting alternative critical household expenditures. Paying for food, medical care, telecommunications, and shelter are often sacrificed in order to make timely utility bill payments (Hernandez et al., 2016; Camprubi et al., 2016). These trade-offs create a negative feedback loop that traps families in an enduring cycle of poverty. For example:

- Low-income families unable to pay their high energy bills become vulnerable to utility shut offs, which can lead to homelessness.

- Cash-strapped families and individuals become prey to predatory payday loans as their only option to pay utility bills and avoid shutoffs, which come with high interest rates that make repayment difficult¹² (Tonn et al., 2015).

Adverse health effects of high energy burdens can span a range of illnesses and conditions. These include exposure to carbon monoxide poisoning and other indoor air pollution due to the inefficient and improper use of unvented and subserviced wood stoves and propane heaters¹³ (Fabian, Adamkiewicz, and Levy, 2012).¹⁴ Other health effects noted in the literature are mental stress, lead exposure, thermal discomfort and respiratory problems such as asthma (Fabian et al., 2014; Wells et al., 2015; Chen, Xu, and Day, 2017). The fear of not being able to pay bills and the potential of losing electricity and home gas heating utility service altogether can stress mental health problems. There are also health effects related to inefficient energy usage and poorly insulated buildings. These effects are amplified for groups vulnerable to these conditions that often have limited adaptive capacity because of fewer resources (Hernandez et al., 2016; Massetti et al., 2017).

¹² https://cepl.gatech.edu/sites/default/files/attachments/SCEN_PPT_Energy_Equity_05-30-18-Final_0.pdf

¹³ <https://ktvl.com/news/local/wood-stove-and-heater-source-of-two-deaths-in-sisikyou-county>

¹⁴ Propane should be burned in an ideal ratio of 4 parts propane to 96 parts oxygen. Otherwise, it can lead to incomplete combustion of the fuel, which in turn releases carbon monoxide, a hazardous substance, especially when used in poorly ventilated areas. See: <https://heattalk.com/propane-heat-pros-and-cons/>

3. THE ECOSYSTEM OF LOW-INCOME ENERGY PROGRAMS AND POLICIES

Across the U.S., many programs and policies could help to address the energy burdens of low-income households.

3.1 TYPES OF PROGRAMS AND LEVELS OF EXPENDITURE

Finding: Many policies and programs that promote energy efficiency and renewable energy (e.g., rebates for Energy Star appliances and utility incentives for rooftop solar) are largely inaccessible to low-income households due to affordability barriers, although several states and coalitions of NGOs have recently launched major low-income solar programs and Energy Efficiency for All initiatives. Funding for temporary assistance (e.g., for bill payments) dwarfs funding for more enduring assistance (e.g., weatherization) (Hoffman et al., 2018; Cluett, Amann, and Ou, 2016), though both serve a critical need and benefit from being linked together. Funding for low-income energy programs peaked as a result of the American Recovery and Reinvestment Act (ARRA); it has returned to levels above the pre-ARRA funding, reflecting modest increases in weatherization funding and more substantial increases in low-income solar programs (O'Dwyer, 2017).

Since the mid-1970s, numerous programs and policies have been implemented in the U.S. to promote residential energy efficiency and reduce household energy bills (Berg et al., 2018; Brown and Wang, 2015). For example, state building codes have improved the energy integrity of new home construction, and appliance standards have raised the energy performance of household equipment, arguably becoming the largest contributor to the energy efficiency of low-income housing today. In addition, financial incentives in the form of income tax credits and tax-free loans are available for taxpaying households to make investments in energy efficiency and renewable energy projects. However, participation from low-income households remains low (Zhao et al., 2012). In contrast, weak energy-efficiency regulations can also disadvantage low-income households. For example, while few low-income households live in new homes, the fact that poor building codes cause homes to be built without a focus on energy creates a missed opportunity with an impact that can last a century and ultimately challenge the affordability of low-income households. Energy Star ratings have helped educate consumers about the energy consequences of the products they purchase, and federal tax policies have subsidized home energy retrofits. Several states also offer low-income homeowners financial incentives to overcome the high up-front cost of energy-efficiency appliances and equipment.¹⁵ However, participating in these programs (purchasing new appliances and retrofitting homes) is not affordable for many low-income households.

More recently, policies and programs have been launched to accelerate the deployment of energy efficiency and renewable energy. These include more than a decade of federal investment tax incentives and utility net metering programs that support rooftop solar panels and home battery storage systems. The federal government provides tax rebates to subsidize the purchase of electric vehicles, and many states are implementing programs to pay for the development of vehicle charging infrastructure (Narassimhan and Johnson, 2018). We do not review this

¹⁵ Database of State Incentives for Renewables & Efficiency (DSIRE) Financial Incentives for Energy Efficiency (2012). <https://programs.dsireusa.org/system/program/tables>

complex ecosystem of policies because low-income households generally cannot afford to purchase new electric vehicles even with the rebates that are offered.

However, questions are being asked about the fairness of incentives that promote a transition to energy efficiency and renewable energy technologies when they are largely inaccessible to low-income households. For example, Cluett et al. (2016) note that a majority of utility energy-efficiency programs require an up-front customer investment to leverage rebates and associated savings, which makes them unaffordable to low-income households. Low-income households often cannot afford the up-front financial “match” required to obtain the rebates and loans available to consumers who buy energy-efficient household appliances. As a final example, the federal government promotes residential energy-efficiency and solar systems investments by offering tax credits. In the case of rooftop solar systems, these are called Investment Tax Credits. Such federal tax credits are worth very little to most low-income homeowners because they typically have limited tax liability.

This inequity is compounded by the fact that energy-efficiency programs raise electric and other utility costs by increasing the share of fixed utility fees for all customers (Johnson et al., 2017; Sigrin and Mooney, 2018). While such inequitable impacts of electricity and natural gas tariffs can be offset by modest low-income energy assistance programs (Borenstein and Davis, 2012), such offsets are rarely established.

Within the U.S. policy ecosystem, numerous and diverse energy programs and policies do target low-income households. Table 3.1 summarizes these in a matrix organized by implementing organization and type of program. Program implementers range from electric and gas utilities and federal and state agencies, to local government and community-based entities and philanthropic and nonprofit organizations. Program types distinguish between utility bill assistance, financial incentives, energy information, and regulations. Initiatives (such as the Clean Energy for Low Income Communities Accelerator or CELICA) have also facilitated cross-organizational coordination in this space. The CELICA program helped lower energy bills for households by facilitating a partnership between the DOE and sub-national governments (DOE, 2017). Gilleo, Nowak, and Drehobl (2017) identify some core practices of successful low-income energy efficiency programs. Some of these include ensuring statewide coordination, targeting program offerings to sections that yield the highest benefits, forming partnerships with local outreach organizations, and providing a single point of contact to participants and contractors.

Table 3.1 Illustrative low-income energy policies and programs

	Energy Bill Assistance	Financial Incentives	Energy Information	Regulations
Electric and Gas Utilities	• Bill forgiveness programs • Budget billing • Prepaid electricity services • Payment plans	• Direct installation of efficiency measures • Round-up assistance programs • On-bill program designs	• Goal setting for low-income programs • Installation of home energy management systems • Real-time appliance and premise level feedback	• Rates and rate design • Shut-off and reconnection policies • Integrated resource planning • Adders for cost-effectiveness tests • Minimum requirements for low-income programs
Federal Agencies	• Low Income Home Energy Assistance Program (LIHEAP) • HUD assisted housing utility allowance subsidies • USDA housing utility allowance subsidies	• Weatherization Assistance Program (WAP) • LIHEAP weatherization • Energy Efficiency and Conservation Loan Program (EECLP) • Low-Income Housing Tax Credit (LIHTC) program • HUD HOME/CDBG home repair funding	• WAP includes education of clients as an allowable activity • WAP Technical Assistance and Training • HUD Utility Benchmarking guidance	• Subsidized housing regulations • Federal Housing Administration (FHA) Duty to Serve • Environmental Protection Agency (EPA) energy justice and climate regulations • Federal Energy Regulatory Commission (FERC) affordable power for all regulations
State Agencies	• Implementation of federal bill assistance programs • State administered ratepayer funding for bill assistance	• Implementation of federal low-income energy efficiency programs including support for local, state and regional initiatives • State and county funds supplement WAP	• Technical assistance • Tools • Case studies • Peer exchange • Goal setting • Convening • Stakeholder engagement	• Subsidized housing regulations • Minimum requirements for low-income utility programs
Local Government, Community-Based Entities, and NGOs	• Bill forgiveness programs	• Weatherize Campaigns • Home repair financing	• Healthy housing programs • CDC Lead Control • Building codes and ordinances • Community education, outreach • Community convening • Pilot projects	• Subsidized housing regulations • Building and energy codes and standards

Based on data principally from 2013 (see the notes for Figure 3.1), approximately 80% (or about \$6.3 billion) of low-income energy funding goes to bill payment assistance, 14% (\$1.17 billion) to energy efficiency, and 5% (\$38 million) to unspecified support (Cluett et al., 2016, p. 7). Altogether, utilities are the single largest source of funding for low-income energy programs. Ratepayer-funded utility programs provide 41% of the total funding for low-income bill assistance and 10% of the total funding for low-income energy-efficiency programs. Thus, Public Service Commissions, Boards of Directors of public utilities, and other state regulators

are critical to establishing the policy ecosystem within which utilities design and implement low-income energy programs. Federal agencies provide 44% of the total (40% from LIHEAP for bill assistance, 2% from LIHEAP for efficiency, and 2% from DOE for the Weatherization Assistance Program). In 2016, the block grant allocation to LIHEAP was \$3.3 billion, reallocation funds were \$1.2 million, and funds carried over from previous year was \$167 million.¹⁶ State and local contributions at 3% and nonprofit organizations at 2% complete the picture. These funds are used for heating and cooling assistance, crisis assistance, administrative and planning needs and any other requirements at the state level. These sources are somewhat dated and cross-cut different years, as would be expected from a review of the literature, which is distinct from a review of information in databases.¹⁷

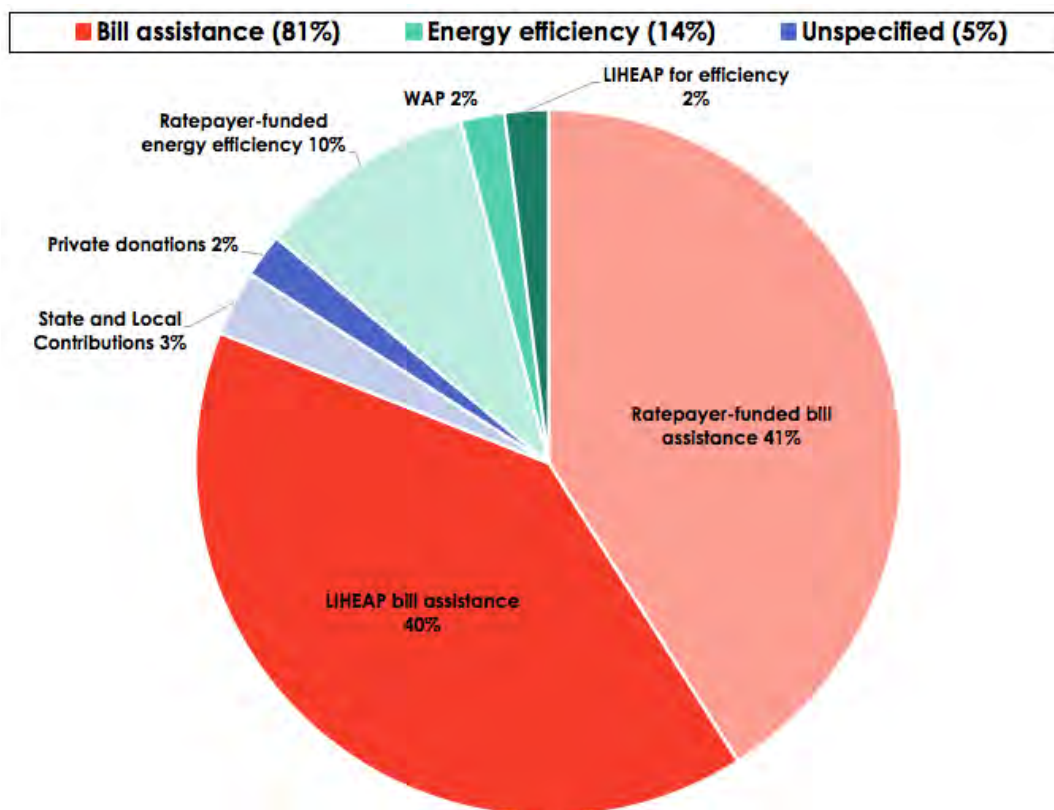


Figure 3.1 Expenditures on low-income energy programs
(Redrawn from Cluett et al., 2016, Figure 2)

(Notes: Funding for most of the categories are based on data for 2013; LIHEAP spending on efficiency is based on 6% of LIHEAP funds spent on efficiency in 2006. Data on state and local contributions and private donations are estimated for 2010, based on LIHEAP Clearinghouse 2016. Excludes solar programs and some affordable housing energy incentives, e.g., tax credit financing.)

¹⁶ <https://liheappm.acf.hhs.gov>

¹⁷ More updated sources for WAP and LIHEAP (including LIHEAP Wx funding) can be found at <https://nascsp.org/wap/weatherization-publications/wap-annual-funding-surveys/>

Over the past decade, annual expenditures on low-income energy-efficiency programs have ranged widely between about \$1-\$3 billion/year. The greatest source of variability is the funding for DOE's WAP. The American Recovery and Reinvestment Act (ARRA) of 2009 raised WAP's appropriations from historic levels of \$150 to \$230 million each year since its inception in the late 1970s, to \$5 billion between 2009 and 2011. As a result, WAP in 2010 spent an unprecedented \$2 billion, implemented by nearly 60 Grantees and about 1,000 Subgrantees. With leveraging, the national weatherization network expenditures rose to \$2.7 billion in program year 2010 (Tonn, et al., 2015, p. xvi).¹⁸ In the post-ARRA period, WAP has been operating at approximately the pre-ARRA Congressional appropriation level, peaking in 2019 at \$254 million.¹⁹

In addition to these funds, some states and counties use General Assistance, emergency assistance, local tax revenues, or similar funds to supplement federal LIHEAP funding. These funds may help low-income families pay for fuel, utilities, furnace repair, or other charges; some also help households avoid utility shut offs during summer/winter. Eligibility criteria vary by state; for example, some states require that applicants must be in an emergency condition.²⁰

Corporate and private funds also support fuel assistance for low-income households. Eligibility is variable, but typically requires an emergency situation. Program administrators are typically state social services agencies. One of the largest funds is managed by the Citizens Energy Corporation, which uses proceeds from natural gas sales to provide charitable emergency assistance to 25 states.²¹

3.2 ELECTRIC AND GAS UTILITY PROGRAMS AND POLICIES

Finding: The share of utility residential energy-efficiency funding that supports low-income households is lower than the percent of residential utility customers who are low-income (Drehobl and Castro-Alvarez, 2017).

Public utility commissions and city councils set customer benefit surcharges that are collected through customer utility bills. Utilities then use this money to fund low-income energy-efficiency programs. In 2014, energy efficiency spending for low-income programs accounted for 18% of residential electric efficiency spending and 34% of residential natural gas efficiency spending. The target segment of the population accounts for roughly one-third of total households, although this depends on how low-income status is defined.

Low-income households are not excluded from programs offered to all residential customers, but data show that they are less likely than other customers to participate in them.²² Non-low-income utility energy-efficiency programs, for example, often target homeowners and not renters, and they typically require participants to pay for a portion of the weatherization costs, which can be prohibitive for low-income households who tend to rent their homes and have limited

¹⁸ To spend the additional funding, income eligibility requirements were extended to 200% of the federal poverty level (rather than 150%), and the maximum WAP investment allowed per home was raised from \$2500 to \$6500. As a result, participating households had higher incomes and fewer vulnerable household members (Tonn, Rose, and Hawkins, 2015).

¹⁹ <https://nascsp.org/wp-content/uploads/2018/02/fy201720wip20fact20sheet.pdf>; <https://www.edf.org/energy/equity-through-energy-efficiency>

²⁰ <http://neada.org/state-tribal-programs/state-energy-assistance-directors/>

²¹ <https://www.ncoa.org/wp-content/uploads/Alternative-Sources-of-Energy-Assistance.pdf>

²² https://beccconference.org/wp-content/uploads/2015/10/presentation_frank.pdf

discretionary income. Because of their limited means, low-income households are also least able to participate in many types of initiatives aimed at reducing energy costs. At the state level, resources are typically insufficient to deliver energy efficiency and renewable energy services for all low-income households. A study of such policies in New York State concluded that markets are not always able to meet the public policy objectives (CEAC, 2017). The study recommends that to address the needs of the state, the utilities and the regulatory commission should follow a holistic approach such that the often-insufficient budgets are used towards cross-cutting initiatives to reach the largest portion of the state's population.

Relf, Baatz, and Nowak (2017) estimate that on average, utilities enabled (through financing and assistance) 5.29 kWh of low-income energy savings per residential customer and spent 8.93% of total energy-efficiency program funds (including residential, commercial, and industrial programs) on low-income programs in 2016. However, the low medians for both of these statistics (2.80 kWh/residential customer and 6.23% of total spending), indicate that the top performers are boosting the group average. For example, 22 utilities offer comprehensive programs including more than one low-income program as well as natural gas programs.

A similar pattern of spending and accomplishment was reported in a survey of the nation's 51 largest metropolitan statistical areas. In 2015, 49 metropolitan statistical areas (MSAs) were served by a low-income electricity efficiency program, and 31 were served by a low-income natural gas efficiency program. But the amount spent and savings achieved are highly variable across programs and fuels (See Table 3.2).

Table 3.2 Summary of Amount Spent and Savings Achieved Across Programs and Fuels, in 2015

(Source of data: Drehobl and Castro-Alvarez, 2017).

Electric energy efficiency programs		
Spending	Average spending on electric efficiency programs per low-income participant was \$1,538	Per low-income customer, these averages drop to \$3.
Savings	Producing 1,377 kWh of savings.	Producing 22 kWh of savings.
Natural gas programs		
Spending	Average spending on electric efficiency programs per low-income participant was \$2,002	Per low-income customer, these averages drop to \$23.
Savings	Producing 135 therms of savings	Producing 3 therms of savings.

The cities with the largest expenditures per low-income customer were Boston, San Antonio, Providence, San Francisco, and Hartford. In terms of kWh of electricity savings per low-income customer, the most impactful cities were Boston, Hartford, San Antonio, Providence, and Louisville, which each saved >50 kWh per low-income customer (Figure 3.2). About half of the

electric and natural gas programs coordinated with WAP in 2015, indicating significant potential for improved leveraging. Many, but not all programs target specific households such as high energy users, which also indicates room for improvement. State WAP grantees specify priority populations in their annual state plans, targeting elderly, disabled, families with children, and high energy users in accordance with the WAP statute. What this map does not show is how much is spent per customer. Some areas have a lot more to spend or may decide to spread resources more broadly on low-income households.

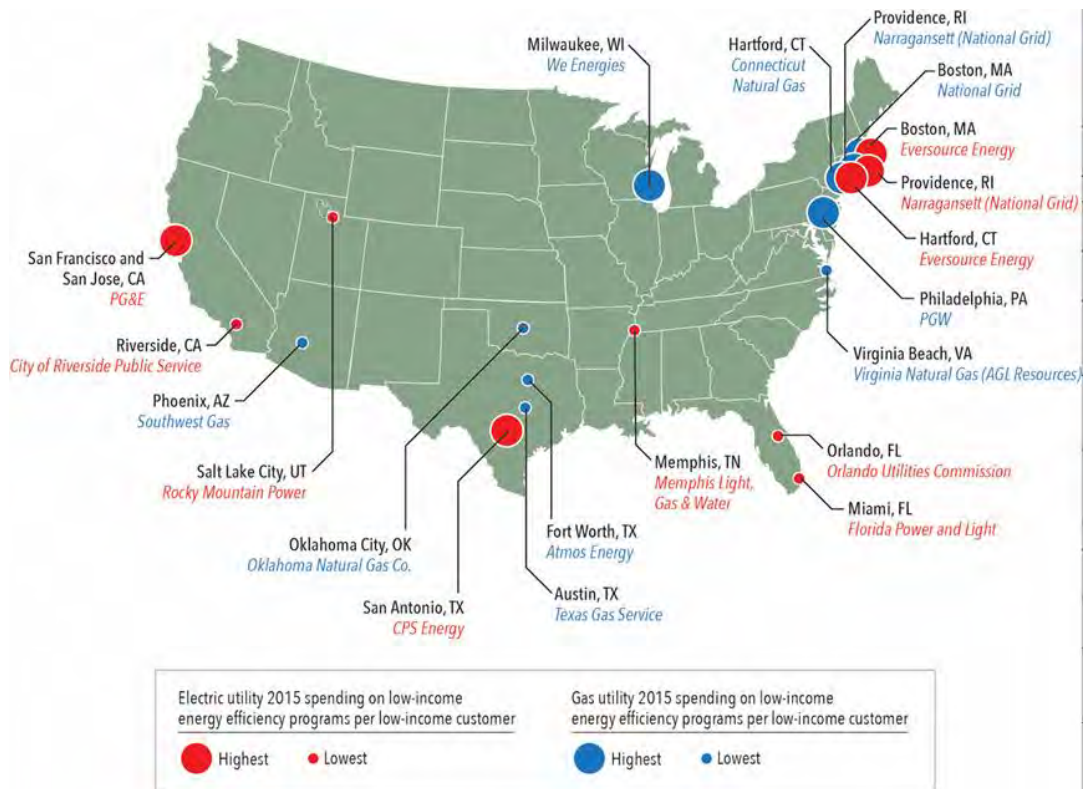


Figure 3.2. Electric and gas utility spending on low-income energy-efficiency programs per low-income customer in 2015.

(Source: Authors, based on data from Dreobl and Castro-Alvarez, 2017)

Across rural America, utility expenditures on energy-efficiency programs are lagging behind. Evidence from 12 utilities offering tariffed on-bill financing (Hummel and Lachman, 2018), and detailed analysis of on-bill programs implemented by a rural electric co-op in Arkansas suggests that the Pay-as-You-Save approach offers an effective approach. Household energy usage was decreased by almost a quarter, and the utility benefited from peak demand reduction, as well (Lin, 2018a). These results suggest a promising approach for the more than 900 cooperatives in the country. (See Section 3.2.2 below.)

Utility companies offer an array of programs and policies to help customers who are in arrears and to recover costs associated with non-payment. Utilities can implement prepaid electric service (see Section 3.2.4 below), offer payment plans (see Section 3.2.5 below), and implement alternatives to shutting off services. They can also eliminate late fees and interest and can promote level billing to reduce spikes in prices during extreme weather events. However, there is also evidence of the potential negative impact of some of these programs leading to “self-

disconnection”, propagating inequities, and adding stress to the households under difficult financial situations.²³

Utility companies and their customers can both benefit from such activities by reducing costs associated with shut-offs and reconnections (Hernandez and Bird, 2010). While these services and procedures are not intended to be long-term solutions to the low-income energy burden problem (Verclas and Hsieh, 2018), they can be effective in the short-run until the housing stock, HVAC equipment, and appliances can be made more energy efficient.

3.2.1 Integrated Resource Planning, Goal Setting, and Cost-Effectiveness Tests

Many utilities have a history of using ratepayer resources to support low-income energy programs. In regulated markets, these programs are often proposed in integrated resource plans (IRPs) that are typically written every three years or so by utilities and reviewed by Public Utility Commissions or other regulatory entities. Goals may be set by these Commissions, and cost-effectiveness tests are often deployed to determine if subsequent investments are cost-justified. Regulators of public utilities, such as the Board of Directors of the Tennessee Valley Authority (TVA) can authorize budgets for such expenditures. This was the case with the “Extreme Energy Makeover Program” low-income program launched in 2015, which was approved by the TVA Board as a response to EPA regulations and fines. The program targeted around 800 old homes (20 years+) located in lower-income communities and it had an electric energy usage reduction target of 25% per home.²⁴

Local power companies can also initiate program and project proposals, which are then reviewed by Utility Commissions and may be discussed in public hearings independent of IRPs. Typically, Utility Commissions specify in advance the cost-effectiveness tests that will be used to evaluate such proposals. Different tests dominate different regions of the U.S. For instance, the Rate Impact Measure (or “nonparticipant test”) is relied upon in the Southeast, while California and the Pacific Northwest emphasize the Total Resource Cost test and the Societal test that allows for the inclusion of the cost of environmental externalities. The more that societal impacts are considered (such as environmental and public health benefits), the higher the benefit-cost ratio of low-income energy-efficiency expenditures.

3.2.2 Residential On-Bill Program Designs

A residential on-bill program is a type of financing design that can be explicitly used to incentivize energy-efficiency projects by low-income utility customers. It is a financial product that is serviced by a utility company for energy-efficiency improvements in a building and is repaid by owners on their monthly utility bills. Such tariff designs can help overcome liquidity and budget constraints of low-income households. The utility pays the up-front cost of a project, and customers repay the utility as savings accrue each month. Following best practices, only those energy efficiency measures that are estimated to provide net bill savings are installed. Tying repayment of energy-efficiency investments to utility bills allows households to consider energy upgrades as an operational savings rather than a capital expenditure (Gillingham, Newell, and Palmer, 2009). While these programs require the participation of a utility, they also often

²³ <https://www.nclc.org/issues/prepaid-utility-service.html>

²⁴ https://www.tva.gov/file_source/TVA/Site%20Content/Environment/Environmental%20Stewardship/Air%20Quality/EPA%20Mitigation%20Projects/Smart%20Communities%20-%20Extreme%20Energy%20Makeovers%20FAQ.pdf

benefit from government support in terms of legal authority and the initial financing, as is the case with the Energy Efficiency and Conservation Loan Program (EECLP). ESPCs and ESAs also address the problem of up-front financing.²⁵

On-bill financing opportunities through utilities are expanding with minimal defaults: more than a dozen states have on-bill financing programs, and other states have pilot programs or are in the process of creating programs (Hummel and Lachman, 2018; Bell, Nadel, and Hayes, 2011; Leventis et al., 2016). The financing model would appear to be promising for owner-occupied housing, but it may not be a good fit for building owners (who take on the liability for the debt) with tenants (who typically have responsibility for the energy bills) (Brown and Wang, 2015). This is called the split-incentive challenge.

Pay-as-you-Save (PAYS) financing is an example of a tariffed on-bill financing program. It is modeled to provide 20% savings to the customer, with 80% going to repayment of cost of project. Lin (2018a) highlights the PAYS potential for success in a case study highlighting a rural Arkansas co-op. The program produced electricity bill savings to customers and benefits to implementing utilities, especially in rural areas. Through its on-bill tariff design, PAYS overcomes many barriers, such as the split-incentive challenge and the need for upfront outlays. Hummel and Lachman (2018) summarize field data reported by 12 utilities offering inclusive financing through tariffed on-bill programs in six states. Cost recovery rates in these programs have exceeded 99.9%, and no utility has reported a case of disconnection for nonpayment of PAYS charges. Their program data produces a striking picture of an inclusive financing mechanism that can reach previously underserved markets even in areas of persistent poverty.

Despite these various benefits, it is important to note that any type of property lien can have negative consequences. For example, Atlanta, Georgia, households with liens on properties were deemed ineligible for accessing a tax relief fund for legacy residents.²⁶

3.2.3 Round-Up Assistance Programs

Round-up assistance programs are designed to provide financial assistance to families and communities in need of help. It is a voluntary program in which utility customers agree to have their utility bill “rounded up” to the next whole dollar amount. The extra money paid on a utility bill, which is a donation to the round-up program fund, goes towards helping the less fortunate pay their bills and other community-based programs.²⁷ The utility designs the program such that the customer can either opt in, or opt out (i.e., customers are automatically enrolled in the program and must “opt out” in order stop contributing to the round-up assistance fund. Utility round-up programs are particularly prevalent amongst municipal and local cooperative utilities. States, however, are now introducing policies that require utilities to pro-actively inform their customers about the round-up programs if they operate on an “opt-out basis”.²⁸

The round-up funds raised from customers, often supplemented by donations from utility companies and local businesses, are put into a fund used to assist local individuals and community organizations with crucial needs. Many of those who receive financial help are low-

²⁵ <https://www4.eere.energy.gov/seeaction/publication/energy-efficiency-financing-low-and-moderate-income-households-current-state-market>

²⁶ Source: Erin Rose, Three Cubed, personal communication, August 2019.

²⁷ https://www.needhelppayingbills.com/html/operation_round_up_assistance_.html

²⁸ <https://legiscan.com/TN/text/SB0308/2019>

income families with children, seniors, and someone just facing a short-term crisis. In some cases, the charity run program also provides cash grants to community projects and local nonprofit organizations such as food pantries, volunteer fire departments, and rural ambulance services. In addition, assistance is also provided directly to individuals. Round-up programs may help with utility bills, rent, food, shelter, health care, clothing, emergency services, education, job training, and other charitable causes.

For example, under Northwest Georgia Electric Membership Cooperative's (NGEMC) Round-up Program, a monthly bill of \$70.01 is rounded up to \$71, with 99 cents going to the program that makes donations to community nonprofit organizations in the seven counties the cooperative serves.²⁹ All of NGEMC's 98,000 customers were enrolled in the program automatically at the outset of the program, and the program has awarded annual grants to individuals, families and communities in need totalling more than \$100,000 each year since 2016.

3.2.4 Prepaid Electric Services

Prepaid services are emerging in many product areas, including prepaid gift cards, transit cards, pay-as-you-go cell phones, and pre-loaded credit cards. They allow customers to manage and budget their expenditures in advance. Many countries around the world have implemented prepaid electric services, and utilities in the U.S. are beginning to implement them, particularly municipal and co-op electric service providers. In this context, prepaid services give the customer more oversight and control over usage, but the short-term credit inherent in the post-paid model is lost (Chen, 2012).

Because prepaid electricity services do not require a deposit, they can be appealing to low-income customers. With the availability of digital meters with remote connection and disconnection capabilities, utilities can respond quickly to a customer's account status, reducing the time required to turn service on and off, thereby reducing disconnection times, and with advance alerts from the utility, the customer can quickly replenish the account and avoid service shut-off.

At the same time, with increased smart meter deployment, there is a potential for increased disconnections. Prior to smart meters, each disconnection required a costly physical trip to the meter. Smart meter technologies allow utilities to disconnect customers remotely (Verclas and Hsieh, 2018).

It has been argued that prepaid service generally costs the distribution utility less than postpaid service because it reduces the utility's carrying costs, uncollectible accounts, and collection costs (Chen, 2012). Reflecting this fact, the National Association of State Utility Consumer Advocates (NASUCA) passed a resolution advising utilities that "Rates for prepaid service are lower than rates for comparable credit-based service..."³⁰ Data on the adoption of prepaid service and its impact on rates and disconnection times are difficult to obtain.

²⁹ <https://www.ngemc.com/ORU>

³⁰ <http://nasuca.org/nwp/wp-content/uploads/2014/01/NASUCA-2011-3.pdf>

3.2.5 Payment Plans

Payment plans allow customers in arrears to pay off their debt over time. State regulations typically require utilities to offer payment plans to customers who are in arrears and at risk of disconnection (Chen, 2012). Customers must repay their arrearage over a predetermined number of months, provide a down payment, and pay a minimum towards their electricity bill. Such payment plans often are based on the amount that the customer owes and do not consider the ability of the household to pay. As a result, the customer debt levels can continue to increase (Verclas and Hsieh, 2018).

In addition, there is evidence that budget billing (BB) and level billing can increase consumption. Both types of billing dilute the price signal because customers do not see seasonal or monthly variations in cost (Treadway, 2018). Getachew et al.³¹ estimates that budget billing increases energy consumption by 3.8% to 4.7%, on average. Sexton (2015) found that automatic bill payments (ABP) and budget billing used by PG&E customers can cause an increase in customers' energy consumption, attributable to a loss of price salience. For low-income customers, this would mean even larger utility bills for consumers who are already struggling with high energy burdens. DNV GL provide evidence that PG&E's Home Energy Report (HER) Program at least partially claws back these increases, which suggests that ABP and BB should be coupled with HERs to combat the loss of price salience.³²

3.2.6 Disconnection Alternatives

Utility companies and their customers can benefit by reducing costs associated with shut-offs and reconnections (Hernandez and Bird, 2010). While these services and procedures are not intended to be long-term solutions to the low-income energy burden problem (Verclas and Hsieh, 2018), they can be effective in the short-run while the housing stock, HVAC equipment, and appliances are made more energy efficient.

Lack of data on the frequency and duration of utility shut-offs makes it difficult to quantify the explicit and implicit costs associated with utility disconnections. Electricity termination can have health and safety consequences, which can be particularly serious for the elderly and young children, and for those needing medical equipment. It can also cause social stigma and ultimately lead to homelessness because many landlords consider disconnection to be grounds for eviction. While some states collect data on utility shut-off and disconnection, for privacy reasons, the data usually only includes the number of accounts disconnected, without indicating whether a limited number of accounts are being disconnected multiple times or if a large number of accounts are getting disconnected and reconnected just once (Verclas and Hsieh, 2018).

The EcoPinion Consumer Survey No. 23 conducted in 2015 (Wimberly, 2016; 2017) provides some assessment of the extent of the problem. Four percent of households with incomes less than \$50,000 had their electric service disconnected within the previous two years. This rate increased to 6% for renters and doubled to 8% for households earning less than \$25,000. With 24.4 million

³¹ . https://becccconference.org/wp-content/uploads/2017/10/sadhasivan_presentation.pdf

³²

<http://calmac.org/results.asp?flag=&searchtext=Auto+Pay&pubsearch=1&selAuthor=252&dFrom=1%2F18%2F1990&dTo=12%2F28%2F2018&yFrom=1980&yTo=2018&selPubDates=1%2F1%2F2003&selToDate=12%2F28-2018&selProgYear=&selToYear=&pubsort=1&Submit=Search>

households earning less than \$25,000,³³ this suggests that nearly 2 million U.S. households have had their electricity disconnected over the past two years.

Most utilities have disconnection policies that make households vulnerable to energy insecurity. To temper the effects of disconnections, most states have policies that protect households by setting procedures consistent with the 1978 case of *Memphis Light, Gas and Water v. Craft* (436 U.S. 1, 1978).³⁴ The U.S. Supreme Court ruling recognized that “The customer's interest in not having services terminated is self-evident, the risk of erroneous deprivation of services is not insubstantial, and the utility's interests are not incompatible with affording the notice and procedure described above.”³⁵ The U.S. Supreme Court has also ruled that all customers have a constitutional right to be given notice prior to termination of utility service.³⁶ Though a minimum level of notice is required, the length of notice and notice procedures vary widely across states. Robust notice policies could protect customers from being disconnected and alert them of their duty to pay for utility service, but delivery is complicated by factors such as language barriers and an inability to reach customers when phone and internet access are unavailable, which is often the case in low-income households.

States typically provide one or more types of disconnection limitations (Verclas and Hsieh, 2018). They range from being date based (to cover winter months), temperature-based, or tied to the need for medical equipment such as nebulizers, life support machines, and dialysis machines.

These procedural protections are not long-term solutions to the low-income energy burden problem. They do not provide financial support or other assistance to provide low-income customers with a chance to overcome debt to the utility in the long term. Additional policies are needed to help customers maintain energy access.

3.3 FEDERAL PROGRAMS AND POLICIES

Finding: At least four federal programs have missions related to low-income energy burdens, with varying levels of inter-agency coordination.

The dominant low-income federal programs and policies are the Weatherization Assistance Program (WAP) operated by the DOE and the Low Income Home Energy Assistance Program (LIHEAP) operated by the U.S. Department of Health and Human Services (HHS). In addition, EECLP, managed by the Rural Utilities Service for the U.S. Department of Agriculture (USDA), and the Low-Income Housing Tax Credit (LIHTC) Program run by the U.S. Housing and Urban Development (HUD) and supported by the US Treasury are also described because of their pertinence to low-income households.

3.3.1 DOE Weatherization Assistance

DOE’s Weatherization Assistance Program was created by Congress in 1976 under Title IV of the Energy Conservation and Production Act. The purpose and scope of this Program is to increase the energy efficiency of dwellings owned or occupied by low-income persons, reduce their total residential energy expenditures, and improve their health and safety, especially low-

³³ <https://www.statista.com/statistics/203183/percentage-distribution-of-household-income-in-the-us/>

³⁴ <https://supreme.justia.com/cases/federal/us/436/1/>

³⁵ *Mathews v. Eldridge*, 424 U. S. 319. Pp. 436 U. S. 16-19.

³⁶ <https://supreme.justia.com/cases/federal/us/436/1/>

income persons who are particularly vulnerable such as the elderly, persons with disabilities, families with children, high residential energy users, and households with a high energy burden (see 10 CFR 440.1 and the discussion of it in Carroll, Kim, and Driscoll, 2014). The program treats single family and mobile homes, and multifamily buildings in all climate zones.

WAP provides grants to U.S. states, territories, and tribes, which then provide grants to local weatherization agencies to weatherize income-eligible low-income homes. These Grantees demarcate their own eligibility criteria, subject to WAP restrictions. The federally stipulated guideline is 200% of the Federal Poverty Level (FPL) or 60% State Median Income. LIHEAP uses a lower income threshold (150% FPL), and utility low-income programs tend to match WAP or LIHEAP, although they may qualify households up to 80% AMI and may also have moderate-income programs.

Households that receive Supplemental Security Income or Temporary Assistance for Needy Families (previously called Aid to Families with Dependent Children) are automatically eligible to receive weatherization services. Per WAP guidance, states give preference to:

- People over 60 years of age
- Families with one or more members with a disability
- Families with children
- Those with a high energy burden
- Those with high energy usage

As noted earlier, bill assistance provides a critical service to low-income households in crisis situations. Weatherization reduces energy usage and thereby decreases energy costs over the long term. Weatherization provides a longer-term solution to energy burden by addressing insulation, air infiltration, baseload energy use, and energy-efficient appliances to make homes more energy efficient. Since 1979 through the Weatherization Assistance Program and other leveraged funding, DOE has funded or otherwise supported energy-efficiency improvements and minor associated repairs for more than 7 million low-income households (Hoffman, 2017).

“Professionally trained weatherization crews use computerized energy assessments and advanced diagnostic equipment, such as blower doors, flue-gas analyzers, and infrared cameras to create a comprehensive analysis of the home to determine the most cost-effective measures appropriate and to identify any health and safety concerns associated with the energy retrofits.

Weatherization providers also thoroughly inspect households served to ensure the occupant’s safety, check for indoor air quality, combustion safety, and carbon monoxide, and identify mold infestations – which are all indications of energy waste. The auditor creates a customized work order, and trained crews install the identified energy efficient and health and safety measures.”³⁷

100% of units served under WAP receive an inspection from a certified Quality Control Inspector who ensures all work is completed correctly and that the home is safe for the occupants. Additionally, State WAP Grantees inspect 5-10% of these units, providing an additional layer of quality assurance.

³⁷ https://nascsp.org/wp-content/uploads/2017/09/WAP_ProgramOverviewFactSheet_3.16.17.pdf

In 2015, utilities and states supplemented DOE funding by providing an additional \$883 million, or \$4.62 for every dollar invested by DOE.³⁸ This estimate includes utility funds, and any state or local funds that were coordinated with DOE's WAP. The National Association of State Community Services Programs (NASCSP) tracks the leveraging of each state; more information on state LIHEAP transfers can be found in the HHS LIHEAP Clearinghouse Database.³⁹

3.3.2 LIHEAP Bill Assistance

LIHEAP bill assistance directly compensates some of the cost of energy burden for qualifying households. It is the primary source of bill assistance to low-income high-energy burden areas. LIHEAP began in response to the increasing price of utility bills in the 70s, and the inability of low-income families to safely live in their homes because they could not afford to pay these bills. It is funded by the federal government, where funding for the program is dependent on the federal budget. HHS and the Office of Community Service within the Administration for Children and Families are the governing agencies over LIHEAP. Grantees must submit annual reports to HHS in order to participate in LIHEAP programs. They are given a block grant to help low-income families. Usually the parameters on how these households are assisted are very broad, but most of the funds are used for two-party checks between the bill payer and the utility company.

The assistance is meant to cover those with the lowest of incomes and relatively highest energy bills. According to the National Energy Assistance Director's Association (NEADA), in 2015, LIHEAP provided essential heating assistance to 6.9 million households, and essential cooling assistance to about 996,000 households. In 2009, LIHEAP was budgeted \$5.1 billion, which was the most it has been in history. LIHEAP's recent annual budgets of about \$3 billion is only able to serve about 20% of the eligible households in the country (Drehobl and Ross, 2016). The most common reason for not applying for bill assistance is a lack of awareness of assistance programs and confusion over how to apply (Treadway, 2018).

Weatherization funding is also available from LIHEAP. Up to 25% of LIHEAP appropriations can be spent on weatherization at the discretion of the authorizing state agency. The LIHEAP Statute⁴⁰ requires that grantees receive a state waiver to increase the maximum from 15% to 25%.⁴¹ NASCSP tracks the leveraging of each state.⁴² Its most recent funding report estimates that in FY 2017, the \$223.5 million of DOE WAP funding leveraged \$423.1 million of LIHEAP funding and \$225.6 million of other funding, mostly from utilities (\$138.3 million).⁴³

HHS requires grantees to have a plan on how to use LIHEAP funds for weatherization and the funds must be expended in accordance to the plan. Grantees can choose to administer the LIHEAP funds according to: entirely DOE WAP rules, entirely LIHEAP rules, mostly LIHEAP rules, or mostly DOE rules.⁴⁴ LIHEAP weatherization investments must be for cost-effective,

³⁸ https://nascsp.org/wp-content/uploads/2017/09/WAP_ProgramOverviewFactSheet_3.16.17.pdf

³⁹ https://liheappm.acf.hhs.gov/data_warehouse/index.php?report=homepage

⁴⁰ <https://liheapch.acf.hhs.gov/pubs/liheapstatute.htm>

⁴¹ <https://liheapch.acf.hhs.gov/delivery/components.htm>

⁴² https://nascsp.org/wp-content/uploads/2019/02/NASCSP-2017-WAP-Funding-Survey_FINAL_2.9.-2019.pdf

⁴³ https://nascsp.org/wp-content/uploads/2019/02/NASCSP-2017-WAP-Funding-Survey_FINAL_2.9.-2019.pdf See Tables 1 and

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⁴⁴ <https://neuac.org/wp-content/uploads/2018/07/1B-Burrin.pdf>

residential weatherization measures or other energy-related home repairs that do not constitute construction.

In about half of the U.S. states, WAP and LIHEAP are located in the same office. The LIHEAP/WAP relationship is valuable. For example, tracking WAP deferrals can be used to effectively target LIHEAP funds and LIHEAP recipients with high energy burden can be directly referred to WAP for services.⁴⁵

3.3.3 Other Federal Programs and Policies

At least two additional federal initiatives have a strong direct impact on the energy burden of low-income households: The Energy Efficiency and Conservation Loan Program (EECLP) operated by the USDA and the LIHTC tax credit monitored by the Internal Revenue Service (IRS). EECLP provides loans to finance energy efficiency and conservation programs of rural electric cooperatives that serve towns or unincorporated areas with no more than 20,000 inhabitants.⁴⁶ Eligible utilities can borrow money tied to Treasury rates of interest and re-lend the money to develop new and diverse energy service products within their service territories. The borrowed funding must be used to improve energy efficiency or encourage the use of renewable energy fuels for demand-side management, including solar PV systems, energy audits, community awareness and outreach, as well as consumer education. For instance, several utilities have used EECLP funds to support the Pay As You Save[®] (PAYS[®]) financing programs described by Lin (2018a).

State and local housing finance agencies have incorporated green building rating systems and associated funding into the construction and retrofit practices of public housing. The federal government spends about \$6 billion annually on the LIHTC program, which has supported more than 2 million housing units to date.⁴⁷ An analysis of units participating in LIHTC in Virginia concluded that they used 12.5% less energy than non-participating units. “The savings equate to 9.3%, 5.6%, and 3.5% of annual income for extremely low-income, very low-income, and low-income households” (Zhao et al., 2018, p. 559). At the same time, Reina and Kontokosta (2017) note that subsidized housing is less efficient than comparable private-sector housing, perhaps as a result of limited public funding for maintenance and upgrades. Low-income households living in subsidized or public housing units are eligible for participation in WAP.

3.4 STATE PROGRAMS AND POLICIES

Finding: States are using minimum requirements and adders to cost-effectiveness tests to promote greater investment in low-income energy programs.

Many State Energy Offices play active roles in extending energy-efficiency benefits and other energy services to low-income customers. The strong roles that States are playing are described

⁴⁵ <https://neuac.org/wp-content/uploads/2018/07/1B-Burrin.pdf>

⁴⁶ <https://www.rd.usda.gov/programs-services/energy-efficiency-and-conservation-loan-program>

⁴⁷

https://betterbuildingssolutioncenter.energy.gov/sites/default/files/PP_Incorporate%20EE%20RE%20Standards%20as%20a%20Criterion%20in%20Tax%20Credits_FINAL_3.pdf

on the Clean Energy States Alliance (CESA) website.⁴⁸ The website also has an array of CESA guides, including:

- [Bringing the Benefits of Solar Energy to Low-Income Consumers](#) by Bentham Paulos of Paulos Analysis
- [Publicly Supported Solar Loan Programs: A Guide for States and Municipalities](#) by Travis Lowder of the National Renewable Energy Laboratory
- [Solar+Storage for Low- and Moderate-Income Communities: A Guide for States and Municipalities](#) by Todd Olinsky-Paul.

State and regional resources used to fund these initiatives include the Regional Greenhouse Gas Initiative (RGGI), State Energy Program (SEP), Qualified Energy Conservation Bonds (QEBS), state revolving loan funds, state treasury funding, general obligation bonds, utility ratepayer funds, and environmental settlements funds.

Berg and Dreihobl (2018) conducted a survey of 40 of the U.S. states, and concluded that state regulators and State Energy Offices can play a key role in encouraging utilities to carefully consider and expand the role of low-income energy-efficiency programs in their program portfolios. A mix of different strategies have been used. Key among these are (1) setting goals that require minimum levels of expenditure or savings for low-income energy-efficiency programs, and (2) special cost-effectiveness testing and provisions that give extra credit for low-income energy-efficiency accomplishments.

State requirements for goal setting include spending thresholds for low-income energy-efficiency programs, customer participation goals, and savings targets for low-income energy-efficiency programs. Special cost-effectiveness testing and provisions include cost-effectiveness exemptions, quantifying non-energy benefits, and coordination of ratepayer-funded low-income programs with WAP services. While a wide array of diverse state policies is itemized by Berg and Dreihobl (2018), the authors also note that 14 of the 15 states with the highest poverty rates do not have either type of policy; many of these states are located in the southeastern U.S.

An increasing number of states are also launching initiatives to facilitate distributed electricity that can contribute to grid resilience. Evens (2015) envisages a future utility-based model where even low- and middle-income households have the option of purchasing power outside the grid, thereby reducing the demand for grid electricity.

3.4.1 Minimum Requirements for Low-Income Energy Programs

Based on a survey conducted in 2017 by the American Council on an Energy-Efficient Economy (ACEEE), more than 20 states have spending or savings requirements for their low-income energy-efficiency programs (Berg and Dreihobl, 2018).

In some states, minimum requirements are set by public utility commissions. For instance, one of the most aggressive quotas was set by California's Public Utilities Code Section 382(e) to provide low-income energy-efficiency measures to 100% of eligible and willing customers by 2020 (Berg and Dreihobl, 2018). In New York, the Public Service Commission ordered NYSEDA to invest at least \$234.5 million of Market Development funds in Low-to-Moderate

⁴⁸ <https://cesa.org/projects/low-income-clean-energy/>

Income (LMI) initiatives for three years beginning in 2016. Thus, the impetus for these minimum requirements can come from state regulators.

State legislators can also be influential. For example, the Illinois Future Energy Jobs Act (FEJA) directed utilities to implement designated levels of low-income energy efficiency. Ameren Illinois Corporation (AIC) was required to spend at least \$8.35 million per year (Simms and Casentini, 2018). AIC established a company-wide commitment to increase its energy-efficiency spending, helping underserved communities to participate in the energy-efficiency economy by solidifying relationships with local partners and community-based organizations.

3.4.2 Adders to Cost-Effectiveness Tests for Low-Income Energy Programs

The type and level of cost-effectiveness tests applied to state low-income programs are key factors guiding investment levels. In contrast to traditional residential efficiency programs, low-income programs often seek to address a wider range of challenges beyond simply achieving energy savings; these can include health and safety issues, home durability, arrearage reduction, and electricity terminations and reconnections. For this reason, low-income programs are sometimes not held to the same cost-benefit requirements or thresholds as other types of residential efficiency programs.

A wide range and variety of approaches to evaluate the cost-effectiveness of low-income programs and program measures exists among states. One such approach to give preferential treatment to low-income energy programs, is to exempt the programs entirely from cost-effectiveness tests. Eleven states have specific regulatory or legislative language that formalizes this practice (Berg and Dreihobl, 2018). For example, the New Jersey Board of Public Utilities (NJBPUB) does not require the low-income Comfort Partners Program to meet any cost-effectiveness requirements. In Minnesota, utilities may opt-out of utilizing cost-effectiveness tests. Minnesota statute 216B.241 directs that “costs and benefits associated with any approved low-income gas or electric conservation improvement program that is not cost effective when considering the costs and benefits to the utility may, at the discretion of the utility, be excluded from the calculation of net economic benefits for purposes of calculating the financial incentive to the utility.”

In other states, commonly used cost-effectiveness screening types for low-income programs include the utility cost test (UCT), total resource cost test (TRC), and the societal cost test (SCT), each tailored by regulators and program administrators to meet state-specific policy priorities or goals. An increasing number of states have taken steps to quantify the value of low-income non-energy benefits, while requirements setting specific savings targets for the low-income sector are less common (Berg and Dreihobl, 2018). For example, Vermont utilizes the societal cost test as their primary test. A 15% adjustment for non-energy benefits is applied in addition to the cost-effectiveness screening tool for low-income customer programs. The Delaware Energy Efficiency Advisory Council approved the Evaluation, Measurement and Verification (EM&V) subcommittee’s proposed estimates of low-income non-energy benefits, which took effect in 2017.⁴⁹

In Pennsylvania, under the Low-Income Usage Reduction Program (LIURP) natural gas utilities are required to devote 0.2% of company revenues towards LIURP services. Electric utilities

⁴⁹ <http://www.dnrec.delaware.gov/energy/Documents/EMVRegs.FINAL.pdf>

collect LIURP funds through a residential distribution cost included in the rates of all residential electric customers. LIURP funding levels are set over three-year periods as part of a utility's Universal Service Plan, which must be approved by the Pennsylvania PUC. Utilities adjust program funding levels for LIURP based on an assessment of the needs of their customer population. LIURP Weatherization measures are selected on the basis of simple payback recovery periods. A simple payback recovery period of seven years or less is required for most measures. Some other measures must meet a twelve-year simple payback recovery period: sidewall insulation, attic insulation, furnace replacement, water heater replacement and refrigerator replacement (Southworth, 2011).

3.5 LOCAL GOVERNMENT, COMMUNITY-BASED, NGO, AND PRIVATELY FUNDED PROGRAMS

Local and community low-income energy programs often focus on opportunities for stimulating economic development, creating liveable-wage jobs, meeting local environmental and sustainability goals, and increasing prosperity by expanding and deepening local collaborations and initiatives. For example, Donovan et al. (2018) used the Wealth Works Value Chain approach to design such programs for communities in upstate New Hampshire. The "Wealth Works" approach was created with funding from the Ford Foundation. It involves value chain coordinators to assist in solving local issues by developing an understanding of the various components of a service, developing and transforming markets, and thereby enhancing a community's prosperity. When applied to energy efficiency, a project would gather information and work with four aspects of the value chain – energy demand, service providers, outside providers and energy supply.

Shoemaker et al. (2018) highlight six energy efficiency programs serving rural areas. Community-based implementation strategies such as "Weatherize" campaigns are overcoming market barriers and accelerating the adoption of energy efficiency in low-income rural communities, Native American villages, and other underserved areas in Northern New England and Alaska (Winner et al., 2018). They are typically supported by loan and rebate programs that resonate in rural areas.

Another trend identified at the local level is the use of environmental settlement funds to support local energy efficiency assistance programs. In Tennessee, the Bristol Energy Efficiency Assistance Program was announced as a part of an environmental settlement in 2014. The program involved coordination between local economic development and community assistance program officials in conjunction with state environmental regulators. Tennessee's State Energy Office worked in partnership with local economic and community development officials to oversee the program's implementation process, coordinate measures and enrolment using existing community assistance programs, and served as technical advisors to local program administrators throughout the project.⁵⁰ The Bristol Energy Efficiency Assistance Program partnered with an existing program in the City of Bristol that provided housing repair assistance

⁵⁰ <https://www.tn.gov/environment/program-areas/energy/state-energy-office--seo-/programs-projects/programs-and-projects/special-energy-projects0/redirect---special-energy-projects/city-of-bristol-energy-efficiency-assistance-program.html>

to economically disadvantaged homeowners. Through this partnership, a ready-made qualified group of people could be targeted for support under the King Consent Decree funding.⁵¹

Many cities are developing climate change adaptation and mitigation plans, and many of them consider their impacts on low-income households alongside other equity issues (Barbier, 2014). For example, in Portland, Oregon, the incorporation of equity considerations in the city's climate action plans resulted in a "Climate Action through Equity" plan in 2016. Towns and cities have also organized Weatherize campaigns, modeled after Solarize campaigns, where goals are set and providers are pre-approved in order to foster local participation.⁵²

NGOs operate energy and affordable housing initiatives at all scales from the local to the international. For example, the National Center for Healthy Housing (NCHH,) provides guiding documents related to safety, ventilation, moisture control, and thermal comfort, all of which impact energy usage and are particularly pertinent to low-income housing where indoor air quality problems can be severe.⁵³ The magnitude of philanthropic funding of the totality of these initiatives has not been estimated in the last decade of searchable publications in the Web of Science.

⁵¹ <https://www.tn.gov/environment/program-areas/energy/state-energy-office--seo-/programs-projects/programs-and-projects/special-energy-projects0/redirect---special-energy-projects/city-of-bristol-energy-efficiency-assistance-program.html>

⁵² <http://www.greenenergytimes.org/2018/12/17/weatherize-campaigns-spread-across-new-hampshire/>

⁵³ <https://nchh.org/information-and-evidence/learn-about-healthy-housing/healthy-homes-principles/>

4. THE IMPACTS AND COST-EFFECTIVENESS OF LOW-INCOME ENERGY PROGRAMS AND POLICIES

This section describes the impacts and cost-effectiveness of the many different types of programs and policies that address the energy burdens of low-income households.

4.1 ESTIMATES OF COSTS, BENEFITS, AND COST EFFECTIVENESS

Extensive assessments of the cost-effectiveness of DOE's Weatherization Assistance Program and utility low-income energy efficiency programs have been conducted, and their results are summarized here. The performance of state, local government, and community-based programs has also been documented in case studies and comparative assessments. Some have also benefited from the same level of systematic assessment typical of national programs, including field surveys, inspections, and utility-bill analysis.

4.1.1 Electric and Gas Utility Low-Income Programs

Finding: Low-income energy efficiency programs operated by electric and gas utilities cost more to implement per household and often deliver more critical service given the lack of resources of participants. Based solely on their energy cost savings, these programs are less cost-effective than energy-efficiency programs that serve higher income groups. Low-income energy programs ensure low-income households can benefit from ratepayer funding that they help pay for but would otherwise not benefit from.

The literature documents that the average cost of saving electricity is higher for low-income programs than for other residential, commercial, and industrial programs. For example, Hoffman et al. (2018) examined data spanning 815 program-years of low-income efficiency programs operated by electric utilities from 2009-2015. Their assessment of cost-effectiveness distinguishes between the program administrator cost per kWh saved and the metric when participant costs are included in addition to the program administrator cost. Across all 815 utility programs in the U.S., saving-weighted average program administrator's cost of saved electricity is \$0.025 (in \$2016) / kWh, and this rises to \$0.050 when participant costs are added. For low-income programs, the average program administrator's cost of saved electricity is \$0.105 (in \$2016) / kWh, and this rises to \$0.145 when participant costs are added (Figure 4.1). Low-income participants contribute about 1.3 cents per kWh saved, which is less than in other programs that serve higher income households. This low contribution by low-income customers is consistent with their limited access to financial resources.

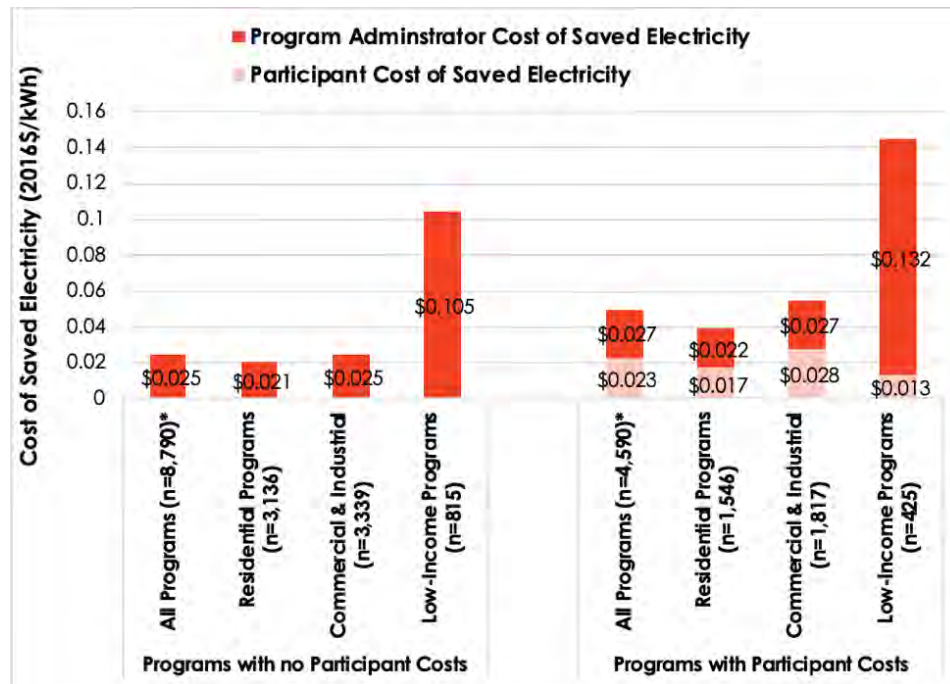


Figure 4.1. Cost of saving electricity in utility energy-efficiency programs.

Source: Redrawn from data published in Hoffman et al. (2018)

4.1.2 DOE Weatherization Assistance Program

Finding: The savings-to-investment ratio of WAP is favorable based on the value of its energy savings alone. The value of the non-energy benefits of WAP and other low-income energy programs are significant.

DOE (2015), Tonn et al. (2014a) and Tonn, Rose, and Hawkins (2018) describe two WAP impact evaluations: one focused on 2008 (before ARRA) and the other focused on 2010, after the Program's funding was significantly boosted by ARRA. The WAP impacts include savings of fossil fuels and firewood as well as electricity (Table 4.1).

The 2008 program supported the weatherization of 97,965 units and reduced energy costs by \$340 million over the lifetime of its installed measures. With an average household energy savings of \$4,243 and energy measure costs of \$2,899, the savings-to-investment ratio (SIR) for the energy measures is 1.4. The 2010 program supported the weatherization of about 340,000 units, reducing energy costs by \$1.2 billion and resulting in an energy-based SIR of 1.0. Environmental, health, and household related benefits were found to be significant in both program evaluations. The 2008 program evaluation results are indicative of the program generally and today because the funding during the ARRA period was an order of magnitude greater than normal and occurred in a condensed timeline.

When communities can enjoy more energy-efficient utilities, they derive a variety of benefits including improved public health, higher investment in the local economy, poverty alleviation and sometimes job creation with weatherization policies.

Table 4.1 Summary of benefits from weatherization assistance program in 2008 and 2010

(Sources: Tonn et al., 2014a; DOE, 2015; Tonn et al., 2018)

Program Wide Benefits for All Housing Types		
	2008	2010
Total Homes Weatherized	97,965	340,158
Average Cost per Weatherized Home	Total Cost: \$4,695 DOE Investment: \$2,301	Total Cost: \$6,812 DOE Investment: \$5,926
Average Energy Measure Costs	\$2,899	\$3,545
Energy Savings Per Household (Present Value)	\$4,243	\$3,190
Total Energy Savings (Present Value)	\$340 million	\$1.2 billion
Savings-to-Investment Ratio	1.4 ⁱ	0.98 ⁱⁱ
Total Benefits per Household Including Health & Safety (Present Value)	\$13,550	\$13,167
Carbon Reduction	2.25 million metric tons	7.38 million metric tons
Savings-to-Investment Ratio for Submarkets		
	2008	2010
Single-Family Homes	1.72	1.12 (0.82-1.53)*
Mobile Homes	1.03	0.79 (0.66-0.79)
Small Multifamily	1.60	
Large Multi-Family (New York City only)	1.82	0.67 (0.55-0.84)

ⁱ These values include funding from some non-DOE sources that are not uniformly subject to DOE's Savings to Investment Ratio (SIR) requirement that is used to guide the measures that are installed. These funds are often used for more costly energy measures that result in lower SIRs for the combined funds.

Tonn et al. (2018) found that the energy savings vary by housing type, with site-built homes saving more than mobile or multi-family homes. Costs and benefits were also influenced by fuel type and climate zone.

A limited number of studies estimate the potential of a “rebound effect” in low-income houses. The concern is that participants in energy-efficiency programs may increase their use of energy services after their home is retrofitted, reducing or potentially negating any energy savings. In an evaluation of households participating in WAP, Tonn et al., (2015) conclude that this effect is negligible based on surveys of behavior pre- and post-weatherization.

4.1.3 State Green Building Policies

Longitudinal analysis has been used in a few studies to examine the time effects of state green building policies (operating independently of WAP) on the energy performance of low-income housing units. In one case, Zhao et al. (2018) evaluated monthly energy use data over three years from 310 residential units across 16 developments in the State of Virginia and conducted profile analysis and multivariate analysis of variance (MANOVA). Their results estimate financial savings of \$648 per year due to reduced energy usage in green buildings. These savings equate to 9.3%, 5.6%, and 3.5% of annual income for extremely low-income, very low-income, and low-

income families, respectively, suggesting that green building incentives and practices can enable housing with affordable energy systems. The broader goal of affordable housing is a much bigger issue tied to regional economics, housing vintage, and many other factors. Energy is just one piece of the poverty puzzle; making energy more affordable and sustainable is important but not a complete solution to the poverty problem.

4.1.4 Community Partnerships

Local partnerships in some states and communities, such as those supported by the DOE initiative called the Clean Energy for Low Income Communities Accelerator (CELICA), have been designed to take a more holistic approach to energy affordability. It required partnerships across different levels of government agencies, where DOE provided assistance to states and local governments on the design and implementation of low-income energy programs. CELICA not only provided support to reduce energy burdens, but also provided tools for managing and monitoring progress (DOE, 2017). Taking a broader perspective, CELICA not only leveraged the Weatherization Assistance Program and its network of providers to expand access to energy efficiency for low income households beyond what federal funding could address, but also promoted distributed renewables to provide stability from rising energy costs, promoted economic development, and improved the environment.

4.2 UNDER-SERVED LOW-INCOME COHORTS

Evidence suggests that three cohorts have been under-served by efforts aimed at addressing the high energy burden of low-income households: multifamily and rental markets, rural communities, and manufactured and mobile homes.

4.2.1 Multifamily and Rental Markets

Finding: The multifamily low-income market has been difficult to reach with traditional energy-efficiency programs due partly to misalignment of incentives. New program designs that address split-incentives and incorporate strong community engagement can help reach multifamily markets. Strong community engagement can expand participation rates and enhance the success of low-income energy programs. Public-private-philanthropic-partnerships and interagency coordination and leveraging can reduce energy costs for low-income households while also delivering non-energy benefits.

Multifamily buildings are home to nearly 25% of the U.S. population and more than half of low-income households (Hernandez et al., 2016; Corso, Garascia, and Scheu, 2017; Frey et al., 2015).⁵⁴ Based on the 63,166 housing units occupied by low-income households that were examined by Hernandez, et al. (2016), the percentage of low-income households living in multifamily housing is 51.9%. Specifically, 32,824 (36.6%) of the 63,166 units were either an attached house or were located in a small apartment building, and 9,725 (15.4%) were located in a large apartment building. For a variety of reasons including high land values, cities and urban areas have a disproportionate number of multifamily buildings (Hernandez and Philips, 2015).

With high rates of various vulnerabilities and a lack of access to housing improvements, households in low-income multifamily housing face disproportionate health and financial

⁵⁴ <https://www.energy.gov/eere/slsc/maps/lead-tool>

challenges (Fabian et al., 2012; Waite et al., 2018). At the same time, these households are often underserved by traditional energy-efficiency programs (Ross, Jarrett, and York, 2016; Berkland et al., 2018). In Program Year 2008, WAP funds supported the weatherization of 97,965 units; 23% of these lived in multifamily buildings (18% large and 5% small multifamily structures) (Tonn, 2014a). These markets have been hard to reach by traditional utility and government programs (Corso et al., 2017; Henderson, 2015). A major reason is that incentives are misaligned as a result of a “principal-agent” or “split-incentive” problem. When tenants pay the energy bills, the building owner may not be motivated to invest in improvements because the bill savings accrue to occupants (Reina and Kontokosta, 2017).

Considering their high concentration, these markets represent a significant potential for energy and cost savings and for improving people’s lives including the quality of the air they breathe (Chant, Schaaf, and Ast, 2016; Henderson, 2015; Frey et al., 2015). Further, government control over multifamily units that form part of public housing makes it possible to integrate different policies (Reina and Kontokosta, 2017). The consensus appears to be that there is a need for scaling up the energy-efficiency and related improvement programs for multifamily and rental markets (Samarripas, York, and Ross, 2017).

Different types of energy-efficiency programs have been implemented to address low-income multifamily market needs. These include programs led by utilities and NGOs; financing programs (Leventis, Karmer, and Schwartz, 2017); and data collection programs (Long et al., 2018). Several lessons can be found in the reports and studies we analyzed. Community support is particularly useful in multifamily programs (Chant et al., 2016; Sanchez, Levine, and Tajina, 2018). In two cities in Ohio, Andrews and Poe (2018) found that local community involvement led to increased participation, ultimately leading to improvements in health and safety for tenants as well as landlords. Similarly, community based social marketing can increase the success of programs (Keilty, 2018). Carefully designing the incentives and utility-managed on-bill financing can help address the problem of misaligned incentives (Bird and Hernandez, 2012). Finally, by integrating energy efficiency into solar projects, energy burdens can be significantly reduced (Samarripas and York, 2018).

4.2.2 Rural America, Island Territories, and Indian Reservations

Finding: Low-income households in rural communities often spend as much as a quarter of their income on energy due partly to the low-density built environment enabled by lower land values. Assistance from local community programs and organizations are particularly critical to success in these markets.

Energy burdens in rural communities are estimated to be as high as 25% (Ross et al., 2018). Thus, rural communities may have the greatest need for energy-efficiency programs. The distribution of burdens in rural areas largely reflects the socio-demographic patterns in the rest of the country with minorities, elderly, and renter households spending a higher share of income to meet utility bills (Ross et al., 2018). This problem can be even more pronounced for island territories (Winner et al., 2018). Rural areas present unique challenges for implementing energy efficiency programs; they are less densely populated, typically have a different fuel and consumer mix, different regulatory structures, and high program implementation costs (Shoemaker et al., 2018). Lower densities can make it difficult to access energy-efficiency programs, and result in higher costs of providing infrastructure including pipeline infrastructure

to support the conversion of electricity, fuel oil, kerosene and other fuels to natural gas, which is often the least-cost fuel for home heating (Ross et al, 2018).

Native American reservations have similar characteristics and account for some of the highest rates of energy poverty in the U.S. Their un-electrified homes span the contiguous United States and Alaska (Begay, 2018a). Provision of energy access to remote areas in the reservations at affordable rates has been a challenge for the traditional electricity development model. Looking to the future, these reservations have a lot of promise because they represent 2% of the U.S. landmass but 5% of the renewable energy resources (Begay, 2018a). Harnessing these resources can be a way of rejuvenating the economies of rural communities (DeSilva, McComb, and Schiller, 2016; Donovan et al., 2018). The rooftop solar solution the Navajo Nation has adopted in collaboration with Sandia National Laboratories offers insights into how the Navajo Tribal Utility Authority's work could serve as a residential model to meet the needs of the 1.2 billion people globally who are without electrical residential power.

Several programs have been piloted and rolled out to reduce energy burdens and increase access in these communities over time. These involve direct funding from government programs, NGO involvement, and funding from charitable organizations. Different agencies are responsible for implementing these projects, including State Energy Offices, electric cooperatives, municipal or investor owned utilities (Donovan et al., 2018; Shoemaker et al., 2018).

Results and findings from pilot projects and other programs focused on rural areas show that gains from targeted rural energy-efficiency programs can be increased by using cooperatives in remote rural locations (Lin, 2018a). This is especially true if the financial support can be earmarked to meet upfront costs and to address the challenge of split incentives. Similarly, community-based programs where partnerships with NGOs is leveraged are also found to be successful (Andrews and Poe, 2018; Donovan et al., 2018). There are significant gains to be made from pooling resources from different projects to achieve economies of scale, and from training workers to operate these new systems (Souba and Mendelson, 2018). It has been estimated that strategies to tackle the energy-efficiency gap in rural and small-town America could reduce energy burdens by as much as 25% (Ross et al., 2018).

4.2.3 Manufactured and Mobile Homes

Finding: The opportunity to address the high energy burdens of low-income households occupying manufactured housing has received limited analysis and policy focus.

This oversight is related to the limited attention given to the energy-efficiency gap in rural America, where 70% of all manufactured homes are situated. Manufactured homes made up 9% of new U.S. homes in 2017 and housed more than 20 million people in total.⁵⁵ Manufactured homes consume 35% less energy than other homes due to their smaller footprint, but unfortunately residents spend 70% more per square foot on energy (Ross et al., 2018). With a median family income of \$30,000, residents of manufactured homes have higher-than-average energy burdens.⁵⁶

⁵⁵ <https://www.manufacturedhousing.org/wp-content/uploads/2017/10/2017-MHI-Quick-Facts.pdf>.

⁵⁶ <https://aceee.org/blog/2016/08/mobile-homes-move-toward-efficiency>

4.3 TECHNOLOGIES AND MEASURES INSTALLED

Finding: Health and safety upgrades are not components of most utility low-income energy-efficiency programs. Information and communication technologies such as smart thermostats support low-cost behavioral approaches to improving energy efficiency, but they tend not to be incorporated into low-income energy programs.

Through its Grantees and its network of hundreds of Subgrantees providing services at the local level, WAP installs energy efficiency measures and a limited amount of energy-related safety/health measures at no financial cost to homeowners. Air sealing and insulation are the two most common measures (Figure 4.2). Some utilities also use contractors to directly install measures. The most common measures installed by contractors under electric utility programs are lighting, air sealing, insulation, and water heater upgrades, typically at no financial cost to the household. Some utilities also offer energy-savings kits with weatherstripping, caulking, LED bulbs, and other low-cost items that homeowners can install themselves.

Drehobl and Castro-Alvarez (2017) found that the majority of cities have access to utility programs with lighting, air sealing, and insulation measures, while smart thermostats and health and safety measures were the least common program measures. In terms of cost-effectiveness, Elsawaf, Abdel-Salam, and Abaza (2013) found that that air-source heat pumps could reduce heating costs in low-income mobile homes by up to 52% when integrated in an electric strip heat system, while also improving thermal comfort in their analysis of eastern North Carolina. They also found that their benefits exceed the initial cost of installation.

Other studies have also documented co-benefits and savings from building improvements. For example, the health and financial benefits of replacing old windows with thermally efficient windows have been documented by Jacobs et al. (2016), who conclude that in addition to saving energy costs, window replacement programs can also reduce the potential exposure to lead from degraded lead paint mixed in soil and dust.

Bradshaw et al. (2016) investigate the benefits and cost-effectiveness of three types of weatherization treatments: replacing a standard thermostat with a programmable thermostat, installing attic insulation, and envelope air sealing. These treatments were modeled for the low-income housing stock of six contrasting American urban areas: Orlando, Florida; Los Angeles-Long Beach, California; Seattle, Washington; Philadelphia, Pennsylvania; Detroit, Michigan; and Milwaukee, Wisconsin. Results show that (1) regional variations have high impact on the cost-effectiveness of weatherization treatments, (2) housing stocks with substantial electric space conditioning tend to offer greater energy cost and greenhouse gas (GHG) savings, (3) the effect of a GHG price is small compared to energy cost savings when evaluating the cost-effectiveness of weatherization treatments, and (4) installing programmable thermostats is the most cost-effective treatment of the three treatments studied. This study highlights the importance of thoughtful consideration of low-income energy-efficiency program goals when selecting cities or regions to prioritize because different goals suggest different approaches.

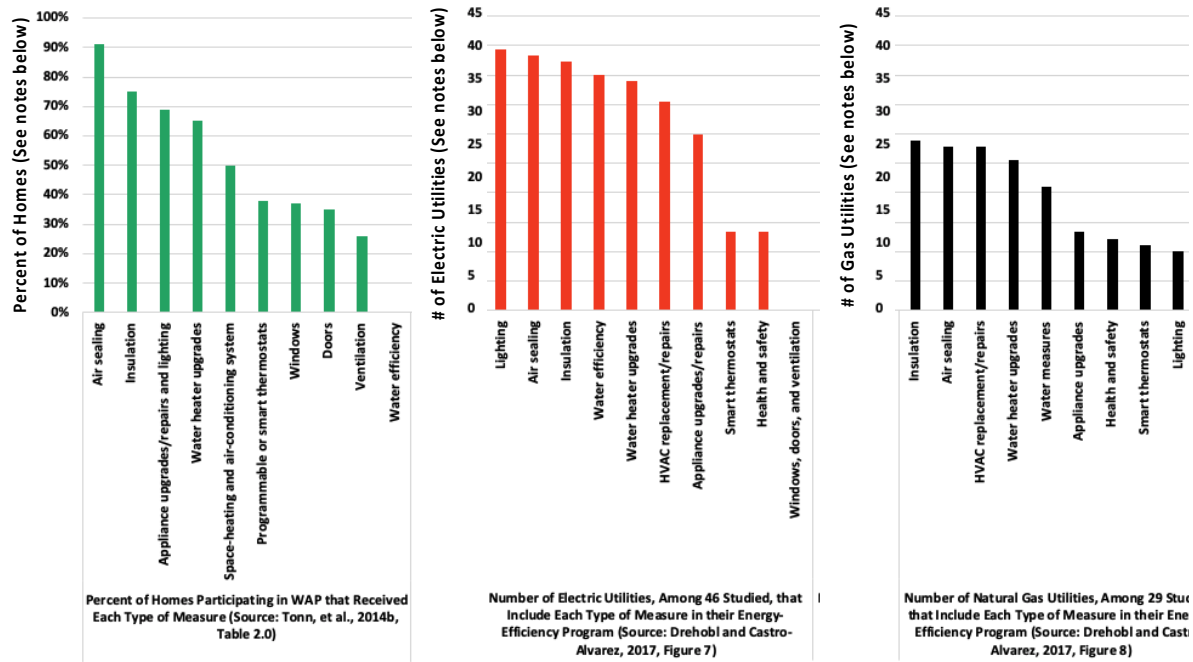


Figure 4.2. Measures installed in low-income programs.

(Source: Authors, based on data from Tonn et al., 2014b; Dreihobl and Castro-Alvarez, 2017)

Vercas and Hsieh (2018) looks at disconnection policies of utilities that make households vulnerable to energy insecurity. The data on disconnections by utilities is not easily available. The authors look at Minnesota and Iowa and identify the policies in place to help customers maintain access to energy resources.

4.4 THE ENERGY SAVING POTENTIAL OF LOW-INCOME HOUSHOLDS IN THE U.S.

In a study of the 48 largest cities in the country, Dreihobl and Ross (2016) estimate that if the low-income housing stock were brought up to the efficiency level of the average U.S. home, 35% of the low-income energy burden could be eliminated.

Focusing specifically on possible electricity savings from weatherization, Hoffman (2017) assessed the implications of pursuing energy efficiency neighborhood-by-neighborhood where low-income households are prevalent. Using data on demographics, housing types and recent savings from low-income retrofits, and assuming that households at 200% of the Federal Poverty Level are eligible, Hoffman (2017) provides rough electricity savings estimates of 51.5 billion kWh. A majority of these savings are in the South (54%) and in hot-humid climate zones (38%), where much of the nation's poverty is concentrated.

5. PROMISING PRACTICES

5.1 SOLAR ENERGY FOR LOW-INCOME HOUSEHOLDS

Finding: Expanding the technology scope of low-income energy-efficiency programs to include solar PV, smart meters, storage, and electric vehicles could significantly improve energy affordability for low-income households. Broadening finance and administrative options (e.g., on-bill program designs) could also expand savings opportunities.

Historically, affluent households have dominated the market for residential solar installations, but with expanding production and declining costs, solar systems are now beginning to reach previously underserved markets. In low-income communities, solar energy can significantly reduce energy burdens, while also generating living-wage jobs. By displacing pollution from traditional sources of energy, solar can also mitigate disproportionate negative environmental impacts on low-income communities (Franklin and Osborne, 2017). Despite these perceived benefits, disparities across the country in the adoption of solar resources continue to persist; this continuing gap can be attributed to social, political, and economic factors, as well as the structural integrity of roofs and the soft costs of running programs (Kann and Toth⁵⁷; Tidwell, Tidwell and Nelson, 2018; Gupta et al., 2018b; Zhang et al.⁵⁸; Sunter et al., 2019). Typically, there has also been a trade-off between reducing bills for low-income households and ensuring returns for utilities (Aznar and Gagane, 2018). Further, the growing adoption of solar by affluent households can potentially reduce sales for utilities and disproportionately affect the share of fixed utility costs that low-income households have to bear.

A detailed analysis of solar adoption presents some interesting patterns of diffusion of solar technology at local and household levels. In their study of solar PV in Connecticut, Graziano and Gillingham (2014) find that the number of previously installed solar systems, and characteristics of the built environment significantly predict adoption of PV systems. This corroborates findings that peer influences, community effects, and word-of-mouth strongly influence solar adoption (Bollinger, Gillingham, and Tsvetanov, 2016; Gillingham and Bollinger, 2017; Gupta et al., 2018a).

Federal and state programs focused on addressing energy poverty have traditionally helped deploy weatherization and bill assistance programs; however, coupling these services with solar financing assistance presents a potentially attractive way to more dramatically reduce the energy burden of low-income households (Ulrich et al., 2018). The Navajo Nation provides a vivid example of rooftop solar systems being installed to tackle energy poverty among its 35,000 remote off-grid Native American members, with dispersed housing, where solar PV rooftop systems are providing a viable solution to this rural electrification dilemma (Begay, 2018b).

Despite the expanding penetration of low-income solar systems, research to date has not yet fully assessed what proportion of low-income housing is suitable for solar PV or what fraction of low-income electricity needs could be met by solar systems (Sigrin and Mooney, 2018). Such assessments need to consider the barriers that make it difficult for low-income households to acquire solar resources, such as:

⁵⁷ <https://www.woodmac.com/our-expertise/focus/Power--Renewables/How-Wealthy-Are-Residential-Solar-Customers/>

⁵⁸ https://beccconference.org/wp-content/uploads/2018/10/jingjang_presentation2018.pdf

- **Access to capital and lower credit ratings.** Investments in solar installation can be prohibitive for low-income families, due to their high cost. This segment of the population can establish a power purchase agreement with a third party to avoid the high upfront cost. However, third parties are likely to reject a low-income customer if they have a low credit score.⁵⁹
- **The landlord/tenant split incentive.** Given that multifamily buildings represent a significant portion of the housing property portfolio, they present an important opportunity for the growth of rooftop solar (Inskeep, Daniel, and Proudlove, 2015).
- **Lack of information and language problems.** Low-income families for whom English is a second language can have trouble making informed decisions about solar installations because of language barriers that impede learning about the benefits of solar technologies (Paulos, 2017).
- **Housing conditions.** To install solar, roofs must have 10-15 years of remaining life, which is rarely the case in low-income housing. Structural repairs, plumbing, insulation and roof maintenance are often more pressing priorities for low-income residents.⁶⁰

The federal government's Investment Tax Credit is one of the most powerful policies currently promoting solar investments in the U.S., but it is inaccessible to most low-income households who typically have limited tax liability.⁶¹ Paulos (2017) estimates that securing a 30% credit on a \$10,000 solar installation would require a taxable income of at least \$26,000.

Traditional utility net metering and solar deployment subsidies also have issues of fairness. Under typical rate structures, net metering shifts costs from solar owners to lower-income ratepayers (Johnson et al., 2017). At the same time, the rapid deployment of rooftop solar systems has raised concerns about the fair distribution of electricity costs through rates (Franklin and Osborne, 2017). Distributed solar programs raise rates, while their subsidies go disproportionately to affluent households. Further, if not accounted for properly, increase in solar penetration can also lead to operational and financial challenges and consequently, result in reduction in the potential environmental benefits (Padhee and Pal, 2018). As with energy efficiency and electric vehicle programs, low-income households have notably low rates of participation in solar programs (Ulrich et al., 2018).⁶² A recent national assessment of residential rooftop solar technical potential estimates that low-income housing accounts for approximately 25% of the nation's total technical potential.⁶³ It should be noted that some low-income households may not be able to participate in solar programs if the building roofs are older and not structurally sound.

At the same time, because of their high levels of energy burden, low-income households are more severely impacted by rising electricity rates compared with other "non-participants" who typically have lower energy burdens. Because some form of dynamic pricing is currently available to most residential customers in the U.S., most low-income households can take advantage of them. The goal of dynamic pricing is to provide accurate price signals so that customers will be motivated to reduce their consumption during hours when the utility is

⁵⁹ http://www.gridalternatives.org/sites/default/files/Low-income%20solar%20policy%20guide%20press%20release_FINAL.pdf

⁶⁰ http://www.gridalternatives.org/sites/default/files/Low-income%20solar%20policy%20guide%20press%20release_FINAL.pdf

⁶¹ <https://www.taxpolicycenter.org/taxvox/new-estimates-how-many-households-pay-no-federal-income-tax>

⁶² <https://emp.lbl.gov/publications/income-trends-residential-pv-adopters>; <https://www.woodmac.com/our-expertise/focus/Power-Renewables/How-Wealthy-Are-Residential-Solar-Customers/>

⁶³ <https://www.nrel.gov/docs/fy18osti/70901.pdf>

experiencing high-priced peak demand. The most common dynamic pricing for residential customers is time-of-use (TOU) rates, where utilities set electricity prices for different time periods in advance. The rates for each time block are usually adjusted two or three times each year to reflect changes in the demand and wholesale market (Brown, Zhou, and Ahmadi, 2018).

For example, to accommodate for high levels of distributed generation and peak hours that are shifting from the afternoon to the evening, California has adopted default TOU rates that have shifted to later peak pricing periods. Waite et al. (2018) shows that these new TOU rate structures in California can increase energy cost burdens and have adverse consequences for low-income customers. Similarly, a randomized experiment conducted in the southwestern U.S., demonstrated that TOU rates can disproportionately increase the bills of households with elderly and disabled occupants, which, for a variety of reasons, may be less able to shift their consumption to low-cost hours of the day (White and Sintov, 2019).

The same fairness concerns would appear to apply to EV rates offered by utilities, where night-time purchasing of electricity by EV owners is offered super-off-peak pricing, which subsidizes electricity usage for those who can afford EVs.

One study of New Jersey solar data, PJM market data, and demand profiles from a PJM utility investigated rate and bill impacts of large-scale solar penetration (Johnson et al., 2017). It concluded that the fear of a utility “death spiral” and significant rate impacts may be exaggerated. Significant solar can be incorporated with only a 2% increase in non-participant bills. On the other hand, at high levels of penetration, distributed solar has the potential to alter the system peak hour which affects the allocation of costs across rate-classes. As the peak hour shifts to the evening when solar production diminishes, residential customers, in particular low-income households, face higher distribution costs. Policy makers and utilities need to be aware of these challenges in designing the next generation of rates that are better aligned with cost causality. Ronen, Gai, and Crampton (2016) find that repurposing the existing programs to cover the cost of rooftop solar could reduce electricity bills for low-income households by about \$9,000 over the lifetime of solar systems. (The authors do not discuss the maintenance and repair costs of the system.)

Programs are emerging that target barriers to solar installations for low-income households. They can be divided into rooftop solar programs and community solar initiatives.

5.1.1 Rooftop Solar Programs

“Solarize” and “Solar for All” campaigns have been popular models for promoting rooftop solar. In general, Solarize campaigns aim to remove barriers and headaches of installing solar in residences (Cook, 2014), while “Solar for All” programs typically include incentives for solar panels so that low-income households can afford to install them. Both models support the creation of “prosumers” who generate and export solar power, thereby reducing their energy bills and burden. The magnitude of electricity bill reductions depends on the utility’s net metering. Another type of program integrates solar panels into low-income home retrofits, and sometimes electric vehicles are part of the expanded program.

“Solar for All” programs typically aim to install PV systems in low-income households and to provide grants to other organizations with similar goals. For example, the Washington DC’s

“Solar for All” program is funded by DC’s Department of Energy and Environment and plans to install solar PV systems on more than 6,000 low-income homes annually with a goal of reaching 100,000 low-income households by 2032. This program helps lower the energy burden of its low-income households and contributes to accomplishing its renewable energy goals.⁶⁴

Another sizeable community-led solar aggregation and energy efficiency program is targeting low-to-moderate-income residents of Northern Manhattan (Roundtree, 2018). A community-led Energy Democracy Working Group (EDWG) selected and evaluated solar installers and is coordinating with the Housing Development Fund Corporation to reach co-op residents who are predominantly low to moderate income people of color. The project team also works with solar installers and the EDWG to promote local job creation related to the initiative.

California’s Multifamily Affordable Solar Housing Program shows that subsidized efforts can bring solar resources successfully to multifamily housing. MASH targets multifamily housing and was created under the California Solar Initiative bill enacted in 2006. Homes must be using either Pacific Gas and Electric, Southern California Edison, or San Diego Gas and Electric as their utility provider. Customers must also have an occupancy permit of two years or more. This program provides fixed, upfront payment based on the system’s potential capacity. Incentives for these multifamily homes are all Expected Performance Based Buydown (EPBB).⁶⁵ As of July 2017, the program has contributed 33.75 MW of interconnected solar capacity, successfully operated 427 projects statewide in multifamily low-income housing, and paid \$95 million in incentives to customers (Coughlin, Irvine, and Johnson, 2013).

Several case studies have shown that risks associated with installing solar on affordable housing can be mitigated by leveraging investments in energy efficiency (Samarripas and York, 2018). Two Michigan communities took advantage of additional WAP-ARRA-funding through the Sustainable Energy Resources for Consumers Grants (SERC) to expand weatherization to include solar. Their efforts concluded that renewable energy may have additional quality of life benefits to offer families beyond the cost savings (Walton, 2014). Similarly, Colorado and New York State have initiated efforts to hybridize weatherization with solar investments in WAP projects; and in a few states, LIHEAP rules allow weatherization projects to incorporate PV as an option to reduce household energy burden (Ulrich et al., 2018). Evidence of cost effectiveness of this energy-efficiency and renewable energy combination has emerged from the efforts of the Colorado Energy Office in a state with high solar irradiance. In their evaluation of the CEO’s efforts, Cook and Shah (2018a) found that regardless of the type of energy-efficiency improvements, incorporating PV as a measure to reduce the cost of electricity cuts customer bills by \$400 or more annually. (This is without taking into account the maintenance costs of the system.) Integrating electric vehicles can reduce costs further, as in the Single Family Affordable Solar Housing (SASH) pilot program (Verclas, 2018), and Vermont has also hybridized all three types of measures – energy efficiency, solar, and electric vehicles – with home energy storage. Further, as in the case of energy efficiency programs, community organizers can also play a role in encouraging pro-social behaviors (Kraft-Todd et al., 2018; Wolske, Stern, and Dietz, 2017).

⁶⁴ <https://doee.dc.gov/solarforall>

⁶⁵ The EPBB is an up-front incentive payment where the incentive amount is adjusted to reflect verifiable system capacity as well as the effect of system orientation and shading on energy production. https://www.cleanpower.com/wp-content/uploads/2012/02/008_EPBB_IncentiveStructure.pdf

Finally, the fact that solar is approaching cost-parity in many areas and can improve the resilience of housing, has led to its increasing role in disaster recovery efforts across the country including the Caribbean Islands. The FEMA Disaster Recovery Act and HUD Community Development Block Grant-Disaster Recovery (CDBGDR) program now have more funding dedicated to solar installations in light of this. DOE and HUD are also implementing solar and energy storage in disaster prone areas for low-income households (Source: DiRamio, Personal Communication, September 2019).

5.1.2 Community Solar Programs

Community-solar helps low-income households take advantage of solar projects by allowing them to purchase a small portion of as little as one panel of an offsite, local solar array in exchange for reductions to their utility bill for the entire life of the solar system (Booth, 2014). Sometimes called “shared solar”, community solar refers to local solar facilities shared by multiple subscribers. Community solar is particularly suitable for low-income renters and multifamily residents who can access solar via two alternative business models (IREC, 2018). With on-site shared solar, energy generation credits can be purchased from a single solar system that is shared virtually among multiple tenant accounts. With off-site shared solar, multiple remote customers can receive credits on their various utility bills for the shares they own in a common system. In sum, community solar provides three benefits. It can make solar accessible to homeowners without a rooftop and to renters, it can be easily transferable, and it may reduce replacement risks for on-site solar systems.

The state level policies on solar vary across states. While many states have some type of policy initiative to support the adoption of community solar, most of these are one-off policies rather than state-wide programs. In the absence of state-led programs, voluntary and utility-led programs are unlikely to reach underserved communities (Vote Solar, 2018). Community solar programs in the U.S. have at least four distinct ownership and management arrangements. In a utility-sponsored model, shares are offered to electric ratepayers. In a special purpose entity model, community investors can receive a return on investment (ROI) and offset their personal electricity use. In a non-profit model, donors contribute to a non-profit that owns the community installation. In a community-shared model, a third-party solar vendor owns the facility and community members sign up to be a part of the solar campaign (Coughlin et al., 2013). Several of these have served low-income multifamily residents, including one non-profit model used by the Co-op Power in New York and two utility-sponsored models including California’s Multifamily Affordable Solar Housing (MASH) and a Maryland PSC pilot program. Like many Solarize programs, Solarize Mass-Somerville is a community solar model that does not have an income qualification (Coughlin et al., 2013). It is available for low-income households, who otherwise would be unable to purchase rooftop solar.

Thus, administrators of low-income programs are learning from models that have successfully served higher-income customers and are creating new types of business models that are adapted and evolved to meet the needs of low-income households (Chan, Ernst, and Newcomb, 2017; Cook and Shah, 2018b; Heeter et al., 2018). However, the applicability of these strategies to low-income markets depends on the type of housing and the ownership status. As a result, Cook and Bird (2018) identified 13 different financing options that could be deployed for low- and moderate-income customers, each with its own unique features and impacts. Policymakers need to weigh the pros and cons of each type when considering applicability to their low-income

communities. IREC (2016) recommends using alternative financing tools such as anchor subscribers and back-up guarantees, direct and tax incentives, loan programs and credit enhancements, and low-cost public financing.

An interesting finding is that utilities are motivated to develop community solar not only to satisfy consumer demand or meet regulatory requirements for renewable energy, but also to alleviate revenue losses related to residential solar PV adoption (Funkhouser, et al., 2015). When net metering of rooftop solar power is set at retail rates, homeowners with rooftop systems pay significantly lower bills and do not pay for all of their associated fixed costs that the utility incurs. In a sense, they become “free riders”, relying on non-participants to cover the fixed charges that they once pay for before installing their solar system (Funkhouser, et al., 2015). Community solar can be designed to keep the utility “whole” with respect to collecting revenues to cover its fixed costs.

Thus, it would appear that community solar for low-income households could thrive because it benefits the business model of the incumbent energy stakeholders – the electric utilities. At the same time, as community solar models get adopted widely, there is a potential for “community washing.” It is unclear if the positive consequences of community solar will be experienced by participating communities, or if benefits will dis-proportionately be enjoyed by utilities or solar developers (Ptak et al., 2018). In addition, to foster the continued adoption of community solar, projects need to be financially beneficial for low-to-moderate income families (Vote Solar, 2018).

Despite the expanding penetration of low-income solar systems, research to date has not yet fully assessed what proportion of low-income housing is suitable for solar PV or what fraction of low-income electricity needs could be met by solar systems (Sigrin and Mooney, 2018). Such assessments need to consider the barriers that make it difficult for low-income households to acquire solar resources.

5.2 LEVERAGING THE HEALTHCARE BENEFITS OF ENERGY-EFFICIENT HOUSING

The healthcare industry has the potential to be a strong ally in the effort to reduce the energy burdens of low-income households. Problems associated with high energy burdens often include adverse health effects. Insufficient heating and cooling systems and leaky homes can cause hypothermia and heat stress. Improper air filtration, cracked heat exchangers, and poor ventilation can exacerbate asthma and other respiratory problems for occupants (Batterman et al., 2012; Doll, Davison, and Painting, 2016). Air conditioning units can transmit bacteria and lead to increased infection rates. Additionally, medical conditions often require electricity for treatment and medicines, such as diabetics needing refrigeration for insulin and those with breathing-related complications needing electrically powered breathing assistance devices. If updates to infrastructure are too costly and energy burdens are too high, households can end up sacrificing their health in order to cope with their energy bills. This in turn can lead to higher healthcare costs that further exacerbate the expenditure burden of households and lead to chronic stress (Hernandez et al., 2016).

The physical and mental health benefits of energy-efficiency upgrades are well documented (Camprubi et al., 2016; Fabian et al., 2012, 2014; Frey et al., 2015; Leventis et al., 2017; Coombs et al., 2018; Tonn et al., 2018). Surveys and case studies of residents systematically

identify favorable health effects (Hernandez and Philips, 2015; Hernandez et al., 2016). Based on the self-reports of public housing residents, Jacobs et al. (2015) found that green and healthy housing produced health benefits; specifically, there were reduced rates of hay fever, asthma, headaches, sinusitis, respiratory allergies, and angina. The latest WAP evaluation indicates that the value of the program's health benefits are significant (Tonn et al., 2018).

Collaboration and co-funding across the energy and healthcare industries offer an opportunity for both industries – and the vulnerable populations they serve – to benefit. The healthcare industry, and in particular Medicaid and Medicare and those states with value-based healthcare, have a vested interest in supporting healthy homes for low-income households that reduce medical costs. The energy industry often cannot invest in energy-efficiency measures or install rooftop solar systems without first making structural and safety investments (Breysse et al., 2011). Co-funded programs can leverage the potential benefits to both sectors (Kravatz et al., 2018; Ulrich et al., 2018). By combining health and safety housing improvements with efficiency retrofits using established energy-efficiency programs, the cost-effectiveness of efficiency investments can be strengthened. Spillman et al. (2016) provides examples of state initiatives where Medicaid funding has been used to make improvements, some of which are also energy-efficiency measures, and to educate residents about the health benefits of home energy upgrades. Healthy home measures include cleaning air conditioners and vents, improving HVAC systems, installing standalone air filters, plugging air leaks, and better insulation. By expanding the labor force of energy retrofit and public health professionals serving vulnerable populations, both stakeholder industries can improve (Dryden, et al., 2018).

5.3 BEHAVIORAL ECONOMICS AND SOCIAL SCIENCE APPROACHES

The study of low-income energy burdens is beginning to benefit from the emergence of behavioral economics and social-psychological approaches to understanding energy behavior.

Behavioral economics is the application of lessons from psychological and experimental studies to “nudge” people to change their behaviour. Well established concepts in behavioral and experimental economics on principal-agent problems, information asymmetry, and bounded rationality inform this research (Allcott and Rogers, 2014; Brown, 2001; Simon, 1976). However, most of these analyses do not focus specifically on low-income households. As a result, there is deep uncertainty about likely responses to information feedback, incentives, and an array of other policy interventions, and program offerings. Extant studies analyze the role of behavioral economics in determining and nudging people’s energy choices (Allcott and Taubinsky, 2015; Chetty, 2015; Sunstein and Reisch, 2014). Behavioral motivations may include monetary gains, information campaigns, education programs, audits and energy reports (Drehobl, Chikumbo, and Tanabe, 2018). The studies span a range of themes – behavioral response to energy efficiency, using green vs grey energy, willingness to pay, and community-based programs (Allcott and Taubinsky, 2015; Chetty, 2015; Sunstein and Reisch, 2014). As noted earlier, the incongruence between households’ values and intrinsic and extrinsic factors can limit their ability to adopt energy saving activities. This gap is especially relevant for low-income households, which generally have lower energy literacy than other income groups.⁶⁶

⁶⁶ <https://nefl.org/wp-content/uploads/2018/11/NEF-National-Energy-Literacy-Survey-White-Paper-181115.pdf>

Local governments are introducing programs that encourage behavior change at the consumer level. Several strategies have been adopted to engage residents and low-income households in energy-efficient behavior, chief among them being in-person engagement and education campaigns (Drehobl et al., 2018; Simms and Casentini, 2018; Craig, 2016). Most low-income adults are interested in learning about ways they can save on their electric or heating bills, and this is especially true among women and homeowners (Treadway, 2018). Further, awareness of utility energy-efficiency programs makes consumers more likely to participate in them (Craig, 2016). This finding was based on a large survey of 2,450 residential consumers, which enabled differences across income groups to be examined. The importance of program awareness as a predictor of program participation was found to be significant across all income groups, including households in the lowest cohort with incomes less than \$20,000. According to the opinion survey conducted by Treadway (2018), more than 80% of the respondents are interested in learning about ways to save on energy bills and low-income households are concerned about paying late fees and reconnection charges. Further, women, homeowners, and higher income households are more likely to be interested in these programs.

Some studies indicate there may also be high non-monetary costs associated with participation in a weatherization program that affect participation (Fowlie et al., 2015; Hirshfield and Iyer, 2012). Lack of knowledge about the features of different appliances and ineffective targeting can also lead to low uptake of these high-efficiency technologies among low-income households (O'Dwyer, 2013). Effective approaches to address different groups and sub-segments are going to be quite distinct (Treadway, 2018). Low-income program services and outreach messaging need to reflect the critical difference between sub-segments of vulnerable populations in the low-income market, including, for example, single mothers working two jobs, fixed-income senior citizens, and Native American populations returning to reservations (Treadway, 2018).

The limitations notwithstanding, local, municipal, and community level initiatives are likely to have greater success as they are closer to their target communities. Consistent with the findings on multifamily rental markets and rural customers, local engagement programs and partnering with local community-based organizations has significant gains and benefits (Hirshfield and Iyer, 2012; Simms and Casentini, 2018). This is also true in the case of household level usage of gas (Long et al., 2018). Niederberger (2018) suggests using “nudges” to encourage low-income energy consumers to buy energy-efficient products. These nudges would especially be effective in cases where the cost of more efficient products is comparable to their inefficient counterparts, because liquidity and budget constraints could otherwise prevent the purchase of more costly options. Further, designing a marketing model of local programs that take into account the role of behavioral changes by continued engagement, paying attention to customer experience, relying on strong stakeholder communication, and using interactions that allow for actionable information to be exchanged are all useful lessons for future program implementation (Keilty, 2018). Donovan, Bleything, and Enterline (2014) also note the potential for increasing energy efficiency by integrating technology that provides information on energy usage to low-income households. Advanced metering, in home displays, energy efficiency coaching, and providing usage information have all been successful strategies (Donovan et al., 2014).

5.4 DATA ANALYTICS

Finding: New publicly available data and tools on low-income energy consumption, are expanding. Nevertheless, more needs to be done to use these at a high spatial and temporal resolution to fine-tune program targeting and design.

New approaches have allowed for visibility into energy affordability and the socio-demographics of households. Data analytics and new digital tools such as the NREL Solar for All⁶⁷, and NREL ResStock⁶⁸ can help explain the relationship between energy affordability and socio-economic indicators to better understand the key factors that would drive changes in energy consumption. These techniques can be instrumental in estimating patterns of consumption and identifying areas where most of the savings can be made at the household levels (Hosgoer and Fischbeck, 2015; Long et al., 2018; Nahmens, Joukar, and Cantrell, 2015; Porse et al., 2016; Reina and Kontokosta, 2017; Wierzba et al., 2011; Zhang et al., 2018).

Jafary and Shephard (2018) use data from appliance usage to characterize consumption patterns of households across different building types. More high-quality data and techniques for analysis can also be useful in estimating the effect of the changing nature and composition of energy consumers. For example, Johnson et al (2017) use data from the PJM (a regional transmission organization) markets to estimate the effect of high solar PV adoption on cross-rate class subsidization and distribution of energy burden. Further, collecting and providing data can facilitate innovative approaches to analysis. It can help estimate the level and severity of the problem (Berry et al., 2018); it can be used to test the effectiveness of different low-income programs and project designs (Hoffman, 2017); to develop databases that predict deployment of new technology such as solar panels (Yu et al., 2018; Gupta et al., 2018b); further, data can be useful to draw more concrete results for utilities in order to target consumers who would gain from programs such as LIHEAP (O'Dwyer, 2017).

Understanding the impacts of low-income energy programs and policies can also be enhanced with data analytics. For example, the Greenlink Group has used mapping sciences to help visualize the relationship between household energy burdens at the county level and utility evictions in the State of Virginia (Figure 5.1).

Integrating new technology for collecting, generating and analyzing data can contribute to improved data analytics (Donovan et al., 2014; O'Dwyer, 2017). Machine learning techniques (Zhang et al., 2018) and agent-based modeling (Zhang et al., 2016) are promising approaches. With high-resolution data, investments in demand-side management can be designed to potentially displace the more expensive options of generation and grid investments (Reames, 2016; Khan and Duffy, 2018). All income groups would benefit from a shift from supply- to demand-side energy utility company investments enabled by data analytics. However, in many regions, such data are not available. The first step in making better data analytics possible will therefore be collecting, analyzing, and visualizing more spatially and temporally high-resolution data to better inform low-income energy programs (Reames, 2016).

⁶⁷ <https://maps.nrel.gov/solar-for-all/?aL=6m-d90%255Bv%255D%3Dt&bL=clight&cE=0&IR=0&mC=38.870832155646326%2C-98.34521484375001&tour=splash&zL=5>

⁶⁸ <https://www.osti.gov/biblio/1436972>

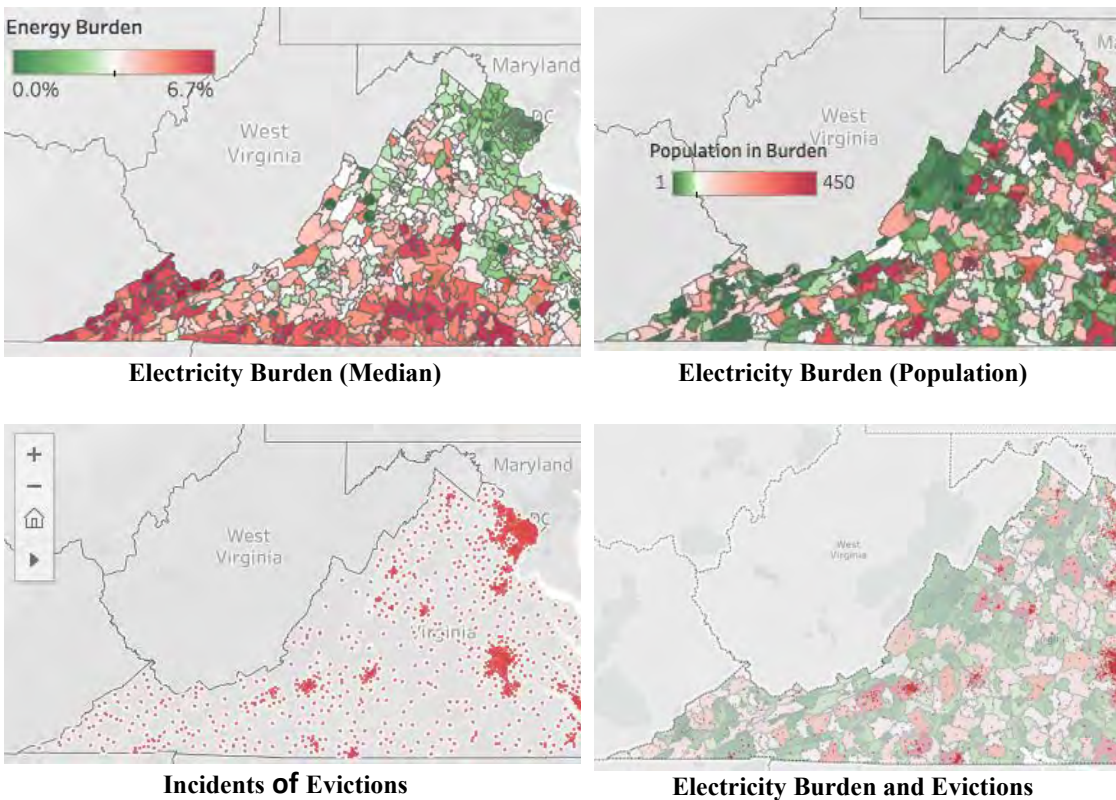


Figure 5.1 Data analytics of energy burden and evictions across zip codes in Virginia⁶⁹

5.5 ADVANCED INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

Finding: Information and communication technologies including smart thermostats and information feedback support low-cost behavioral approaches to improving energy efficiency, but they tend not to be incorporated into low-income energy programs.

Digital, market-based programs are being used to educate, incentivize, and “nudge” consumers to purchase energy-efficient products (Niederberger, 2018). Adopting behavioral strategies supported by technology and data to target online marketing for greatest impact can scale participation and improve the cost-effectiveness of residential programs to reduce energy burdens. Digital platforms and smart meter data are being deployed to reach households with high energy burdens (Sovacool et al., 2017). Energy burdens could be reduced if low-income tenants had a more expansive knowledge of how best to conserve energy, and ICT can help achieve this greater energy literacy. However, low-income households often lack Internet access – a “digital divide” exists. At best, they are unable to use such platforms or at worst, could be harmed by such business models.

When low-income respondents were asked how they would like to receive daily account information from their local utility, e-mailing was the dominant response, representing 45% of the households. Text messaging was viewed as the preferred information mechanism by 15%,

⁶⁹ <https://www.thegreenlinkgroup.com/energy-equity>

and the use of a mobile app by 12% of respondents (Table 5.1). Consistent with the digital divide, elderly and lower-income households are less likely to prefer the use of mobile apps (Treadway, 2018).

Table 5.1. Favorite way to receive daily account information from local electric utility
(Source of data: Treadway, 2018)

	Age			Household Income	
	Total	18-54	55+	< \$25K	\$25K to \$49
Total Respondents with HH Income Less than \$50,000	(534)	(364)	(170)	(232)	(302)
	%	%	%	%	%
Email	45	42	53*	41	48*
Text message	15	16	12	19*	12
Mobile app notification	12	15*	4	8	15*
More than one channel (phone, text message, email or app)	10	11	10	10	11
Recorded phone call	4	4	5	6*	3
Don't know/no opinion	13	12	17	16	12

Q. B18: If you elected to receive daily account from your local electric utility, how would you receive it? Please choose your top choice. *Indicates figure is significantly higher than other sub-group at a 95% confidence level. The Russell Omnibus was conducted via the Internet among 1,092 adults 18 years of age or older from October 21-24, 2016.

One way for households to easily access and recognize their energy consumption is through the use of smart meters and smart thermostats. Smart meters enable a wireless two-way communication with the utility company (Brown, Zhou, and Ahmadi, 2018). These smart meters allow the utility companies to track peak demand times and usage. Nest thermostats are WiFi enabled and can be controlled by computers and cell phones. They display the current energy consumption of the home and have sensors for temperature, humidity, and motion. The Nest thermostat learns the user's behavior, guarantees that no energy is wasted if no one is home, and helps manage usage during peak and off-peak times to help low-income households lower their total energy bill. Nest thermostats can be expensive at \$250 before installation, deterring many low-income households from purchasing the device. Georgia Power currently offers a \$100 rebate on Nest thermostats, but for low-income households, \$150 is still a large sum of their monthly income. Therefore, implementing a monthly payment plan, on top of the rebates as an incentive program, is more feasible for these families. A Nest thermostat, on average, saves a household \$140 per year, hence the price per month that they will pay for the Nest thermostat would be equivalent to the monthly savings made through their electric bill.⁷⁰

“Peer-to-peer electricity” sharing could create a more affordable marketplace for electricity. In this marketplace, the people who can afford power generating sources such as solar panels can

⁷⁰ Nest Thermostat Real Savings. (n.d.). Retrieved April 22, 2018, from <https://nest.com/thermostats/real-savings/>

sell electricity to people who are unable to afford generating sources or who might have access to electricity but require more electricity at certain times (Inam et al., 2015). While this concept appears to not be operational in the U.S., it is beginning to enter markets in the Netherlands and Australia.⁷¹

5.6 GRID RESILIENCY

Electric and natural gas service disruptions due to extreme weather events and other hazards have brought increasing attention to, and study of, the resiliency benefits of energy system resources. In that vein, study of low-income energy efficiency and renewable programs, community-level microgrid infrastructure projects, and programs that may facilitate these local energy programs is an emerging area of study. While the definition of how-to value “resiliency” varies depending on program perspective and evaluation context, generally speaking, resiliency concepts refer to the flexibility of energy system resource(s), and the ability to “bounce back” and recover from system disruptions (natural and otherwise), as well as to adapt and improve over time.

Ribeiro et al. (2015) suggest that value and risks relating to resilience can be understood in terms of hazards, vulnerability, and capacity to cope.

Risk = Hazards x Vulnerability

Capacity to cope

Green Mountain Power has initiated a bold experiment to turn a low-income community into a virtual power plant. It is currently implementing the first community rooftop solar arrays for local low-income households in conjunction with battery storage that are helping customers move off the central grid for several hours every day.⁷²

As utilities become more targeted in deploying energy efficiency to strengthen grid reliability by considering the time-varying and locational value of demand management, there is an opportunity to address challenges of economically distressed communities at the same time. This was achieved in a “non-wires alternatives” pilot program located in an economically depressed area, offering a learning experience for program design and implementation under such circumstances. Energy analytics played an important role in assessing the demand side management potential in the target area and to drive targeted and personalized customer interactions during implementation (Khan and Duffy, 2018).

⁷¹ <https://vandebron.nl/about>; <https://arena.gov.au/assets/2017/10/Final-Report-MHC-AGL-IBM-P2P-DLT.pdf>

⁷² New York Times, Utility helps wean Vermonters from the electric grid,
<https://www.nytimes.com/2017/07/29/business/energy-environment/vermont-green-mountain-power-grid.html>

6. CONCLUSIONS

In the midst of a rapidly transforming energy system, this paper reviews the literature to assess how low-income energy burdens are changing, what policies and programs are impacting them, and what opportunities hold promise for progress in the future. Our literature review uses an energy equity lens to focus on procedural, distributional, and intergenerational issues related to low-income energy burdens.

Our literature review is complicated by several methodological challenges:

- Variable and inconsistent definitions and metrics are used to describe the energy consumption patterns of low-income households.
- The extent and nature of energy burden, and the estimated impact and value of solutions, depend upon the metrics used.
- There is limited publicly available data on low-income energy consumption, particularly at high spatial and temporal resolution, which constrains the ability of data analytics to fine-tune program targeting and design by federal, state, and local agencies, communities and NGOs, and utility companies.

The last decade has produced a large and expanding literature on low-income energy burden. Several broad conclusions are derived from that literature, which have equity implications.

- Energy burden is higher among low-income households than other income groups.
- The average energy burden of low-income households is not declining, and it continues to be high in particular geographies and socio-economic groups.
- Many policies and programs that promote energy efficiency and renewable energy technologies (e.g., rooftop solar PV and home battery systems) are largely inaccessible to low-income households, although several states have recently launched major low-income solar programs.
- The share of utility residential energy-efficiency funding that supports low-income households is lower than the percent of residential utility customers who are low-income.

The literature also documents a number of new approaches to the design and implementation of low-income energy programs and policies that appear to offer opportunities to amplify their success.

6.1 IMPROVING ENERGY EQUITY THROUGH PROGRAM DESIGN AND IMPLEMENTATION

A majority of low-income energy program funding focuses on short-term fixes to energy insecurity and not long-term solutions to reduce energy burden.

- Funding for temporary assistance (e.g., for bill payments) dwarfs funding for more enduring assistance (e.g., weatherization), though both serve a critical need and benefit from being linked.
- Funding for low-income energy programs peaked as a result of ARRA; it has returned to levels above the pre-ARRA funding, reflecting modest increases in weatherization funding and more substantial increases in low-income solar programs.

A number of submarkets and socio-demographic groups tend to be underserved by current low-income energy programs. Programs like WAP serve both to reduce energy burden and to improve the low-income housing stock across the country by making it more energy-efficient, comfortable, and healthier. Because many low-income energy programs serve homeowners, they also mainly serve white households (a distributive justice concern). Eliminating barriers to serving rental properties could drastically reduce energy burden and insecurity for households of color while reducing health and other racial disparities. This would benefit from additional research on the nature and role of landlords and property owners, which was found to be a notable gap in our review of stakeholders covered in the literature.

- The multifamily low-income market has been difficult to reach with traditional energy-efficiency programs due partly to misalignment of incentives.
- The opportunity to address the high energy burden of low-income households occupying manufactured and mobile homes has received limited analysis and policy focus.
- Low-income households in rural communities often spend as much as a quarter of their income on energy due partly to their low-density geography; assistance from local community programs and organizations are particularly critical to success in these markets.

Several promising technology approaches are not generally well integrated into low-income energy programs.

- Rooftop and community solar systems are now cost effective in many states as the result of declining costs and their involvement in low-income energy programs is beginning to take hold in some states.
- Health and safety upgrades are not components of most utility low-income energy-efficiency programs, and they are not fully integrated into the cost-benefit calculations of the WAP or state low-income energy programs.
- Information and communication technologies including smart thermostats and information feedback support low-cost behavioral approaches to improving energy efficiency; while they tend not to be incorporated into low-income energy programs, their presence in these programs is increasing.
- Electric vehicles and other approaches to affordable transportation have played limited roles in federal, state, local, and utility low-income energy programs to date.

Policies can be designed to address these gaps.

- States are using minimum requirements and adders to cost-effectiveness tests to promote greater investment in low-income energy programs.
- New program designs can align incentives more effectively for building owners and tenants.
- Strong community engagement and effective building owner and property manager partnerships can help reach multifamily markets.
- Active community involvement can expand participation rates and enhance the success of low-income energy programs.

6.2 SCALING IMPACTS WITH LEVERAGING, PARTNERSHIPS, AND PROGRAM INTEGRATION

Scalable approaches to reduce low-income energy burden require linking programs and policies to tackle the complex web of causes and impacts that households face, who have limited resources to pay energy bills. Two distinct opportunities exist: inter-agency cooperation and integrated technology-policy approaches.

Inter-agency partnerships offer greater resources and leverage, particularly if they span multiple scales (national, regional, state, and community) and multiple agencies with missions that touch on low-income energy burden. Evidence of the potential payback to engagement of non-energy agencies is provided by the significant non-energy benefits that are created by low-income energy programs.

- At least four parallel federal programs have missions related to low-income energy burdens, with varying levels of inter-agency coordination at the federal, state, and local levels.
- The savings-to-investment ratio of WAP is favorable based on the value of its energy savings alone.
- Without monetizing non-energy benefits, low-income energy-efficiency programs operated by electric and gas utilities cost more to implement per household and are less cost-effective than utility-operated energy-efficiency programs serving higher income groups. Low-income energy programs ensure low-income households can benefit from ratepayer funding that they help pay for but would otherwise not benefit from.
- The value of the non-energy benefits of WAP and other low-income energy programs are significant.

Integrated technology-policy approaches offer opportunities to leverage a broader array of rapidly advancing technologies (advanced efficiency, solar PV, storage assets, smart meters, and more). Expanding implementation of these technologies can be achieved with novel and integrated approaches to inclusive financing, philanthropic partnerships, energy assistance, and payment arrangements. More holistic approaches can maximize benefits and minimize costs.

- Expanding the technology scope of low-income energy-efficiency programs to include solar PV, smart meters, storage, and electric vehicles could significantly improve energy affordability for low-income households.
- Broadening finance and administrative options (e.g., on-bill tariff designs) can maximize benefits and minimize costs, if designed effectively.
- Public-private-philanthropic-partnerships and interagency coordination and leveraging can reduce energy costs for low-income households while also delivering non-energy benefits.

Both funding and execution will require finely meshed and interwoven delivery systems that engage all the stakeholders shown in Figure 1.1. A coordinated approach to home energy, health, safety, and housing that integrates programs across geographies could reduce low-income energy burden while delivering numerous other benefits to both current and future generations. As the U.S. transitions to a new energy economy, these solutions offer low-income households the opportunity to meet their energy service requirements more affordably.

7. REFERENCES

- Allcott, Hunt, and Dmitry Taubinsky. (2015). Evaluating Behaviorally Motivated Policy: Experimental Evidence from the Lightbulb Market. *American Economic Review*, 105 (8): 2501-38. <https://pubs.acaweb.org/doi/pdfplus/10.1257/aer.20131564>.
- Allcott, H., and T. Rogers. (2014). The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. *American Economic Review*, 104(10), 3003-37. <https://www.acaweb.org/articles?id=10.1257/aer.104.10.3003>.
- Andrews, Adrian, and Sarah Poe. (2018). Reaching the Underserved: A Collaborative Approach to Serving Income Qualified Customers. *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p388>.
- Aznar, A.Y., and D.A. Gagne. (2018). Low-Income Community Solar: Utility Return Considerations for Electric Cooperatives (No. NREL/TP-7A40-70536). National Renewable Energy Laboratory (NREL), Golden, CO. <https://www.nrel.gov/docs/fy18osti/70536.pdf>.
- Barbier, E. B. (2014). "Climate change mitigation policies and poverty." *Wiley Interdisciplinary Reviews Climate Change* 5(4): 483-491. <http://wires.wiley.com/WileyCDA/WileyArticle/wisId-WCC281.html>.
- Batterman, S., L. Du, G. Mentz, B. Mukherjee, E. Parker, C. Godwin, J.Y. Chin, A. O'Toole, R. Robins, Z. Rowe, T. and T. Lewis. (2012). "Particulate matter concentrations in residences: an intervention study evaluating stand-alone filters and air conditioners." *Indoor Air*, 22(3), pp.235-252. <https://www.ncbi.nlm.nih.gov/pubmed/22145709>.
- Bednar, D.J., T.G. Reames, and G.A. Keoleian. (2017). The intersection of energy and justice: Modeling the spatial, racial/ethnic and socioeconomic patterns of urban residential heating consumption and efficiency in Detroit, Michigan. *Energy and Buildings*, 143: 25-34. <https://doi.org/10.1016/j.enbuild.2017.03.028>.
- Begay, S. K. (2018a). How Citizen Potawatomi Nation utilizes energy efficiency and renewable energy to address its high energy burden. *The Electricity Journal*. Vol. 31(6), 16-22. <https://doi.org/10.1016/j.tej.2018.07.005>.
- Begay, S. K. (2018b). Navajo residential solar energy access as a global model. *The Electricity Journal*. Vol.31(6), 9-15. <https://doi.org/10.1016/j.tej.2018.07.003>.
- Bell, C. J., S. Nadel, and S. Hayes. (2011). "On-Bill Financing for Energy Efficiency Improvements: A Review of Current Program Challenges, Opportunities, and Best Practices." ACEEE Research Report E118. <https://aceee.org/research-report/e118>.
- Berg, Weston, and Ariel Dreobl. (2018). "State-level Strategies for Tackling the Energy Burden: A Review of Policies Extending State- and Ratepayer-funded Energy Efficiency to Low-income Households." *2018 ACEEE Summer Study on Energy Efficiency in Buildings*:

Making Efficiency Easy and Enticing.

<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p390>.

Berg, Weston, Seth Nowak, Grace Relf, Shruti Vaidyanathan, Eric Junga, Marianne DiMascio, and Emma Cooper. (2018). "The 2018 State Energy Efficiency Scorecard." ACEEE Research Report U1808. <https://aceee.org/research-report/u1808>.

Berkland, Stephanie., T.A. Pande, and T.M. Moezzi. (2018). "Putting People Back into the Equation: Impacts of Cultural and Demographic Factors on Multifamily Energy Use Patterns." 2018 ACEEE Summer Study on Energy Efficiency in Buildings. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p392>.

Berry, Chip, Carolyn Hronis, and Maggie Woodward. (2018). "Who's Energy Insecure? You Might be Surprised." 2018 ACEEE Summer Study on Energy Efficiency in Buildings: *Making Efficiency Easy and Enticing.* <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p393>.

Bird, Stephen, and Diana Hernandez. (2012). "Policy options for the split incentive: Increasing energy efficiency for low-income renters." *Energy Policy* 48: 506-514. <https://doi.org/10.1016/j.enpol.2012.05.053>.

Bollinger, B., K. Gillingham, and T. Tsvetanov. (2016). The Effect of Group Pricing and Deal Duration on Word-of-Mouth and Durable Good Adoption: The Case of Solarize CT. Working paper. http://environment.yale.edu/gillingham/BollingerGillinghamTsvetanov_SalesDurationGroupBuys.pdf.

Booth, S. (2014). "Here Comes the Sun: How Securities Regulations Cast a Shadow on the Growth of Community Solar in the United States." *UCLA Law Review* 61(3): 760-811. <https://www.uclalawreview.org/pdf/61-3-4.pdf>.

Borenstein, S., and L. W. Davis. (2012). "The Equity and Efficiency of Two-Part Tariffs in US Natural Gas Markets." *Journal of Law & Economics* 55(1): 75-128. <https://doi.org/10.1086/661958>.

Bradshaw, J. L., Elie Bou-Zeid, and Robert H. Harris. (2016). "Greenhouse gas mitigation benefits and cost-effectiveness of weatherization treatments for low-income, American, urban housing stocks." *Energy and Buildings* 128: 911-920. <https://doi.org/10.1016/j.enbuild.2016.07.020>.

Bradshaw, J.L., E. Bou-Zeid, and R.H. Harris. (2014). Comparing the effectiveness of weatherization treatments for low-income, American, urban housing stocks in different climates. *Energy and Buildings*, 69, 535-543. <https://doi.org/10.1016/j.enbuild.2013.11.035>.

Breyse, J., D.E. Jacobs, W. Weber, S. Dixon, C. Kawecki, Aceti, S., and J. Lopez. (2011). Health outcomes and green renovation of affordable housing. *Public Health Reports*, 126(1_suppl), 64-75. <https://www.ncbi.nlm.nih.gov/pubmed/21563714>.

- Brown, M. A. (2001). Market failures and barriers as a basis for clean energy policies. *Energy policy*, 29(14): 1197-1207. [https://doi.org/10.1016/S0301-4215\(01\)00067-2](https://doi.org/10.1016/S0301-4215(01)00067-2).
- Brown, M. A. and B. K. Sovacool. (2018). “Theorizing the Behavioral Dimension of Energy Consumption: Energy Efficiency and the Value-Action Gap”, in *Oxford Handbook of Energy and Society*, Oxford University Press (eds D. J. Davidson and M. Gross), pp. 201-221. <https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780190633851.001.0001/oxfordhb-9780190633851-e-9>.
- Brown, M. A., S. Zhou, and M. Ahmadi. (2018). Smart grid governance: An international review of evolving policy issues and innovations. *Wiley Interdisciplinary Reviews: Energy and Environment*, <https://onlinelibrary.wiley.com/doi/full/10.1002/wene.290>.
- Brown, Marilyn A., and Yu Wang. (2015). *Green Savings: How Policies and Market Drive Energy Efficiency* (Praeger Press). <https://www.abc-clio.com/Praeger/product.aspx?pc=A4272C>.
- Cabeza, L.F., D. Urge-Vorsatz, M.A. McNeil, C. Barreneche, and S. Serrano. (2014). Investigating greenhouse challenge from growing trends of electricity consumption through home appliances in buildings. *Renewable and Sustainable Energy Reviews*, 36: 188-193. <https://doi.org/10.1016/j.rser.2014.04.053>.
- Carley, S., T.P. Evans, M. Graff, and D.M. Konisky. (2018). A framework for evaluating geographic disparities in energy transition vulnerability. *Nature Energy*, 3:621-627. <https://doi.org/10.1038/s41560-018-0142-z>.
- Camprubí, L., D. Malmusi, R. Mehdipanah, L. Palència, A. Molnar, C. Muntaner, and C. Borrell. (2016). Façade insulation retrofitting policy implementation process and its effects on health equity determinants: A realist review. *Energy Policy* 91: 304-314. <https://doi.org/10.1016/j.enpol.2016.01.016>.
- Carroll, David, Chisoo Kim, and Colleen Driscoll. (2014). National Weatherization Assistance Program Evaluation: Eligible Population Report, Oak Ridge National Lab, https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_312.pdf.
- Chan, Coreina, Kendall Ernst, and James Newcomb. (2017). “Breaking Ground New Models that Deliver Energy Solutions to Low-Income Customers.” e-Lab. https://rmi.org/wp-content/uploads/2017/04/eLabLeap_Breaking-Ground-report-2016.pdf.
- Chant, Elizabeth and Frances Huessy. (2018). “Justice For All: Measures of Equity for Low-Income Programs” *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p394>.
- Chant, E., R. Schaaf, and T. Ast. (2016). “[Swiftly and Massively: Moving 115,000 Units of Multifamily Affordable Housing to Higher Efficiency](#).” *2016 ACEEE Summer Study on*

Energy Efficiency in Buildings From Components to Systems, From Buildings to Communities. https://aceee.org/files/proceedings/2016/data/papers/2_203.pdf.

- Chen, S. (2012). “Prepaid Energy and Low Income Assistance Programs” (Prepay Energy Working Group paper) Washington, DC: Distributed Energy Financial Group LLC <http://defgllc.com/publication/prepaid-energy-and-low-income-assistance-programs/>.
- Chen, C.F., X. Xu, and J.K. Day. (2017). Thermal comfort or money saving? Exploring intentions to conserve energy among low-income households in the United States. *Energy Research & Social Science*, 26, 61-71. <https://www.sciencedirect.com/science/article/pii/S2214629617300099>.
- Chetty, R. (2015). Behavioral economics and public policy: A pragmatic perspective. *American Economic Review* 105(5): 1-33. <https://www.aeaweb.org/articles?id=10.1257/aer.p20151108>.
- Clean Energy Advisory Council (CEAC). (2017). Report on Alternative Approaches to Providing Low and Moderate Income (LMI) Clean Energy Services. *LMI Clean Energy Initiatives Working Group*. <file:///C:/Users/f67/Downloads/%7BB56F124C-0EB9-417B-9886-74F640EC36A9%7D.pdf>.
- Cluett, Rachel, Jennifer Amann, and Sodavy Ou. (2016). “Building better energy efficiency programs for low-income households.” American Council for an Energy-Efficient Economy, Report Number A1601. <https://www.aceee.org/research-report/a1601>.
- Colton, R.D. (2011). “Home Energy Affordability in New York: The Affordability Gap (2008 – 2010).” Prepared for New York State Energy Research Development Authority (NYSERDA) Albany, New York. <http://www.nyserda.ny.gov/-/media/Files/EDPPP/LIFE/Resources/2008-2010-affordability-gap.pdf>.
- Cook, Jeffrey J., and Lori Bird. (2018). “Unlocking Solar for Low- and Moderate-Income Residents: A Matrix of Financing Options by Resident, Provider, and Housing Type.” NREL/TP-6A20-70477. National Renewable Energy Laboratory (NREL). <https://www.osti.gov/biblio/1416133>.
- Cook, J., and M. Shah. (2018a). Reducing Energy Burden with Solar: Colorado’s Strategy and Roadmap for States. National Renewable Energy Laboratory. NREL/TP-6A20-70965. <https://www.osti.gov/biblio/1431421>.
- Cook, J.J., and M.R. Shah. (2018b). Focusing the Sun: State Considerations for Designing Community Solar Policy (No. NREL/TP-6A20-70663). National Renewable Energy Laboratory (NREL), Golden, CO. <https://www.nrel.gov/docs/fy18osti/70663.pdf>.
- Cook, Ryan. (2014). Solarize America: how policy networks adopt and adapt good ideas. *DSpace@MIT*. <https://dspace.mit.edu/handle/1721.1/90198>.
- Coombs, K., D. Taft, D.V. Ward, B.J. Green, G.L. Chew, B. Shamsaei, J. Meller, R. Indugula, and T. Reponen. (2018). Variability of indoor fungal microbiome of green and non-green

- low-income homes in Cincinnati, Ohio. *Science of The Total Environment* 610: 212-218.
<https://www.ncbi.nlm.nih.gov/pubmed/28803198>.
- Corso, A., M. Garascia, and R. Scheu. (2017). Segmenting Chicago Multifamily Housing To Improve Energy Efficiency Programs. *Elevate Energy, Chicago, Illinois*.
<http://www.elevateenergy.org/wp/wp-content/uploads/Chicago-Multifamily-Segmentation.pdf>.
- Coughlin, G., J. Irvine, and P. Johnson. (2013). Guide to Community Solar: Utility, Private, and Non-profit Project Development. *Transmission and Distribution World*.
<https://www.tdworld.com/generation-renewables/guide-community-solar-utility-private-and-non-profit-project-development>.
- Craig, C. A. (2016). "Energy consumption, energy efficiency, and consumer perceptions: A case study for the Southeast United States." *Applied Energy* 165: 660-669.
<https://www.sciencedirect.com/science/article/abs/pii/S0306261915016426>.
- Curti, Julie, Farrah Andersen, and Kathryn Wright. (2018). "A Guidebook on Equitable Clean Energy Program Design for Local Governments and Partners." The Cadmus Group.
<https://cadmusgroup.com/papers-reports/a-guidebook-on-equitable-clean-energy-program-design-for-local-governments-and-partners/>.
- De Silva, D.G., R.P. McComb, and A.R. Schiller. (2016). "What blows in with the wind?" *Southern Economic Journal*, 82(3): 826-858. <https://doi.org/10.1002/soej.12110>.
- Doll, S.C., E.L. Davison, and B.R. Painting. (2016). "Weatherization impacts and baseline indoor environmental quality in low income single-family homes." *Building and Environment*, 107: 181-190. <https://doi.org/10.1016/j.buildenv.2016.06.021>.
- Donovan, C., S. Bleything, and S. Enterline. (2014). "Increasing Energy Efficiency in Buildings through Smart-Grid Enabled Residential Programs." *2014 ACEEE Summer Study on Energy Efficiency in Buildings The Next Generation: Reaching for High Energy Savings*.
<https://aceee.org/files/proceedings/2014/data/papers/2-221.pdf#page=1>.
- Donovan, Christine, Adam Sherman, Jennifer Wallace-Brodeur, Kristen Scobie, Neil and Louise Tillotson, and Barbara Wyckoff. (2018). "Empowering Those with High Energy Burdens - While Increasing Local Wealth in the North Country." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p395>.
- Drehobl, A., M. Chikumbo, and K. Tanabe. (2018). "Reducing Energy Waste through Municipally Led Behavior Change Programs." ACEEE Research Report U1810.
<https://aceee.org/research-report/u1810>.
- Drehobl, Ariel, and Fernando Castro-Alvarez. (2017). Low-Income Energy Efficiency Programs: A Baseline Assessment of Programs Serving the 51 Largest Cities. American Council for an Energy-Efficient Economy (ACEEE). <https://aceee.org/white-paper/low-income-ee-baseline>.

- Drehobl, Ariel and Lauren Ross. (2016). "Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low Income and Underserved Communities." American Council for an Energy-Efficient Economy (ACEEE). <https://aceee.org/research-report/u1602>.
- Dryden, A., J. Tisinger, A.K. Lamb, and M. Kent. (2018). Bringing Together Climate Equity, Health and Energy Efficiency for Low Income Communities. *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p396>.
- Eisenberg, Joel. (2014). Weatherization Assistance Program Technical Memorandum Background Data and Statistics on Low-Income Energy Use and Burdens. ORNL/TM-2014/133. Oak Ridge National Laboratory, Oak Ridge, TN. <https://info.ornl.gov/sites/publications/Files/Pub49042.pdf>.
- Elnakat, A., J.D. Gomez, and N. Booth. (2016). A zip code study of socioeconomic, demographic, and household gendered influence on the residential energy sector. *Energy Reports* 2: 21-27. <https://doi.org/10.1016/j.egyr.2016.01.003>.
- Elsawaf, N., T Abdel-Salam, and H Abaza. (2013). "Economic evaluation and calculations of energy savings by upgrading the heating systems in pre manufactured homes." *Energy and Buildings*. 59: 187-193. <https://doi.org/10.1016/j.enbuild.2012.12.036>.
- Evens, A. (2015). "The utility of the future and low-income households." *The Electricity Journal*, 28(10): 43-52. <https://www.sciencedirect.com/science/article/pii/S104061901500247X>.
- Fabian, M.P., G. Adamkiewicz, N.K. Stout, M. Sandel, J.I. Levy. (2014). "A simulation model of building intervention impacts on indoor environmental quality, pediatric asthma, and costs." *Journal of Allergy and Clinical Immunology* 133(1): 77-84. [10.1016/j.jaci.2013.06.003](https://doi.org/10.1016/j.jaci.2013.06.003).
- Fabian, P., G. Adamkiewicz, and J.I. Levy. (2012). "Simulating indoor concentrations of NO₂ and PM_{2.5} in multifamily housing for use in health-based intervention modeling." *Indoor Air*, 22(1): 12-23. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3248980/>.
- Fisher, Sheehan and Colton. (2013). "Home Energy Affordability Gap." *Public Finance and General Economics*. <http://homeenergyaffordabilitygap.com/>.
- Fowlie, M., M. Greenstone, and C. Wolfram. (2015). "Are the non-monetary costs of energy efficiency investments large? Understanding low take-up of a free energy efficiency program." *American Economic Review* 105(5): 201-04. <https://doi.org/10.1257/aer.p20151011>.
- Fox, Abby. (2016). "Utility-Administered Low-Income Programs in the Southeast." Southeast Energy Efficiency Alliance (SEEA). <https://www.seealliance.org/wp-content/uploads/Low-Income-Landscape-Assessment-FINAL.pdf>.

- Franklin, R., and T. Osborne. (2017). "Toward an urban political ecology of energy justice: the case of rooftop solar in Tucson, AZ." *Journal of Political Ecology* 24: 1055-1076. <https://journals.uair.arizona.edu/index.php/JPE/article/view/22003>.
- Frey, S.E., H. Destailats, S. Cohn, S. Ahrentzen, and M.P. Fraser. (2015). The effects of an energy efficiency retrofit on indoor air quality. *Indoor air* 25(2): 210-219. <https://www.ncbi.nlm.nih.gov/pubmed/24920242>.
- Funkhouser, E., Griselda Blackburn, Clare Magee, and Varun Rai. (2015). "Business model innovations for deploying distributed generation: The emerging landscape of community solar in the U.S." *Energy Research & Social Science* 10: 90-101. <https://www.sciencedirect.com/science/article/pii/S2214629615300104>.
- Gilleo, A, S. Nowak, and A. Dreihobl. (2017). Making a Difference: Strategies for Successful Low-Income Energy Efficiency Programs, ACEEE. <https://aceee.org/research-report/ul713>.
- Gillingham, K., and B. Bollinger, B. (2017). Solarize your community: An evidence-based guide for accelerating the adoption of residential solar. Yale Center for Business and the Environment. <https://cbey.yale.edu/research/solarize-your-community-an-evidence-based-guide-for-accelerating-the-adoption-of>.
- Gillingham, K., R. Newell, and K. Palmer. (2009). Energy Efficiency Economics and Policy. *Resources for the Future*. <https://media.rff.org/documents/RFF-DP-09-13.pdf>.
- Goldberg, Laura, and Anne McKibbin. (2018). "Breakthroughs in Equity and Energy in Illinois." 2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing." <https://aceee.org/files/proceedings/2018/index.html#paper/event-data/p406>.
- Graziano, M., and K. Gillingham. (2014). Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. *Journal of Economic Geography*, 15(4), 815-839. <https://doi.org/10.1093/jeg/ibu036>.
- Grevatt, Jim, Elizabeth Marx, Sara Ralich, and Levana Layendecker. (2018). "Small Steps in Coordination Equal Leaps and Bounds for Pennsylvania's Underserved Families: Driving Policy Improvements through Collaborative Advocacy." 2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing. <https://aceee.org/files/proceedings/2018/index.html#paper/event-data/p399>.
- Gupta, A., S. Swarup, A. Marathe, A. Vullikanti, K. Lakkaraju, and J. Letchford. (2018a). Designing Incentives to Maximize the Adoption of Rooftop Solar Technology. In Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems (pp. 1950-1952). *International Foundation for Autonomous Agents and Multiagent Systems*. <http://ifaamas.org/Proceedings/aamas2018/pdfs/p1950.pdf>.
- Gupta, A., Z. Hu, A. Marathe, S. Swarup, and A. Vullikanti, A. (2018b). Predictors of Rooftop Solar Adoption in Rural Virginia. *The Computational Social Science Conference*. Santa Fe NM, USA. http://people.virginia.edu/~ss7rs/papers/gupta_etal_css2018.pdf.

- Healy, N., and J. Barry. (2017). "Politicizing energy justice and energy system transitions: Fossil fuel divestment and a "just transition." *Energy Policy* 108: 451-459.
<https://www.sciencedirect.com/science/article/abs/pii/S0301421517303683>.
- Heeter, J.S., L.A. Bird, E.J. OShaughnessy, and S. Koebrich. (2018). Design and Implementation of Community Solar Programs for Low-and Moderate-Income Customers (No. NREL/TP-6A20-71652). National Renewable Energy Laboratory (NREL), Golden, CO.
<https://www.nrel.gov/docs/fy19osti/71652.pdf>.
- Henderson, Philip. (2015). "Program Design Guide: Energy Efficiency Programs in Multifamily Affordable Housing." Joint effort of Natural Resources Defense Council, National Housing Trust, Energy Foundation, and Elevate Energy.
<https://www.energyefficiencyforall.org/resources/program-design-guide-energy-efficiency-programs-multifamily-affordable-housing/>.
- Hernandez, D., and S. Bird. (2010). Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy. *Poverty & Public Policy* 2(4): 5-25.
<http://doi.org/10.2202/1944-2858.1095>.
- Hernández, D., Y. Aratani, and Y. Jiang. (2014). Energy insecurity among families with children. National Center for Children in Poverty.
http://www.nccp.org/publications/pdf/text_1086.pdf.
- Hernández D., Y. Jiang, D. Carrión, D. Phillips D, and Y. Aratani. (2016). "Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States." *Journal of children & poverty* 22(2):77-92.
<https://doi.org/10.1080/10796126.2016.1148672>.
- Hernandez, D., and D. Phillips. (2015). "Benefit or burden? Perceptions of energy efficiency efforts among low-income housing residents in New York City." *Energy Research & Social Science* 8: 52-59.
<https://www.sciencedirect.com/science/article/pii/S2214629615000535>.
- Hirshfield, Shayna, and P.J. Iyer. (2012). "[The Community Energy Champions Grant: Building Local Organizational Capacity to Catalyze Community Energy Behavior Change](https://www.aceee.org/files/proceedings/2012/data/papers/0193-000205.pdf)." 2012 ACEEE Summer Study on Energy Efficiency in Buildings Fueling Our Future with Efficiency. <https://aceee.org/files/proceedings/2012/data/papers/0193-000205.pdf>.
- Hoffman, Ian M. (2017). "Gauging the Impact of Various Definitions of Low- and Moderate-Income Communities on Possible Electricity Savings From Weatherization." Lawrence Berkeley National Laboratory (LBNL) Technical Brief.
<https://emp.lbl.gov/sites/default/files/lbnl-1007114.pdf>.
- Hoffman, Ian, Charles A. Goldman, Sean Murphy, Natalie Mims, Greg Leventis, and Lisa Schwartz. (2018). "The Cost of Saving Electricity Through Energy Efficiency Programs Funded by Utility Customers: 2009–2015." Lawrence Berkeley National Laboratory (LBNL). <http://www.swenergy.org/Data/Sites/1/medFclueia/lbnl-cse-report-june-2018.pdf>.

- Hosgoer, E., and P. S. Fischbeck (2015). “Virtual home energy auditing at scale: Predicting residential energy efficiency using publicly available data.” *Energy and Buildings* 92: 67-80. <https://doi.org/10.1016/j.enbuild.2015.01.037>.
- Hummel, H., and H. Lachman. (2018). “What is inclusive financing for energy efficiency, and why are some of the largest states in the country calling for it now?” *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
- Inam W., D. Strawser, K.K. Afridi, R.J. Ram, and D.J. Perreault. (2015). “Architecture and system analysis of microgrids with peer-to-peer electricity sharing to create a marketplace which enables energy access.” In proceedings *9th International Conference on Power Electronics and ECCE Asia (ICPE 2015-ECCE Asia)* (pp. 464-469).
https://www.researchgate.net/publication/308671416_Architecture_and_System_Analysis_of_Microgrids_with_Peer-to-Peer_Electricity_Sharing_to_Create_a_Marketplace_which_Enables_Energy_Access.
- Inskeep D., K. Daniel, and A. Proudlove. (2015). “Solar on Multi-unit buildings.” NC Clean Energy Technology Center.
- Interstate Renewable Energy Council (IREC). (2018). “Expanding Solar Access: Pathways for Multifamily Housing.” <https://irecusa.org/expanding-solar-access-pathways-for-multifamily-housing/>.
- Interstate Renewable Energy Council (IREC). (2016). Shared Renewable Energy for Low-to Moderate-Income Consumers: Policy Guidelines and Model Provisions. *LMI Guidelines*.
https://www.energy.gov/sites/prod/files/2016/04/f30/IREC-LMI-Guidelines-Model-Provisions_FINAL.pdf.
- Jacobs, D.E., E Ahonen, S.L. Dixon, S. Dorevitch, J. Breysse, J. Smith, J., A. Evens, D. Dobrez, D., M. Isaacson, C. Murphy, L. Conroy, P. Levavi. (2015). “Moving into green healthy housing.” *Journal of Public Health Management and Practice* 21(4): 345-354.
<https://www.ncbi.nlm.nih.gov/pubmed/24378632>.
- Jacobs, D.E., M. Tobin, L. Targos, D. Clarkson, S.L. Dixon, J. Breysse, P. Pratap, and S. Cali. (2016). “Replacing windows reduces childhood lead exposure: results from a state-funded program.” *Journal of Public Health Management and Practice*, 22(5): 482-491.
<https://www.ncbi.nlm.nih.gov/pubmed/26910871>.
- Jafary, M., and L. Shephard. (2018). Modeling the Determinants of Residential Appliance Electricity Use Single-Family Homes, Homes with Electric Vehicles and Apartments. *2018 IEEE Green Technologies Conference*: 119-126. DOI: [10.1109/GreenTech.2018.00030](https://doi.org/10.1109/GreenTech.2018.00030).
- Jaske, M. (2016). “Translating Aggregate Energy Efficiency Savings Projections Into Hourly System Impacts.” California Energy Commission Staff Report. Publication Number CEC-200-2016-007. <https://www.energy.ca.gov/2016publications/CEC-200-2016-007/CEC-200-2016-007.pdf>.

- Jenkins, K., D. McCauley, R. Heffron, H. Stephan, and R. Rehner. (2016). Energy justice: a conceptual review. *Energy Research & Social Science*, 11, 174-182.
<https://www.sciencedirect.com/science/article/pii/S2214629615300669?via%3Dihub>.
- Johnson, E., R. Beppler, C. Blackburn, B. Staver, M. Brown, M., and D. Matisoff. (2017). Peak shifting and cross-class subsidization: The impacts of solar PV on changes in electricity costs. *Energy Policy*, 106: 436-444, <http://dx.doi.org/10.1016/j.enpol.2017.03.034>.
- Keilty, Kristina. (2018). "Washing with Cold Water: Are You Up for the Challenge? A CBSM Strategy for Engaging Low and Moderate Income Populations." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p402>.
- Khan, Haider, and Kevin Duffy. (2018). "Non-Wires Alternatives: A Case Study in an Economically Depressed Location." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p187>.
- Kontokosta, Constantine E., Vincent J. Reina and Bartosz Bonczak. (2019). "Energy Cost Burdens for Low-Income and Minority Households." *Journal of the American Planning Association*. <https://www.tandfonline.com/doi/full/10.1080/01944363.2019.1647446>.
- Kraft-Todd, G.T., B. Bollinger, K. Gillingham, S. Lamp, and D.G. Rand. (2018). Credibility-enhancing displays promote the provision of non-normative public goods. *Nature*, 563(7730): 245. <https://doi.org/10.1038/s41586-018-0647-4>.
- Kravatz, M. A., E. Belliveau, B. Tonn, and G. Clendenning, G. (2018). Co-Funded Health-Focused Housing Intervention Measure Benefits: Establishing a Co-Funded Low-Income Residential Program Model. *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p403>.
- Langevin, J., P.L. Gurian, and J. Wen. (2013). Reducing energy consumption in low income public housing: Interviewing residents about energy behaviors. *Applied Energy*, 102, 1358-1370. <https://www.sciencedirect.com/science/article/pii/S0306261912005144>.
- Lapsa, Melissa V., Marilyn A. Brown, and Anmol Soni. (2020). "Annotated Bibliography of Literature Addressing the Low-Income Energy Affordability in the U.S." Oak Ridge National Laboratory, ORNL/SPR-2019/1169.
- Leventis, Greg, Emily Martin Fadrhonc, Chris Kramer, and Charles Goldman. (2016). "Current Practices in Efficiency Financing: An Overview for State and Local Governments." Lawrence Berkeley National Laboratory, LBNL-1006406. <http://eta-publications.lbl.gov/sites/default/files/lbnl-1006406.pdf>.
- Leventis, G., C. Kramer, and L.C. Schwartz. (2017). "Energy Efficiency Financing for Low-and Moderate-Income Households: Current State of the Market, Issues, and Opportunities." <https://www4.eere.energy.gov/seeaction/system/files/documents/LMI-final0914.pdf>.

- Lin, J. (2018a). The Pay As You Save program in rural Arkansas: An opportunity for rural distribution cooperative profits. *The Electricity Journal* 31(6): 33-39.
<https://emp.lbl.gov/sites/all/files/lbnl-1006406.pdf>.
- Lin, J. (2018b). Affordability and access in focus: Metrics and tools of relative energy vulnerability. *The Electricity Journal* 31(6): 23-32.
<https://doi.org/10.1016/j.tej.2018.06.005>.
- Long, M., P. Zhao, H. Yaptinchay, M. Prado, S. Walmsley, and E. Giarta. (2018). "Data Driven Approaches to Understanding Occupant Natural Gas Use Behavior in Low-Income Multifamily Communities." *ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p254>.
- Massetti, Emanuele, Marilyn Brown, Melissa Lapsa, Isha Sharma, James Bradbury, Colin Cunliff, Yufei Li. (2017). "Environmental Quality and the U.S. Power Sector: Air Quality, Water Quality, Land Use and Environmental Justice." Oak Ridge National Laboratory, ORNL/SPR-2016/772. <http://info.ornl.gov/sites/publications/files/Pub60561.pdf>.
- Monyei, C.G., B.K. Sovacool, M.A. Brown, K.E. Jenkins, S. Viriri, and Y. Li. (2019). Justice, poverty, and electricity decarbonization. *The Electricity Journal*, 32(1): 47-51.
<https://doi.org/10.1016/j.tej.2019.01.005>.
- Nahmens, I., A. Joukar, and R. Cantrell. (2015). "Impact of Low-Income Occupant Behavior on Energy Consumption in Hot-Humid Climates." *Journal of Architectural Engineering* 21(2).
[https://doi.org/10.1061/\(ASCE\)AE.1943-5568.0000162](https://doi.org/10.1061/(ASCE)AE.1943-5568.0000162).
- Narassimhan, E., and C. Johnson. (2018). "The role of demand-side incentives and charging infrastructure on plug-in electric vehicle adoption: analysis of US States." *Environmental Research Letters* 13(7). <https://iopscience.iop.org/article/10.1088/1748-9326/aad0f8>.
- National Research Council. (2010a). *America's Climate Choices: Advancing the Science of Climate Change*. Washington, D.C.: National Academies Press.
<https://www.nap.edu/catalog/12782/advancing-the-science-of-climate-change>.
- National Research Council. (2010b). *America's Climate Choices: Adapting to the Impacts of Climate Change*. Washington, D.C.: National Academies Press.
<https://www.nap.edu/catalog/12783/adapting-to-the-impacts-of-climate-change>.
- Niederberger, A. A. (2018). "Empowering Low-Income Customers to Shop Energy Smart at Scale." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p389>.
- Nordman, B. and M.C. Sanchez. (2006). "Electronics Come of Age: Taxonomy for Miscellaneous and Low Power Products," *2006 ACEEE Summer Study on Energy Efficiency in Buildings*, pp. 9-248–9-259.
https://aceee.org/files/proceedings/2006/data/papers/SS06_Panel9_Paper22.pdf.

- Norton, Bryan G. (2005). *Sustainability: A Philosophy of Adaptive Ecosystem Management*. University of Chicago Press.
<https://www.press.uchicago.edu/ucp/books/book/chicago/S/bo3641681.html>.
- O'Dwyer, C. (2017). "Eligibility for Payment Assistance: A Historical Perspective & A Look Forward." (Low Income Energy Issues Forum paper) Washington, DC: Distributed Energy Financial Group LLC.
- O'Dwyer, C.B. (2013). "Engaging and Enrolling Low Income Consumers in Demand Side Management Programs." (Low Income Energy Issues Forum paper) Washington, DC: Distributed Energy Financial Group LLC <http://defgllc.com/publication/engaging-and-enrolling-low-income-consumers-in-demand-side-management-programs/>.
- Padhee, M., and A. Pal. (2018, September). Effect of Solar PV Penetration on Residential Energy Consumption Pattern. In 2018 North American Power Symposium (NAPS) (pp. 1-6). IEEE. <https://ieeexplore.ieee.org/document/8600657>.
- Paulos, B. (2017). "Bringing the benefits of solar to low-income consumers: a guide for states and municipalities." Sun Shot Initiative, Clean Energy State Alliance.
<https://www.cesa.org/assets/2017-Files/Bringing-the-Benefits-of-Solar-to-Low-Income-Consumers.pdf>.
- Porse, Erik, Joshua Derenski, Hannah Gustafson, Zoe Elizabeth, and Stephanie Pincetl. (2016). "Structural, geographic, and social factors in urban building energy use: Analysis of aggregated account-level consumption data in a megacity." *Energy Policy* 96: 179-192.
<https://www.sciencedirect.com/science/article/abs/pii/S0301421516302853?via%3Dihub>.
- Power, Meg. (2008). "Fuel Poverty in the USA: The Overview and the Outlook." *Energy Action*, Issue No. 98, March. <http://www.opportunitystudies.org/wp-content/uploads/2011/11/fuel-poverty.pdf>.
- Ptak, T., A. Nagel, S.M. Radil, and D. Phayre. (2018). Rethinking community: Analyzing the landscape of community solar through the community-place nexus. *The Electricity Journal*, 31(10): 46-51. <https://doi.org/10.1016/j.tej.2018.11.006>.
- Rawls, John. (1971). *A Theory of Justice*. Harvard University Press.
- Reames, Tony Gerard. (2016). "A community-based approach to low-income residential energy efficiency participation barriers." *Local Environment* 21(12): 1449-1466. DOI: <https://www.tandfonline.com/doi/full/10.1080/13549839.2015.1136995>.
- Reames, T.G., M.A. Reiner, and M.B. Stacey. (2018). An incandescent truth: Disparities in energy-efficient lighting availability and prices in an urban US county. *Applied energy*, 218, 95-103. <https://doi.org/10.1016/j.apenergy.2018.02.143>.
- Reina, V. J., and C. Kontokosta. (2017). "Low hanging fruit? Regulations and energy efficiency in subsidized multifamily housing." *Energy Policy* 106: 505-513.
<https://www.sciencedirect.com/science/article/abs/pii/S0301421517302276?via%3Dihub>.

- Relf, Grace, Brendon Baatz, and Seth Nowak. (2017). *2017 Utility Energy Efficiency Scorecard*. American Council for an Energy-Efficient Economy. Report U1707.
<https://aceee.org/research-report/u1707>.
- Ribeiro, David, Eric Mackres, Brendon Baatz, and Rachel Cluett. (2015). “Enhancing Community Resilience through Energy Efficiency.” American Council for an Energy-Efficient Economy.
<https://aceee.org/sites/default/files/publications/researchreports/u1508.pdf>.
- Ronen, A., D.H.B. Gai, and L. Crampton. (2016). *Can electricity rate subsidies be reallocated to boost low-income solar? GW Solar Institute Working Paper*.
<https://solar.gwu.edu/sites/g/files/zaxdzs2391/f/image/Reallocating%20Subsidized%20Rates%20for%20Low-Income%20Solar.pdf>.
- Rose, E., B. Hawkins, B. Conlon, and I. Treitler. (2015). “Assessing the Potential of Social Networks as a Means for Information Diffusion – the Weatherization Experiences (WE) Project.” Oak Ridge National Laboratory, ORNL/TM-2014/405.
https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRecoveryActEvalFinalReports/ORNLTM-2014_405.pdf.
- Ross, L., M. Jarrett, and D. York. (2016). “Reaching More Residents: Opportunities for Increasing Participation in Multifamily Energy Efficiency Programs.” American Council for an Energy-Efficient Economy. <https://aceee.org/research-report/u1603>.
- Ross, Lauren, Ariel Dreihobl, and Brian Stickles. (2018). “The High Cost of Energy in Rural America: Household Energy Burdens and Opportunities for Energy Efficiency.” ACEEE Research Report U1806. <https://aceee.org/research-report/u1806>.
- Roundtree, Jr., Stephan K. (2018). “Community-led Solar Aggregation, Energy Efficiency Outreach and Education in Northern Manhattan.” 2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p408>.
- Samarripas, Stefan, and Dan York. (2018). “Integrating Energy Efficiency and Solar to Benefit Affordable Multifamily Buildings.” *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p409>.
- Samarripas, Stefan, Dan York, and Lauren Ross. (2017). “More Savings for More Residents: Progress in Multifamily Housing Energy Efficiency.” ACEEE Research Report U1702.
<https://aceee.org/research-report/u1702>.
- Sanchez, D.R., A. Levine, and L. Tajina. (2018). *Using Partnerships to Drive Energy Efficiency and Preserve Affordability. 2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p410>.
- Scheu, R., P. Azimi, M.E. Guest, A. Gramigna, and B. Stephens. (2018). *Why Equity Matters: Energy Use and Air Quality Disparities by Neighborhood: Stories (and Data) from*

- Families Living in Chicago's Bungalow Belt. *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p411>.
- Schwartz, J. (2014). "Low Income Consumer Decision Making." (Low Income Energy Issues Forum paper) Washington, DC: Distributed Energy Financial Group LLC
<http://defgllc.com/publication/low-income-consumer-decision-making/>.
- Sexton, Steven. (2015). "Automatic Bill Payment and Salience Effects: Evidence from Electricity Consumption." *The Review of Economics and Statistics* 97(2): 229–241.
https://doi.org/10.1162/REST_a_00465.
- Shoemaker, Mary, Annie Gilleo, and Jill Ferguson. (2018). "Reaching Rural Communities with Energy Efficiency Programs." ACEEE Research Report U1807. <https://aceee.org/research-report/u1807>.
- Sigrin, Benjamin, and Meghan Mooney. (2018). "Rooftop Solar Technical Potential for Low-to-Moderate Income Households in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70901.
<https://www.nrel.gov/docs/fy18osti/70901.pdf>.
- Simms, Kristol, and Lauren Casentini. (2018). "Making Efficiency Easy and Enticing. Leveraging Community Engagement for Maximum Energy Efficiency Impact." *2018 ACEEE Summer Study on Energy Efficiency in Buildings*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p413>.
- Simon, H.A. (1976). "From substantive to procedural rationality." In *25 years of economic theory* (pp. 65-86). Springer, Boston, MA. https://doi.org/10.1007/978-1-4613-4367-7_6.
- Souba, F., and P.B. Mendelson. (2018). "Chaninik Wind Group: Lessons learned beyond wind integration for remote Alaska." *The Electricity Journal* 31(6): 40-47.
<https://www.sciencedirect.com/science/article/pii/S1040619018301349>.
- Southworth, Katie. (2011). "Pennsylvania's Low-Income Usage Reduction Program (LIURP) Economic Opportunities Studies."
http://www.opportunitystudies.org/repository/File/weatherization/LIURP_Program_Features.pdf.
- Sovacool, Benjamin K., Paula Kivimaa, Sabine Hielscher, and Kristen Jenkins. (2017). Vulnerability and resistance in the United Kingdom's smart meter transition. *Energy Policy* 109(2017): 767-781. <https://doi.org/10.1016/j.enpol.2017.07.037>.
- Spillman, Brenda C., Josh Leopold, Eva H. Allen, and Pamela Blumenthal. (2016). "Developing Housing and Health Collaborations Opportunities and Challenges." Urban Institute.
https://www.urban.org/sites/default/files/publication/89581/hh_brief_final_0.pdf.
- Sunstein, C.R., and L.A. Reisch. (2014). "Automatically green: Behavioral economics and environmental protection." *Harv. Envtl. L. Rev.* 38: 127.
<https://harvardelr.com/2013/11/18/automatically-green/>.

- Sunter, D. A., S. Castellanos, and D.M. Kammen. (2019). Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nature Sustainability*, 2(1), 71. <https://doi.org/10.1038/s41893-018-0204-z>.
- Thorve, S., S. Swarup, A. Marathe, Y. Chungbaek, E.K. Nordberg, and M.V. Marathe. (2018, December). Simulating Residential Energy Demand in Urban and Rural Areas. In 2018 Winter Simulation Conference (WSC) (pp. 548-559). IEEE. DOI: [10.1109/WSC.2018.8632203](https://doi.org/10.1109/WSC.2018.8632203).
- Tidwell, J., A. Tidwell, and S. Nelson. (2018). Surveying the Solar Power Gap: Assessing the Spatial Distribution of Emerging Photovoltaic Solar Adoption in the State of Georgia, USA. *Sustainability*, 10(11): 4117. <https://doi.org/10.3390/su10114117>.
- Tonn, Bruce, David Carroll, Scott Pigg, Michael Blasnik, Greg Dalhoff, Jacqueline Berger, Erin Rose, Beth Hawkins, Joel Eisenberg, Ferit Ucar, Ingo Mensch, and Claire Cowan. (2014a). "Weatherization Works – Summary of Findings From The Retrospective Evaluation of the U.S. Department of Energy's Weatherization Assistance Program." Oak Ridge National Laboratory, ORNL/TM-2014/338. <https://www.energy.gov/sites/prod/files/2015/09/f26/weatherization-works-retrospective-evaluation.pdf>.
- Tonn, Bruce, Erin Rose, Beth Hawkins, and Brian Conlon. (2014b). "Health and Household-Related Benefits Attributable to the Weatherization Assistance Program." Oak Ridge National Laboratory, ORNL/TM-2014/345. https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_345.pdf.
- Tonn, Bruce, David Carroll, Erin Rose, Beth Hawkins, Scott Pigg, Daniel Bausch, Greg Dalhoff, Michael Blasnik, Joel Eisenberg, Claire Cowan, Brian Conlon. (2015). "Weatherization Works II–Summary of Findings from the ARRA Period Evaluation of the U.S. Department of Energy's Weatherization Assistance Program," Oak Ridge National Laboratory, ORNL/TM-2015/139. <https://www.energy.gov/sites/prod/files/2015/09/f26/weatherization-works-II-ARRA-period-eval.pdf>.
- Tonn, B., E. Rose, and B. Hawkins. (2015). "Survey of Recipients of Weatherization Assistance Program Services: Assessment of Household Budget and Energy Behavior Pre-to Post-Weatherization." ORNL/TM-2015/64, Oak Ridge National Laboratory, Oak Ridge, TN. <https://info.ornl.gov/sites/publications/Files/Pub54436.pdf>.
- Tonn, B., B. Hawkins, and E. Rose. (2016). Assessment of the American Recovery and Reinvestment Act upon the Department of Energy weatherization assistance program. *Review of Policy Research* 33(2), 178-200. <https://doi.org/10.1111/ropr.12164>.
- Tonn, B., E. Rose, and B. Hawkins. (2018). "Evaluation of the US Department of Energy's weatherization assistance program: Impact results." *Energy Policy* 118: 279-290. <https://www.sciencedirect.com/science/article/abs/pii/S0301421518301836>.
- Treadway, N. (2018). *The Long Struggle Continues: Improving Service to Low-Income Customers in the Utility Sector* (EcoPinion Consumer Survey Report 31) Washington,

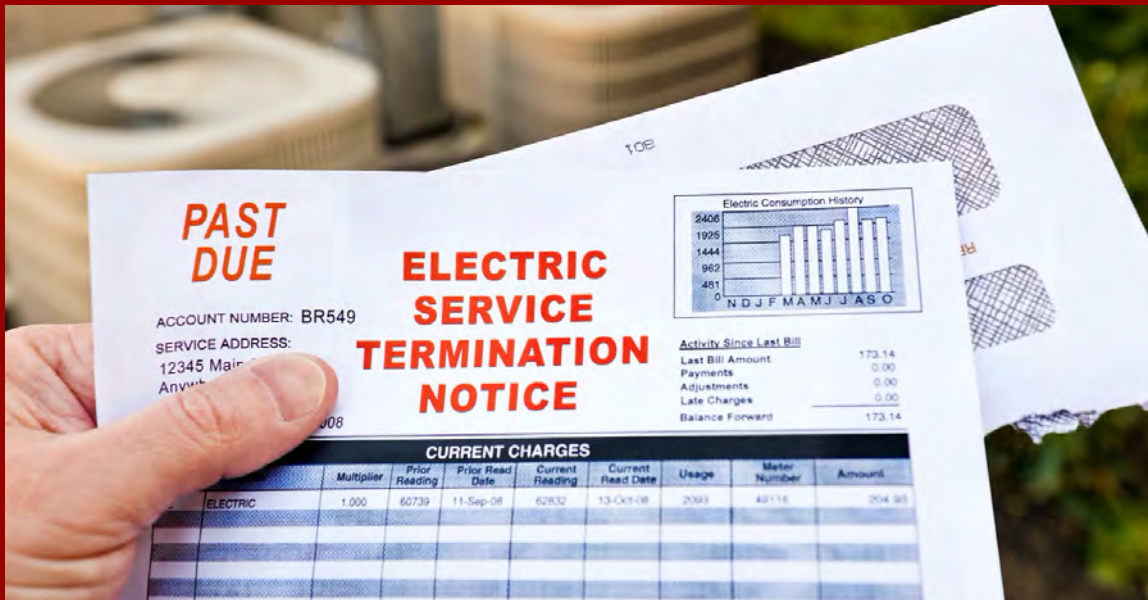
- DC: Distributed Energy Financial Group LLC <http://defgllc.com/publication/the-long-struggle-continues-improving-service-to-low-income-customers-in-the-utility-sector/>.
- Ulrich, Elaine, Monisha Shah, Joseph Pereira, David Hepinstall, David Feldman, Jeffrey Cook, Amy Hollander, Gillian Weaver, Kosol Kiatreungwattana, and Jason Edens. (2018). Using Federal Energy Assistance Funds for PV to Reduce Energy Burden for Low Income Households. *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p412>.
- United Nations Development Program (UNDP). (2005). Time for Bold Ambition Together We Can Cut Poverty in Half. *United Nations Development Program*. <http://www.undp-aci.org/publications/other/undp/reports/annualreport-05e.pdf>.
- U.S. Department of Energy (DOE). (2017). "Clean Energy for Low Income Communities Accelerator (CELICA): Year 1 Review". *Better Buildings: U.S. Department of Energy*.
<https://www.energy.gov/sites/prod/files/2017/12/f46/CELICA-year-review.pdf>.
- U.S. Department of Energy (DOE). (2015). National Evaluations: Summary of Results.
https://nascsp.org/wp-content/uploads/2017/09/WAP_NationalEvaluation_WxWorks_v14_blue_82052015.pdf.
- U.S. Energy Information Administration (EIA). (2000). Energy Consumption and Renewable Energy Development Potential on Indian Lands. SR/CNEAF/2000-01. April 2000. Table ES-3. <https://www.energy.gov/sites/prod/files/2017/06/f34/EIA2000.pdf>.
- Verclas, Kristen. (2018). "Electric vehicle and solar energy pilot: Opportunity to address suburban energy challenges." *The Electricity Journal* 31(6), 48-56.
<https://www.sciencedirect.com/science/article/pii/S1040619018301453>.
- Verclas, Kristen, and Eric Hsieh. (2018). "From utility disconnection to universal access." *The Electricity Journal* 31(6), 108.
<https://www.sciencedirect.com/science/article/pii/S104061901830143X?via%3Dihub>.
- Vote Solar. (2018). The Vision for U.S. Community Solar: A Roadmap to 2030. *Vote Solar and GTM Research*. <https://votesolar.org/policy/policy-guides/shared-renewables-policy/csvisionstudy/#reportdownload>.
- Waite, Wayne, Sara Baldwin Auck, Mari Hernandez, and Erica McConnell. (2018). "Shifting the Burden: How Utility Rate Design Changes are Impacting Energy Costs and Clean Energy Access for Low-Income Renters." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*.
<https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p415>.
- Walton, K. C. (2014). "Renewable energy for low income clients: benefits beyond the money." *Energy Procedia* 57: 826-833.
<https://www.sciencedirect.com/science/article/pii/S1876610214016580?via%3Dihub>.

- Wells, E. M., M. Berges, M. Metcalf, A. Kinsella, K. Foreman, D.G. Dearborn, and S. Greenberg. (2015). "Indoor air quality and occupant comfort in homes with deep versus conventional energy efficiency renovations." *Building and Environment*, 93: 331-338. <https://www.sciencedirect.com/science/article/pii/S0360132315300354>.
- White, L.V. and N.D. Sintov. (2019) "Health and financial impacts of demand-side response measures differ across sociodemographic groups," *Nature Energy*. <https://www.nature.com/articles/s41560-019-0507-y>.
- Wierzba, A.L., M.A. Morgenstern, S.A. Meyer, T.H. Ruggles, and J. Himmelreich. (2011). "A study to optimize the potential impact of residential building energy audits." *Energy efficiency*, 4(4): 587-597. <https://doi.org/10.1007/s12053-011-9106-x>.
- Wimberly, J. (2017). "The Best Service for Utility Customers with the Least.) (EcoPinion Consumer Survey Report 27) Washington, DC: Distributed Energy Financial Group LLC <http://defgllc.com/publication/the-best-service-for-utility-customers-with-the-least/>.
- Wimberly, J. (2016). "The Nut Within The Nut: Focusing on Truly Vulnerable Energy Consumers." (EcoPinion Consumer Survey Report 23) Washington, DC: Distributed Energy Financial Group LLC. <http://defgllc.com/publication/focusing-on-truly-vulnerable-energy-consumers/>.
- Winner, Brooks, Suzanne MacDonald, Juliette Juillerat, and Lisa Smith. (2018). "Bridging the Rural Efficiency Gap: Expanding Access to Energy Efficiency Upgrades in Remote and High Energy Cost Communities." *2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing*. <https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p416>.
- Wolske, K.S., P.C. Stern, and T. Dietz. (2017). Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. *Energy research & social science*, 25, 134-151. <https://doi.org/10.1016/j.erss.2016.12.023>.
- Yu, J., Z. Wang, A. Majumdar, and R. Rajagopal. (2018). Deep Solar: A Machine Learning Framework to Efficiently Construct a Solar Deployment Database in the United States. *Joule*, 2(12), 2605-2617. <https://doi.org/10.1016/j.joule.2018.11.021>.
- Zhang, H., Y. Vorobeychik, J. Letchford, and K. Lakkaraju. (2016). Data-driven agent-based modeling, with application to rooftop solar adoption. *Autonomous Agents and Multi-Agent Systems*, 30(6): 1023-1049. <https://link.springer.com/article/10.1007%2Fs10458-016-9326-8>.
- Zhang, W., C. Robinson, S. Guhathakurta, V.M. Garikapati, B. Dilkina, M.A. Brown, and R.M. Pendyala. (2018). Estimating residential energy consumption in metropolitan areas: A microsimulation approach. *Energy*, 155: 162-173. <https://www.sciencedirect.com/science/article/abs/pii/S0360544218307849?via%3Dihub>.
- Zhao, D., A.P. McCoy, P. Agee, Y. Mo, G. Reichard, and F. Paige. (2018). "Time effects of green buildings on energy use for low-income households: A longitudinal study in the

United States.” *Sustainable cities and society* 40: 559-568.
<https://doi.org/10.1016/j.scs.2018.05.011>.

Zhao, T., L. Bell, M.W. Horner, J. Sulik, and J. Zhang. (2012). Consumer responses towards home energy financial incentives: A survey-based study. *Energy Policy*, 47, 291-297.
<https://www.sciencedirect.com/science/article/abs/pii/S0301421512003758?via%3Dihub>.

HOUSEHOLD ENERGY INSECURITY SURVEY



Winter 2021-2022



ENERGY JUSTICE LAB
INDIANA UNIVERSITY

Household Energy Insecurity Survey

Authors

Sanya Carley
David Konisky
Trevor Memmott

About the survey

The Household Energy Insecurity Survey measures the prevalence of energy insecurity among a nationally-representative sample of low-income households (households with incomes at or below 200% of the Federal Poverty Line) in the United States. The survey was administered to a sample of 1,000 respondents, and includes questions about household energy insecurity, household composition and dwelling characteristics, and strategies American families use to manage their energy consumption and cope with energy-related materials hardships.

This survey was administered online in January 2022 and pertains to conditions experienced between November 2021 and January 2022, a three-month winter time space. The survey was administered on behalf of the Indiana University research team by YouGov, a private polling and market research firm. The survey has a margin of error of 3 percentage points.

For more information, please contact the Principal Investigators for this study: Sanya Carley (scarley@indiana.edu) or David Konisky (dkonisky@indiana.edu).

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About the Energy Justice Lab

The [Energy Justice Lab](#) at Indiana University is a research group conducting studies about the equity and justice dimensions of the clean energy transition. Through research, the lab offers insights on what energy justice means as it relates to the energy transition and what individuals and communities on the frontlines are facing, what vulnerability means in the energy justice context, what types of policies and programs are in place to address these issues, and how well government is doing to protect vulnerable communities. Professors [Sanya Carley](#) and [David Konisky](#) serve as Co-Directors of the Energy Justice Lab.

Energy insecurity in the United States

Energy insecurity, or the inability to meet one's energy needs, is a widespread and growing problem among low-income households in the United States. When households are unable to pay their energy bills or are disconnected from their utility service, they may struggle to keep their home at a comfortable temperature and often must engage in strategies that can be detrimental to their physical, mental, and financial well-being.

Recognizing that energy insecurity continues to impact and endanger vulnerable populations across the United States, the Household Energy Insecurity Survey regularly measured the prevalence and patterns of energy insecurity among a nationally-representative sample of low-income households. This Winter 2021-2022 survey covers the winter months of November and December 2021, and January 2022, which included periods of severe cold and storms, as well as extremely high prices for natural gas.

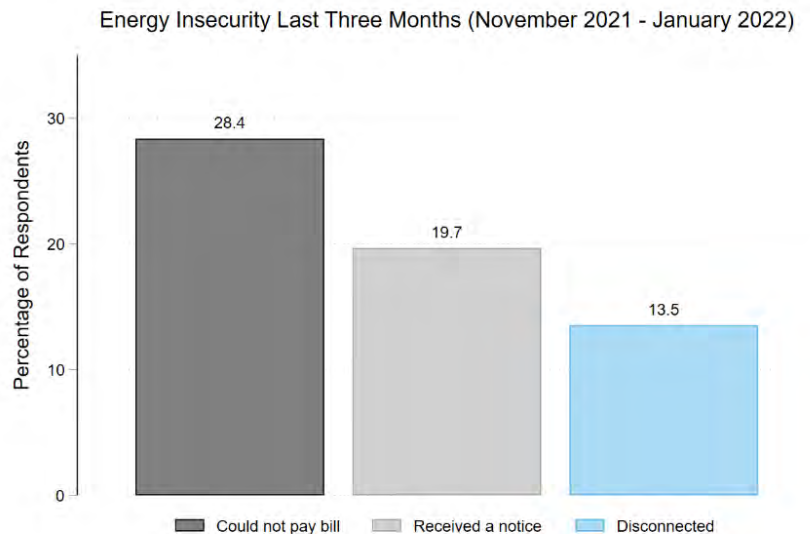
Key findings

- o Household energy insecurity is prevalent among low-income households in the United States.
- o Black and Hispanic households experience higher levels of energy insecurity.
- o Energy insecurity is widespread among households with vulnerable populations, especially families with children.
- o Households often forgo other basic household needs to pay their energy bills.
- o To cope with the expense of energy, households often adjust the temperature in their homes to uncomfortable levels and accumulate utility debt.

Household energy insecurity is prevalent among low-income households in the United States.

The survey asked respondents whether they were able to pay their energy bill, whether they received a notice of disconnection, and whether their energy services were disconnected by a utility provider over the course of the last three months (November 2021 through January 2022).

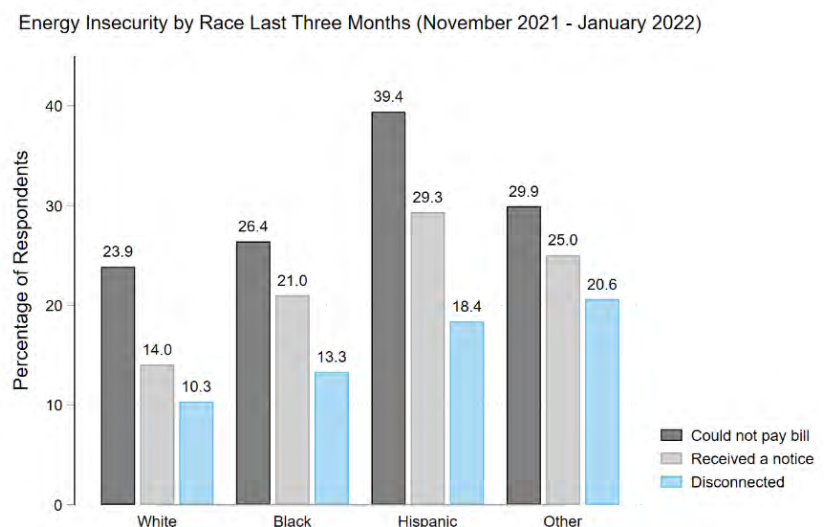
More than 28% of respondents reported being unable to pay their energy bill, nearly 20% received a disconnection notice, and 13.5% had their energy service (e.g., electricity, natural gas) disconnected by their utility provider.



Black and Hispanic households experience higher levels of energy insecurity

From November 2021 through January 2022, almost 40% of Hispanic respondents and more than 26% of Black respondents were not able to pay an energy bill. Hispanic households were about 50% more likely than white households to report being unable to pay an energy bill during this period.

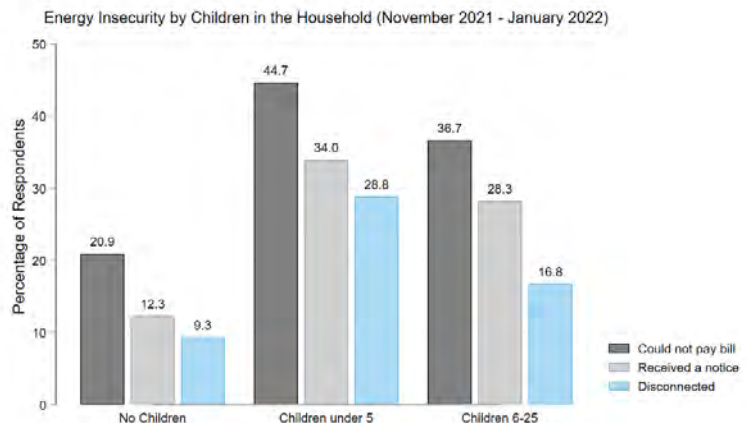
In addition, 29% of Hispanic respondents and 21% of Black respondents received a disconnection notice, and more than 18% of Hispanic respondents and 13% of Black respondents had their energy service disconnected by their utility provider. Compared to white respondents, Hispanic and Black respondents were 80% and 30%, respectively, more likely to have their service disconnected by their utility provider.



Energy insecurity is widespread among households with vulnerable populations, especially families with children

From November 2021 through January 2022, nearly 45% of households with children younger than 5 years old in the household could not pay an energy bill, 34% received a disconnection notice, and 29% were disconnected from their utility service.

For those with children in the household between the ages of 6 and 17 years old, nearly 37% could not pay their bill, 26% received a notice, and 17% were shut off by their utility.



Other vulnerable households also experienced high rates of energy insecurity; 31% of households with a disability could not pay a bill and 12% had their service disconnected by their utility provider. For households with a member over the age of 65, 27% could not pay their bill and 13% were disconnected.

Households often forgo other basic household needs to pay their energy bills.

More than 21% of respondents reported that, between November 2021 and January 2022, they had to forgo basic household expenses like food or medical care to afford their energy bill “on multiple occasions” (15%) or “all the time” (6%).

About 37% of respondents indicated that they had to either give up energy needs to afford other expenses or had to give up other expenses in order to afford their household energy bill. Approximately 33% of respondents reported that they reduced their energy consumption “Most of the time” (19%) or “Always” (14%) in order to save money on their energy bill.

To cope with the expense of energy, households often adjust the temperature in their homes to uncomfortable levels and accumulate utility debt.

From November 2021 through January 2022, 14% of respondents reported that they never had a comfortable temperature in their home and 30% reported only having a comfortable temperature in their home some of the time.

Around 38% of respondents reported having some level of utility debt, and the average level of debt was \$129.



Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic

Trevor Memmott, Sanya Carley  , Michelle Graff and David M. Konisky 

Energy insecurity is a growing public health threat among low-income populations in the United States. Prior research has shown that energy insecurity is associated with adverse health effects and can lead people to engage in risky coping strategies. Here we evaluate rates of energy insecurity, which factors contribute to it, and how the early months of the COVID-19 pandemic exacerbated the problem. We show that energy insecurity is highly prevalent among households at or below 200% of the federal poverty line. We further show that Black and Hispanic households are more likely to experience energy insecurity and face utility disconnection, as are households with young children, individuals that require electronic medical devices and those in dwellings with inefficient or poor conditions. These conditions exist under normal circumstances, and the COVID-19 pandemic seems to have exacerbated the overall incidence of energy insecurity.

Energy insecurity—conceptualized as the inability of a household to meet its basic energy needs^{1,2}—is a pervasive problem in the United States and elsewhere³. Scholars use terms such as energy poverty, fuel poverty and energy vulnerability to capture similar conditions^{4–8} that involve both affordability and access to reliable energy sources. Although electricity is necessary for essential services (for example, heating, cooling, cooking, lighting and medical devices), policymakers have failed to recognize the scope and scale of the energy insecurity problem⁹. In response to energy insecurity, vulnerable households are more likely to engage in risky behaviours to meet their energy needs¹⁰, which include using high-interest payday loans¹¹, a reliance on dangerous heating sources, such as space heaters or ovens¹², or forgoing other basic needs, such as food and medical care¹³. Individuals in energy-insecure households are more likely to remain in poverty for longer periods of time¹⁴ and are more likely to suffer adverse mental and physical health consequences^{15–18}, which include an increased incidence of death¹⁹; these impacts are especially prevalent for children^{20,21} and the elderly^{22,23}.

The economic disruption thus far caused by the COVID-19 pandemic has increased pre-existing inequalities, which include those associated with energy insecurity. Black and Hispanic communities have been impacted by disproportionate rates of coronavirus-related infections, hospitalizations and mortality^{24,25}; and Black and Hispanic populations, young workers, mothers of school-aged children, and low-educated individuals have experienced large employment shocks^{26–29}. This study expands this work by examining which American families experience energy insecurity during a public health crisis. In so doing, we also contribute to a growing literature on energy justice, material hardship and vulnerable populations^{1,30,31}.

The extant literature on energy insecurity has found that Blacks, Hispanics, those without a college degree and households with young children are all more likely to be energy insecure^{2,31,32}. These studies provide a strong foundation that scholars and practitioners currently rely on to understand the problem of domestic energy insecurity. Current knowledge of the scope and scale of energy insecurity, however, primarily comes from the analysis of two limited data

sources: the Residential Energy Consumption Survey (RECS)³³ and the American Community Survey (ACS). The RECS contains few energy insecurity questions, is administered only every four years, does not provide state-level geographical identifiers, and examines the public at large rather than the most vulnerable populations; and, although the ACS contains items on energy expenditures, it does not capture affordability³⁴. Analyses using these datasets have made important contributions to our understanding of energy insecurity, but neither the ACS nor the RECS enable a comprehensive empirical analysis of US energy insecurity.

To address these shortcomings, we administered a nationally representative survey of 2,381 adults with household incomes at or below 200% of the Federal Poverty Level (FPL) in April and May 2020. The survey captures multiple measures of energy insecurity, collects demographic, health and housing conditions information, and enables the evaluation of energy insecurity over the course of a year, which allows us to compare the prevalence and correlates of energy insecurity during both ‘normal’ circumstances and in the early months of the COVID-19 pandemic^{35,36}.

To summarize our findings, energy insecurity is highly prevalent among low-income American households, especially among households that identify as Black and Hispanic. We found that those who require use of an electronic medical device and live in poor or less-efficient housing conditions experience higher rates of energy insecurity. The COVID-19 pandemic has thus far deepened the prevalence of energy insecurity among low-income households, as some speculated may occur³⁷, with some indication of growing disparities.

Describing energy insecure households

We evaluate energy insecurity across three measures, which represent a range in severity: inability to pay an energy bill, receipt of a utility disconnection notice and disconnection from energy service. All measures rely on respondent recall about conditions over the past year (from roughly April/May 2019 to April/May 2020) and over the past month (April/May 2020), respectively. Although we cannot rule out recall bias, we believe it is likely that most

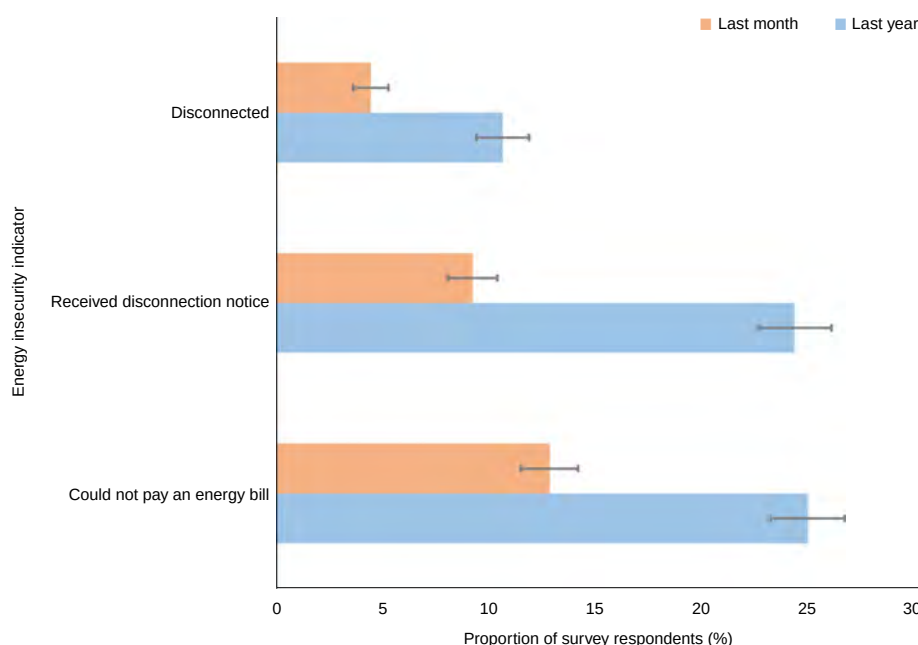


Fig. 1 | Proportion of survey respondents facing energy insecurity. Respondents who reported an inability to pay their energy bill, received a disconnection notice or were disconnected in the past year (blue) and in the past month (orange). The grey bars represent 95% CIs ($n = 2,381$).

respondents accurately remember events such as being unable to pay a bill, learning that they will soon be disconnected unless urgent action is taken, or being disconnected from the grid and losing access to electricity.

The survey results (Fig. 1) reveal that 25% (the 95% confidence interval (CI) is 23.0–27.0%) of low-income households could not afford to pay an energy bill in the past year and nearly 13% (95% CI 10.9–14.9%) could not afford their bill in the past month. In the past year, just over 25% (95% CI 23.6–27.6%) of respondents received a notice from their utility provider that their power may be disconnected due to lack of payment, and over 10% (95% CI 8.6–12.6%) had their service disconnected. In the past month, during the onset of the economic dislocation from the COVID-19 pandemic, 9% (95% CI 7.2–11.2%) of respondents had received a notice and 4% (95% CI 2.4–6.4%) were disconnected.

To further characterize the general prevalence of energy insecurity among low-income US households, as well as its incidence since the onset of the COVID-19 pandemic, we combined the survey data with estimates from the 2018 ACS for those who live at or below 200% of the FPL to approximate the number of US households and individuals that are energy insecure. Specifically, we extrapolated from the survey data to the US population by multiplying the proportion of survey respondents that reported some level of energy insecurity by the number of US households (individuals) that the ACS estimates to be at or below 200% of the FPL. As shown in Table 1, we estimate that, in the past year, approximately 4.7 (24.3) million households (individuals) could not pay an energy bill, and just over 50%—2.4 (12.5) million households (individuals)—indicated that at least one of the bills they could not pay was in the past month. Although we estimate that 4.8 (24.9) million households (individuals) received a disconnection notice and approximately 41% of these households were disconnected in the past year, the proportion of households that were disconnected from the grid after they received a notice rose to about 48% during the COVID-19 pandemic.

To put these estimates into context, we compared them with the RECS survey, which provides a nationally representative snapshot

Table 1 | Estimates of US households experiencing energy insecurity

	Could not pay an energy bill	Received notice	Disconnected
Number of households $\times 10^6$ (estimate range)			
Past year (April/May 2019 to April/May 2020)	4.7 (4.4–5.2)	4.8 (4.5–5.3)	2.0 (1.6–2.4)
Past month (April/May 2020)	2.4 (2.1–2.8)	1.7 (1.4–2.1)	0.8 (0.5–1.2)
Number of individuals $\times 10^6$ (estimate range)			
Past year (April/May 2019 to April/May 2020)	24.3 (22.4–26.3)	24.9 (23.0–26.9)	10.3 (8.4–12.3)
Past month (April/May 2020)	12.5 (10.6–14.5)	8.9 (7.0–10.9)	4.3 (2.3–6.2)

The approximate number of households—defined by the ACS as family members who reside together—and individuals who suffer from energy insecurity in the United States based on the 2018 ACS estimates²⁴ of households that live at or below 200% of the FPL and the proportion of respondents that reported they could not pay an energy bill, received a disconnection notice or were disconnected from energy service. The range represents the 95% CIs for the estimates.

of all domestic housing units in the United States. According to the most recent RECS, 17 million households received a disconnection notice in 2015, and 3 million households had their electricity disconnected. We can approximate from our 2020 survey that roughly 30% of all US households who received disconnection notices had incomes at or below 200% of the FPL, and nearly two-thirds of those that were disconnected came from households at or below 200% of the FPL. Although these approximations should be interpreted cautiously given differences in survey methodology and timing, we can infer that low-income households are being disconnected at much

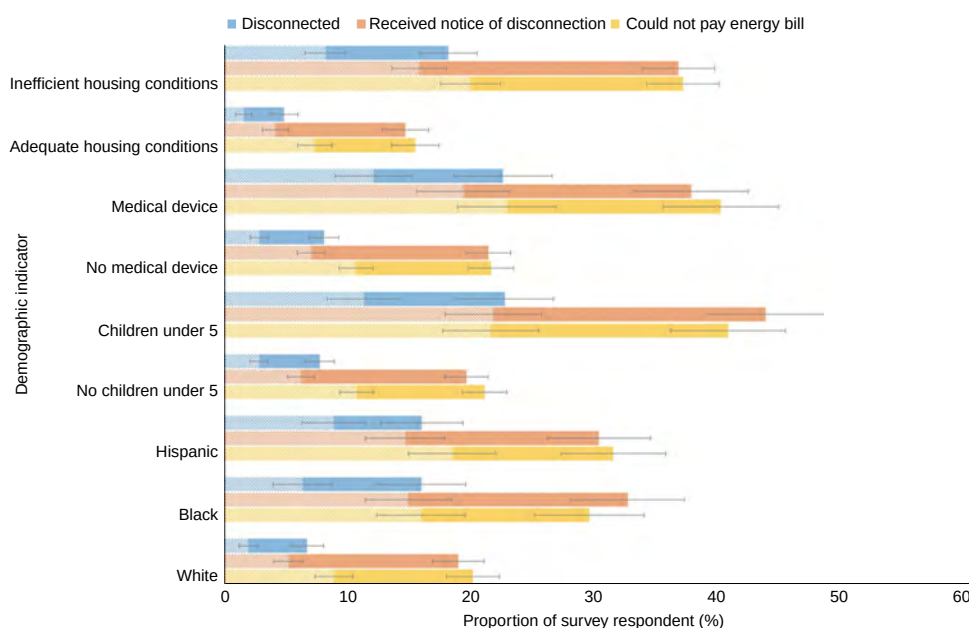


Fig. 2 | Energy insecurity by demographic characteristics. The proportion of households that could not afford an energy bill (yellow), received a disconnection notice (orange), or were disconnected from the grid (blue) in the past year (full bars) compared with those in the past month alone (dashed components), according to key indicators. Grey bars represent the 95% CIs ($n = 2,381$).

higher rates after receipt of a notice from their utility than average-to high-income households.

To further understand energy insecure households, we disaggregated the indicators of energy insecurity by race, number of dependents, health and housing conditions. These findings are illustrated in Fig. 2, in which each full bar represents the proportion of survey respondents who reported being energy insecure in the past year. We find that Black households, Hispanic households, households with young children, those with a member that relies on an electronic medical device and those who reside in poor housing conditions (for example, mould, holes in the wall and/or floor, plumbing problems, broken heating and air conditioning, exposed electrical sockets, non-working stove and/or refrigerator, or poor insulation) all reported higher incidences of energy insecurity. These characteristics are positively associated with all three energy insecurity measures, which demonstrates that these disparities are prevalent during typical circumstances (that is, the year prior to the onset of the COVID-19 pandemic, which was characterized by a normal-to-strong US domestic economy³⁸).

Figure 2 further suggests that many of these disparities have grown since the beginning of the COVID-19 pandemic. Although the survey data do not enable us to make precise year-on-year comparisons, there was a higher prevalence of energy insecurity across many of these sociodemographic and household attributes during the early period of the COVID-19 pandemic (dashed bars in Fig. 2). For example, 20% of White households and 30% of Black households could not pay an energy bill in the past year, which accounts for 12 full months; whereas 9% of White households and 16% of Black households indicated that they had trouble paying their energy bill in just the past month alone, a month that is not typically a weather aberration, nor was it extreme in 2020. Additionally, Hispanic respondents were 2.4 times more likely than White respondents to be disconnected from the grid in the past 12 months, but 4.7 times more likely to be disconnected during the early period of the COVID-19 pandemic. Similar patterns emerged across the other indicators displayed in Fig. 2, which provides some evidence

of an increase in disparities in energy insecurity during the beginning of the public health and economic crisis that results from the COVID-19 pandemic.

Sociodemographic predictors of energy insecurity

To better identify the determinants of household energy insecurity, we estimated a series of logistic regression models. This analysis evaluated the correlates of energy insecurity over the past year and in the past month to compare patterns of household energy insecurity during typical circumstances and the potential unique hardships that these households experienced since the onset of the pandemic. For brevity, we present the results of our models in Fig. 3 for the demographic, health and housing characteristics that are consistently statistically associated with at least two of our indicators of energy insecurity. For clarity, we discuss our findings in terms of odds ratios. Full model regression results are also presented in Supplementary Table 1. In the models, we also include measures for households with a disabled member, other race categories (which include Asian, Native American and mixed households), whether the household is situated in an urban or rural zip code, whether the household received government assistance and the respondent's age, gender, employment status and level of educational attainment (see Supplementary Table 2 for a full list of variables).

As illustrated in Fig. 3, Black respondents were more likely than White respondents to be energy insecure across all three energy insecurity measures in the past year, with Hispanic households more likely to receive a notice of disconnection or be disconnected from the electric grid. More specifically, compared with White households, Black and Hispanic households experienced more severe forms of energy insecurity at higher rates. Black households experienced 1.9 times greater odds of receiving a disconnection notice and 2.2 times greater odds of having their utility service disconnected than the White household respondents. Hispanic households faced disconnection at 1.9 times greater odds than White household respondents.

Moreover, the COVID-19 pandemic appears to have increased racial disparities. The regression analysis suggests that Black

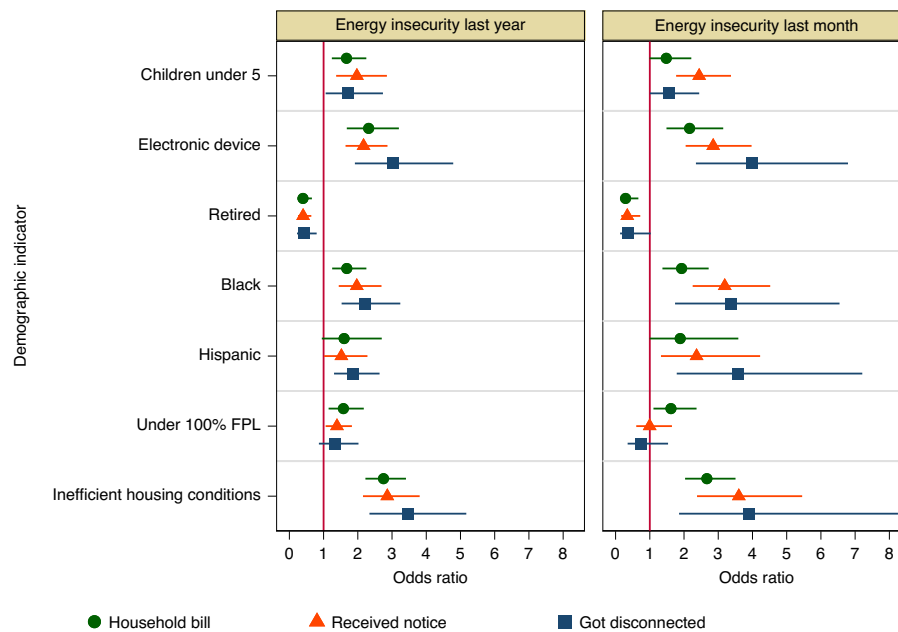


Fig. 3 | Sociodemographic correlates of energy insecurity. Values are odds ratios with 95% CIs, estimated from logistic regression models ($n = 2,359$). The models also include variables for household member with a disability, unemployed, other race or ethnicity, gender, age, education, dwelling type (mobile home, apartment or attached home), percentage of urban area within the zip code and receipt of government assistance. The full model estimates are provided in Supplementary Table 1.

respondents were more likely to face all three forms of insecurity and Hispanic respondents were more likely to receive a notice or be disconnected in the time since the pandemic began compared to over the course of the previous year. Blacks (Hispanics) were at 3.4 (3.6) greater odds of being disconnected from their utility service during the pandemic than White respondents. These temporal differences in prevalence across racial groups suggest that energy insecurity intensified during the early months of the pandemic, although we cannot infer this definitively from the statistical analysis because the CIs for the coefficients across the models overlap.

Similarly, respondents who live in households in which at least one person requires the use of a home electronic medical device were more likely to be unable to pay their bills, to receive a notice and to be disconnected, both over the course of the prior year and during the early period of the COVID-19 pandemic. During the early months of the pandemic, for example, electronic device users faced 4.0 times greater odds of having their utility service disconnected compared with those who did not require the use of a medical device, which suggests that this vulnerable population is at high risk of losing power and facing tangible health risks. In addition, households with children under the age of five, those who live in poor or inefficient dwelling conditions, and those that have received government assistance in the past month also faced a higher risk of experiencing energy insecurity. We found that retired individuals, on average, were less energy insecure.

Lastly, respondents that had a household income under 100% of the FPL were more likely to be unable to pay their energy bill in both the past year and the past month as well as more likely to receive a disconnection notice in the past year, as compared with those whose household incomes were between 150 and 200% of the FPL. The lack of a statistical association between income levels and disconnection from the electric grid is a noteworthy null finding. It suggests that economic characteristics are not the sole predictors of the most severe measure of energy insecurity and that race, health and

housing conditions remain positive correlates of energy insecurity across all three measures, even when income is accounted for.

The impact of COVID-19 on energy insecurity

To this point, the analysis has provided suggestive evidence about the relationship between the early period of the COVID-19 pandemic and energy insecurity by comparing the prevalence and determinants of energy insecurity at different points in time. To further examine this relationship, we analysed the responses to several COVID-19-related survey items: whether they had received a COVID-19 stimulus payment (part of the Coronavirus Aid, Relief and Economic Security Act), whether their employment status had changed due to the pandemic and whether someone in their household had symptoms of or a positive test for COVID-19. Lastly, we included a factor score (see Supplementary Table 3) to measure 'COVID-19 hardship' or the material hardship (for example, financial, food and medical insecurity) a respondent experienced in the immediate aftermath of the pandemic.

A larger proportion of households that were adversely affected by the public health crisis also experienced all three levels of energy insecurity in the past month (Fig. 4). Additionally, those that received a stimulus cheque were less likely to face issues as the pandemic began to unfold.

Next, we re-estimated the logistic regression model for the energy insecurity measures reported during the early COVID-19 period and included these variables as regressors. The full set of results (Supplementary Table 4) reveals that, in general, the same set of covariates that were correlated with energy insecurity in the past year remained statistically associated with energy insecurity in the past month, even when we controlled for the potential confounding effects of COVID-19.

Conditions associated with COVID-19 are positively associated with energy insecurity (Fig. 5). Material hardship and unemployment and/or lost hours due to the pandemic are statistically associated

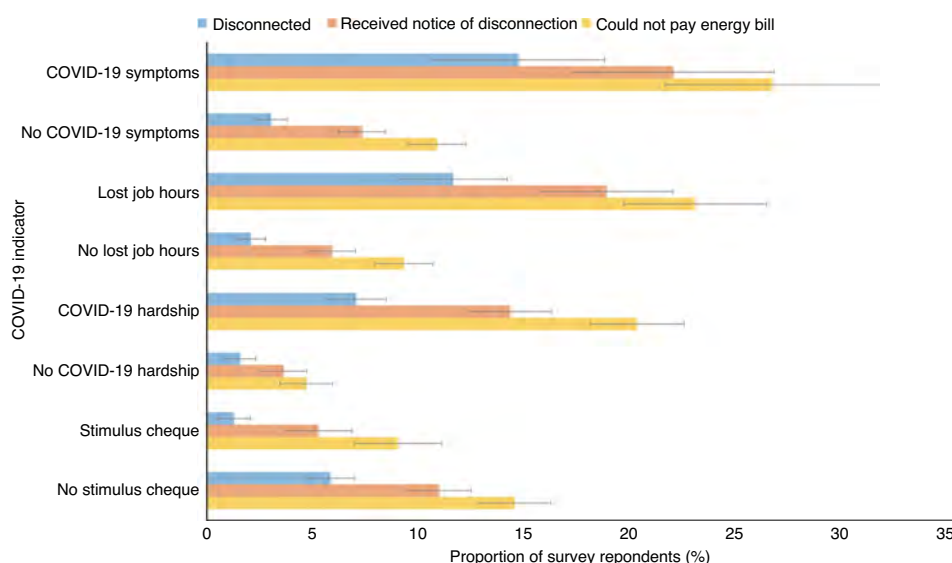


Fig. 4 | COVID-19-related conditions and energy insecurity. The proportion of households that could not afford an energy bill (yellow), received a disconnection notice (orange), or were disconnected from the grid (blue) in the past month by various COVID-19-related measures. Grey bars represent 95% CIs ($n = 2,381$).

with all three forms of energy insecurity. Those that reported having a household member with symptoms or a COVID-19 diagnosis had greater odds of reporting an inability to pay one's energy bill, whereas those who received a stimulus cheque had greater odds of avoiding utility disconnection. The results regarding the COVID-19 stimulus assistance may also capture unobserved characteristics about those that received this cash assistance (that is, stable residence and bank accounts). It is important to note that only about one-third of respondents reported that they had received a stimulus cheque.

Addressing energy insecurity is imperative

This study provides estimates of the prevalence of energy insecurity among low-income households in the United States, which reveal that approximately 4.8 million households were unable to pay at least one energy bill during the past year and a similar number received a notice from their utility that they faced the threat of disconnection from energy service. Of those that received a notice, more than two in five families had their energy shut off. These numbers equate to tens of millions of Americans.

We also found notable disparities across all three indicators of energy insecurity, which include race, families with young children, households with an individual who relies on an electronic medical device, and people who live in residences in poor condition. The latter results are consistent with previous works that identify housing conditions and inefficient housing stock as a leading contributor to energy insecurity in the United States^{18,34,39–41}. It is important to emphasize, moreover, that these inequalities exist, especially between Black and Hispanic households and White households, even when income is accounted. Given that people who experience these circumstances also tend to suffer from other types of material hardship, such as food insecurity^{13,20} and limited access to affordable health care¹⁸, these disparities in energy insecurity probably amplify the challenges that these vulnerable populations face.

Further, our analysis indicates that energy insecurity has intensified because of the COVID-19 pandemic. Both the economic dislocation and, to some extent, the virus itself are associated with difficulty in meeting household energy needs during the early period of the pandemic. Moreover, our results provide strong

suggestive evidence that the sociodemographic disparities that existed prepandemic—that is, during 'normal' circumstances—widened during the early months of the crisis. This finding is consistent with past research that showed that economic downturns tend to exacerbate material hardship among already vulnerable populations^{42,43}.

During the early months of the pandemic, US federal, state and local governments put a range of emergency measures in place to help households cope with material hardship (for example, eviction and utility shutoff moratoriums, expanded unemployment insurance, discounted housing payments and direct cash assistance). In the case of the electricity service specifically, many states adopted temporary shutoff protections to supplement the patchwork of existing state-level policies that limit the circumstances in which utilities can disconnect customers⁴⁴. As these temporary measures elapse, one might anticipate further incidence and severity of energy insecurity. In the short term, additional financial assistance programmes, extensions of state-level protections and the establishment of a national moratorium on electricity disconnections would mitigate household energy insecurity through the duration of the pandemic. In the long term, potential government interventions might include investments in energy efficiency programmes to help households afford energy.

There remains much to learn about the prevalence and determinants of energy insecurity. The findings in this study about race and ethnicity require further inquiry. Past work emphasizes that Blacks and Hispanics disproportionately experience energy insecurity⁴⁵; the analysis presented here indicates that this association holds, even after controlling for income and housing conditions. That is, there is something left unexplained about the energy experiences of Black and Hispanic households that needs to be identified to fully understand the prevalence of energy insecurity in these groups.

Among other unanswered questions are what strategies people employ to cope with energy insecurity. There are at least two important dimensions to examine. The first dimension relates to the financial strategies that people adopt to balance their energy needs with material hardship. Sociological research on material hardship, for example, found that households engage in credit balancing and strategic non-payment to manage their overall expenses⁴⁶. This type

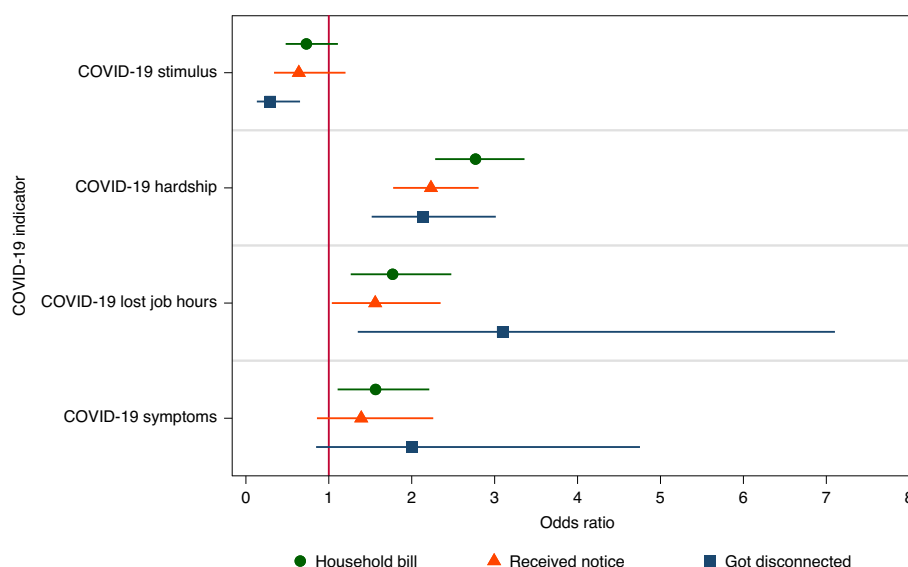


Fig. 5 | COVID-19-related correlates of energy insecurity. Odds ratios with 95% CIs, estimated from logistic regression models ($n = 2,287$). Models also include variables for households with children under 5, household member with a disability, unemployed, household member using an electronic device, retired, Black, Hispanic, other race or ethnicity, gender, age, income, education, dwelling type (mobile home, apartment, attached home), housing conditions, percent zip code urban and receipt of government assistance. Full model estimates are provided in Supplementary Table 4. Robustness checks using ordinary least squares estimation and other variations defined in the Methods section are presented in Supplementary Tables 5–12.

of behaviour may result in households accruing long-term debts, which may turn a short-term problem into a longer-term one. Households may also seek out relief or financial assistance from both formal (for example, utilities and government programmes such as the Low Income Home Energy Assistance Program or the Weatherization Assistance Program) and informal sources (for example, family and friends, faith-based organizations and other non-profit organizations).

Beyond the financial aspects, scholars should also continue to examine the behavioural response of individuals to energy insecurity¹, by which we mean how people cope with less electricity consumption, either because of concerns about affordability or due to the loss of service as a result of non-payment. For example, little is known, at least from large, quantitative studies, about how people stay cool during the summer months or warm during the winter months if they cannot afford to turn on their air conditioning or heat. Research on behaviours during times of crisis suggests that individuals may do more risky things¹⁰, which in this context could lead to severe adverse effects to health and well-being.

Methods

Survey design and implementation. The survey was fielded in an online format through a contract with YouGov, a private polling and market research firm. YouGov generates representative samples using a matched sample methodology. YouGov develops a target population from general population studies, from which it draws a random set of respondents to create a target sample. Using a matching algorithm, the firm selects potential respondents from its US panel of approximately two million opt-in participants that match the target sample⁴⁷, working with partner organizations to enhance its sample when necessary. YouGov's survey approach has been validated extensively^{47–49}.

For this survey, YouGov interviewed a total of 2,914 respondents who were matched down to the final dataset of 2,381 participants, using a sampling frame on gender, age, race and education constructed by stratified sampling from the 2017 ACS one-year sample of individuals whose income is at or below 200% of the FPL. The matched cases were weighted to the sampling frame using propensity scores, and then the matched cases and the frame were combined and a logistic regression was estimated for inclusion in the frame. The propensity score function included age, gender, race and/or ethnicity, education and geographical region. The propensity scores were grouped into deciles of the estimated propensity score

in the frame and poststratified according to these deciles. The weights were then poststratified on a four-way stratification of gender, age (four categories), race (four categories) and education (four categories) to produce the final weight, which was used in all the reported results and analyses. The survey has a margin of error of 2%.

Our research design focused on low-income households because energy insecurity tends to be more heavily concentrated among households in this economic category⁵⁰. We selected an income threshold of at or below 200% of the FPL for several reasons: (1) scholars⁵¹ and practitioners⁵² have previously relied on 200% of the FPL as an indicator of low-income households in the United States; (2) federal energy assistance programmes set their income limits at 150% of the FPL, so surveying households at or below 200% of the FPL allows us to collect a sample of households that are within and above income eligibility thresholds, and (3) we were more likely to achieve a nationally representative sample of US households by sampling households at or below 200% of the FPL, rather than 100% of the FPL.

The survey was administered between 30 April and 25 May 2020, and took respondents, on average, ten minutes to complete. We asked survey respondents to answer a series of questions about their housing conditions, health status and energy insecurity over the past year, as well as over the past month (a period that we define in this study as during April or May 2020). We also asked a series of questions specifically about how respondents' circumstances had changed since the onset of the COVID-19 pandemic, which we defined as beginning in the second week of March 2020, which roughly coincides with the timing of when state governments began to enact stay-at-home orders and social distancing measures.

Statistical analysis. To measure the determinants of energy insecurity, we employed a series of logistic regressions. The binary dependent variables measure whether (1) a respondent's household could not pay their energy bill, (2) their household received a disconnection notice and (3) their household electricity was disconnected. The survey asked respondents about these outcomes for different time frames, which enabled us to compare energy insecurity over the course of the past year with that in the past month (during the economic crisis brought about by the pandemic). To control for potential omitted variable biases due to unobserved interstate (across state) variation, we included a series of state dummy variables, which allowed us to exploit within-state variation. We further clustered standard errors at the state level to account for within-cluster correlations. We also conducted the year, month and COVID-19 specific analyses using linear regression analysis (Supplementary Tables 5 and 6). As for the logistic regressions, we included state dummy variables and clustered our standard errors at the state level. We found consistent outcomes across both the logistic and linear empirical specification for all three of our models.

Lastly, we conducted a final set of robustness checks that employed both the logistic and linear regression empirical specifications. To test whether our

COVID-19 measures were accounting for unmeasured variation, we narrowed the sample to those who experienced energy insecurity in the past year but not in the past month. This allowed us to check whether the material hardship, economic and health factors that relate to the pandemic remain statistically linked to energy insecurity. If the factors remained correlated, it suggests that the COVID-19 measures were merely accounting for some omitted variable and were not specific contributors to energy insecurity in the past month, or as the public health crisis began to unfold. Both the logistic (Supplementary Table 7) and linear (Supplementary Table 8) models largely revealed a loss of significance across the COVID-19 measures, which indicates that the pandemic and the economic disruption it caused is, in fact, responsible for deepening energy insecurity in the past month across our survey population. We also tested a set of regressions with an additional control variable for respondents' self-reported average monthly energy bill expenditure. Although household energy expenditures is a positive and significant predictor of our measures of energy insecurity in both time periods, we did not include this as a variable in our main models because 110 survey respondents did not report this value. Therefore, the missing observations would reduce our sample size by roughly 5 percent. Importantly, when controlling for energy expenditures, our results remain relatively consistent for both the logistic (Supplementary Tables 9 and 10) and linear (Supplementary Tables 11 and 12) models.

Ethics. This research involved human subjects. It was approved by the Indiana University Office of Research Compliance, under protocol number 2004296209. In accordance with this protocol, informed consent was provided by all the study participants.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Data and associated materials used in this study are available in the Harvard Dataverse repository³³, which includes the original survey data and codebook, the STATA data-processing do-file and the STATA data analysis do-file. Replication sources can be found at <https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/OMJWNB>.

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References

- Hernández, D. Understanding 'energy insecurity' and why it matters to health. *Soc. Sci. Med.* **167**, 1–10 (2016).
- Hernández, D., Aratani, Y. & Jiang, Y. (2014). *Energy Insecurity among Families with Children* (National Center for Children in Poverty, 2014).
- Residential Energy Consumption Survey 2015* (US Energy Information Administration, 2015).
- Thomson, H., Bouzarovski, S. & Snell, C. Rethinking the measurement of energy poverty in Europe: a critical analysis of indicators and data. *Indoor Built Environ.* **26**, 879–901 (2017).
- Thomson, H. & Snell, C. Quantifying the prevalence of fuel poverty across the European Union. *Energy Policy* **52**, 563–572 (2013).
- Bouzarovski, S. & Petrova, S. A global perspective on domestic energy deprivation: overcoming the energy poverty–fuel poverty binary. *Energy Res. Soc. Sci.* **10**, 31–40 (2015).
- Bouzarovski, S. Energy poverty in the European Union: landscapes of vulnerability. *Wiley Interdiscip. Rev. Energy Environ.* **3**, 276–289 (2014).
- Ürge-Vorsatz, D. & Herrero, S. T. Building synergies between climate change mitigation and energy poverty alleviation. *Energy Policy* **49**, 83–90 (2012).
- Bednar, D. J. & Reames, T. G. Recognition of and response to energy poverty in the United States. *Nat. Energy* **5**, 432–439 (2020).
- Meder, B., Le Lec, F. & Osman, M. Decision making in uncertain times: what can cognitive and decision sciences say about or learn from economic crises? *Trends Cogn. Sci.* **17**, 257–260 (2013).
- Levy, R. & Sledge, J. A. *Complex Portrait: An Examination of Small-Dollar Credit Consumers* (Center for Financial Services Innovation, 2012).
- Campbell, R. B. *Home Fires Involving Heating Equipment* (National Fire Protection Association, 2016).
- Bhattacharya, J., DeLeire, T., Haider, S. & Currie, J. Heat or eat? Cold-weather shocks and nutrition in poor American families. *Am. J. Public Health* **93**, 1149–1154 (2003).
- Bohr, J. & McCreery, A. C. Do energy burdens contribute to economic poverty in the United States? A panel analysis. *Soc. Forces* **99**, 155–177 (2020).
- Liddell, C. & Morris, C. Fuel poverty and human health: a review of recent evidence. *Energy Policy* **38**, 2987–2997 (2010).
- Mendell, M. J., Mirer, A. G., Cheung, K., Tong, M. & Douwes, J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. *Environ. Health Perspect.* **119**, 748–756 (2011).
- Shenassa, E. D., Daskalakis, C., Liebhaber, A., Braubach, M. & Brown, M. Dampness and mold in the home and depression: an examination of mold-related illness and perceived control of one's home as possible depression pathways. *Am. J. Public Health* **97**, 1893–1899 (2007).
- Hernández, D. & Siegel, E. Energy insecurity and its ill health effects: a community perspective on the energy–health nexus in New York City. *Energy Res. Soc. Sci.* **47**, 78–83 (2019).
- Berko, J., Ingram, D. D., Saha, S. & Parker, J. D. *Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006–2010* Report 76 (National Center for Health Statistics, Centers for Disease Control and Prevention, US Department of Health and Human Services, 2014).
- Cook, J. T. et al. A brief indicator of household energy security: associations with food security, child health, and child development in US infants and toddlers. *Pediatrics* **122**, e867–e875 (2008).
- Frank, D. A. et al. Heat or eat: the Low Income Home Energy Assistance Program and nutritional and health risks among children less than 3 years of age. *Pediatrics* **118**, e1293–e1302 (2006).
- Nord, M. & Kantor, L. S. Seasonal variation in food insecurity is associated with heating and cooling costs among low-income elderly Americans. *J. Nutr.* **136**, 2939–2944 (2006).
- Snyder, L. P. & Baker, C. A. Affordable home energy and health: making the connections. *AARP Public Policy Inst.* **1**, 5–36 (2010).
- Garg, S. et al. Hospitalization rates and characteristics of patients hospitalized with laboratory-confirmed coronavirus disease 2019—COVID-NET, 14 States, March 1–30, 2020. *Morbidity Mortal Wkly Rep.* **69**, 458–464 (2020).
- Thebault, R., Ba Tran, A., Williams, V. The coronavirus is infecting and killing black Americans at an alarmingly high rate. *Washington Post* (7 April 2020).
- Oppel Jr, R., Gebeloff, R. Lai, K., Wright, W., Smith, M. (2020). The Fullest Look Yet at the Racial Inequity of Coronavirus. *New York Times* (5 July 2020).
- Collins, C., Landivar, L. C., Ruppanner, L. & Scarborough, W. J. (2020). COVID-19 and the Gender Gap in Work Hours. *Gend. Work Organ.* <https://doi.org/10.1111/gwao.12506> (2020).
- Fairlie, R. W., Couch, K. & Xu, H. *The Impacts of COVID-19 on Minority Unemployment: First Evidence from April 2020 CPS Microdata* IZA DP no. 13264 (IZA Institute of Labor Economics, 2020).
- Montenovo, L. et al. *Determinants of Disparities in COVID-19 Job Losses* Working Paper 27132 (National Bureau of Economic Research, 2020).
- Carley, S. & Konisky, D. M. The justice and equity implications of the clean energy transition. *Nat. Energy* **5**, 569–577 (2020).
- Jenkins, K. E., Stephens, J. C., Reames, T. G. & Hernández, D. Towards impactful energy justice research: transforming the power of academic engagement. *Energy Res. Soc. Sci.* **67**, 101510 (2020).
- Hernández, D., Jiang, Y., Carrión, D., Phillips, D. & Aratani, Y. Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States. *J. Child. Poverty* **22**, 77–92 (2016).
- Mohr, T. M. Fuel poverty in the US: evidence using the 2009 residential energy consumption survey. *Energy Econ.* **74**, 360–369 (2018).
- Reames, T. G. Targeting energy justice: exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy* **97**, 549–558 (2016).
- Lyubich, E. *The Race Gap in Residential Energy Expenditures* Energy Institute WP 306 (Energy Institute at Haas, 2020).
- Jessel, S., Sawyer, S. & Hernández, D. Energy, poverty, and health in climate change: a comprehensive review of an emerging literature. *Front. Public Health* **7**, 357 (2019).
- Graff, M. & Carley, S. COVID-19 assistance needs to target energy insecurity. *Nat. Energy* **5**, 352–354 (2020).
- Gross Domestic Product, Fourth Quarter and Year 2019 (Advance Estimate)* (Bureau of Economic Analysis, 2020).
- Min, J., Hausfather, Z. & Lin, Q. F. A high-resolution statistical model of residential energy end use characteristics for the United States. *J. Ind. Ecol.* **14**, 791–807 (2010).
- Dubois, U. From targeting to implementation: the role of identification of fuel poor households. *Energy Policy* **49**, 107–115 (2012).
- Santamouris, M. et al. On the relation between the energy and social characteristics of the residential sector. *Energy Build.* **39**, 893–905 (2007).
- Pilkas, N. V., Currie, J. M. & Garfinkel, I. The great recession, public transfers, and material hardship. *Soc. Serv. Rev.* **86**, 401–427 (2012).
- Huang, J., Birkenmaier, J. & Kim, Y. Job loss and unmet health care needs in the economic recession: different associations by family income. *Am. J. Public Health* **104**, e178–e183 (2014).
- Flaherty, M., Carley, S. & Konisky, D. M. Electric utility disconnection policy and vulnerable populations. *Electr. J.* **33**, 106859 (2020).
- Lewis, J., Hernández, D. & Geronimus, A. Energy efficiency as energy justice: addressing racial inequities through investments in people and places. *Energy Effic.* **13**, 419–423 (2020).

46. Seefeldt, K. S. Constant consumption smoothing, limited investments, and few repayments: the role of debt in the financial lives of economically vulnerable families. *Soc. Serv. Rev.* **89**, 263–300 (2015).
47. Vavreck, L. & Rivers, D. The 2006 cooperative congressional election study. *J. Elect. Public Opin. Parties* **18**, 355–366 (2008).
48. Ansolabehere, S. & Rivers, D. Cooperative survey research. *Annu. Rev. Political Sci.* **16**, 307–329 (2013).
49. Ansolabehere, S. & Schaffner, B. F. Does survey mode still matter? Findings from a 2010 multi-mode comparison. *Political Anal.* **22**, 285–303 (2014).
50. Ross, L., Drehtobl, A. & Stickles, B. *The High Cost of Energy in Rural America: Household Energy Burdens and Opportunities for Energy Efficiency* (American Council for an Energy Efficient Economy, 2018).
51. She, P. & Livermore, G. A. Material hardship, poverty, and disability among working-age adults. *Soc. Sci. Q.* **88**, 970–989 (2007).
52. Karpman, M., Gonzalez, D., Zuckerman, S. & Adams, G. *What Explains the Widespread Material Hardship among Low-Income Families with Children?* (Urban Institute, 2018).
53. Memmott, T., Konisky, D., Carley, S. & Graff, M. *Replication Data for: Sociodemographic Disparities in Energy Insecurity among Low-Income Households Before and During the COVID-19 Pandemic* (Harvard Dataverse, 2020); <https://doi.org/10.7910/DVN/OMJWNB>
54. *Distribution of Total Population by Federal Poverty Level* (Kaiser Family Foundation, 2018).

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Author contributions

All the authors contributed to the conceptualization, research design, analysis and writing of this article.

Competing interests

The authors declare no competing interests.

Additional information

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Study description	A quantitative cross-sectional study of energy insecurity before and during the COVID-19 pandemic
Research sample	A nationally representative sample of 2,381 respondents at or below 200% of the Federal Poverty Line.
Sampling strategy	The survey was fielded through YouGov, which generates representative samples using a matched sample methodology. YouGov develops a target population from general population studies, from which it draws a random set of respondents to create a target sample.
Data collection	The survey was fielded in an online format through a contract with YouGov.
Timing	The survey was administered between April 30 and May 25, 2020.
Data exclusions	No data were excluded.
Non-participation	No participants dropped out/declined participation.
Randomization	N/A

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Describe the sequencing depth for each experiment, providing the total number of reads, uniquely mapped reads, length of reads and whether they were paired- or single-end.

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Experimental design

- Design type *Indicate task or resting state; event-related or block design.*
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- Imaging type(s) *Specify: functional, structural, diffusion, perfusion.*
- Field strength *Specify in Tesla*
- Sequence & imaging parameters *Specify the pulse sequence type (gradient echo, spin echo, etc.), imaging type (EPI, spiral, etc.), field of view, matrix size, slice thickness, orientation and TE/TR/flip angle.*
- Area of acquisition *State whether a whole brain scan was used OR define the area of acquisition, describing how the region was determined.*
- Diffusion MRI ☐ Used ☐ Not used

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- Preprocessing software *Provide detail on software version and revision number and on specific parameters (model/functions, brain extraction, segmentation, smoothing kernel size, etc.).*
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Statistical modeling & inference

Model type and settings *Specify type (mass univariate, multivariate, RSA, predictive, etc.) and describe essential details of the model at the first and second levels (e.g. fixed, random or mixed effects; drift or auto-correlation).*

Effect(s) tested *Define precise effect in terms of the task or stimulus conditions instead of psychological concepts and indicate whether ANOVA or factorial designs were used.*

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both

Statistic type for inference (See [Eklund et al. 2016](#)) *Specify voxel-wise or cluster-wise and report all relevant parameters for cluster-wise methods.*

Correction *Describe the type of correction and how it is obtained for multiple comparisons (e.g. FWE, FDR, permutation or Monte Carlo).*

Models & analysis

n/a | Involved in the study
☐ ☐ Functional and/or effective connectivity
☐ ☐ Graph analysis
☐ ☐ Multivariate modeling or predictive analysis

Functional and/or effective connectivity *Report the measures of dependence used and the model details (e.g. Pearson correlation, partial correlation, mutual information).*

Graph analysis *Report the dependent variable and connectivity measure, specifying weighted graph or binarized graph, subject- or group-level, and the global and/or node summaries used (e.g. clustering coefficient, efficiency, etc.).*

Multivariate modeling and predictive analysis *Specify independent variables, features extraction and dimension reduction, model, training and evaluation metrics.*

Community Organizing and Family Issues (COFI)
and Legal Action Chicago
Ex. 1.0 (CORR)

State of Illinois
Illinois Commerce Commission

The Peoples Gas Light and Coke	)	
Company	)	
	)	
Proposed general increase in rates and	)	
Revisions to service classifications,	)	
riders and terms and conditions of	)	
service	)	
	)	
and	)	Docket Nos. 23-0068 / 23-0069 (cons.)
	)	
North Shore Gas Company	)	
	)	
Proposed general increase in rates and	)	
Revisions to service classifications,	)	
riders and terms and conditions of	)	
service	)	

Direct Testimony of
Roger D. Colton
On Behalf Of
Community Organizing and Family Issues (COFI)
and
Legal Action Chicago
(Corrected)

Community Organizing and Family Issues (COFI)
and Legal Action Chicago
Ex. 1.0 (CORR)

May 9, 2023

Community Organizing and Family Issues (COFI)
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Community Organizing and Family Issues (COFI)
and Legal Action Chicago
Ex. 1.0 (CORR)

1 **Q. PLEASE STATE YOUR NAME AND ADDRESS.**

2 A. My name is Roger Colton. My address is 34 Warwick Road, Belmont, MA 02478.

3 **Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT POSITION?**

4 A. I am the owner of the firm Fisher Sheehan & Colton, Public Finance and General
5 Economics of Belmont, Massachusetts. In that capacity, I provide technical assistance to
6 a variety of federal and state agencies, consumer organizations and public utilities on rate
7 and customer service issues involving water/sewer, natural gas and electric utilities.

8 **Q. ON WHOSE BEHALF ARE YOU TESTIFYING IN THIS PROCEEDING?**

9 A. I am testifying on behalf of Community Organizing and Family Issues (COFI) and Legal
10 Action Chicago, both of Chicago, Illinois. COFI's mission is to build the power and
11 voice of parents, primarily mothers and grandmothers from Black and Brown
12 communities, to shape the public decisions that affect their lives and the lives of their
13 families. COFI envisions a world with racial, economic, and educational justice where all
14 children and families have an equal opportunity to succeed in life. In addition to its
15 Chicago-based office, COFI also has offices in Aurora, Elgin and East St. Louis.

16 Legal Action Chicago is a not-for-profit legal agency that focuses not on individual
17 disputes, but on policies and systems that harm groups of people or even entire
18 communities, with a priority on addressing racial equity. Working with and for people
19 living in poverty, and in collaboration with community leaders, Legal Action Chicago
20 advocates for broad positive changes through various approaches, which includes
21 legislative initiatives, regulatory advocacy, and class action lawsuits.

Community Organizing and Family Issues (COFI)
and Legal Action Chicago
Ex. 1.0 (CORR)

1 **Q. PLEASE DESCRIBE YOUR PROFESSIONAL BACKGROUND.**

2 A. I work primarily on low-income utility issues. This involves regulatory work on rate and
3 customer service issues, as well as research into low-income usage, payment patterns,
4 and affordability programs. At present, I am working on various projects in the states of
5 Connecticut, Maryland, Pennsylvania, Ohio, Michigan, Illinois, and Washington. My
6 clients include state agencies (e.g., Pennsylvania Office of Consumer Advocate,
7 Maryland Office of People’s Counsel, Connecticut Office of Consumers Council), federal
8 agencies (e.g., the U.S. Department of Health and Human Services), community-based
9 organizations (e.g., National Housing Trust, Natural Resources Defense Council, Sierra
10 Club), and private utilities (e.g., Toledo Water).

11
12 Not all of my work involves rate case testimony. For example, I recently completed,
13 under contract to the City of Toledo, Ohio, a draft Water Affordability Plan for that city.
14 In May of last year, I completed a detailed report examining the affordability of water
15 service in Knoxville, Kentucky for a community-based organization, Knoxville Water
16 and Energy for All (KWEA). In October of 2022, I completed an evaluation of the
17 Electric Assistance Program (EAP) for the New Hampshire Public Utilities Commission.

18 In addition to state-specific and utility-specific work, I engage in national work
19 throughout the United States. For example, in 2020, I represented a coalition of major
20 national consumer organizations to comment on the Environmental Protection Agency’s
21 proposed framework by which to judge community financial capability. I also continue
22 to be “Of Counsel” to the National Coalition for Legislation on Affordable Water

Community Organizing and Family Issues (COFI)
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(NCLA-Water). A brief description of my professional background is provided in
Appendix A.

Q. PLEASE DESCRIBE YOUR EDUCATIONAL BACKGROUND.

A. After receiving my undergraduate degree in 1975 (Iowa State University), I obtained
further training in both law and economics. I received my law degree in 1981 from the
University of Florida. I received my Master's Degree in Regulatory Economics from the
MacGregor School at Antioch University in 1993.

**Q. HAVE YOU EVER PUBLISHED ON PUBLIC UTILITY REGULATORY
ISSUES?**

A. Yes. I have published three books and more than 80 articles in scholarly and trade
journals, primarily on low-income utility and housing issues. I have published three
times that number of technical reports for various clients on energy, water,
telecommunications and other associated low-income utility issues. My most recent
publication (2018) was a chapter in a book published by the London-based Edward Elgar
Publishing, which book was titled "Energy Justice: US and International Perspectives."
My chapter, "The equities of efficiency: distributing energy usage reduction dollars," set
forth a methodology grounded in law and economics by which to objectively measure
whether utility investments in energy efficiency are being equitably distributed.

**Q. HAVE YOU EVER TESTIFIED BEFORE THIS OR OTHER UTILITY
COMMISSIONS?**

Community Organizing and Family Issues (COFI)
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1 A. Yes. I have testified before the Illinois Commerce Commission (“ICC” or
2 “Commission”) on several occasions over the past 35 years on issues affecting universal
3 service and customer service for electric, natural gas, and water providers. Most recently,
4 I testified on behalf the Office of the Attorney General in the 2018 uncollectible
5 reconciliation proceedings involving Commonwealth Edison (Docket No. 18-1456),
6 Ameren Energy (Docket No. 18-1486), Nicor Gas (Docket No. 18-1437), and Peoples
7 Gas/North Shore Gas (Docket Ns. 18-1464 / 18-1465). I also previously worked as an
8 attorney for the Illinois Governor’s Office of Consumer Services (GOCS).

9 Overall, I have testified before state utility regulatory commissions on more than 320
10 occasions regarding utility issues affecting low-income customers and customer service.
11 I have testified in regulatory proceedings in 43 states and various Canadian provinces on
12 a wide range of utility issues. A list of the jurisdictions in which I have testified as an
13 expert witness is listed in Appendix A.

14 **Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?**

15 A. The purpose of my Direct Testimony is to examine and respond to the Company’s
16 proposed low-income discount rate and rate design in this proceeding. In my testimony, I
17 examine:

- 18 ➤ the affordability of the natural gas rates of Peoples Gas Light and Coke
19 Company and North Shore Gas Company for each company’s low-income
20 customers;
- 21 ➤ the relationship between low-income bill affordability and a range of
22 traditional utility regulatory policies, including using utility rates to provide
23 price signals; using utility rates to encourage the efficient use of energy; and
24 promoting efficient and effective collections practices;

Community Organizing and Family Issues (COFI)
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- a set of reasonable modifications to PGL/NSG's proposed low-income discounts that will better promote affordability and, by extension, will better achieve the identified traditional utility regulatory objectives; and
- the Companies' current and proposed residential customer charges, and propose modifications that better align with affordability principles.

**Q. PLEASE SUMMARIZE THE RECOMMENDATIONS YOU MAKE
THROUGHOUT YOUR TESTIMONY.**

A. Based on the data and analysis I present throughout my testimony, I recommend as follows:

- 1) The PGL and NSG low-income discounts should be comprised of five tiers rather than two tiers. The tiers should be: (1) Below 50% of FPL; (2) 50% to 100% of FPL; (3) 100% to 150% of FPL; (4) 150% to 200% of FPL; and a fifth tier not covered by the Companies' current proposal, (5) 200% to 300% of FPL.
- 2) The tiered discounts provided through PGL/NSG discounts should be based on the total bill.
- 3) The tiered discounts provided through PGL should be as follows: (1) Tier 1: 83%; (2) Tier 2: 68%; (3) Tier 3: 45%; (4) Tier 4: 20%; and (5) Tier 5: 5%. The Tiered discounts provided through NSG should be as follows: (1) Tier 1: 79%; (2) Tier 2: 60%; (3) Tier 3: 36%; (4) Tier 4: 12%; and (5) Tier 5: 5%.
- 4) For those customers at or below 200% of FPL, tiered discounts provided through PGL/NSG should be applied to customers who are income-eligible for LIHEAP, rather than limited to customers who are current *participants* in a LIHEAP program.

Community Organizing and Family Issues (COFI)
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1 5) The Companies' proposed increases to the customer charge portion of the bill take
2 a higher proportion of household resources out of monthly incomes, and make it
3 more difficult for low-income customers to control their exposure to unaffordable
4 bills through the implementation of energy efficiency measures. In addition, the
5 actions that low-income customers are forced to take as efforts to control their
6 bills (e.g., keeping their homes too hot or too cold, shutting off their home but for
7 a limited space) have less of an impact on reducing their bills to more affordable
8 levels the higher the fixed customer charge. In any rate order approved in this
9 proceeding, the Commission should not increase the customer charge and, in fact,
10 should reduce the percentage of revenues collected through the customer charge
11 over the levels the Companies now collect.

12 This is a summary of my recommendations. Each recommendation is presented in more
13 detail in the body of my testimony.

14 **Part 1. The Affordability of PGL/NSG Natural Gas Service.**

15 **Q. PLEASE EXPLAIN THE PURPOSE OF THIS SECTION OF YOUR**
16 **TESTIMONY.**

17 **A. In this section of my testimony, I assess the ongoing affordability of natural gas service**
18 **provided by Peoples Gas Light and Coke Company (hereafter "PGL" or "Peoples") and**
19 **North Shore Gas Company (hereafter "NSG" or "North Shore").**

20 **Q. HAVE YOU HAD OCCASION TO REVIEW THE HISTORY OF PGL'S AND**
21 **NSG'S RESIDENTIAL BILLS?**

Community Organizing and Family Issues (COFI)
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1 A. Yes. I have reviewed average PGL and NSG residential bills as reported in the
2 Commission's annual "Comparison of Gas Sales Statistics." I have set forth in the Chart
3 below the data reported by the Commission for each year from 2013 through 2021 (the
4 last year for which the Commission has published data). As can be seen, there was a
5 short-term spike in PGL bills in 2014 (to \$1,478). Even setting aside that short-term
6 spike, PGL bills have consistently been higher than average natural gas bills for the State
7 as a whole. In 2021, PGL bills were nearly 20% higher than the statewide average. From
8 2013 through 2019, PGL's residential bills were consistently between 30% and 45%
9 higher than the statewide average.

10 I compare these trends in bills to low-income status in the PGL and NSG service
11 territories. More specifically, I examine the First Quintile (Q1) of Income for the zip
12 codes comprising each utility's service territory.¹ I matched each company's zip codes
13 with average Q1 incomes² by zip code reported by the Census Bureau for 2021.³ I

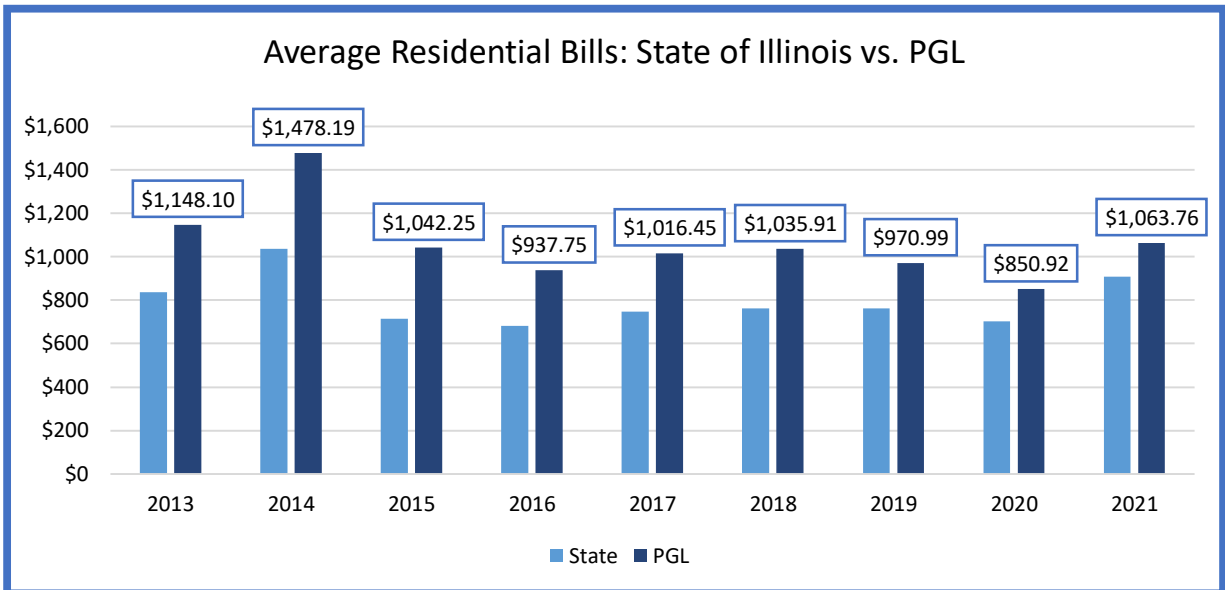
¹ The zip codes for the PGL and NSG service territories are those reported in each utility's filing of Disconnections and Credit and Collection Report filed monthly with the Commission.

² American Community Survey, 5-year data, 2021, Table B19081.

³ The Census data I use is for Zip Code Tabulation Areas (ZCTAs). ZCTAs are nearly, but not quite, identical to Zip Codes. ZCTAs are used by the U.S. Census Bureau, while Zip Codes are creatures of the U.S. Postal Service. According to the U.S. Census Bureau: "ZIP Code Tabulation Areas (ZCTAs) are generalized areal representations of United States Postal Service (USPS) ZIP Code service areas. The USPS ZIP Codes identify the individual post office or metropolitan area delivery station associated with mailing addresses. USPS ZIP Codes are not areal features but a collection of mail delivery routes. The term ZCTA was created to differentiate between this entity and true USPS ZIP Codes." For a generalized discussion of the differences between Zip Codes and ZCTA, *See* U.S. Census Bureau, *ZIP Code Tabulation Areas*, <https://www.census.gov/programs-surveys/geography/guidance/geo-areas/zctas.html> (last accessed May 9, 2023).

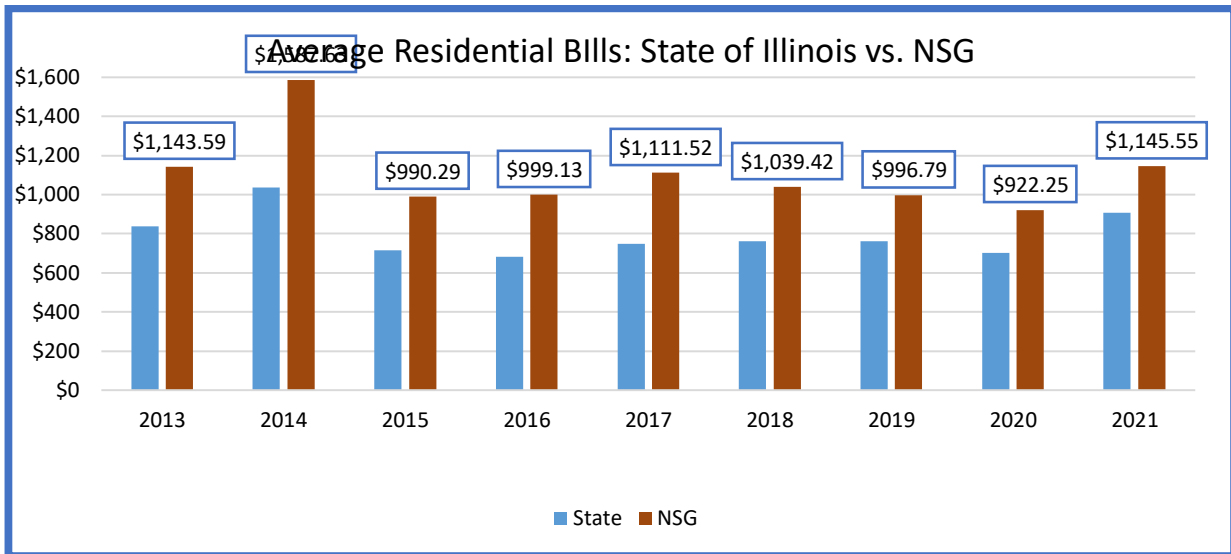
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examine the zip code with the lowest Q1 income amongst PGL's and NSG's zip codes
and tracked that Q1 income for the time period 2013 through 2021.



A similar trend can be seen in NSG rates. Since 2013, NSG residential bills have been higher than statewide average bills in every single year. NSG bill been at least 25% higher than statewide average residential bills in the period 2013 through 2021. From 2014 through 2017, NSG residential bills were roughly 50% higher than the statewide average residential bills. From 2018 through 2021, NSG residential bills were between 25% and 35% higher than the statewide average.

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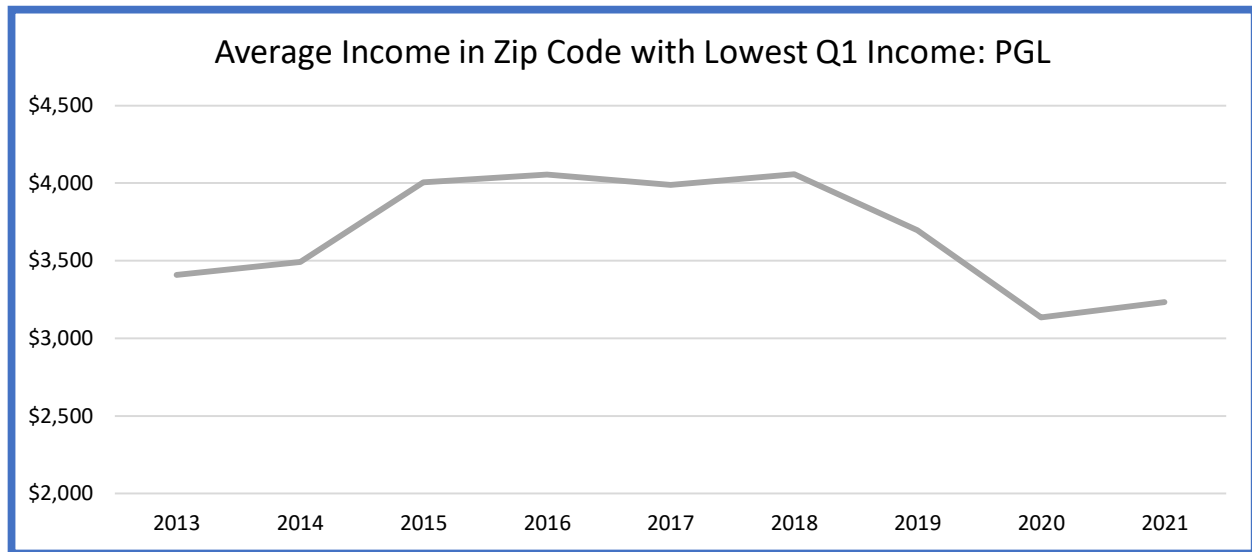
Q. HAVE YOU HAD AN OPPORTUNITY TO COMPARE THESE NATURAL GAS BILLS TO THE INCOMES OF LOWER-INCOME HOUSEHOLDS?

A. Yes. In the Chart below, I track the average income in the zip code with the lowest First Quintile (Q1) income⁴ in the PGL service territory.⁵ Two observations are evident from this data. First, the average Q1 income is lower in 2021 than it was in 2016 through 2018, even without accounting for inflation. Thus, while PGL bills were 13% higher in 2021 than they were in 2016, Q1 incomes were lower. While PGL bills increased by 25% from 2020 to 2021, Q1 incomes in the group of households with the lowest incomes served by PGW increased by only 3%.

⁴ The Census Bureau rank orders households by income, from the lowest income to the highest income in each geographic area for which it publishes data. It then divides that rank ordering into five equal parts, each part of which is called a "quintile." The one-fifth of households with the lowest income is known as the First Quintile (Q1) (sometimes referred to as the Bottom Quintile), while the one-fifth of households with the highest income is known as the Fifth Quintile (sometimes referred to as the Top Quintile).

⁵ U.S. Census Bureau, American Community Survey, Table B19081, 2013–2021.

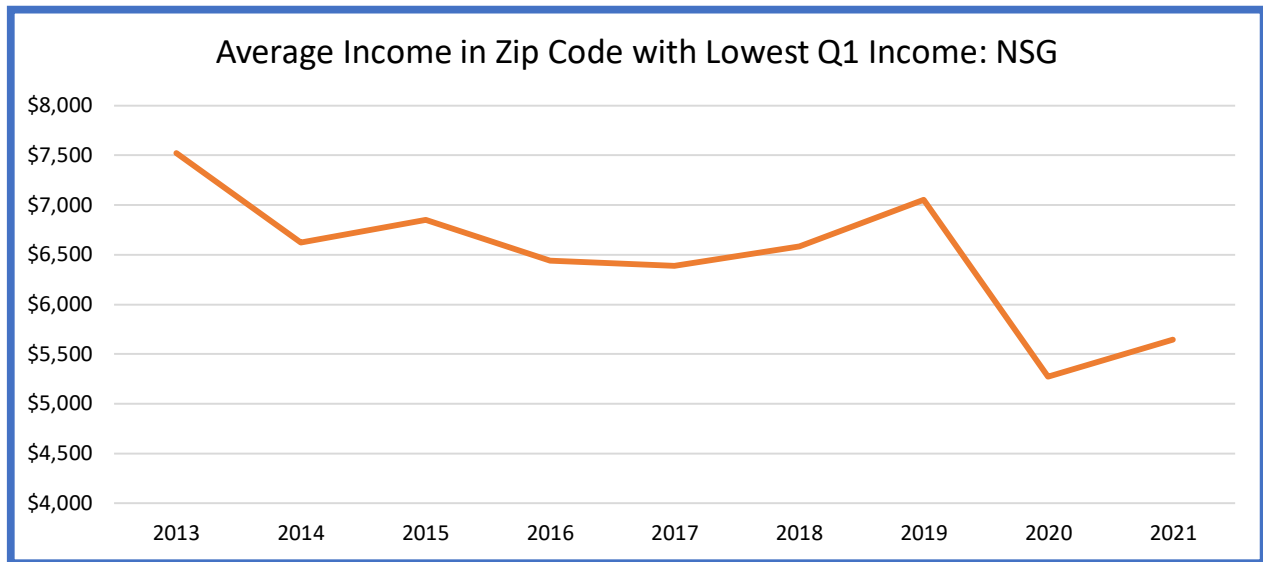
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The lowest incomes in the NSG service territory show an even more dramatic difference.

The Chart below shows the equivalent data I discuss above, except with respect to the NSG service territory. As can be seen, in the zip code with the lowest Q1 income in the NSG service territory, the average income has seen a sharp decline since 2013. Even with the slight uptick in Q1 income in 2021 as compared to 2020, the average Q1 income in 2021 was 25% lower than it was in 2013. The average 2021 Q1 income ranged from 12% to 15% lower than the average Q1 income had been in the period 2016 through 2018.

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As with PGL, there is a mismatch between the movement in NSG bills and the movement in NSG low incomes. For example, at the same time the Q1 incomes had declined by 20% (2019 through 2021), NSG bills had increased by 20% (from \$997 in 2019 to \$1,146 in 2021). Over the same period NSG bills had increased by 20% (2015 to 2021), NSG Q1 incomes had declined by 18%.

Finally, it is worth noting that across both PGL's and NSG's service territory, the real-world purchasing power of customers' incomes—including Q1 customers—has shrunk due to the effects of inflation. These customers' average incomes have dropped in raw dollars, while at the same time, the cost of necessary goods and services has continued to rise, particularly over the past two years.⁶

⁶ U.S. Dep't of Labor, Bureau of Labor Statistics, CPI Inflation Calculator, https://www.bls.gov/data/inflation_calculator.htm (last accessed May 9, 2023); U.S. Dep't of Labor, Bureau of Labor Statistics, CPI for All Urban Consumers (CPI-U), https://data.bls.gov/timeseries/CUUR0000SA0L1E?output_view=pct_12mths (last accessed May 9, 2023).

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Q. HAVE YOU EXAMINED PGL AND NSG BILL BURDENS?

A. Yes. I have examined both PGL and NSG bill burdens from two different perspectives: (1) existing rates; and (2) proposed rates. Using data provided by PGL and NSG,⁷ I have examined bills as a percentage of income (i.e., “bill burdens”) both at existing and at proposed rates.⁸ Throughout my testimony, my reference to bill burdens or natural gas burdens references this total bill burden, unless I expressly note to the contrary. I then calculate average natural gas burdens for each zip code served by the two utilities at differing ranges of the Federal Poverty Level (given average household size in each zip code). Using data from PGL’s Schedule A-3 filed in this proceeding, I calculated the average annual revenue for PGL heating customers.

PGL Annual Avg Revenue ⁹ (Schedule A-3, Line 3)	Current Rates	Proposed Rates
Residential Heating ¹⁰	\$1,136	\$1,472

⁷ (Part 1), 285 Filing (Schedules), Schedule A-3, filed pursuant to 83 Ill. Admin. Code, §285.1015.

⁸ “Bill burdens” represent a simple ratio. I place the average annual bill in the numerator and the annual household income in the denominator. The resulting ratio is the “bill burden.” For example, if a household has an annual bill of \$1,200 and an annual income of \$8,000, that household’s “bill burden” is 15% ($\$1,200 / \$8,000 = 0.15$).

⁹ Base rate revenues reported by the Company exclude revenue from Riders 1, and excludes ratemaking adjustments for Rider UEA, UEA-GC, ICTA, VITA and VBA. Schedule A-3.

¹⁰ PGL reports that it has 655,786 heating customers and 92,604 non-heating customers. Accordingly, the focus in my discussion will be on natural gas heating customers.

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I then use the revenues reported in NSG’s Schedule A-3 filed in this proceeding to
determine average annual residential heating revenues.¹¹

NSG Annual Avg Revenue ¹² (Schedule A-3, Line 3)	Current Rates	Proposed Rates
Residential Heating ¹³	\$1,261	\$1,345

For purposes here, I define “affordability” to be a total home energy burden of 6%. That
6% burden has been the standard most frequently relied upon by policymakers with
respect to affordable home energy.¹⁴ The 6% burden has been frequently adopted,¹⁵

¹¹ NSG reports that it served 135,666 heating customers and 1,485 non-heating customers. Accordingly, the focus in my discussion will be on natural gas heating customers.

¹² Base rate revenues reported by the Company exclude revenue from Riders 1, and excludes ratemaking adjustments for Rider UEA, UEA-GC, ICTA, VITA and VBA. Schedule A-3.

¹³ PGL reports that it has 655,786 heating customers and 92,604 non-heating customers. Accordingly, the focus in my discussion will be on natural gas heating customers.

¹⁴ Throughout my testimony, unless I explicitly note to the contrary, the terms “home energy burdens” and “energy bill burdens” are intended to be used interchangeably.

¹⁵ 6% is based on the recognition that total shelter costs are generally deemed to be unaffordable to the extent that they exceed 30% of income. Moreover, utility costs tend to equal 20% of total shelter costs. A multiplication of those two data points (20% times 30%) yields the 6% figure.

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1 including in the states of Washington,¹⁶ New Hampshire,¹⁷ New York,¹⁸ New Jersey,¹⁹
2 and Illinois.²⁰ In addition, the Pennsylvania PUC has capped home energy burdens for
3 households with annual income at or below 50% of Poverty Level at 6% of income.²¹
4 Most recently, the Connecticut Public Utilities Regulatory Authority (PURA) held that a
5 6% burden for total home energy costs was the appropriate definition of affordability.²²

6 Having defined an affordable total home energy burden as being equal to 6%, that
7 burden needs to be allocated between natural gas bills and electric bills. Non-
8 governmental organizations have also widely adopted this affordability measure.²³ I then

¹⁶ WASH ADMIN. CODE § 194-40-030 (2021) (“‘Energy assistance need’ means the amount of assistance necessary to achieve an energy burden equal to six percent for utility customers”).

¹⁷ New Hampshire Pub. Utils. Comm’n, Dkt. No. DE 06-079, Order No. 24,664, 3–4 (Sept. 1, 2006). (“[T]he current [Electric Assistance Program] was designed with the goal of making electricity affordable at 4 % of gross household income for non-electric heat customers (and at 6% of income for households with electric heat).”).

¹⁸ New York Pub. Serv. Comm’n, Case 14-M-0565, *Order Adopting Low Income Program Modifications and Directing Utility Filings*, 7–48 (effective May 20, 2016) (favoring a 6% energy burden level because it appears to be a widely accepted limit for utility payments, including in New Jersey and Ohio; and also reflected by EIA data).

¹⁹ New Jersey Dep’t of Community. Affairs, *Universal Service Fund (USF)*, <https://www.state.nj.us/dca/divisions/dhcr/faq/usf.html#q1> (last visited Mar. 24, 2023). (requiring USF customers who use natural gas for heating and electricity to pay 2% for their natural gas service and 2% for their electricity service. If, however, the customer uses electricity for heating, the entire 4% is devoted to the electricity service. The discount provided to customers is based on the difference between their annual utility bill (after LIHEAP is applied) and the required percentage of household income.).

²⁰ 305 ILCS 20/18(c)(2) (2022) (Illinois administers a percentage of income plan (PIP) that charges customers a maximum of 6% of their income for gas and electric service.).

²¹ Pennsylvania Pub. Util. Comm’n, Docket M-2019-3012599, Final Policy Statement and Order, 29–31 (Sept. 19, 2019).

²² Connecticut Pub. Util. Reg. Auth., Dkt. No. 17-12-03RE11, Decision, 2 (Oct. 19, 2022).

²³ See e.g., Am. Council for an Energy-Efficient Economy, *Understanding Energy Affordability*, available at <https://aceee.org/sites/default/files/energy-affordability.pdf> (last accessed May 9, 2023); Sierra Club, *Calculate Your Energy Burden*, available at <https://www.sierraclub.org/energy-burden-calculator> (last accessed May 9, 2023).

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1 allocate the 6% burden as 3% for electricity and 3% for natural gas, consistent with
2 Illinois policy as expressed in the Energy Assistance Act.²⁴ (The Companies appear to
3 support this allocation as well. (See NSG Response to JM 3.01 (“The goal [of the low-
4 income rate proposal as the Companies structured it] was to get as many LIHEAP and
5 PIPP customers to a point where they were paying approximately 3% of their income
6 towards their natural gas bill.”))

7 Whatever specific home energy burden is ultimately used to define
8 “affordability,” however, the affordability of PGL/NSG bills should be structured to
9 adopt the principle that it is most appropriate to measure bill affordability by reference to
10 bills as an affordable percentage of income. The adoption of a percentage-based
11 benchmark by various states and other actors in the utilities space, discussed above,
12 supports this perspective. Furthermore, using a percentage of household income analysis
13 is consistent with the approach to assessing the cost burden of other housing-relating
14 expenses, including water/sewer, mortgages and rent. Finally, it is consistent with
15 common sense: a good or service is not “affordable” merely because it costs five, ten, or
16 twenty dollars; it is only “affordable” relative to a person’s actual ability to purchase it
17 within their household budget.

18 The results of my analysis are presented from two perspectives. First, I examine
19 the “depth” of unaffordability. In examining the depth of Poverty, the question presented
20 is “how unaffordable are PGL/NSG bills.” Second, I examine the “breadth” of

²⁴ 305 ILCS 20/18(c)(2) (2022) (“If the [PIPP program] participant takes both gas and electric service, 50% of the credit shall be allocated to the entity that provides the participant’s primary energy suppl for heating.”)

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unaffordability. In examining the breadth of unaffordability, I examine the question
“how prevalent are unaffordable PGL/NSG bills.”

**Q. WHAT DO YOU FIND REGARDING THE DEPTH OF PGL/NSG
UNAFFORDABILITY?**

A. Table 1 presents a summary of the depth of PGL/NSG unaffordability. For both utilities,
customers with income at or below 50% of Poverty have bill burdens more than four
times higher than the affordable level (of 3%). Not surprisingly, as incomes increase, the
depth of unaffordability declines. By the time incomes reach between 100% and 150%
of Poverty, the bill burden is only 1.5 times higher than that which is affordable. By the
time incomes reach between 150% and 200% of Poverty, both NSG and PGL bill
burdens reach 3.1% (both remaining higher than the affordable level).

Table 1. Average PGL/NSG Bill Burdens at Selected Poverty Ranges (Existing Rates)			
PGL Bill Burdens			
0 – 50% FPL	50 – 100% FPL	100 – 150% FPL	150 – 200% FPL
13.4%	7.2%	4.3%	3.1%
NSG Bill Burdens			
0 – 50% FPL	50 – 100% FPL	100 – 150% FPL	150 – 200% FPL
13.6%	7.3%	4.4%	3.1%

Both utilities, however, propose substantial rate hikes in this proceeding. The
Table below shows the extent to which the affordability of natural gas burdens in each
service territory will decline even further given those rate increases. PGL bill burdens
climb even higher than NSG burdens do— nearly six times higher than that which is

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deemed to be affordable at incomes less than 50% of Poverty. Bills for both PGL and NSG remain substantially in excess of an affordable burden for both natural gas utilities.

Table 2. Average PGL/NSG Bill Burdens at Selected Poverty Ranges (Proposed Rates)			
PGL Bill Burdens			
0 – 50% FPL	50 – 100% FPL	100 – 150% FPL	150 – 200% FPL
17.4%	9.3%	5.6%	4.0%
NSG Bill Burdens			
0 – 50% FPL	50 – 100% FPL	100 – 150% FPL	150 – 200% FPL
14.5%	7.8%	4.7%	3.3%

Q. WHAT DO YOU FIND REGARDING THE BREADTH OF PGL/NSG UNAFFORDABILITY?

A. The Tables above show only the depth of unaffordability in the PGL/NSG service territories. The breadth of unaffordability is shown in Table 3 (PGL) and Table 4 (NSG) below. My focus in these Tables is on burdens at the proposed rates of the two respective utilities. The Tables show the unreasonable burdens that would be imposed on the low-income customers in the PGL and NSG service territories at the rates proposed in this proceeding.

Of the 56 zip codes studied in the PGL service territory, average PGL burdens fell between 13% and 23% of income for households with income less than 50% of Poverty at proposed rates. In the vast majority of zip codes, average PGL bill burdens fell between 15% and 20% of income (41 of 56 zip codes). No PGL zip code had a burden exceeding 23% at proposed rates, and no zip code had a burden of less than 13 at proposed rates.

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As would be expected, as incomes increase, the PGL/NSG burdens decline. Even with the decline, PGL/NSG burdens never reach an affordable level. At incomes between 50% and 100% of Poverty, average NSG burdens are between 7% and 12% of income. At incomes between 100% and 150% of Poverty, natural gas burdens are between 4% and 5% of income in 55 of PGL's 56 zip codes.

<i>Table 3. PGL Natural Gas Bill Burdens at Proposed Rates and Selected Ranges of Federal Poverty Level (FPL)</i>							
<i><50% FPL</i>		<i>50 – 100% FPL</i>		<i>100 – 150% FPL</i>		<i>150 – 200% FPL</i>	
<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>
<i><13%</i>	<i>0</i>	<i><7%</i>	<i>0</i>	<i><4%</i>	<i>0</i>	<i><3%</i>	<i>0</i>
<i>13-14%</i>	<i>2</i>	<i>7-8%</i>	<i>6</i>	<i>4-5%</i>	<i>14</i>	<i>3-4%</i>	<i>32</i>
<i>14-15%</i>	<i>4</i>	<i>8-9%</i>	<i>21</i>	<i>5-6%</i>	<i>27</i>	<i>4-5%</i>	<i>23</i>
<i>15-16%</i>	<i>13</i>	<i>9-10%</i>	<i>14</i>	<i>6-7%</i>	<i>14</i>	<i>5-6%</i>	<i>1</i>
<i>16-17%</i>	<i>9</i>	<i>10-11%</i>	<i>8</i>	<i>7-8%</i>	<i>1</i>	<i>>6%</i>	<i>0</i>
<i>17-18%</i>	<i>6</i>	<i>11-12%</i>	<i>7</i>	<i>>8%</i>	<i>0</i>		
<i>18-19%</i>	<i>8</i>	<i>>12%</i>	<i>0</i>				
<i>19-20%</i>	<i>5</i>						
<i>20-21%</i>	<i>5</i>						
<i>21-22%</i>	<i>3</i>						
<i>22-23%</i>	<i>1</i>						
<i>>23%</i>	<i>0</i>						

The range of unaffordable burdens is narrower for NSG, a not surprising result given its smaller service territory and customer base. For customers with income less than 50% of FPL, no zip code had an average NSG burden in excess of 17%, but no zip code had an average burden of less than 12% of income. By the time incomes had increased to between 150% and 200% of income, 27 of the 28 zip codes studied had average burdens

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of between 3% and 4% of income. The intermediate ranges of FPL had burdens falling between those two ends of the continuum of burdens for low-income customers, with maximum burdens for customers at 50% to 100% of Poverty not exceeding 9% of income, and maximum burdens for customers at 100% to 150% of Poverty not exceeding 6% of income.

<i>Table 4. NSG Natural Gas Bill Burdens at Proposed Rates and Selected Ranges of Federal Poverty Level (FPL)</i>							
<i><50% FPL</i>		<i>50 – 100% FPL</i>		<i>100 – 150% FPL</i>		<i>150 – 200% FPL</i>	
<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>	<i>Burden</i>	<i>No. Zip Codes</i>
<i><12%</i>	<i>0</i>	<i><6%</i>	<i>0</i>	<i><4%</i>	<i>0</i>	<i><2%</i>	<i>0</i>
<i>12-13%</i>	<i>1</i>	<i>6-7%</i>	<i>1</i>	<i>4-5%</i>	<i>26</i>	<i>2-3%</i>	<i>1</i>
<i>13-14%</i>	<i>4</i>	<i>7-8%</i>	<i>20</i>	<i>5-6%</i>	<i>2</i>	<i>3-4%</i>	<i>27</i>
<i>14-15%</i>	<i>16</i>	<i>8-9%</i>	<i>7</i>	<i>>6%</i>	<i>0</i>	<i>>4%</i>	<i>0</i>
<i>15-16%</i>	<i>6</i>	<i>>9%</i>	<i>0</i>				
<i>16-17%</i>	<i>1</i>						
<i>>17</i>	<i>0</i>						

Even the burdens at the higher income ranges give rise for concern. Given that these burdens are calculated using the mid-point of the FPL tier, and at average bills, the burdens for these FPL tiers could easily exceed the percentage of income deemed to be affordable.

Q. ARE THERE SUBSTANTIAL NUMBERS OF CUSTOMERS AFFECTED BY THESE HIGH ELECTRIC BURDENS IN THE SELECTED POVERTY RANGES YOU EXAMINED IN THE PGL AND NSG ELECTRIC SERVICE TERRITORIES?

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1 A. Yes. I estimate that there are 282,634 customers with income at or below 200% of the
2 Federal Poverty Level in the PGL service territory and 29,544 in the NSG service
3 territory. I estimate this number by multiplying the Census Bureau's percentage of
4 population at the selected Poverty ranges²⁵ in each zip code times the total number of
5 customers in each zip code as reported by the two utilities. Of the PGL customers with
6 income at or below 200% of FPL, I estimate that 23.0% have income less than 50% of
7 FPL, 25.8%% have income between 50% and 100% of FPL, 26.2% have income between
8 100% and 150% of FPL, and 25.1% have income between 150% and 200% of Poverty. I
9 estimate a smaller proportion of NSG customers falling in the lowest range of FPL, with
10 an estimated 18.3% having income below 50% of Poverty; 19.3% having income
11 between 50% and 100% of Poverty; 32.4% having income between 100% and 150% of
12 Poverty; and 30.1% having income between 150% and 200% of Poverty.

²⁵ U.S. Census Bureau, American Community Survey, 5-year data, Table C17002.

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EDUCATION	University of Michigan, School of Environment and Sustainability • Master of Science – concentration in Sustainable Systems, GPA: 4.00	Graduated May '22
	University of Michigan, College of Engineering – BSE - Cum Laude • Major: Computer Science, Minor: International Engineering	Graduated May '20
RESEARCH EXPERIENCE	Lead Data Scientist – Energy Equity Project, University of Michigan • Developing and adjusting a set of indices and metrics to evaluate energy equity in the US, based on stakeholder feedback (100+ responses) • Surveying practitioners, regulators, community members, utilities, and philanthropists (100 + representatives), to assess their priorities and challenges evaluating energy equity • Creating a series of vector based maps to highlight energy equity across the US at a state, county and census tract level	Ann Arbor, MI May '21 - Present
	Seafood and Food Security Data Scientist, American University • Developing the ARTIS seafood supply chain database, mapping global seafood trade from production through trade to consumption. • Designed and maintained ARTIS API for distribution of ARTIS data • Developed an R pipeline to automatically generate country, species and product reports	Washington D.C May '22- Present
	Researcher – Seafood Globalization Lab, American University • Leading a research project investigating the relationships between global seafood trade with the US and news coverage, using US Trade Census data and the GDELT news repository • Developed a web application that searches newspaper articles worldwide and summarizes results with interactive data visualizations • Created a database of US seafood imports, highlighting transport, species, product, and country to estimate their transportation GHG emissions	Washington D.C May '20 – May '22
	Research Assistant – SEAS, University of Michigan • Developing an R Shiny web application, using GIS maps, that allows users to simulate the impacts of urban development and greening projects around the Great Lakes Region	Ann Arbor, MI August '21 - Present
	Researcher – School of Information, University of Michigan • Evaluated a coding curriculum (based in web scraping) for non-CS majors using Eccles expectancy value theory, and steps to completion • Created a script that scraped 20 million+ Github repositories to retrieve current ways/examples of industry experts using web scraping • Developed scripts to visualize and analyze the impact of gender, SES, and prior experience in participant survey data • Analyzed and coded interview transcripts to discover trends that refer to identity as a barrier to future class involvement	Ann Arbor, MI May '19 – Nov '20
	Midwest Big Data Hub <i>Data Science and Software Engineering Consultant</i> • Managing current fellows' projects and advising in the Curricular Innovation Program, specifically on how to create effective environment data tools that communicate a clear data narrative • Composed a tutorial series on web development, using R Shiny, targeted towards researchers with very little to no coding experience, with the goal of having them develop a complete web application within 2 hours <i>Curricular Innovation Program Fellow</i> • Developed an accessible data analytics platform for undergraduates (100+, at 2 universities) to test their own hypotheses using Serengeti Snapshot data from Zooniverse	Ann Arbor, MI May '21 – Present Feb '21 – May '21
OTHER EXPERIENCE		

	Software Developer – Harvard University, School of Public Health Developing an automated workflow that cleans and transfers public health data to usable CSV/spreadsheet format to analyze food security	Ann Arbor, MI July '21 – Sept '21
	Software Development Intern – Kraken Foods - Created an automated email delivery service, that analyzed stake-holder priorities and delivered relevant personalized feedback - Coordinated operational projects, such as sourcing vendors and distributors and coordinating early involvement with potential partners	Ann Arbor, MI April '17 – Jan '18
LEADERSHIP EXPERIENCE	MPowered Entrepreneurship <i>Chief Operating Officer</i> - Developed partnerships with local startups and businesses bringing unique guest speakers and workshops to the organization - Led weekly professional development & planning meetings (80+ people). <i>Project Director: Startup High School</i> - Led outreach efforts, coordinating with local schools and businesses for a HS student startup competition - Recruited, interviewed and led a team of four (from 40 applicants)	Ann Arbor, MI Mar '18 – May '19 Mar '17 – Mar '18
SKILLS	Programming and Software - C/C++, Python, R, R Shiny, ReactJS, JavaScript, SQL, HTML, CSS Foreign Languages - Spanish – Bilingual Proficiency (Speaking, Reading, Writing)	
PUBLICATIONS	- Van Berkel, Estabrook, Fox, Agrawal Bejarano, Maillard, Gill, Goto, Lemos “PPGISr: An R Package for Public Participatory GIS.” <i>SoftwareX</i>, vol. 22, May 2023, p. 101389, https://doi.org/10.1016/j.softx.2023.101389. - Willis, Klemens, Agrawal Bejarano, Hebert, Russell, Snapshot Serengeti Online: a fully online, open-source inquiry lab on tropical ecology, ATBC Abstract 2021 - Easton R. White, Halley E., Froehlich, Jessica A. Gephart, Richard S. Cottrell, Trevor A. Branch, Rahul Agrawal Bejarano, Julia K. Baum, Early effects of COVID-19 on US fisheries and seafood consumption. <i>Fish Fish.</i> 2021; 22: 232– 239. https://doi-org.proxy.lib.umich.edu/10.1111/faf.12525 - Kathryn Cunningham, Barbara J. Ericson, Rahul Agrawal Bejarano, and Mark Guzdial. 2021. Avoiding the Turing Tarpit: Learning Conversational Programming by Starting from Code’s Purpose. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, Article 61, 1–15. DOI:https://doi-org.proxy.lib.umich.edu/10.1145/3411764.3445571 - Cunningham, K., Bejarano, R. A., Guzdial, M., & Ericson, B. (2020). “I’m Not a Computer”: How Identity Informs Value and Expectancy During a Programming Activity. In Gresalfi, M. and Horn, I. S. (Eds.), <i>The Interdisciplinarity of the Learning Sciences</i>, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2 (pp. 705-708). Nashville, Tennessee: International Society of the Learning Sciences.	



QuickFacts
Michigan

QuickFacts provides statistics for all states and counties. Also for cities and towns with a *population of 5,000 or more*.

All Topics	Michigan
Population Estimates, July 1, 2022, (V2022)	10,033,281
PEOPLE	
Population	
Population estimates, July 1, 2023, (V2023)	10,037,261
Population Estimates, July 1, 2022, (V2022)	10,033,281
Population estimates base, April 1, 2020, (V2023)	10,077,674
Population estimates base, April 1, 2020, (V2022)	10,077,674
Population, percent change - April 1, 2020 (estimates base) to July 1, 2023, (V2023)	-0.4%
Population, percent change - April 1, 2020 (estimates base) to July 1, 2022, (V2022)	-0.4%
Population, Census, April 1, 2020	10,077,331
Population, Census, April 1, 2010	9,883,640
Age and Sex	
Persons under 5 years, percent	5.3%
Persons under 18 years, percent	21.0%
Persons 65 years and over, percent	18.7%
Female persons, percent	50.3%
Race and Hispanic Origin	
White alone, percent	78.8%
Black or African American alone, percent (a)	14.1%
American Indian and Alaska Native alone, percent (a)	0.7%
Asian alone, percent (a)	3.5%
Native Hawaiian and Other Pacific Islander alone, percent (a)	Z
Two or More Races, percent	2.8%
Hispanic or Latino, percent (b)	5.7%
White alone, not Hispanic or Latino, percent	74.0%
Population Characteristics	
Veterans, 2018-2022	498,788
Foreign born persons, percent, 2018-2022	6.9%
Housing	
Housing units, July 1, 2022, (V2022)	4,611,660
Owner-occupied housing unit rate, 2018-2022	72.5%
Median value of owner-occupied housing units, 2018-2022	\$201,100
Median selected monthly owner costs -with a mortgage, 2018-2022	\$1,472
Median selected monthly owner costs -without a mortgage, 2018-2022	\$565
Median gross rent, 2018-2022	\$1,037
Building permits, 2022	21,983 ¹
Families & Living Arrangements	
Households, 2018-2022	4,009,253
Persons per household, 2018-2022	2.45
Living in same house 1 year ago, percent of persons age 1 year+, 2018-2022	87.8%
Language other than English spoken at home, percent of persons age 5 years+, 2018-2022	9.9%
Computer and Internet Use	
Households with a computer, percent, 2018-2022	93.4%
Households with a broadband Internet subscription, percent, 2018-2022	87.8%
Education	
High school graduate or higher, percent of persons age 25 years+, 2018-2022	91.8%
Bachelor's degree or higher, percent of persons age 25 years+, 2018-2022	31.1%
Health	
With a disability, under age 65 years, percent, 2018-2022	10.1%
Persons without health insurance, under age 65 years, percent	5.5%

Economy	
In civilian labor force, total, percent of population age 16 years+, 2018-2022	61.4%
In civilian labor force, female, percent of population age 16 years+, 2018-2022	57.1%
Total accommodation and food services sales, 2017 (\$1,000) (c)	23,056,352
Total health care and social assistance receipts/revenue, 2017 (\$1,000) (c)	74,194,505
Total transportation and warehousing receipts/revenue, 2017 (\$1,000) (c)	25,019,797
Total retail sales, 2017 (\$1,000) (c)	143,437,054
Total retail sales per capita, 2017 (c)	\$14,377
Transportation	
Mean travel time to work (minutes), workers age 16 years+, 2018-2022	24.5
Income & Poverty	
Median household income (in 2022 dollars), 2018-2022	\$68,505
Per capita income in past 12 months (in 2022 dollars), 2018-2022	\$37,929
Persons in poverty, percent	 13.4%
 BUSINESSES	
Businesses	
Total employer establishments, 2021	224,676
Total employment, 2021	3,768,321
Total annual payroll, 2021 (\$1,000)	216,772,518
Total employment, percent change, 2020-2021	-5.8%
Total nonemployer establishments, 2021	774,125
All employer firms, Reference year 2017	165,460
Men-owned employer firms, Reference year 2017	106,137
Women-owned employer firms, Reference year 2017	29,706
Minority-owned employer firms, Reference year 2017	13,091
Nonminority-owned employer firms, Reference year 2017	141,153
Veteran-owned employer firms, Reference year 2017	8,714
Nonveteran-owned employer firms, Reference year 2017	142,782
 GEOGRAPHY	
Geography	
Population per square mile, 2020	178.0
Population per square mile, 2010	174.8
Land area in square miles, 2020	56,608.22
Land area in square miles, 2010	56,538.90
FIPS Code	26

[About datasets used in this table](#)

Value Notes

1. Includes data not distributed by county.

 Methodology differences may exist between data sources, and so estimates from different sources are not comparable.

Some estimates presented here come from sample data, and thus have sampling errors that may render some apparent differences between geographies statistically indistinguishable. Click the Quick Info  icon to the left of each row in TABLE view to learn about sampling error.

The vintage year (e.g., V2023) refers to the final year of the series (2020 thru 2023). Different vintage years of estimates are not comparable.

Users should exercise caution when comparing 2018-2022 ACS 5-year estimates to other ACS estimates. For more information, please visit the [2022 5-year ACS Comparison Guidance](#) page.

Fact Notes

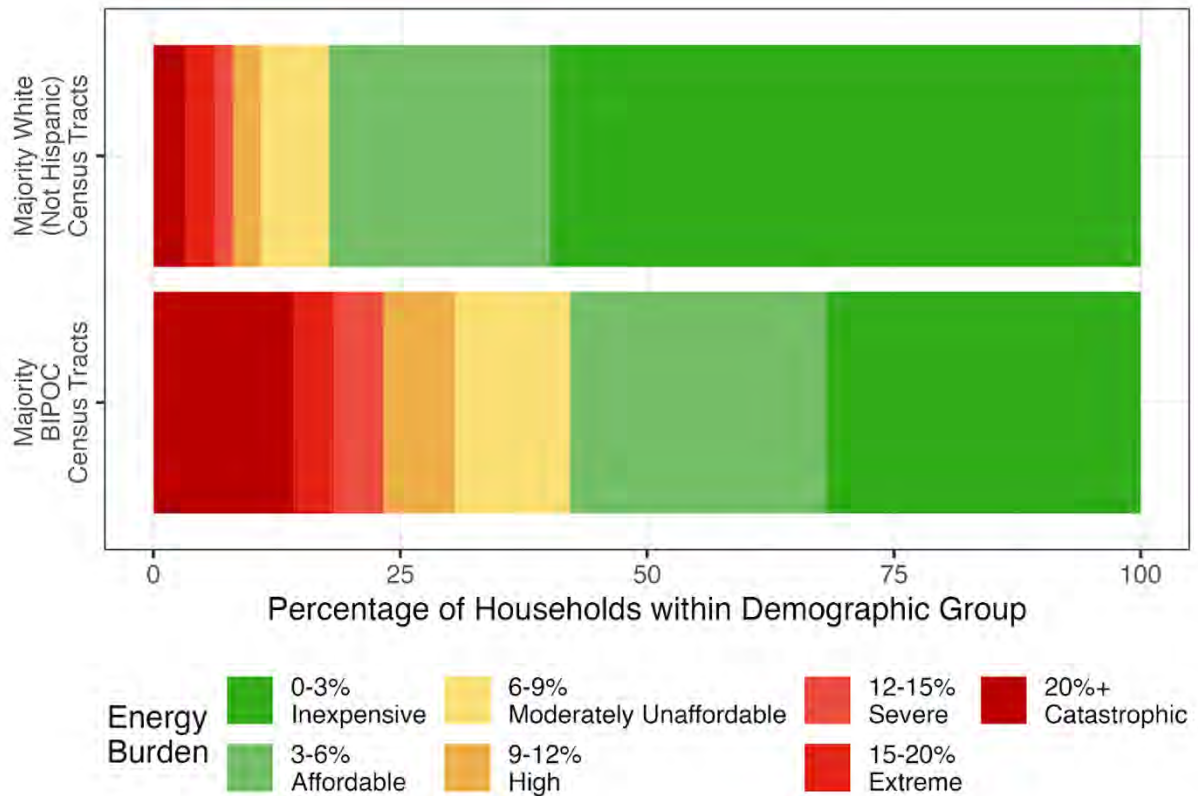
- (a) Includes persons reporting only one race
(c) Economic Census - Puerto Rico data are not comparable to U.S. Economic Census data
(b) Hispanics may be of any race, so also are included in applicable race categories

Value Flags

- Either no or too few sample observations were available to compute an estimate, or a ratio of medians cannot be calculated because one or both of the median estimates falls in the lowest or upper interval of an open ended distribution
F Fewer than 25 firms
D Suppressed to avoid disclosure of confidential information
N Data for this geographic area cannot be displayed because the number of sample cases is too small.
FN Footnote on this item in place of data
X Not applicable
S Suppressed; does not meet publication standards
NA Not available
Z Value greater than zero but less than half unit of measure shown

QuickFacts data are derived from: Population Estimates, American Community Survey, Census of Population and Housing, Current Population Survey, Small Area Health Insurance Estimates, Small Area Income and Poverty Estimates, State and County Housing Unit Estimates, County Business Patterns, Nonemployer Statistics, Economic Census, Survey of Business Owners, Building Permits.

JS Workpaper 3 – Energy burden disparities by race and income.



Majority White census tracts have 18% of households with an unaffordable. Majority BIPOC census tracts have 42% of households with an unaffordable energy burden. Proportionally there are 2.4 times as many households in majority BIPOC census tracts with an unaffordable energy burden as households in majority white households. This divide is further exacerbated when taking Severe to Catastrophic energy burdens (12%+). Majority BIPOC census tracts proportionately have 2.9 times more households with a Severe to Catastrophic energy burden, 23%, compared to majority white census tracts, 8%.

	Energy Burden Classification	Energy Burden Range	Number of Households	Energy Burden	Percent of Households
Majority BIPOC Census Tracts	Inexpensive	0-3%	135,439	2.2	31.9
	Affordable	3-6%	109,879	5.0	25.9
	Moderately Unaffordable	6-9%	49,602	7.8	11.7
	High	9-12%	30,773	11.2	7.2
	Severe	12-15%	21,364	13.9	5.0
	Extreme	15-20%	17,417	17.7	4.1
	Catastrophic	20%+	60,071	31.5	14.1

Majority White (Not Hispanic) Census Tracts	Inexpensive	0-3%	1,209,708	1.9	59.8
	Affordable	3-6%	453,146	4.5	22.4
	Moderately Unaffordable	6-9%	139,337	7.8	6.9
	High	9-12%	56,900	10.9	2.8
	Severe	12-15%	37,081	14.1	1.8
	Extreme	15-20%	60,836	17.9	3.0
	Catastrophic	20%+	65,189	26.6	3.2

Sources:

o Energy Burden Data

(Raw data for MI energy burdens and number of BIPOC households collected from DOE LEAD:
<https://www.energy.gov/scep/slsc/lead-tool>)

o MI census tracts

(US Census Bureau <https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2010&layergroup=Census+Tracts>)

o DTE service territory

(DTE service territory GIS layer collected from
<https://atlas.eia.gov/datasets/f4cd55044b924fed9bc8b64022966097/explore?filters=eyJJOQU1FIjpbIkRURSBFTEVDVFJJQyBDT01QQU5ZII19&location=42.911225%2C-81.880048%2C6.78>)

o FLO JS Workpaper 2k (code file that get list of census tracts within DTE Service territory)

o FLO JS Workpaper 2j (final GIS layer with MI census tracts within DTE service territory)

o Doe_lead_profiles_fpl.Rmd (code that creates figure 4)

JS Workpaper 4 - High Energy Burden Low-Income Tracts vs. % Black

DATA SOURCE: Climate and Economic Justice Screening Tool (CEJST) - Council on Environmental Quality (CEQ). Downloaded April 1, 2024.
<https://screeningtool.geoplatform.gov/en/downloads#4.27/34.38/-99.17>

Location	Energy Burden (% income)	Avg. Annual Energy Cost (\$)	Total Households	Household Income	Black/ African American (%) pop.)	American Indian/ Native Alaskan (%) pop.)	Asian (%) pop.)	Native Hawaiian/ Other Pacific Islander (%) pop.)	White Hispanic or Latino (%) pop.)	White Non- Hispanic or Latino (%) pop.)	Two or More Races (%) pop.)	Other Races (% pop.)	Less Than High School (% pop.)	High School (% pop.)	Associates or Some College (% pop.)	Bachelors or Higher (%) pop.)
Census Tract 5112, Wayne County, Michigan	49	\$3,536	298	\$7,221	93	0	0	0	0	6	0	0	6	29	55	9
Census Tract 5382, Wayne County, Michigan	45	\$3,869	67	\$8,589	94	0	0	0	0	6	0	0	0	10	18	72
Census Tract 5301, Wayne County, Michigan	42	\$2,900	569	\$6,931	99	0	0	0	0	0	1	0	36	21	40	3
Census Tract 5231, Wayne County, Michigan	39	\$3,009	410	\$7,651	18	0	0	0	24	33	10	16	46	22	26	6
Census Tract 5313, Wayne County, Michigan	39	\$3,000	201	\$7,622	94	0	0	0	0	2	4	0	26	24	45	5
Census Tract 1527, Oakland County, Michigan	38	\$2,658	87	\$7,036	3	0	0	0	1	95	0	0	0	1	10	89
Census Tract 9854, Wayne County, Michigan	36	\$3,174	4	\$8,764	0	0	0	0	0	100	0	0	0	53	47	0
Census Tract 5451, Wayne County, Michigan	35	\$2,793	131	\$7,996	97	1	0	0	0	1	1	0	17	53	26	5
Census Tract 5452, Wayne County, Michigan	35	\$3,524	387	\$10,192	100	0	0	0	0	0	0	0	25	26	43	6
Census Tract 5002, Wayne County, Michigan	32	\$3,491	208	\$10,818	99	0	0	0	0	1	0	0	2	22	67	9
Census Tract 5071, Wayne County, Michigan	32	\$3,137	449	\$9,934	96	0	0	0	0	1	3	0	13	50	23	14
Census Tract 5190, Wayne County, Michigan	31	\$2,910	121	\$9,438	90	0	0	0	0	9	0	0	15	55	26	5
Census Tract 5265, Wayne County, Michigan	30	\$2,896	326	\$9,738	81	0	0	0	10	1	0	9	44	22	26	8
Census Tract 5393, Wayne County, Michigan	30	\$3,537	375	\$11,758	100	0	0	0	0	0	0	0	6	12	49	33
Census Tract 5113, Wayne County, Michigan	29	\$3,709	427	\$12,639	39	0	9	0	0	48	3	1	25	30	33	13
Census Tract 5333, Wayne County, Michigan	29	\$3,109	154	\$10,810	91	0	1	0	0	5	3	0	17	46	24	12
Census Tract 5391, Wayne County, Michigan	29	\$3,591	267	\$12,206	98	1	0	0	0	0	0	0	31	29	34	7
Census Tract 5406, Wayne County, Michigan	29	\$2,752	267	\$9,399	78	0	0	0	0	7	2	13	9	36	40	15
Census Tract 5074, Wayne County, Michigan	28	\$3,152	336	\$11,401	97	1	0	0	0	1	0	1	16	38	40	6
Census Tract 5303, Wayne County, Michigan	28	\$3,990	235	\$14,065	97	0	0	0	0	1	2	0	8	53	35	4
Census Tract 5334, Wayne County, Michigan	28	\$3,015	692	\$10,959	100	0	0	0	0	0	0	0	11	41	42	6
Census Tract 5336, Wayne County, Michigan	28	\$2,982	353	\$10,784	97	0	0	0	0	2	1	0	32	39	25	4
Census Tract 5368, Wayne County, Michigan	28	\$3,380	287	\$11,925	97	1	0	0	0	1	1	0	11	52	31	6
Census Tract 5401, Wayne County, Michigan	28	\$3,294	649	\$11,915	94	0	0	0	0	6	0	0	26	37	32	5
Census Tract 5517, Wayne County, Michigan	28	\$3,170	92	\$11,272	0	0	3	0	0	96	1	0	4	16	33	47
Census Tract 2473.02, Macomb County, Michigan	27	\$2,577	33	\$9,608	0	0	0	0	0	99	1	0	0	13	80	7
Census Tract 1981, Oakland County, Michigan	27	\$3,081	416	\$11,537	2	0	40	0	0	55	0	3	61	14	14	11
Census Tract 5015, Wayne County, Michigan	27	\$3,348	676	\$12,340	95	0	0	0	0	4	0	1	17	40	33	11
Census Tract 5248, Wayne County, Michigan	27	\$3,109	344	\$11,336	65	0	0	0	12	8	5	10	21	32	40	6
Census Tract 5318, Wayne County, Michigan	27	\$2,643	400	\$9,685	98	0	0	0	0	2	1	0	29	30	37	4
Census Tract 5378, Wayne County, Michigan	27	\$3,340	300	\$12,256	98	0	0	0	0	1	0	1	25	39	34	2
Census Tract 5403, Wayne County, Michigan	27	\$3,487	718	\$12,820	95	0	0	0	0	2	0	3	16	33	42	9
Census Tract 5411, Wayne County, Michigan	27	\$2,918	322	\$10,757	85	0	2	0	0	5	4	3	32	27	38	3
Census Tract 5423, Wayne County, Michigan	27	\$2,642	622	\$9,788	98	0	0	0	0	2	0	0	14	28	50	8
Census Tract 5508, Wayne County, Michigan	27	\$2,923	45	\$10,680	3	0	2	0	0	94	1	0	2	13	34	50
Census Tract 5132, Wayne County, Michigan	26	\$3,247	187	\$12,489	89	0	1	0	0	10	1	0	35	30	26	8
Census Tract 5224, Wayne County, Michigan	26	\$2,030	235	\$7,679	93	0	0	0	1	3	2	0	7	47	35	12
Census Tract 5364, Wayne County, Michigan	26	\$3,609	452	\$13,695	100	0	0	0	0	0	0	0	11	51	31	8
Census Tract 5367, Wayne County, Michigan	26	\$3,470	148	\$13,256	99	0	1	0	0	0	0	0	16	39	44	2
Census Tract 5370, Wayne County, Michigan	26	\$3,208	566	\$12,555	99	0	0	0	0	1	0	0	15	33	46	5
Census Tract 5371, Wayne County, Michigan	26	\$3,406	330	\$12,912	98	0	0	0	0	1	1	0	20	35	38	6
Census Tract 5402, Wayne County, Michigan	26	\$3,555	483	\$13,803	99	0	0	0	0	0	0	0	29	37	31	3
Census Tract 5404, Wayne County, Michigan	26	\$2,879	590	\$11,197	99	0	0	0	0	1	0	0	19	36	42	3
Census Tract 5530, Wayne County, Michigan	26	\$2,550	193	\$9,845	93	0	0	0	0	7	0	0	31	29	34	7
Census Tract 1580, Oakland County, Michigan	25	\$2,568	48	\$10,074	3	0	1	0	0	96	1	0	0	3	7	91
Census Tract 5014, Wayne County, Michigan	25	\$3,851	333	\$15,198	94	0	0	0	0	6	0	0	23	29	39	8
Census Tract 5027, Wayne County, Michigan	25	\$2,471	581	\$9,762	98	0	0	0	0	2	0	0	32	37	29	2
Census Tract 5070, Wayne County, Michigan	25	\$3,059	477	\$12,204	97	0	0	0	0	1	1	0	18	43	31	8
Census Tract 5073, Wayne County, Michigan	25	\$3,378	183	\$13,619	98	0	0	0	0	1	1	0	8	27	53	12
Census Tract 5128, Wayne County, Michigan	25	\$2,840	536	\$11,570	95	0	0	0	0	2	0	2	26	50	17	6
Census Tract 5264, Wayne County, Michigan	25	\$3,390	149	\$13,650	10	1	0	0	49	6	9	25	59	28	13	0

Census Tract 5311, Wayne County, Michigan	25	\$2,296	187	\$9,041	89	0	0	0	1	9	1	0	15	45	37	3
Census Tract 5373, Wayne County, Michigan	25	\$3,105	298	\$12,272	99	0	0	0	0	0	0	0	19	40	41	0
Census Tract 5377, Wayne County, Michigan	25	\$2,967	421	\$11,758	99	0	0	0	0	0	0	0	28	40	29	3
Census Tract 5425, Wayne County, Michigan	25	\$3,423	269	\$13,781	98	0	0	0	0	1	1	0	9	29	50	12
Census Tract 5435, Wayne County, Michigan	25	\$2,738	174	\$10,922	88	1	0	0	0	7	4	0	23	38	32	7
Census Tract 5751, Wayne County, Michigan	25	\$2,056	224	\$8,184	0	0	0	0	3	95	1	0	19	25	37	18
Census Tract 5061, Wayne County, Michigan	24	\$3,228	245	\$13,508	90	1	1	0	0	7	0	0	17	39	39	4
Census Tract 5192, Wayne County, Michigan	24	\$2,378	301	\$9,972	79	0	13	0	0	8	0	0	23	27	26	23
Census Tract 5302, Wayne County, Michigan	24	\$3,062	388	\$12,818	91	0	1	0	0	7	1	0	12	37	37	15
Census Tract 5338, Wayne County, Michigan	24	\$3,093	362	\$12,755	89	0	0	0	3	5	2	1	28	28	41	3
Census Tract 5358, Wayne County, Michigan	24	\$2,874	723	\$12,224	86	0	0	0	0	4	0	9	24	47	28	1
Census Tract 5375, Wayne County, Michigan	24	\$3,545	392	\$14,761	96	0	0	0	0	3	0	0	26	29	35	10
Census Tract 5422, Wayne County, Michigan	24	\$3,207	564	\$13,387	99	0	0	0	0	0	1	0	16	42	35	7
Census Tract 5509, Wayne County, Michigan	24	\$3,305	54	\$13,721	2	0	6	0	0	90	1	0	3	17	29	51
Census Tract 2588, Macomb County, Michigan	23	\$1,854	359	\$8,073	69	0	0	0	1	29	1	0	8	19	43	30
Census Tract 1846, Oakland County, Michigan	23	\$1,546	162	\$6,642	3	0	1	0	0	95	1	0	10	8	19	64
Census Tract 5017, Wayne County, Michigan	23	\$3,068	258	\$13,557	74	1	0	0	0	25	1	0	21	43	31	4
Census Tract 5065, Wayne County, Michigan	23	\$3,237	270	\$13,952	96	0	0	0	0	4	0	0	18	42	35	5
Census Tract 5081, Wayne County, Michigan	23	\$3,341	205	\$14,833	78	0	0	0	9	7	6	0	29	39	22	10
Census Tract 5246, Wayne County, Michigan	23	\$2,969	495	\$12,861	16	0	0	0	18	26	12	28	33	55	11	2
Census Tract 5247, Wayne County, Michigan	23	\$2,858	508	\$12,386	80	0	0	0	8	1	1	9	22	50	23	4
Census Tract 5279, Wayne County, Michigan	23	\$2,983	376	\$13,167	73	0	0	0	8	5	11	3	21	18	49	12
Census Tract 5321, Wayne County, Michigan	23	\$3,040	188	\$13,022	84	0	0	0	0	14	0	1	21	24	37	17
Census Tract 5331, Wayne County, Michigan	23	\$2,509	248	\$10,922	97	0	0	0	0	2	1	0	20	27	47	5
Census Tract 5332, Wayne County, Michigan	23	\$3,001	183	\$13,250	86	0	0	0	0	10	5	0	3	44	37	17
Census Tract 5356, Wayne County, Michigan	23	\$2,883	749	\$12,612	95	0	0	0	0	4	1	0	10	29	55	6
Census Tract 5381, Wayne County, Michigan	23	\$3,227	118	\$14,236	88	0	0	0	0	11	0	0	17	14	25	44
Census Tract 5397, Wayne County, Michigan	23	\$3,096	312	\$13,217	100	0	0	0	0	0	0	0	38	31	23	7
Census Tract 5405, Wayne County, Michigan	23	\$2,981	417	\$13,176	99	0	0	0	0	1	0	0	5	43	44	8
Census Tract 5407, Wayne County, Michigan	23	\$3,392	398	\$14,538	89	0	0	0	1	4	2	4	36	23	39	3
Census Tract 5424, Wayne County, Michigan	23	\$3,318	376	\$14,551	98	0	0	0	0	2	0	0	8	27	55	10
Census Tract 5426, Wayne County, Michigan	23	\$3,192	493	\$13,730	100	0	0	0	0	0	0	0	4	49	43	5
Census Tract 5461, Wayne County, Michigan	23	\$3,144	627	\$13,734	89	0	0	0	1	6	5	0	34	25	33	8
Census Tract 5466, Wayne County, Michigan	23	\$3,000	280	\$12,876	94	0	0	0	0	3	4	0	25	31	41	3
Census Tract 1545, Oakland County, Michigan	22	\$2,918	51	\$13,210	1	0	2	0	0	96	0	0	11	8	14	67
Census Tract 1684, Oakland County, Michigan	22	\$1,908	21	\$8,784	18	0	2	0	0	77	2	1	2	16	34	48
Census Tract 1700, Oakland County, Michigan	22	\$1,629	83	\$7,318	1	0	0	0	1	97	1	0	4	10	25	61
Census Tract 5041, Wayne County, Michigan	22	\$2,912	209	\$13,049	100	0	0	0	0	0	0	0	26	48	19	7
Census Tract 5056, Wayne County, Michigan	22	\$3,368	619	\$15,100	98	0	0	0	0	1	1	1	19	34	40	8
Census Tract 5063, Wayne County, Michigan	22	\$3,185	277	\$14,276	96	0	0	0	0	2	1	1	17	43	33	7
Census Tract 5064, Wayne County, Michigan	22	\$3,254	155	\$14,621	72	0	0	0	1	21	5	0	48	30	15	7
Census Tract 5211, Wayne County, Michigan	22	\$2,213	283	\$9,921	30	0	0	0	17	25	2	26	30	21	42	6
Census Tract 5214, Wayne County, Michigan	22	\$2,643	178	\$11,931	64	0	1	0	0	23	0	12	17	53	19	11
Census Tract 5223, Wayne County, Michigan	22	\$2,145	416	\$9,627	90	0	0	0	0	3	8	0	19	49	28	4
Census Tract 5258, Wayne County, Michigan	22	\$3,597	273	\$16,525	14	0	0	0	11	19	20	37	58	27	14	1
Census Tract 5305, Wayne County, Michigan	22	\$2,848	356	\$12,760	95	0	0	0	0	3	2	0	26	22	31	20
Census Tract 5315.01, Wayne County, Michigan	22	\$3,072	265	\$13,834	67	1	0	0	0	3	29	0	5	46	49	0
Census Tract 5412, Wayne County, Michigan	22	\$2,411	332	\$11,073	93	0	0	0	1	6	0	0	43	25	23	9
Census Tract 5415, Wayne County, Michigan	22	\$2,874	442	\$13,317	98	0	0	0	0	1	1	0	10	32	49	9
Census Tract 5455, Wayne County, Michigan	22	\$2,969	789	\$13,590	85	0	0	0	0	9	3	3	25	32	37	7
Census Tract 5457, Wayne County, Michigan	22	\$3,075	554	\$14,067	61	0	0	0	5	31	2	1	23	41	25	11
Census Tract 5460, Wayne County, Michigan	22	\$2,965	549	\$13,419	84	0	0	0	0	5	6	4	13	30	56	2
Census Tract 5563, Wayne County, Michigan	22	\$1,633	313	\$7,399	3	0	2	0	0	95	0	0	7	46	20	27
Census Tract 5795.01, Wayne County, Michigan	22	\$2,003	310	\$9,037	25	0	0	3	5	52	6	9	22	31	46	1
Census Tract 5819, Wayne County, Michigan	22	\$1,907	178	\$8,569	0	1	1	0	1	96	1	0	3	45	49	4
Census Tract 5847, Wayne County, Michigan	22	\$2,441	265	\$10,985	1	0	0	0	0	98	0	0	30	35	33	1
Census Tract 1506, Oakland County, Michigan	21	\$2,672	32	\$12,894	1	0	2	0	0	97	0	0	1	1	10	88
Census Tract 1565, Oakland County, Michigan	21	\$2,856	144	\$13,769	3	0	1	0	0	96	0	0	3	3	11	83
Census Tract 1733, Oakland County, Michigan	21	\$1,295	170	\$6,066	10	0	0	0	0	88	1	0	1	9	11	78
Census Tract 1976, Oakland County, Michigan	21	\$1,996	40	\$9,341	2	0	3	0	1	93	1	0	4	56	10	29
Census Tract 5005, Wayne County, Michigan	21	\$3,495	108	\$16,431	95	0	0	0	0	5	0	0	10	24	62	3
Census Tract 5032, Wayne County, Michigan	21	\$3,603	324	\$17,180	95	0	0	0	0	5	0	0	11	45	44	1

Census Tract 5035, Wayne County, Michigan	21	\$3,744	294	\$17,620	100	0	0	0	0	0	0	0	11	39	48	2
Census Tract 5043, Wayne County, Michigan	21	\$3,278	230	\$15,987	96	0	0	0	0	4	0	0	33	36	25	6
Census Tract 5057, Wayne County, Michigan	21	\$2,997	469	\$14,386	98	0	1	0	0	1	0	0	33	30	33	5
Census Tract 5062, Wayne County, Michigan	21	\$3,155	274	\$15,070	97	0	0	0	0	2	1	0	9	65	20	6
Census Tract 5066, Wayne County, Michigan	21	\$3,380	365	\$16,197	94	0	5	0	0	1	0	0	13	31	37	19
Census Tract 5068, Wayne County, Michigan	21	\$2,885	571	\$14,055	98	0	0	0	0	1	1	0	8	47	36	9
Census Tract 5138, Wayne County, Michigan	21	\$2,554	400	\$12,028	96	0	0	0	0	2	2	0	27	33	32	8
Census Tract 5145, Wayne County, Michigan	21	\$3,022	165	\$14,634	100	0	0	0	0	0	0	0	13	27	59	1
Census Tract 5164, Wayne County, Michigan	21	\$2,792	80	\$13,572	79	2	0	0	0	13	6	0	13	48	26	13
Census Tract 5173, Wayne County, Michigan	21	\$1,808	410	\$8,772	87	0	1	0	0	10	1	0	29	24	29	18
Census Tract 5215, Wayne County, Michigan	21	\$2,415	156	\$11,626	86	0	0	0	0	12	0	1	24	41	15	19
Census Tract 5220, Wayne County, Michigan	21	\$2,191	317	\$10,677	96	0	0	0	0	3	0	1	23	18	56	3
Census Tract 5263, Wayne County, Michigan	21	\$3,134	533	\$14,955	10	0	0	0	43	14	3	31	68	16	13	3
Census Tract 5314, Wayne County, Michigan	21	\$2,909	278	\$13,789	97	0	0	0	0	3	0	0	30	35	27	8
Census Tract 5330, Wayne County, Michigan	21	\$2,291	268	\$10,720	86	0	5	0	0	8	0	1	26	26	31	18
Census Tract 5341, Wayne County, Michigan	21	\$2,487	239	\$11,744	97	0	0	0	0	2	1	0	22	29	45	4
Census Tract 5342, Wayne County, Michigan	21	\$3,190	515	\$15,520	96	0	0	0	0	3	1	0	20	29	45	5
Census Tract 5343, Wayne County, Michigan	21	\$2,744	239	\$12,994	92	0	4	0	3	0	0	1	15	47	36	2
Census Tract 5351, Wayne County, Michigan	21	\$2,985	207	\$14,008	100	0	0	0	0	0	0	0	40	16	42	1
Census Tract 5352, Wayne County, Michigan	21	\$2,751	406	\$13,104	97	0	0	0	0	2	1	0	27	29	36	7
Census Tract 5357, Wayne County, Michigan	21	\$2,966	183	\$14,081	85	0	0	0	0	3	12	0	34	26	36	4
Census Tract 5366, Wayne County, Michigan	21	\$2,925	412	\$14,128	99	0	0	0	0	0	0	0	22	47	22	9
Census Tract 5369, Wayne County, Michigan	21	\$3,007	413	\$14,283	97	0	0	0	0	0	3	0	16	37	38	8
Census Tract 5386, Wayne County, Michigan	21	\$3,309	654	\$15,424	98	0	0	0	0	2	0	0	6	36	40	18
Census Tract 5387, Wayne County, Michigan	21	\$3,399	478	\$15,960	96	0	0	0	0	1	0	3	14	32	40	14
Census Tract 5389, Wayne County, Michigan	21	\$2,941	308	\$13,772	97	0	2	0	0	1	0	0	18	39	27	16
Census Tract 5394, Wayne County, Michigan	21	\$3,373	502	\$16,418	99	0	0	0	0	0	0	0	2	23	66	9
Census Tract 5413, Wayne County, Michigan	21	\$2,852	363	\$13,553	78	0	0	0	1	20	0	1	12	32	44	12
Census Tract 5421, Wayne County, Michigan	21	\$3,131	536	\$15,048	99	0	0	0	0	0	0	0	23	37	35	5
Census Tract 5432, Wayne County, Michigan	21	\$3,069	279	\$14,656	97	0	0	0	0	0	1	1	34	28	27	11
Census Tract 5456, Wayne County, Michigan	21	\$3,109	645	\$14,734	13	0	0	0	5	75	0	7	31	23	28	18
Census Tract 5458, Wayne County, Michigan	21	\$3,197	740	\$15,409	50	0	0	0	8	42	0	0	32	32	27	9
Census Tract 5604, Wayne County, Michigan	21	\$2,045	189	\$9,885	1	0	1	0	0	98	0	0	0	9	24	67
Census Tract 5760.01, Wayne County, Michigan	21	\$2,210	169	\$10,309	6	0	1	0	3	81	4	4	26	37	26	11
Census Tract 1501, Oakland County, Michigan	20	\$2,307	169	\$11,552	9	0	1	0	1	89	1	0	21	6	10	63
Census Tract 1509, Oakland County, Michigan	20	\$2,159	153	\$10,750	4	0	1	0	0	93	1	0	19	3	11	67
Census Tract 1520, Oakland County, Michigan	20	\$2,421	29	\$12,398	1	0	1	0	0	96	2	0	0	9	8	83
Census Tract 1569, Oakland County, Michigan	20	\$2,814	108	\$13,819	5	0	2	0	0	92	0	0	4	2	15	79
Census Tract 1962, Oakland County, Michigan	20	\$2,014	153	\$10,051	0	0	5	0	1	93	0	0	0	7	34	58
Census Tract 5016, Wayne County, Michigan	20	\$3,160	276	\$15,563	86	0	0	0	0	10	0	4	16	35	44	5
Census Tract 5019, Wayne County, Michigan	20	\$3,215	433	\$16,422	97	0	0	0	0	3	0	0	16	46	35	4
Census Tract 5031, Wayne County, Michigan	20	\$3,377	326	\$16,883	97	0	0	0	0	2	1	0	7	33	52	9
Census Tract 5044, Wayne County, Michigan	20	\$3,103	261	\$15,176	99	0	0	0	0	1	0	0	23	47	28	2
Census Tract 5054, Wayne County, Michigan	20	\$3,210	291	\$16,189	90	1	0	0	0	6	2	1	16	54	23	7
Census Tract 5069, Wayne County, Michigan	20	\$3,287	441	\$16,324	97	0	0	0	0	1	2	0	19	37	29	15
Census Tract 5090, Wayne County, Michigan	20	\$2,573	227	\$13,027	86	0	0	0	0	10	4	0	34	31	14	21
Census Tract 5114, Wayne County, Michigan	20	\$2,811	412	\$13,895	89	0	0	0	0	9	1	1	17	46	26	10
Census Tract 5133, Wayne County, Michigan	20	\$2,919	177	\$14,637	83	0	0	0	0	17	0	0	14	26	40	21
Census Tract 5141, Wayne County, Michigan	20	\$2,645	608	\$13,096	99	0	0	0	0	1	0	0	48	16	31	5
Census Tract 5152, Wayne County, Michigan	20	\$3,256	230	\$16,465	88	0	0	0	0	12	0	0	17	40	36	7
Census Tract 5154, Wayne County, Michigan	20	\$2,535	21	\$12,612	56	0	1	0	0	42	0	0	6	18	32	45
Census Tract 5193, Wayne County, Michigan	20	\$2,874	242	\$14,165	80	0	0	0	0	18	1	1	27	28	34	12
Census Tract 5240.01, Wayne County, Michigan	20	\$2,750	368	\$14,030	5	0	0	0	16	15	4	60	39	38	16	7
Census Tract 5309, Wayne County, Michigan	20	\$2,611	212	\$12,905	95	0	0	0	0	3	2	0	36	33	31	0
Census Tract 5317, Wayne County, Michigan	20	\$2,505	289	\$12,707	97	0	2	0	0	0	0	0	25	27	34	13
Census Tract 5319, Wayne County, Michigan	20	\$2,574	86	\$12,652	91	0	0	0	2	4	2	1	16	7	54	24
Census Tract 5344, Wayne County, Michigan	20	\$2,481	341	\$12,127	92	0	0	0	2	6	0	0	30	40	30	0
Census Tract 5350, Wayne County, Michigan	20	\$3,030	320	\$15,192	95	0	0	0	2	0	0	3	25	26	32	16
Census Tract 5361, Wayne County, Michigan	20	\$3,121	532	\$15,941	97	0	0	0	0	3	0	0	29	32	30	8
Census Tract 5385, Wayne County, Michigan	20	\$2,910	691	\$14,288	98	0	0	0	0	1	0	0	7	25	53	15
Census Tract 5392, Wayne County, Michigan	20	\$3,329	657	\$16,842	100	0	0	0	0	0	0	0	11	39	41	9
Census Tract 5395, Wayne County, Michigan	20	\$2,886	283	\$14,220	99	0	0	0	0	1	0	0	6	47	43	3

Census Tract 5396, Wayne County, Michigan	20	\$3,119	391	\$15,215	98	0	0	0	0	0	1	0	7	31	45	18
Census Tract 5418, Wayne County, Michigan	20	\$2,657	210	\$13,063	72	0	6	0	0	17	1	4	18	38	37	7
Census Tract 5443, Wayne County, Michigan	20	\$3,201	372	\$15,730	79	0	0	0	0	18	2	0	7	31	53	10
Census Tract 5448, Wayne County, Michigan	20	\$2,852	320	\$14,459	88	0	0	0	0	11	1	0	24	35	34	7
Census Tract 5462.01, Wayne County, Michigan	20	\$3,350	239	\$16,942	57	0	0	0	0	41	0	1	21	25	42	12
Census Tract 5637, Wayne County, Michigan	20	\$2,131	26	\$10,741	7	0	2	0	0	91	0	0	12	14	43	31
Census Tract 2406.02, Macomb County, Michigan	19	\$2,812	187	\$14,631	0	0	0	0	0	100	0	0	6	48	30	16
Census Tract 2408.02, Macomb County, Michigan	19	\$2,869	494	\$15,410	14	0	0	0	0	84	1	0	16	34	47	4
Census Tract 1504, Oakland County, Michigan	19	\$2,724	38	\$13,989	3	0	4	0	1	92	1	0	0	2	14	83
Census Tract 1526, Oakland County, Michigan	19	\$2,325	76	\$12,404	4	0	1	0	1	94	1	0	0	6	10	84
Census Tract 1570, Oakland County, Michigan	19	\$2,824	29	\$14,940	3	0	1	0	0	95	2	0	2	8	15	74
Census Tract 1839, Oakland County, Michigan	19	\$1,500	202	\$8,028	2	0	1	0	6	89	1	0	0	25	19	57
Census Tract 1870, Oakland County, Michigan	19	\$1,911	38	\$10,166	2	0	0	0	0	96	2	0	1	8	11	81
Census Tract 1968, Oakland County, Michigan	19	\$3,010	21	\$15,505	0	0	56	0	0	44	0	0	0	4	37	60
Census Tract 5003, Wayne County, Michigan	19	\$3,092	167	\$16,542	91	0	4	0	0	4	0	0	14	36	47	2
Census Tract 5020, Wayne County, Michigan	19	\$3,425	176	\$17,867	97	0	0	0	0	2	1	0	20	22	45	12
Census Tract 5026, Wayne County, Michigan	19	\$2,714	650	\$14,393	99	0	0	0	0	1	0	0	26	46	24	5
Census Tract 5036, Wayne County, Michigan	19	\$2,958	196	\$15,634	96	0	3	0	0	1	0	0	7	51	38	3
Census Tract 5039, Wayne County, Michigan	19	\$3,131	298	\$16,282	98	0	0	0	0	2	0	0	32	30	36	3
Census Tract 5040, Wayne County, Michigan	19	\$3,217	218	\$17,140	98	1	0	0	0	1	0	0	18	48	31	3
Census Tract 5051, Wayne County, Michigan	19	\$2,260	787	\$11,592	93	0	0	0	0	7	0	0	23	46	27	4
Census Tract 5052, Wayne County, Michigan	19	\$2,535	476	\$13,086	95	0	0	0	0	1	0	4	5	58	35	2
Census Tract 5075, Wayne County, Michigan	19	\$2,825	373	\$14,515	96	0	0	0	0	4	0	0	23	35	36	6
Census Tract 5091, Wayne County, Michigan	19	\$3,204	744	\$17,152	18	0	74	0	0	7	0	0	27	32	31	10
Census Tract 5137, Wayne County, Michigan	19	\$2,386	488	\$12,603	99	0	0	0	0	1	0	0	30	29	37	4
Census Tract 5143, Wayne County, Michigan	19	\$2,418	477	\$12,447	96	0	0	0	0	3	0	0	21	33	43	3
Census Tract 5168, Wayne County, Michigan	19	\$3,342	118	\$17,483	89	0	0	0	0	10	0	1	8	59	23	10
Census Tract 5191, Wayne County, Michigan	19	\$2,900	182	\$15,132	78	0	8	0	0	13	1	0	17	36	41	6
Census Tract 5233, Wayne County, Michigan	19	\$3,423	348	\$18,058	3	0	0	0	38	10	1	49	49	24	18	8
Census Tract 5234, Wayne County, Michigan	19	\$2,436	278	\$12,493	42	1	0	0	22	17	4	14	27	22	39	12
Census Tract 5308, Wayne County, Michigan	19	\$2,898	237	\$15,367	94	0	0	0	0	4	1	0	36	32	27	5
Census Tract 5348, Wayne County, Michigan	19	\$2,909	356	\$14,983	84	0	0	0	9	5	2	0	10	33	50	7
Census Tract 5362, Wayne County, Michigan	19	\$3,492	371	\$18,244	97	0	0	0	0	3	1	0	9	16	62	13
Census Tract 5365, Wayne County, Michigan	19	\$2,976	259	\$15,504	79	0	0	0	0	12	9	0	14	18	58	10
Census Tract 5372, Wayne County, Michigan	19	\$2,809	104	\$14,502	98	0	0	0	0	2	1	0	20	35	44	1
Census Tract 5376, Wayne County, Michigan	19	\$3,319	546	\$17,147	99	0	0	0	0	1	0	0	16	54	23	8
Census Tract 5429, Wayne County, Michigan	19	\$3,108	322	\$15,972	89	0	0	0	0	10	1	0	7	21	39	34
Census Tract 5437, Wayne County, Michigan	19	\$2,801	468	\$15,117	97	0	0	0	1	2	1	0	30	45	21	4
Census Tract 5442, Wayne County, Michigan	19	\$2,645	341	\$13,609	91	0	0	0	0	8	0	0	20	26	48	6
Census Tract 5472, Wayne County, Michigan	19	\$2,495	589	\$12,947	92	0	0	0	0	4	3	0	20	34	37	9
Census Tract 5506, Wayne County, Michigan	19	\$2,871	24	\$14,804	0	0	1	0	0	96	3	0	0	5	7	89
Census Tract 5731, Wayne County, Michigan	19	\$3,031	316	\$15,674	6	0	2	0	2	89	0	0	9	41	21	28
Census Tract 5746, Wayne County, Michigan	19	\$2,581	298	\$13,915	2	0	0	0	4	94	0	0	4	21	31	44
Census Tract 5749, Wayne County, Michigan	19	\$1,935	177	\$10,257	2	0	1	0	3	95	0	0	12	14	48	26
Census Tract 2566, Macomb County, Michigan	18	\$2,204	376	\$12,426	25	0	2	0	1	67	4	1	10	45	36	9
Census Tract 1348, Oakland County, Michigan	18	\$1,851	121	\$10,324	0	0	3	0	0	97	0	0	36	21	10	33
Census Tract 1507, Oakland County, Michigan	18	\$2,588	49	\$14,385	1	0	2	0	0	95	2	0	1	2	8	88
Census Tract 1541, Oakland County, Michigan	18	\$2,705	108	\$14,817	1	0	0	0	0	98	0	0	0	53	12	35
Census Tract 1578, Oakland County, Michigan	18	\$1,701	118	\$9,448	28	0	1	0	1	69	0	0	0	15	25	60
Census Tract 1612, Oakland County, Michigan	18	\$2,165	201	\$11,711	86	3	0	0	0	10	1	0	1	15	29	55
Census Tract 1662, Oakland County, Michigan	18	\$2,146	33	\$11,795	5	0	0	0	0	92	1	1	3	5	22	71
Census Tract 5001, Wayne County, Michigan	18	\$3,408	242	\$19,474	97	0	0	0	0	2	0	0	9	28	57	7
Census Tract 5008, Wayne County, Michigan	18	\$2,835	515	\$15,757	93	1	0	0	0	5	0	0	18	43	35	4
Census Tract 5012, Wayne County, Michigan	18	\$3,093	188	\$17,652	99	0	0	0	0	1	1	0	19	49	30	1
Census Tract 5013, Wayne County, Michigan	18	\$3,377	364	\$18,416	99	0	0	0	0	1	0	0	21	51	25	3
Census Tract 5033, Wayne County, Michigan	18	\$3,325	471	\$18,119	98	0	1	0	0	1	0	0	10	38	49	3
Census Tract 5042, Wayne County, Michigan	18	\$3,324	237	\$18,856	97	0	0	0	0	3	0	0	23	43	27	7
Census Tract 5072, Wayne County, Michigan	18	\$3,156	154	\$17,747	88	1	0	0	0	1	10	0	21	42	27	10
Census Tract 5106, Wayne County, Michigan	18	\$3,521	873	\$19,742	21	0	46	0	0	31	1	1	29	37	23	11
Census Tract 5166, Wayne County, Michigan	18	\$2,103	696	\$11,605	96	0	0	0	0	3	0	1	32	25	33	10
Census Tract 5204, Wayne County, Michigan	18	\$1,831	273	\$10,444	68	0	14	0	0	16	2	1	39	9	37	16
Census Tract 5228, Wayne County, Michigan	18	\$2,754	355	\$15,580	73	0	0	0	15	9	0	2	18	29	40	13

Census Tract 5316, Wayne County, Michigan	18	\$2,429	291	\$13,355	95	0	0	0	0	2	2	0	10	30	53	8
Census Tract 5353, Wayne County, Michigan	18	\$3,164	605	\$17,118	98	0	0	0	0	1	1	0	14	42	36	8
Census Tract 5363, Wayne County, Michigan	18	\$3,141	344	\$17,155	99	0	0	0	0	0	1	0	30	20	41	9
Census Tract 5390, Wayne County, Michigan	18	\$3,006	395	\$16,488	95	0	0	0	0	3	1	1	14	28	51	7
Census Tract 5410, Wayne County, Michigan	18	\$2,423	461	\$13,814	99	0	0	0	0	0	1	0	25	20	51	5
Census Tract 5431, Wayne County, Michigan	18	\$3,095	91	\$16,755	85	0	0	0	0	11	3	0	5	22	53	20
Census Tract 5433, Wayne County, Michigan	18	\$2,899	295	\$16,221	88	0	0	0	0	10	2	0	5	33	43	19
Census Tract 5439, Wayne County, Michigan	18	\$2,587	197	\$14,047	77	1	0	0	1	17	3	0	24	35	39	2
Census Tract 5467, Wayne County, Michigan	18	\$2,868	285	\$15,739	86	0	0	0	0	7	1	6	7	27	54	12
Census Tract 5470, Wayne County, Michigan	18	\$2,661	520	\$14,428	95	0	0	0	0	5	0	0	24	28	38	10
Census Tract 5471, Wayne County, Michigan	18	\$2,790	592	\$15,351	96	0	0	0	0	2	2	0	17	28	37	18
Census Tract 5502, Wayne County, Michigan	18	\$2,703	162	\$15,179	13	0	6	0	0	76	5	0	4	11	40	46
Census Tract 5511, Wayne County, Michigan	18	\$2,977	96	\$16,493	2	0	4	0	0	93	1	0	3	8	36	53
Census Tract 5531, Wayne County, Michigan	18	\$2,917	206	\$15,802	89	0	0	0	0	11	0	0	2	42	50	6
Census Tract 5603, Wayne County, Michigan	18	\$1,843	152	\$10,251	2	0	3	0	1	94	1	0	0	9	44	47
Census Tract 5689, Wayne County, Michigan	18	\$2,033	330	\$11,211	6	0	6	0	3	81	4	1	20	38	32	10
Census Tract 5706, Wayne County, Michigan	18	\$2,187	237	\$11,943	93	0	0	0	0	4	3	1	30	29	32	9
Census Tract 5718, Wayne County, Michigan	18	\$3,253	185	\$18,264	13	0	1	0	3	79	4	1	5	36	40	19
Census Tract 5722, Wayne County, Michigan	18	\$2,756	534	\$14,989	1	0	2	0	1	95	1	0	7	40	33	20
Census Tract 5766, Wayne County, Michigan	18	\$1,915	214	\$10,458	3	0	0	0	5	90	1	0	5	21	59	15
Census Tract 5832, Wayne County, Michigan	18	\$2,764	218	\$15,445	3	1	0	0	1	88	7	1	31	32	36	1
Census Tract 2408.01, Macomb County, Michigan	17	\$2,532	63	\$14,609	6	0	0	0	0	94	0	0	3	45	38	14
Census Tract 2412, Macomb County, Michigan	17	\$2,901	373	\$17,347	17	0	0	0	0	81	1	1	13	47	38	3
Census Tract 2683, Macomb County, Michigan	17	\$2,020	468	\$11,985	50	0	0	0	2	47	2	0	29	36	33	2
Census Tract 1563, Oakland County, Michigan	17	\$2,470	46	\$14,283	4	0	4	0	0	91	1	0	0	1	11	88
Census Tract 1579, Oakland County, Michigan	17	\$2,337	72	\$14,159	11	0	6	0	0	82	1	0	10	15	28	46
Census Tract 1980, Oakland County, Michigan	17	\$2,167	123	\$12,435	0	0	21	0	2	77	0	0	0	6	26	68
Census Tract 5007, Wayne County, Michigan	17	\$3,405	429	\$19,809	97	0	0	0	0	2	0	0	23	37	33	7
Census Tract 5011, Wayne County, Michigan	17	\$2,906	457	\$17,278	97	0	0	0	0	2	0	0	22	30	45	3
Census Tract 5058, Wayne County, Michigan	17	\$3,227	691	\$18,792	53	0	1	0	0	35	8	2	35	33	28	4
Census Tract 5139, Wayne County, Michigan	17	\$2,868	257	\$16,923	100	0	0	0	0	0	0	0	43	30	22	6
Census Tract 5219, Wayne County, Michigan	17	\$2,331	444	\$13,347	74	0	0	0	0	23	1	2	26	21	36	17
Census Tract 5232, Wayne County, Michigan	17	\$2,972	466	\$17,969	2	0	0	0	25	20	5	48	42	35	20	3
Census Tract 5241.01, Wayne County, Michigan	17	\$2,576	636	\$15,224	16	1	0	0	15	23	1	44	39	44	16	0
Census Tract 5260, Wayne County, Michigan	17	\$3,430	428	\$19,908	3	0	0	0	18	59	4	17	68	21	10	1
Census Tract 5261, Wayne County, Michigan	17	\$3,368	464	\$20,017	1	0	0	0	10	65	10	13	38	28	28	5
Census Tract 5324, Wayne County, Michigan	17	\$2,479	262	\$14,376	92	0	0	0	0	7	1	0	14	28	53	5
Census Tract 5326, Wayne County, Michigan	17	\$1,936	223	\$11,562	81	3	0	0	0	9	5	2	12	33	33	22
Census Tract 5388, Wayne County, Michigan	17	\$3,527	184	\$20,972	97	0	0	0	0	0	2	0	2	34	54	9
Census Tract 5409, Wayne County, Michigan	17	\$3,190	295	\$18,789	98	0	0	0	0	2	0	0	12	28	48	12
Census Tract 5414, Wayne County, Michigan	17	\$2,782	247	\$16,347	82	0	0	0	0	8	2	8	14	41	42	4
Census Tract 5434, Wayne County, Michigan	17	\$3,121	300	\$17,934	96	0	0	0	0	3	1	0	21	24	47	8
Census Tract 5441, Wayne County, Michigan	17	\$2,753	417	\$16,277	95	1	0	0	0	3	0	1	7	35	46	12
Census Tract 5459, Wayne County, Michigan	17	\$2,963	622	\$16,995	84	0	0	0	4	10	1	1	12	38	38	11
Census Tract 5463.01, Wayne County, Michigan	17	\$3,262	167	\$19,567	90	0	0	0	0	5	1	4	22	45	29	3
Census Tract 5503, Wayne County, Michigan	17	\$2,602	14	\$15,064	5	0	0	0	0	93	1	0	7	5	25	64
Census Tract 5504, Wayne County, Michigan	17	\$2,309	74	\$13,959	7	0	0	0	0	90	3	0	6	7	43	44
Census Tract 5532, Wayne County, Michigan	17	\$2,488	154	\$14,538	80	0	0	0	0	9	10	1	8	58	30	3
Census Tract 5568, Wayne County, Michigan	17	\$2,376	53	\$14,189	0	0	4	0	0	95	0	0	4	26	45	25
Census Tract 5571, Wayne County, Michigan	17	\$1,900	109	\$10,971	5	0	4	0	0	90	1	0	1	22	50	27
Census Tract 5577, Wayne County, Michigan	17	\$1,975	84	\$11,572	0	0	0	0	0	100	0	0	2	19	41	38
Census Tract 5627, Wayne County, Michigan	17	\$2,162	83	\$12,644	1	0	0	0	0	99	0	0	4	24	17	55
Census Tract 5640, Wayne County, Michigan	17	\$1,721	168	\$10,423	11	0	10	0	1	66	12	0	11	45	21	23
Census Tract 5785, Wayne County, Michigan	17	\$2,122	692	\$12,724	11	0	0	0	9	72	2	5	23	36	30	11
Census Tract 5857, Wayne County, Michigan	17	\$2,545	131	\$14,978	41	0	0	0	0	59	0	0	10	44	44	2
Census Tract 5951, Wayne County, Michigan	17	\$1,830	341	\$10,688	16	0	0	0	1	83	0	0	4	46	27	23
Census Tract 2413, Macomb County, Michigan	16	\$2,841	123	\$17,876	23	0	0	0	0	74	3	0	15	48	29	9
Census Tract 2421, Macomb County, Michigan	16	\$2,336	144	\$14,885	25	0	0	0	0	65	2	8	14	20	49	17
Census Tract 2425, Macomb County, Michigan	16	\$2,309	380	\$14,730	17	0	0	0	0	82	1	0	5	46	44	5
Census Tract 2430, Macomb County, Michigan	16	\$2,470	85	\$15,219	4	0	1	0	0	94	0	0	7	16	68	10
Census Tract 2440, Macomb County, Michigan	16	\$2,594	56	\$16,276	2	0	0	0	0	97	0	0	21	35	32	13
Census Tract 2471, Macomb County, Michigan	16	\$1,763	155	\$11,111	1	0	0	0	0	84	16	0	38	10	29	24

Census Tract 1510, Oakland County, Michigan	16	\$2,428	55	\$14,821	0	0	0	0	0	100	0	0	0	7	10	82
Census Tract 1529, Oakland County, Michigan	16	\$2,034	179	\$12,701	1	0	1	0	0	97	1	0	10	10	15	65
Census Tract 1531, Oakland County, Michigan	16	\$2,524	50	\$15,377	1	0	1	0	2	95	0	0	1	8	9	83
Census Tract 1533, Oakland County, Michigan	16	\$2,592	94	\$16,398	2	0	2	0	0	96	0	0	0	9	7	84
Census Tract 1560, Oakland County, Michigan	16	\$2,225	75	\$14,083	4	0	4	0	2	89	1	0	1	6	20	73
Census Tract 1571, Oakland County, Michigan	16	\$2,882	37	\$17,639	5	0	7	0	0	85	3	0	2	8	22	68
Census Tract 1577, Oakland County, Michigan	16	\$3,107	54	\$19,441	7	0	3	0	0	90	0	0	11	7	15	66
Census Tract 1582, Oakland County, Michigan	16	\$2,216	64	\$14,220	1	0	0	0	1	98	0	0	0	3	12	85
Census Tract 1590, Oakland County, Michigan	16	\$2,468	94	\$15,050	4	0	2	0	1	93	1	0	1	7	15	78
Census Tract 1619, Oakland County, Michigan	16	\$2,227	101	\$13,789	76	0	0	0	0	17	6	0	9	17	40	34
Census Tract 1965, Oakland County, Michigan	16	\$1,651	127	\$10,635	0	0	8	0	3	86	3	0	16	13	14	58
Census Tract 1969, Oakland County, Michigan	16	\$1,616	96	\$10,220	0	0	34	0	0	65	0	0	0	12	39	49
Census Tract 1971, Oakland County, Michigan	16	\$2,303	56	\$14,617	0	0	23	0	2	75	1	0	0	13	12	75
Census Tract 5004, Wayne County, Michigan	16	\$2,871	195	\$17,900	97	0	0	0	0	2	1	0	22	57	20	1
Census Tract 5006, Wayne County, Michigan	16	\$3,664	158	\$23,499	100	0	0	0	0	0	0	0	5	40	47	8
Census Tract 5010, Wayne County, Michigan	16	\$2,972	346	\$19,090	99	0	0	0	0	1	0	0	37	36	26	1
Census Tract 5142, Wayne County, Michigan	16	\$1,893	368	\$11,830	97	0	0	0	0	3	0	0	24	40	27	9
Census Tract 5160, Wayne County, Michigan	16	\$3,456	194	\$21,516	95	0	0	0	0	4	0	1	26	33	29	12
Census Tract 5203, Wayne County, Michigan	16	\$1,143	193	\$7,009	22	0	49	0	9	16	3	0	13	25	24	38
Census Tract 5242, Wayne County, Michigan	16	\$3,080	717	\$19,464	6	0	0	0	19	30	2	42	58	23	15	4
Census Tract 5304, Wayne County, Michigan	16	\$1,934	173	\$11,815	98	0	0	0	0	2	0	0	38	24	38	0
Census Tract 5315.02, Wayne County, Michigan	16	\$2,635	95	\$16,095	90	0	0	0	0	0	10	0	13	33	48	6
Census Tract 5327, Wayne County, Michigan	16	\$2,920	79	\$18,166	98	0	0	0	0	2	0	0	13	42	30	15
Census Tract 5384, Wayne County, Michigan	16	\$3,548	96	\$21,990	91	0	0	0	0	5	0	4	1	34	40	26
Census Tract 5408, Wayne County, Michigan	16	\$3,232	224	\$19,924	99	0	0	0	0	1	0	0	15	23	46	17
Census Tract 5512, Wayne County, Michigan	16	\$2,855	61	\$17,734	16	0	0	0	0	82	2	0	0	15	37	48
Census Tract 5579.01, Wayne County, Michigan	16	\$1,950	118	\$12,147	1	0	2	0	1	96	0	0	2	30	20	48
Census Tract 5592, Wayne County, Michigan	16	\$2,051	102	\$12,922	2	0	2	0	1	95	1	0	3	22	46	29
Census Tract 5648, Wayne County, Michigan	16	\$2,489	167	\$15,768	9	0	13	0	1	77	0	0	3	8	28	61
Census Tract 5708, Wayne County, Michigan	16	\$2,158	447	\$13,347	89	0	0	0	1	10	0	1	29	40	28	4
Census Tract 5715, Wayne County, Michigan	16	\$2,791	495	\$17,731	5	0	0	0	1	90	3	1	14	13	48	25
Census Tract 5719, Wayne County, Michigan	16	\$2,861	278	\$17,345	14	0	1	0	0	85	0	0	36	21	24	18
Census Tract 5720, Wayne County, Michigan	16	\$3,058	131	\$19,111	2	0	1	0	1	94	1	0	15	15	40	31
Census Tract 5721, Wayne County, Michigan	16	\$2,655	603	\$16,646	4	0	0	0	0	95	0	0	15	36	32	17
Census Tract 5830.01, Wayne County, Michigan	16	\$2,946	239	\$18,457	6	0	0	0	1	93	1	0	13	44	37	6
Census Tract 5841, Wayne County, Michigan	16	\$2,446	133	\$14,853	3	2	0	0	0	94	1	0	12	57	30	1
Census Tract 5848.01, Wayne County, Michigan	16	\$1,825	780	\$11,646	69	4	0	0	0	27	0	0	18	58	19	5
Census Tract 5855, Wayne County, Michigan	16	\$2,581	190	\$16,551	9	0	0	0	6	82	1	2	18	50	27	5
Census Tract 2417, Macomb County, Michigan	15	\$2,792	344	\$18,436	18	0	4	0	0	71	3	5	12	53	34	2
Census Tract 2512, Macomb County, Michigan	15	\$1,933	188	\$12,913	2	0	0	0	1	95	3	0	2	36	32	30
Census Tract 1340, Oakland County, Michigan	15	\$1,937	154	\$13,042	0	0	1	0	0	99	0	0	3	26	34	37
Census Tract 1360, Oakland County, Michigan	15	\$1,732	129	\$11,401	0	0	0	0	0	99	1	0	12	27	12	49
Census Tract 1503, Oakland County, Michigan	15	\$2,291	79	\$15,331	1	0	3	0	0	95	0	0	0	9	22	69
Census Tract 1540, Oakland County, Michigan	15	\$2,273	53	\$15,115	2	0	0	0	1	97	0	0	0	12	22	66
Census Tract 1546, Oakland County, Michigan	15	\$3,117	72	\$20,462	4	0	1	0	0	94	0	0	1	13	22	63
Census Tract 1561, Oakland County, Michigan	15	\$3,054	69	\$20,541	5	0	3	0	0	91	1	0	2	4	26	67
Census Tract 1574, Oakland County, Michigan	15	\$2,708	94	\$18,566	8	0	2	0	0	89	1	0	2	28	19	52
Census Tract 1606, Oakland County, Michigan	15	\$2,054	152	\$13,744	49	0	0	0	0	48	2	1	5	6	35	54
Census Tract 1620, Oakland County, Michigan	15	\$2,108	218	\$13,938	69	0	0	0	0	28	0	2	5	22	41	31
Census Tract 1670, Oakland County, Michigan	15	\$1,897	155	\$12,777	14	2	2	0	0	82	0	0	1	23	19	58
Census Tract 1687, Oakland County, Michigan	15	\$2,012	129	\$13,013	28	0	3	0	0	68	0	0	2	9	36	53
Census Tract 1735, Oakland County, Michigan	15	\$1,572	163	\$10,409	8	0	1	0	0	88	3	0	2	11	57	30
Census Tract 1802, Oakland County, Michigan	15	\$1,545	122	\$10,476	1	0	1	0	1	96	2	0	6	21	35	38
Census Tract 1967, Oakland County, Michigan	15	\$1,996	27	\$13,144	0	0	3	0	1	95	0	0	0	4	13	83
Census Tract 6480, St. Clair County, Michigan	15	\$1,526	65	\$10,220	0	0	0	0	0	98	2	0	20	26	38	16
Census Tract 5009, Wayne County, Michigan	15	\$2,716	334	\$18,542	96	0	0	0	0	3	1	0	28	39	30	4
Census Tract 5018, Wayne County, Michigan	15	\$2,646	291	\$17,869	83	0	0	0	0	15	2	0	4	12	66	18
Census Tract 5034, Wayne County, Michigan	15	\$2,564	166	\$16,733	87	0	11	0	0	2	1	0	10	65	21	4
Census Tract 5167, Wayne County, Michigan	15	\$1,707	461	\$11,275	98	0	0	0	0	0	2	0	27	29	32	12
Census Tract 5180, Wayne County, Michigan	15	\$1,702	307	\$11,361	67	0	7	0	1	23	2	0	7	27	31	35
Census Tract 5245, Wayne County, Michigan	15	\$2,967	24	\$19,742	7	0	0	0	71	22	0	0	5	27	68	0
Census Tract 5254, Wayne County, Michigan	15	\$2,488	369	\$16,542	48	0	0	0	21	15	7	9	42	31	25	3

Census Tract 5347, Wayne County, Michigan	15	\$2,613	527	\$17,721	80	4	0	0	0	0	4	13	0	7	55	30	8
Census Tract 5417, Wayne County, Michigan	15	\$1,801	303	\$11,925	98	0	0	0	0	0	1	0	0	8	31	41	20
Census Tract 5440, Wayne County, Michigan	15	\$2,517	340	\$16,524	88	0	0	0	0	0	8	1	2	19	24	46	10
Census Tract 5501, Wayne County, Michigan	15	\$2,979	101	\$19,768	7	0	1	0	0	0	91	0	0	0	12	66	22
Census Tract 5507, Wayne County, Michigan	15	\$3,060	99	\$20,045	1	0	2	0	2	94	1	0	27	20	13	40	
Census Tract 5514, Wayne County, Michigan	15	\$2,705	315	\$17,823	63	0	8	0	0	28	1	0	7	32	33	29	
Census Tract 5516, Wayne County, Michigan	15	\$2,946	430	\$19,373	79	1	0	0	0	18	2	0	9	36	44	11	
Census Tract 5521, Wayne County, Michigan	15	\$2,509	633	\$16,737	23	0	26	0	0	41	9	1	19	36	36	9	
Census Tract 5523, Wayne County, Michigan	15	\$2,631	474	\$18,132	2	0	45	0	0	48	1	5	22	44	24	10	
Census Tract 5538, Wayne County, Michigan	15	\$1,758	417	\$12,118	84	0	0	0	0	4	11	0	8	13	23	55	
Census Tract 5551, Wayne County, Michigan	15	\$2,320	308	\$15,954	23	0	0	0	0	76	1	0	5	30	44	21	
Census Tract 5626, Wayne County, Michigan	15	\$1,887	81	\$12,765	1	0	1	0	0	98	1	0	10	22	29	39	
Census Tract 5629, Wayne County, Michigan	15	\$2,351	144	\$15,866	1	0	0	0	0	98	1	0	15	38	28	19	
Census Tract 5633, Wayne County, Michigan	15	\$2,381	151	\$16,182	6	0	3	0	0	87	4	0	3	32	33	32	
Census Tract 5687, Wayne County, Michigan	15	\$2,818	290	\$18,926	20	0	0	0	0	49	30	0	11	13	31	45	
Census Tract 5694, Wayne County, Michigan	15	\$2,279	218	\$15,068	6	0	1	0	0	93	0	0	13	33	47	8	
Census Tract 5710, Wayne County, Michigan	15	\$2,163	232	\$14,149	92	0	0	0	0	6	2	0	25	38	34	3	
Census Tract 5724, Wayne County, Michigan	15	\$2,693	97	\$18,157	5	0	0	0	1	93	2	0	6	49	23	23	
Census Tract 5726, Wayne County, Michigan	15	\$2,469	535	\$16,229	8	0	0	0	1	89	2	0	9	31	43	17	
Census Tract 5727, Wayne County, Michigan	15	\$2,498	266	\$16,273	3	0	1	0	4	90	1	1	14	31	39	16	
Census Tract 5743.01, Wayne County, Michigan	15	\$2,628	241	\$17,578	1	0	1	0	1	97	0	0	12	14	38	36	
Census Tract 5748, Wayne County, Michigan	15	\$2,720	94	\$17,563	0	0	0	0	1	97	1	0	14	13	21	53	
Census Tract 5750, Wayne County, Michigan	15	\$1,982	167	\$13,633	1	0	0	0	0	98	0	0	32	21	20	27	
Census Tract 5755, Wayne County, Michigan	15	\$2,473	179	\$16,571	3	0	0	0	1	87	8	0	6	21	45	28	
Census Tract 5773, Wayne County, Michigan	15	\$2,305	321	\$15,130	2	0	0	0	11	82	2	3	24	38	29	9	
Census Tract 5796, Wayne County, Michigan	15	\$2,038	264	\$13,610	72	0	0	0	2	2	15	9	12	52	24	13	
Census Tract 5797, Wayne County, Michigan	15	\$1,989	617	\$13,428	16	6	0	0	11	54	3	10	39	33	26	2	
Census Tract 5818, Wayne County, Michigan	15	\$2,239	208	\$15,418	2	0	0	0	1	97	0	0	7	36	53	5	
Census Tract 5862.01, Wayne County, Michigan	15	\$2,571	347	\$17,314	46	0	0	0	0	53	1	0	17	20	56	8	
Census Tract 5950, Wayne County, Michigan	15	\$2,104	326	\$14,081	0	0	0	0	1	94	3	2	13	33	47	7	
Census Tract 2324, Macomb County, Michigan	14	\$2,056	433	\$14,611	0	0	8	0	0	91	1	0	9	38	34	20	
Census Tract 2419, Macomb County, Michigan	14	\$2,765	257	\$20,012	14	0	0	0	1	80	2	3	8	49	42	2	
Census Tract 2473.01, Macomb County, Michigan	14	\$1,734	98	\$12,056	4	0	4	0	0	92	0	0	2	27	61	10	
Census Tract 2507, Macomb County, Michigan	14	\$1,849	167	\$12,907	4	0	0	0	2	93	1	0	4	37	47	12	
Census Tract 2587, Macomb County, Michigan	14	\$2,776	212	\$19,461	47	0	2	0	1	44	5	1	11	42	37	10	
Census Tract 1366.02, Oakland County, Michigan	14	\$2,199	48	\$15,674	0	0	2	0	0	98	0	0	8	21	26	45	
Census Tract 1502, Oakland County, Michigan	14	\$2,683	31	\$19,779	4	0	6	0	0	90	0	0	0	5	14	81	
Census Tract 1505, Oakland County, Michigan	14	\$2,527	29	\$18,103	2	0	2	0	0	96	0	0	0	5	18	77	
Census Tract 1542, Oakland County, Michigan	14	\$2,368	216	\$16,829	1	0	2	0	7	90	0	0	9	28	24	39	
Census Tract 1623, Oakland County, Michigan	14	\$1,773	211	\$12,602	91	0	0	0	0	6	2	0	3	20	38	38	
Census Tract 1678, Oakland County, Michigan	14	\$1,950	98	\$13,745	12	0	3	0	0	81	0	4	3	16	21	60	
Census Tract 1734, Oakland County, Michigan	14	\$1,712	253	\$12,055	5	0	1	0	0	93	1	0	16	8	42	33	
Census Tract 1837, Oakland County, Michigan	14	\$1,445	146	\$9,980	1	0	1	0	1	96	1	0	1	32	17	50	
Census Tract 1964, Oakland County, Michigan	14	\$2,054	43	\$15,149	0	0	17	0	0	82	0	0	0	10	14	75	
Census Tract 5119, Wayne County, Michigan	14	\$1,438	273	\$10,425	87	0	1	0	1	11	0	0	24	33	27	16	
Census Tract 5238, Wayne County, Michigan	14	\$2,814	485	\$20,507	12	0	0	0	20	29	3	36	53	17	25	4	
Census Tract 5257, Wayne County, Michigan	14	\$2,863	453	\$20,560	4	0	0	0	50	19	4	23	44	35	8	13	
Census Tract 5262, Wayne County, Michigan	14	\$2,869	424	\$20,017	3	0	0	0	42	36	5	14	59	22	14	4	
Census Tract 5312, Wayne County, Michigan	14	\$3,009	110	\$21,726	82	1	0	0	0	16	2	0	3	25	33	39	
Census Tract 5513, Wayne County, Michigan	14	\$2,164	265	\$15,719	52	0	1	0	0	37	10	0	17	24	40	19	
Census Tract 5515, Wayne County, Michigan	14	\$3,421	67	\$25,253	68	0	2	0	0	28	2	0	5	35	50	10	
Census Tract 5518, Wayne County, Michigan	14	\$2,611	153	\$18,978	9	0	2	0	0	89	0	0	2	15	35	48	
Census Tract 5524, Wayne County, Michigan	14	\$2,934	377	\$20,380	12	0	28	0	0	53	6	1	34	30	24	11	
Census Tract 5528.01, Wayne County, Michigan	14	\$2,700	546	\$18,935	4	0	13	0	0	68	14	0	43	35	14	8	
Census Tract 5541, Wayne County, Michigan	14	\$2,334	364	\$16,829	54	0	0	0	0	44	2	0	4	38	49	9	
Census Tract 5545, Wayne County, Michigan	14	\$2,222	279	\$15,422	37	0	0	0	0	61	1	0	9	43	36	12	
Census Tract 5567, Wayne County, Michigan	14	\$2,153	41	\$15,425	1	0	1	0	0	98	0	0	1	43	30	26	
Census Tract 5583.01, Wayne County, Michigan	14	\$1,934	87	\$13,439	3	0	0	0	0	96	1	0	15	30	44	10	
Census Tract 5584, Wayne County, Michigan	14	\$2,124	76	\$15,675	2	0	2	0	0	95	0	0	2	16	58	25	
Census Tract 5588, Wayne County, Michigan	14	\$2,137	84	\$15,634	1	0	3	0	0	94	1	0	11	21	37	30	
Census Tract 5602.02, Wayne County, Michigan	14	\$1,705	91	\$12,093	2	0	5	0	1	92	0	0	0	22	30	48	
Census Tract 5638, Wayne County, Michigan	14	\$2,917	84	\$21,605	20	0	2	0	0	77	1	0	0	17	52	31	

Census Tract 5646, Wayne County, Michigan	14	\$2,412	112	\$17,251	1	0	17	0	0	80	1	0	0	13	20	66
Census Tract 5651, Wayne County, Michigan	14	\$2,067	309	\$14,546	40	0	4	0	0	53	1	1	7	30	51	12
Census Tract 5656, Wayne County, Michigan	14	\$2,409	41	\$17,031	1	0	0	0	0	97	1	0	11	26	54	9
Census Tract 5658, Wayne County, Michigan	14	\$2,033	284	\$14,069	12	0	0	0	2	84	0	1	20	35	37	7
Census Tract 5666, Wayne County, Michigan	14	\$2,096	88	\$15,079	24	3	0	0	2	70	1	0	12	35	38	16
Census Tract 5696, Wayne County, Michigan	14	\$2,209	153	\$15,456	3	0	1	0	0	95	0	0	7	41	44	8
Census Tract 5709, Wayne County, Michigan	14	\$2,191	296	\$15,405	95	0	0	0	0	3	1	1	26	27	41	6
Census Tract 5725, Wayne County, Michigan	14	\$2,624	119	\$18,419	9	0	0	0	2	87	2	0	9	42	39	9
Census Tract 5729, Wayne County, Michigan	14	\$2,411	210	\$16,925	8	0	0	0	0	91	0	0	13	42	33	13
Census Tract 5734, Wayne County, Michigan	14	\$2,567	378	\$18,224	2	0	0	0	0	97	1	0	19	27	38	16
Census Tract 5735.01, Wayne County, Michigan	14	\$2,599	567	\$18,665	3	0	1	0	0	90	6	0	54	15	22	10
Census Tract 5737.01, Wayne County, Michigan	14	\$2,886	164	\$20,489	3	0	0	0	1	86	11	0	34	20	19	26
Census Tract 5737.02, Wayne County, Michigan	14	\$2,831	644	\$20,426	1	0	0	0	0	98	1	0	33	32	22	13
Census Tract 5752, Wayne County, Michigan	14	\$2,483	225	\$18,367	3	0	1	0	2	91	2	0	6	28	47	19
Census Tract 5753, Wayne County, Michigan	14	\$2,256	127	\$15,570	4	0	0	0	2	92	1	0	6	21	49	24
Census Tract 5754.01, Wayne County, Michigan	14	\$2,406	149	\$17,699	1	0	0	0	2	94	3	0	2	22	55	22
Census Tract 5761, Wayne County, Michigan	14	\$2,100	450	\$14,630	2	0	0	0	11	82	2	4	8	28	44	20
Census Tract 5771, Wayne County, Michigan	14	\$1,828	336	\$13,299	8	1	0	0	10	58	9	14	28	49	22	1
Census Tract 5777, Wayne County, Michigan	14	\$2,105	98	\$14,864	1	1	0	0	1	85	2	10	11	45	32	12
Census Tract 5799, Wayne County, Michigan	14	\$1,886	283	\$13,360	2	0	5	0	1	91	1	0	13	21	26	40
Census Tract 5806, Wayne County, Michigan	14	\$1,633	218	\$11,853	2	1	0	0	3	85	0	9	12	45	32	11
Census Tract 5811.01, Wayne County, Michigan	14	\$2,005	201	\$14,842	13	0	11	0	0	75	1	0	6	26	53	15
Census Tract 5821, Wayne County, Michigan	14	\$2,381	119	\$16,790	0	0	0	0	1	97	1	0	5	36	46	13
Census Tract 5834, Wayne County, Michigan	14	\$2,387	283	\$16,534	4	0	0	0	2	92	1	1	9	41	44	6
Census Tract 5835, Wayne County, Michigan	14	\$2,663	133	\$18,858	2	0	0	0	1	97	0	0	7	59	27	8
Census Tract 5836, Wayne County, Michigan	14	\$2,450	121	\$17,942	1	0	0	0	0	97	1	0	17	32	33	18
Census Tract 5845.01, Wayne County, Michigan	14	\$2,334	125	\$16,565	30	2	0	0	0	64	0	3	15	54	29	3
Census Tract 5848.02, Wayne County, Michigan	14	\$2,118	356	\$15,459	48	0	0	0	0	51	0	0	16	44	26	14
Census Tract 5859, Wayne County, Michigan	14	\$1,471	334	\$10,357	34	0	0	0	0	61	1	3	30	36	12	21
Census Tract 5879, Wayne County, Michigan	14	\$2,022	468	\$14,841	52	0	2	0	0	45	1	0	27	40	16	17
Census Tract 5880.02, Wayne County, Michigan	14	\$2,541	104	\$18,557	8	0	0	0	0	87	5	0	4	36	31	29
Census Tract 5884, Wayne County, Michigan	14	\$3,029	112	\$21,662	3	1	1	0	0	95	1	0	22	17	24	37
Census Tract 2406.01, Macomb County, Michigan	13	\$2,186	200	\$16,427	15	0	5	0	5	69	6	0	7	49	37	7
Census Tract 2418, Macomb County, Michigan	13	\$1,798	451	\$13,572	40	0	3	0	0	54	0	3	9	46	38	6
Census Tract 2420.01, Macomb County, Michigan	13	\$2,105	66	\$16,676	4	0	0	0	0	93	3	0	13	39	46	1
Census Tract 2508, Macomb County, Michigan	13	\$1,945	124	\$14,905	2	0	0	0	1	96	1	0	9	34	42	15
Census Tract 2511, Macomb County, Michigan	13	\$2,216	61	\$16,444	4	0	0	0	0	94	1	0	2	24	52	22
Census Tract 2520, Macomb County, Michigan	13	\$1,803	123	\$14,056	3	0	0	0	0	89	4	3	6	14	58	22
Census Tract 2561, Macomb County, Michigan	13	\$1,985	231	\$15,052	20	0	0	0	2	72	2	4	15	39	40	6
Census Tract 2564, Macomb County, Michigan	13	\$1,941	79	\$14,519	23	0	0	0	1	69	7	0	10	53	34	3
Census Tract 2586, Macomb County, Michigan	13	\$2,183	402	\$16,517	57	0	0	0	0	39	3	0	12	31	42	15
Census Tract 2621, Macomb County, Michigan	13	\$2,046	95	\$15,175	16	0	0	0	0	76	9	0	31	29	23	17
Census Tract 1345, Oakland County, Michigan	13	\$2,339	34	\$18,040	0	0	0	0	0	100	0	0	67	7	14	12
Census Tract 1423, Oakland County, Michigan	13	\$1,469	408	\$11,626	81	0	4	0	0	13	2	0	31	35	26	8
Census Tract 1500, Oakland County, Michigan	13	\$2,057	232	\$15,497	5	0	3	0	1	91	0	0	10	7	14	69
Census Tract 1562, Oakland County, Michigan	13	\$2,310	260	\$17,964	0	0	1	0	1	98	0	0	1	16	56	28
Census Tract 1564, Oakland County, Michigan	13	\$2,594	96	\$20,181	2	0	2	0	0	95	0	0	3	10	11	76
Census Tract 1573, Oakland County, Michigan	13	\$2,115	79	\$16,299	10	0	2	0	0	88	0	0	4	6	16	75
Census Tract 1576, Oakland County, Michigan	13	\$2,519	123	\$19,272	10	0	6	0	0	84	1	0	10	17	9	63
Census Tract 1600, Oakland County, Michigan	13	\$2,028	65	\$15,573	63	0	0	0	1	36	0	0	2	15	26	58
Census Tract 1607, Oakland County, Michigan	13	\$2,706	19	\$20,324	81	0	0	0	0	19	1	0	4	8	22	65
Census Tract 1610, Oakland County, Michigan	13	\$1,510	149	\$12,025	85	0	1	0	0	14	1	0	26	15	27	32
Census Tract 1613, Oakland County, Michigan	13	\$1,985	187	\$15,273	60	0	0	0	0	40	0	0	6	28	23	43
Census Tract 1616, Oakland County, Michigan	13	\$1,521	147	\$11,319	74	0	1	0	1	21	3	0	4	31	43	22
Census Tract 1625, Oakland County, Michigan	13	\$1,656	311	\$12,864	76	0	0	0	0	23	0	0	7	33	46	14
Census Tract 1661, Oakland County, Michigan	13	\$1,701	112	\$13,024	28	0	1	0	0	71	0	0	6	16	45	32
Census Tract 1667, Oakland County, Michigan	13	\$2,389	56	\$18,260	35	1	3	0	1	50	10	0	2	29	16	53
Census Tract 1669, Oakland County, Michigan	13	\$2,386	109	\$18,298	28	0	0	0	0	65	6	0	5	5	23	67
Census Tract 1686.02, Oakland County, Michigan	13	\$1,782	135	\$13,799	16	0	10	0	0	74	0	0	1	23	34	42
Census Tract 1689.01, Oakland County, Michigan	13	\$1,440	81	\$11,496	27	0	27	0	1	37	8	0	0	15	36	48
Census Tract 1833, Oakland County, Michigan	13	\$1,504	105	\$11,375	3	0	1	0	1	95	0	0	3	15	32	51
Census Tract 1836, Oakland County, Michigan	13	\$1,438	120	\$11,259	3	0	1	0	0	96	0	0	4	12	24	60

Census Tract 1842, Oakland County, Michigan	13	\$1,453	194	\$11,235	6	0	2	0	5	83	5	0	14	7	23	56
Census Tract 1961, Oakland County, Michigan	13	\$1,948	115	\$15,431	0	0	9	0	0	90	0	0	0	9	22	69
Census Tract 1979, Oakland County, Michigan	13	\$1,968	43	\$15,558	0	0	4	0	1	95	0	0	0	5	22	73
Census Tract 5067, Wayne County, Michigan	13	\$3,160	49	\$24,484	98	0	0	0	1	2	0	0	13	36	46	4
Census Tract 5208, Wayne County, Michigan	13	\$500	46	\$3,812	50	0	49	0	0	1	0	0	0	0	45	55
Census Tract 5218, Wayne County, Michigan	13	\$1,237	427	\$9,581	94	0	0	0	0	5	1	1	25	26	44	6
Census Tract 5243, Wayne County, Michigan	13	\$2,971	372	\$23,121	4	0	0	0	23	21	5	47	55	29	14	2
Census Tract 5259, Wayne County, Michigan	13	\$3,125	299	\$23,552	22	0	0	0	23	13	7	36	45	25	24	6
Census Tract 5339, Wayne County, Michigan	13	\$1,303	418	\$10,374	64	0	12	0	1	22	1	0	11	25	46	18
Census Tract 5383, Wayne County, Michigan	13	\$1,238	216	\$9,839	93	0	5	0	0	2	0	0	11	23	21	45
Census Tract 5505, Wayne County, Michigan	13	\$2,693	61	\$20,494	2	0	2	0	0	94	2	0	2	36	16	45
Census Tract 5522, Wayne County, Michigan	13	\$2,682	368	\$20,080	3	0	26	0	0	66	4	0	26	37	23	14
Census Tract 5542, Wayne County, Michigan	13	\$2,069	235	\$16,333	19	0	0	0	1	75	5	0	13	45	32	9
Census Tract 5544, Wayne County, Michigan	13	\$2,341	207	\$17,606	49	0	2	0	0	47	3	0	9	41	43	8
Census Tract 5546, Wayne County, Michigan	13	\$1,953	124	\$14,622	25	0	0	0	2	73	1	0	7	26	48	19
Census Tract 5547, Wayne County, Michigan	13	\$1,918	65	\$14,911	37	0	0	0	0	62	0	0	24	36	23	17
Census Tract 5562, Wayne County, Michigan	13	\$1,686	166	\$13,213	6	0	1	0	0	93	0	0	52	15	21	13
Census Tract 5569, Wayne County, Michigan	13	\$1,991	84	\$15,517	1	0	3	0	1	95	0	0	2	25	45	29
Census Tract 5580, Wayne County, Michigan	13	\$1,920	125	\$15,326	1	0	0	0	0	96	2	0	1	27	42	30
Census Tract 5581, Wayne County, Michigan	13	\$2,121	115	\$16,908	4	0	1	0	1	92	2	0	11	27	36	26
Census Tract 5582, Wayne County, Michigan	13	\$2,387	93	\$18,592	5	0	0	0	0	93	1	0	11	23	38	28
Census Tract 5586, Wayne County, Michigan	13	\$2,063	25	\$16,134	4	0	1	0	1	94	0	0	19	20	40	21
Census Tract 5598, Wayne County, Michigan	13	\$1,562	845	\$12,391	95	0	0	0	0	3	1	0	40	21	30	9
Census Tract 5616, Wayne County, Michigan	13	\$1,722	254	\$13,662	3	0	1	0	0	96	0	0	9	25	27	39
Census Tract 5639, Wayne County, Michigan	13	\$2,652	38	\$20,329	4	0	15	0	0	80	2	0	1	18	29	52
Census Tract 5642, Wayne County, Michigan	13	\$2,112	216	\$16,492	5	0	4	0	0	90	1	0	26	26	18	30
Census Tract 5649, Wayne County, Michigan	13	\$2,231	207	\$17,126	1	0	0	0	1	86	13	0	10	44	43	3
Census Tract 5665, Wayne County, Michigan	13	\$1,420	231	\$10,737	31	0	4	0	0	64	1	0	42	19	38	1
Census Tract 5668, Wayne County, Michigan	13	\$2,005	196	\$15,756	43	1	0	0	2	54	0	1	22	21	45	12
Census Tract 5692, Wayne County, Michigan	13	\$1,859	237	\$14,002	8	0	0	0	2	89	1	0	37	27	27	9
Census Tract 5699, Wayne County, Michigan	13	\$2,168	181	\$16,432	2	0	1	0	3	93	2	0	13	42	37	7
Census Tract 5701, Wayne County, Michigan	13	\$1,859	536	\$14,331	70	0	1	0	0	27	2	0	21	23	47	9
Census Tract 5704, Wayne County, Michigan	13	\$2,136	661	\$16,160	80	0	0	0	0	19	1	0	41	34	23	1
Census Tract 5716, Wayne County, Michigan	13	\$1,819	263	\$14,274	13	0	0	0	0	87	0	0	18	38	31	13
Census Tract 5717, Wayne County, Michigan	13	\$2,454	237	\$18,685	14	0	0	0	1	83	2	0	35	15	40	10
Census Tract 5730, Wayne County, Michigan	13	\$2,827	98	\$21,126	1	0	1	0	2	94	1	0	14	18	42	26
Census Tract 5733, Wayne County, Michigan	13	\$2,780	376	\$21,939	0	0	0	0	0	95	4	0	38	17	21	24
Census Tract 5741, Wayne County, Michigan	13	\$2,618	492	\$19,922	1	0	1	0	0	93	5	0	24	22	28	26
Census Tract 5763, Wayne County, Michigan	13	\$2,325	60	\$18,100	1	0	0	0	2	92	3	1	5	38	35	21
Census Tract 5764, Wayne County, Michigan	13	\$1,887	150	\$14,169	3	0	0	0	4	87	5	1	3	27	43	27
Census Tract 5776, Wayne County, Michigan	13	\$2,190	344	\$17,264	1	1	0	0	6	86	2	4	9	37	40	14
Census Tract 5786, Wayne County, Michigan	13	\$1,831	669	\$14,593	8	1	0	0	7	77	3	5	26	43	24	7
Census Tract 5792, Wayne County, Michigan	13	\$1,652	621	\$12,740	36	0	0	0	5	53	1	5	20	52	24	4
Census Tract 5793, Wayne County, Michigan	13	\$1,780	500	\$13,664	93	0	0	0	0	3	3	0	24	23	47	5
Census Tract 5815, Wayne County, Michigan	13	\$2,147	91	\$16,193	0	1	0	0	1	95	1	2	6	44	42	8
Census Tract 5816, Wayne County, Michigan	13	\$1,810	203	\$13,930	6	0	8	0	0	79	5	1	7	32	45	16
Census Tract 5820, Wayne County, Michigan	13	\$1,708	264	\$12,972	10	0	3	0	4	68	1	14	7	51	35	7
Census Tract 5831.01, Wayne County, Michigan	13	\$2,475	309	\$19,638	7	2	0	0	1	89	1	0	32	44	21	3
Census Tract 5833, Wayne County, Michigan	13	\$2,369	162	\$18,271	3	0	0	0	0	93	3	1	17	46	34	3
Census Tract 5842, Wayne County, Michigan	13	\$2,040	289	\$15,196	21	0	1	0	0	77	0	0	12	46	40	2
Census Tract 5844, Wayne County, Michigan	13	\$2,107	190	\$16,506	15	0	0	0	0	82	2	0	17	57	18	8
Census Tract 5856, Wayne County, Michigan	13	\$1,929	312	\$14,821	87	0	1	0	0	10	1	0	30	30	35	6
Census Tract 5916, Wayne County, Michigan	13	\$2,257	33	\$17,993	7	0	3	0	2	86	0	2	18	26	36	21
Census Tract 2306.04, Macomb County, Michigan	12	\$1,871	100	\$15,454	1	0	2	0	0	98	0	0	23	8	36	33
Census Tract 2315, Macomb County, Michigan	12	\$2,329	245	\$18,640	0	0	4	0	0	95	1	0	28	23	28	21
Census Tract 2325, Macomb County, Michigan	12	\$2,203	178	\$18,479	2	0	1	0	0	96	0	0	9	20	40	31
Census Tract 2407, Macomb County, Michigan	12	\$2,181	82	\$18,354	1	0	1	0	0	97	1	0	8	24	52	16
Census Tract 2453, Macomb County, Michigan	12	\$1,651	373	\$13,626	9	0	0	0	0	90	0	0	27	38	30	5
Census Tract 2472.01, Macomb County, Michigan	12	\$1,565	95	\$12,956	7	0	0	0	1	92	0	0	5	46	40	9
Census Tract 2474, Macomb County, Michigan	12	\$1,848	76	\$16,041	0	0	0	0	0	99	0	0	6	33	56	6
Census Tract 2505, Macomb County, Michigan	12	\$1,917	105	\$15,870	2	0	0	0	0	96	2	0	12	23	37	28
Census Tract 2515, Macomb County, Michigan	12	\$1,918	136	\$15,947	9	0	0	0	1	90	0	0	12	21	48	19

Census Tract 2516, Macomb County, Michigan	12	\$1,622	219	\$13,040	3	0	0	0	0	94	2	0	2	51	39	9
Census Tract 2517, Macomb County, Michigan	12	\$1,498	238	\$12,907	10	0	1	0	1	87	1	0	9	31	43	17
Census Tract 2540, Macomb County, Michigan	12	\$2,213	53	\$19,015	2	0	0	0	0	97	0	0	3	18	60	18
Census Tract 2584, Macomb County, Michigan	12	\$2,175	362	\$18,017	45	0	1	0	1	48	5	0	18	31	43	7
Census Tract 2629, Macomb County, Michigan	12	\$2,034	390	\$17,493	16	0	2	0	1	79	2	0	26	39	31	4
Census Tract 2684, Macomb County, Michigan	12	\$1,909	458	\$16,309	24	0	0	0	0	72	4	0	9	54	37	1
Census Tract 1508, Oakland County, Michigan	12	\$2,158	64	\$17,525	5	0	4	0	0	90	1	0	1	6	10	84
Census Tract 1530, Oakland County, Michigan	12	\$1,796	114	\$14,785	0	0	1	0	2	97	0	0	3	5	13	79
Census Tract 1605, Oakland County, Michigan	12	\$2,051	176	\$17,232	52	0	0	0	0	46	1	0	18	12	28	42
Census Tract 1650, Oakland County, Michigan	12	\$1,397	167	\$11,594	7	0	1	0	0	91	1	0	3	18	45	34
Census Tract 1652, Oakland County, Michigan	12	\$1,917	108	\$16,085	36	0	6	0	0	47	10	1	0	14	28	58
Census Tract 1665, Oakland County, Michigan	12	\$1,956	89	\$16,399	8	1	3	0	0	87	0	0	4	20	26	51
Census Tract 1668, Oakland County, Michigan	12	\$1,934	83	\$16,644	47	0	0	0	0	51	2	0	11	18	13	57
Census Tract 1673, Oakland County, Michigan	12	\$1,597	159	\$12,848	22	0	5	0	1	71	1	0	6	17	42	36
Census Tract 1675, Oakland County, Michigan	12	\$1,625	680	\$12,994	11	0	1	0	1	86	2	0	6	65	14	14
Census Tract 1701, Oakland County, Michigan	12	\$1,693	57	\$13,544	2	0	0	0	1	88	9	0	0	14	36	49
Census Tract 1730, Oakland County, Michigan	12	\$1,564	324	\$12,793	4	0	0	0	0	92	3	0	4	16	42	38
Census Tract 1731, Oakland County, Michigan	12	\$1,688	79	\$14,074	7	0	0	0	0	90	2	0	10	10	34	46
Census Tract 1752, Oakland County, Michigan	12	\$1,841	557	\$15,398	17	0	1	0	0	77	5	0	7	45	35	13
Census Tract 1803, Oakland County, Michigan	12	\$1,343	210	\$11,660	0	0	0	0	1	97	1	0	4	35	30	31
Census Tract 1834, Oakland County, Michigan	12	\$1,408	116	\$11,959	3	0	1	0	2	92	2	0	13	9	15	64
Census Tract 1960, Oakland County, Michigan	12	\$2,107	81	\$17,147	0	0	14	0	0	85	1	0	0	12	31	58
Census Tract 1972, Oakland County, Michigan	12	\$2,202	56	\$18,824	0	0	19	0	0	81	0	0	0	13	20	67
Census Tract 1973, Oakland County, Michigan	12	\$1,864	151	\$15,924	0	0	6	0	0	92	1	0	16	25	20	38
Census Tract 1977.01, Oakland County, Michigan	12	\$1,181	102	\$9,954	1	0	10	0	3	85	1	0	4	1	15	79
Census Tract 5080, Wayne County, Michigan	12	\$1,506	434	\$12,619	79	0	0	0	0	20	0	1	28	48	23	2
Census Tract 5153, Wayne County, Michigan	12	\$1,335	532	\$10,702	72	0	0	0	0	21	4	2	32	37	18	13
Census Tract 5175, Wayne County, Michigan	12	\$1,129	722	\$9,634	77	0	7	0	0	14	1	1	20	40	21	19
Census Tract 5561, Wayne County, Michigan	12	\$2,607	176	\$21,444	5	0	2	0	1	87	5	0	13	33	36	17
Census Tract 5564, Wayne County, Michigan	12	\$1,715	140	\$14,351	0	0	0	0	0	99	0	0	0	23	50	27
Census Tract 5572, Wayne County, Michigan	12	\$1,923	107	\$15,842	1	0	1	0	1	97	1	0	3	27	46	24
Census Tract 5573, Wayne County, Michigan	12	\$2,117	45	\$17,336	3	0	0	0	1	96	0	0	21	24	44	12
Census Tract 5576, Wayne County, Michigan	12	\$1,954	47	\$16,932	0	0	0	0	1	99	1	0	3	21	37	39
Census Tract 5585, Wayne County, Michigan	12	\$2,056	149	\$17,261	1	0	0	0	1	98	0	0	2	29	49	20
Census Tract 5587, Wayne County, Michigan	12	\$2,614	61	\$21,197	2	0	1	0	0	96	0	0	1	19	44	36
Census Tract 5591, Wayne County, Michigan	12	\$2,422	93	\$20,336	6	0	0	0	3	90	1	0	1	30	34	35
Census Tract 5643, Wayne County, Michigan	12	\$2,151	66	\$17,485	1	0	6	0	1	92	0	0	18	12	29	42
Census Tract 5667, Wayne County, Michigan	12	\$2,242	326	\$18,250	3	0	0	0	0	92	3	1	14	41	41	3
Census Tract 5669, Wayne County, Michigan	12	\$1,885	438	\$15,388	33	0	0	0	0	65	1	0	14	41	42	3
Census Tract 5672.02, Wayne County, Michigan	12	\$1,718	130	\$14,406	32	0	1	0	0	62	4	0	21	21	35	23
Census Tract 5678, Wayne County, Michigan	12	\$1,721	393	\$14,698	24	0	1	0	0	73	1	0	13	33	37	17
Census Tract 5682, Wayne County, Michigan	12	\$2,376	153	\$19,461	11	0	0	0	1	86	2	0	33	35	24	7
Census Tract 5683, Wayne County, Michigan	12	\$2,031	269	\$16,966	23	0	0	0	1	72	3	1	20	35	38	7
Census Tract 5684, Wayne County, Michigan	12	\$2,377	231	\$19,452	13	0	1	0	1	76	8	1	12	38	47	4
Census Tract 5685, Wayne County, Michigan	12	\$1,970	531	\$16,370	21	0	0	0	1	71	3	4	25	29	44	2
Census Tract 5693, Wayne County, Michigan	12	\$1,881	185	\$15,756	1	0	0	0	1	96	1	0	7	46	39	8
Census Tract 5695, Wayne County, Michigan	12	\$2,201	200	\$18,832	0	0	0	0	0	94	5	0	9	39	47	6
Census Tract 5705, Wayne County, Michigan	12	\$1,987	264	\$16,423	76	0	0	0	1	20	3	0	18	34	43	5
Census Tract 5728, Wayne County, Michigan	12	\$2,461	372	\$20,821	4	0	1	0	2	93	0	0	11	44	28	17
Census Tract 5736, Wayne County, Michigan	12	\$2,333	873	\$19,667	3	0	0	0	1	96	1	0	49	21	16	14
Census Tract 5738, Wayne County, Michigan	12	\$2,562	599	\$20,950	0	0	1	0	0	89	9	0	43	24	19	13
Census Tract 5739, Wayne County, Michigan	12	\$2,807	509	\$23,037	0	0	0	0	0	100	0	0	29	33	18	19
Census Tract 5740, Wayne County, Michigan	12	\$2,427	584	\$20,893	0	0	0	0	0	97	3	0	30	29	28	12
Census Tract 5747, Wayne County, Michigan	12	\$2,895	132	\$24,066	0	0	0	0	2	97	1	0	3	12	47	38
Census Tract 5756, Wayne County, Michigan	12	\$2,602	115	\$21,246	4	0	5	0	1	90	0	0	6	25	43	27
Census Tract 5762, Wayne County, Michigan	12	\$1,707	70	\$14,206	2	0	0	0	2	95	0	0	15	42	34	9
Census Tract 5767, Wayne County, Michigan	12	\$2,081	164	\$17,757	5	0	0	0	2	89	3	1	12	22	45	22
Census Tract 5778, Wayne County, Michigan	12	\$2,081	280	\$17,676	2	0	0	0	5	90	0	3	26	36	33	5
Census Tract 5791, Wayne County, Michigan	12	\$1,704	318	\$14,430	31	1	0	0	1	63	1	3	16	47	37	0
Census Tract 5798, Wayne County, Michigan	12	\$1,959	256	\$16,280	53	3	0	0	4	31	9	0	13	31	42	14
Census Tract 5837, Wayne County, Michigan	12	\$2,093	142	\$17,469	10	0	0	0	1	87	1	1	18	37	31	14
Census Tract 5863, Wayne County, Michigan	12	\$2,554	59	\$21,585	4	0	0	0	0	95	0	0	13	44	39	5

Census Tract 9851, Wayne County, Michigan	12	\$1,406	10	\$11,880	74	0	0	0	0	0	26	0	16	3	0	81
Census Tract 9853, Wayne County, Michigan	12	\$1,160	13	\$9,464	27	0	0	0	64	9	0	0	40	11	35	14
Census Tract 2304, Macomb County, Michigan	11	\$1,821	186	\$16,542	0	0	0	0	0	95	5	0	4	27	37	32
Census Tract 2305.02, Macomb County, Michigan	11	\$790	20	\$7,148	0	0	0	0	0	100	0	0	0	100	0	0
Census Tract 2306.02, Macomb County, Michigan	11	\$2,194	387	\$19,198	1	0	5	0	0	93	0	0	24	22	35	19
Census Tract 2307, Macomb County, Michigan	11	\$2,406	190	\$22,199	0	0	7	0	0	91	1	0	24	17	31	29
Census Tract 2311, Macomb County, Michigan	11	\$1,627	279	\$15,227	2	0	3	0	0	93	3	0	14	40	23	24
Census Tract 2323.01, Macomb County, Michigan	11	\$1,808	356	\$17,005	1	0	4	0	0	94	1	0	22	32	30	16
Census Tract 2400, Macomb County, Michigan	11	\$1,626	612	\$14,526	34	0	0	0	0	60	5	0	17	47	31	5
Census Tract 2404, Macomb County, Michigan	11	\$1,665	330	\$15,048	5	0	0	0	0	94	0	0	12	42	38	8
Census Tract 2435.01, Macomb County, Michigan	11	\$1,827	93	\$17,000	1	0	0	0	4	95	0	0	17	17	34	32
Census Tract 2450, Macomb County, Michigan	11	\$1,575	558	\$14,858	37	0	0	0	0	60	2	0	29	42	24	6
Census Tract 2452, Macomb County, Michigan	11	\$1,892	144	\$17,287	22	0	0	0	0	77	1	0	7	44	46	3
Census Tract 2476.02, Macomb County, Michigan	11	\$1,354	487	\$12,654	4	0	0	0	0	95	0	0	9	38	41	12
Census Tract 2501, Macomb County, Michigan	11	\$1,958	117	\$18,319	7	0	0	0	0	91	2	0	4	28	43	24
Census Tract 2506, Macomb County, Michigan	11	\$2,067	128	\$19,583	0	0	0	0	0	97	2	0	5	34	46	16
Census Tract 2510, Macomb County, Michigan	11	\$1,938	61	\$17,884	1	0	0	0	0	96	3	0	9	20	50	21
Census Tract 2513, Macomb County, Michigan	11	\$2,125	99	\$18,586	0	0	0	0	2	97	1	0	5	25	50	20
Census Tract 2514, Macomb County, Michigan	11	\$2,024	153	\$18,835	1	0	0	0	1	97	1	0	5	33	52	10
Census Tract 2542, Macomb County, Michigan	11	\$1,646	305	\$14,352	1	0	0	0	0	98	1	0	15	49	28	8
Census Tract 2551, Macomb County, Michigan	11	\$1,622	271	\$15,268	6	0	0	0	2	89	0	2	19	41	32	8
Census Tract 2553, Macomb County, Michigan	11	\$1,785	344	\$15,576	24	0	1	2	0	68	1	5	13	35	43	9
Census Tract 2554, Macomb County, Michigan	11	\$2,168	91	\$20,375	5	0	0	0	0	91	4	0	30	26	43	2
Census Tract 2555, Macomb County, Michigan	11	\$1,750	88	\$15,440	14	0	0	0	0	84	0	1	12	29	49	10
Census Tract 2556, Macomb County, Michigan	11	\$1,998	255	\$18,099	8	0	0	0	0	85	7	0	14	35	39	12
Census Tract 2557, Macomb County, Michigan	11	\$2,021	111	\$18,249	21	0	0	0	0	78	1	0	24	27	44	5
Census Tract 2558, Macomb County, Michigan	11	\$1,901	124	\$18,002	19	0	0	0	0	79	1	0	16	47	33	4
Census Tract 2559, Macomb County, Michigan	11	\$2,126	164	\$19,975	16	0	0	1	4	77	2	1	12	28	57	2
Census Tract 2562, Macomb County, Michigan	11	\$1,761	157	\$15,632	15	0	0	0	0	78	7	0	16	37	38	9
Census Tract 2568, Macomb County, Michigan	11	\$2,005	140	\$17,742	7	0	0	0	1	91	1	0	18	39	38	6
Census Tract 2581, Macomb County, Michigan	11	\$2,169	196	\$20,340	32	0	0	0	0	63	3	3	8	35	38	20
Census Tract 2583, Macomb County, Michigan	11	\$1,768	224	\$16,517	40	0	0	0	0	56	3	0	20	27	43	11
Census Tract 2604, Macomb County, Michigan	11	\$1,644	179	\$15,636	4	0	7	0	1	88	1	0	7	35	44	14
Census Tract 2606, Macomb County, Michigan	11	\$2,060	233	\$19,470	3	0	6	0	0	89	2	0	16	38	31	15
Census Tract 2612, Macomb County, Michigan	11	\$1,717	111	\$14,961	8	0	2	0	0	88	1	0	11	28	50	10
Census Tract 2613, Macomb County, Michigan	11	\$1,893	133	\$16,947	5	0	1	0	2	92	0	0	8	40	41	10
Census Tract 2625, Macomb County, Michigan	11	\$1,569	572	\$14,785	13	0	17	0	1	68	1	0	20	36	34	10
Census Tract 2628, Macomb County, Michigan	11	\$1,813	190	\$16,325	22	0	4	0	4	70	1	0	23	27	47	2
Census Tract 2636, Macomb County, Michigan	11	\$2,304	600	\$20,690	42	3	23	0	1	29	1	0	16	28	47	9
Census Tract 2639, Macomb County, Michigan	11	\$2,030	363	\$18,130	41	0	1	0	5	51	2	1	14	43	40	3
Census Tract 2642, Macomb County, Michigan	11	\$1,957	597	\$17,308	46	0	2	0	1	50	1	0	22	43	28	8
Census Tract 1349, Oakland County, Michigan	11	\$1,466	279	\$13,246	1	0	0	0	0	97	2	0	12	41	18	29
Census Tract 1363, Oakland County, Michigan	11	\$1,950	61	\$18,237	0	0	0	0	0	99	0	0	1	35	14	50
Census Tract 1365, Oakland County, Michigan	11	\$1,986	101	\$17,882	0	0	1	0	0	98	1	0	0	5	42	53
Census Tract 1367, Oakland County, Michigan	11	\$1,892	70	\$17,864	0	0	0	0	1	99	0	0	14	48	3	34
Census Tract 1575, Oakland County, Michigan	11	\$1,351	238	\$12,096	9	0	3	0	0	87	1	0	2	22	17	60
Census Tract 1581, Oakland County, Michigan	11	\$1,933	92	\$16,823	15	0	1	0	1	83	0	0	0	4	12	83
Census Tract 1615, Oakland County, Michigan	11	\$2,109	28	\$18,884	86	0	0	0	0	12	2	0	3	16	35	46
Census Tract 1618, Oakland County, Michigan	11	\$1,736	228	\$15,770	73	0	0	0	1	22	4	0	6	22	38	34
Census Tract 1624, Oakland County, Michigan	11	\$2,033	110	\$19,287	73	0	1	0	0	13	12	1	7	30	25	38
Census Tract 1651, Oakland County, Michigan	11	\$1,811	137	\$16,799	10	0	0	0	0	88	1	0	3	15	34	49
Census Tract 1664, Oakland County, Michigan	11	\$2,392	39	\$21,798	8	0	0	0	0	90	1	0	15	16	9	60
Census Tract 1679, Oakland County, Michigan	11	\$2,151	23	\$19,872	36	0	1	0	0	61	2	0	4	6	17	73
Census Tract 1702, Oakland County, Michigan	11	\$1,829	57	\$16,162	4	0	0	0	1	93	1	0	10	27	31	32
Census Tract 1711, Oakland County, Michigan	11	\$1,840	100	\$16,172	43	0	1	0	0	50	6	0	2	32	36	30
Census Tract 1712, Oakland County, Michigan	11	\$1,739	143	\$16,446	35	0	3	0	1	59	3	0	9	12	46	33
Census Tract 1716, Oakland County, Michigan	11	\$1,886	193	\$17,139	60	0	1	0	0	37	1	0	23	21	38	18
Census Tract 1751, Oakland County, Michigan	11	\$1,523	637	\$14,033	6	0	0	0	0	89	4	0	12	38	42	9
Census Tract 1753, Oakland County, Michigan	11	\$1,975	339	\$17,313	23	0	0	0	0	73	2	0	11	23	44	22
Census Tract 1801, Oakland County, Michigan	11	\$1,737	133	\$15,774	0	0	0	0	1	99	0	0	5	19	50	26
Census Tract 1815, Oakland County, Michigan	11	\$1,747	201	\$15,950	6	0	0	0	2	87	4	0	21	39	25	15
Census Tract 1816, Oakland County, Michigan	11	\$1,800	463	\$15,915	10	0	0	0	0	86	3	0	15	35	28	22

Census Tract 1831, Oakland County, Michigan	11	\$1,679	199	\$15,908	1	0	1	0	1	92	3	1	3	13	27	57
Census Tract 1840, Oakland County, Michigan	11	\$1,593	39	\$15,103	2	0	1	0	0	96	1	0	1	11	25	63
Census Tract 1841, Oakland County, Michigan	11	\$1,795	51	\$16,906	11	0	0	0	0	85	3	0	0	14	36	50
Census Tract 1844, Oakland County, Michigan	11	\$1,383	178	\$12,956	3	0	2	0	1	93	1	0	6	26	28	40
Census Tract 1845, Oakland County, Michigan	11	\$1,648	44	\$14,505	1	0	0	0	1	94	4	0	4	12	34	50
Census Tract 1847, Oakland County, Michigan	11	\$1,703	57	\$16,005	5	0	0	0	1	89	5	0	7	15	24	54
Census Tract 1963, Oakland County, Michigan	11	\$1,962	73	\$17,126	0	0	14	0	0	85	0	0	2	11	14	74
Census Tract 1970, Oakland County, Michigan	11	\$1,961	94	\$17,924	0	0	33	0	0	67	0	0	34	14	10	41
Census Tract 5170, Wayne County, Michigan	11	\$836	178	\$7,892	63	0	10	0	0	23	2	2	6	13	33	48
Census Tract 5189, Wayne County, Michigan	11	\$1,519	317	\$14,092	95	0	0	0	0	3	0	1	27	34	30	8
Census Tract 5430, Wayne County, Michigan	11	\$2,637	111	\$23,796	82	0	0	0	0	11	6	0	4	10	26	60
Census Tract 5520, Wayne County, Michigan	11	\$2,858	343	\$25,091	2	0	51	0	0	39	3	6	14	44	27	15
Census Tract 5536.01, Wayne County, Michigan	11	\$1,897	165	\$16,572	90	0	0	0	0	6	1	4	14	47	15	24
Census Tract 5543, Wayne County, Michigan	11	\$2,162	164	\$20,584	25	0	0	0	2	67	6	0	2	40	34	25
Census Tract 5548, Wayne County, Michigan	11	\$2,381	120	\$21,882	25	0	0	0	1	73	0	0	4	54	24	18
Census Tract 5553, Wayne County, Michigan	11	\$2,380	226	\$22,458	58	0	0	0	0	42	1	0	2	54	37	6
Census Tract 5555, Wayne County, Michigan	11	\$1,780	295	\$16,604	59	0	0	0	0	39	2	0	6	48	33	13
Census Tract 5556, Wayne County, Michigan	11	\$1,967	187	\$17,915	26	0	1	0	2	71	1	0	3	47	37	13
Census Tract 5565, Wayne County, Michigan	11	\$1,342	167	\$11,720	11	0	1	0	0	87	1	0	20	35	32	13
Census Tract 5566, Wayne County, Michigan	11	\$2,184	68	\$19,070	0	0	0	0	0	98	2	0	2	14	40	44
Census Tract 5589, Wayne County, Michigan	11	\$2,312	30	\$20,390	3	0	3	0	0	92	2	0	3	38	29	31
Census Tract 5602.01, Wayne County, Michigan	11	\$1,588	54	\$14,456	0	1	9	0	0	89	1	0	0	11	37	53
Census Tract 5628, Wayne County, Michigan	11	\$2,322	113	\$21,315	2	0	1	0	0	95	1	0	6	20	25	49
Census Tract 5653.01, Wayne County, Michigan	11	\$1,044	410	\$9,699	65	0	5	0	0	30	0	0	18	21	54	8
Census Tract 5670, Wayne County, Michigan	11	\$2,678	312	\$23,431	75	2	0	0	1	20	2	0	17	21	52	10
Census Tract 5674, Wayne County, Michigan	11	\$1,777	148	\$15,799	4	0	0	0	0	93	1	0	8	37	37	17
Census Tract 5680, Wayne County, Michigan	11	\$1,680	201	\$15,430	15	0	0	0	0	80	2	2	18	36	33	12
Census Tract 5691, Wayne County, Michigan	11	\$2,325	116	\$22,072	0	0	0	0	1	96	1	2	5	38	53	4
Census Tract 5698, Wayne County, Michigan	11	\$2,435	149	\$21,222	8	0	1	0	1	88	1	1	26	37	32	5
Census Tract 5702, Wayne County, Michigan	11	\$2,365	337	\$20,655	69	0	0	0	2	25	1	3	14	30	53	3
Census Tract 5770, Wayne County, Michigan	11	\$1,620	477	\$15,159	24	0	0	0	7	43	4	23	24	39	28	9
Census Tract 5772, Wayne County, Michigan	11	\$2,005	342	\$18,878	9	5	0	0	5	61	2	17	21	55	21	3
Census Tract 5775, Wayne County, Michigan	11	\$2,071	229	\$19,452	12	0	0	0	8	63	3	14	11	54	31	5
Census Tract 5807, Wayne County, Michigan	11	\$1,374	494	\$12,891	4	0	1	0	1	86	1	6	8	33	46	13
Census Tract 5812, Wayne County, Michigan	11	\$1,520	322	\$14,460	9	0	1	0	2	86	1	1	11	47	33	9
Census Tract 5838, Wayne County, Michigan	11	\$1,829	206	\$16,822	11	0	0	0	0	87	1	1	19	35	43	3
Census Tract 5843, Wayne County, Michigan	11	\$1,769	140	\$16,319	23	0	1	0	1	72	2	1	19	37	37	7
Census Tract 5846, Wayne County, Michigan	11	\$1,539	196	\$14,363	37	0	19	0	2	40	1	1	23	49	19	9
Census Tract 5858, Wayne County, Michigan	11	\$2,343	257	\$21,387	53	0	0	0	0	46	1	0	7	40	45	7
Census Tract 5915.01, Wayne County, Michigan	11	\$2,185	333	\$19,051	17	0	36	0	0	43	3	1	22	55	19	4
Census Tract 5963, Wayne County, Michigan	11	\$2,392	9	\$21,239	0	0	1	0	0	98	1	0	0	8	48	44
Census Tract 2308, Macomb County, Michigan	10	\$2,158	380	\$22,054	2	0	2	0	0	87	9	0	32	24	17	28
Census Tract 2309.01, Macomb County, Michigan	10	\$2,098	249	\$20,807	0	0	0	0	0	100	0	0	8	28	27	37
Census Tract 2314, Macomb County, Michigan	10	\$2,402	324	\$23,229	1	0	6	0	0	93	0	0	33	19	25	23
Census Tract 2316, Macomb County, Michigan	10	\$1,774	349	\$18,319	9	0	9	0	0	82	1	0	33	21	31	16
Census Tract 2321, Macomb County, Michigan	10	\$1,999	358	\$19,779	8	0	3	0	0	89	0	0	18	24	35	23
Census Tract 2409, Macomb County, Michigan	10	\$1,975	72	\$20,106	1	0	0	0	0	94	5	0	12	27	59	2
Census Tract 2416, Macomb County, Michigan	10	\$1,923	163	\$19,355	48	0	0	0	1	50	1	0	4	40	55	1
Census Tract 2451, Macomb County, Michigan	10	\$1,651	399	\$16,241	35	0	0	0	1	62	2	0	9	68	21	3
Census Tract 2454, Macomb County, Michigan	10	\$1,790	118	\$18,508	57	0	0	0	0	37	2	4	4	52	39	6
Census Tract 2500, Macomb County, Michigan	10	\$1,850	70	\$19,387	1	0	0	0	1	95	3	0	10	32	45	14
Census Tract 2502, Macomb County, Michigan	10	\$1,882	122	\$18,653	0	0	0	0	0	97	3	0	3	44	37	16
Census Tract 2509, Macomb County, Michigan	10	\$2,201	150	\$21,760	0	0	1	0	0	96	3	0	11	32	40	17
Census Tract 2518, Macomb County, Michigan	10	\$1,550	262	\$16,208	19	0	0	0	0	78	2	0	14	30	42	15
Census Tract 2550, Macomb County, Michigan	10	\$1,464	454	\$14,667	28	0	1	0	0	70	1	1	9	32	50	9
Census Tract 2567, Macomb County, Michigan	10	\$1,880	164	\$18,011	7	0	1	0	7	81	4	0	9	56	29	7
Census Tract 2580, Macomb County, Michigan	10	\$1,925	133	\$18,458	31	0	0	0	4	60	5	1	9	41	27	23
Census Tract 2617, Macomb County, Michigan	10	\$1,637	272	\$15,986	32	0	0	0	0	66	1	0	9	52	32	8
Census Tract 2619, Macomb County, Michigan	10	\$1,755	192	\$17,502	24	0	3	0	2	62	9	0	18	41	30	11
Census Tract 2620, Macomb County, Michigan	10	\$1,858	146	\$17,732	9	0	6	0	1	83	1	0	8	33	33	26
Census Tract 2622, Macomb County, Michigan	10	\$1,727	253	\$17,088	1	0	20	0	0	79	0	0	12	26	47	16
Census Tract 2624, Macomb County, Michigan	10	\$1,828	340	\$17,969	7	0	24	0	0	65	3	0	41	25	23	11

Census Tract 2627, Macomb County, Michigan	10	\$1,775	308	\$18,458	23	0	16	0	1	57	2	0	13	26	47	14
Census Tract 2632, Macomb County, Michigan	10	\$1,810	402	\$17,670	22	0	9	0	0	59	10	0	11	40	45	4
Census Tract 2634, Macomb County, Michigan	10	\$2,045	286	\$20,156	11	0	20	0	0	67	2	0	12	31	41	15
Census Tract 2635, Macomb County, Michigan	10	\$1,646	578	\$16,313	8	0	5	0	3	77	6	0	14	36	42	8
Census Tract 2637, Macomb County, Michigan	10	\$1,904	423	\$19,034	51	0	3	0	2	41	4	0	6	48	40	6
Census Tract 2676, Macomb County, Michigan	10	\$1,759	57	\$16,957	1	0	5	0	0	93	0	0	8	25	43	23
Census Tract 2681, Macomb County, Michigan	10	\$1,751	213	\$18,017	36	2	5	0	0	54	3	0	7	32	47	14
Census Tract 1344, Oakland County, Michigan	10	\$1,795	103	\$17,732	0	0	0	0	0	100	0	0	1	8	48	43
Census Tract 1347, Oakland County, Michigan	10	\$1,533	210	\$14,870	0	0	0	0	1	98	0	0	5	68	14	13
Census Tract 1368, Oakland County, Michigan	10	\$2,093	248	\$21,927	0	0	0	0	1	89	10	0	24	21	25	31
Census Tract 1608, Oakland County, Michigan	10	\$1,670	79	\$17,497	71	0	0	0	0	24	5	0	1	28	37	33
Census Tract 1614, Oakland County, Michigan	10	\$1,317	384	\$13,660	55	0	0	0	0	45	0	0	18	32	20	30
Census Tract 1622, Oakland County, Michigan	10	\$1,013	62	\$9,700	91	0	1	0	0	9	0	0	1	47	42	10
Census Tract 1666, Oakland County, Michigan	10	\$1,199	382	\$12,267	32	0	7	0	1	60	0	0	13	25	20	43
Census Tract 1688, Oakland County, Michigan	10	\$2,513	20	\$24,273	15	0	2	0	0	80	3	0	1	7	17	74
Census Tract 1704, Oakland County, Michigan	10	\$1,336	167	\$12,886	7	0	0	0	0	91	2	0	9	23	41	27
Census Tract 1713, Oakland County, Michigan	10	\$1,847	232	\$17,638	80	0	0	0	0	18	2	0	20	24	41	16
Census Tract 1725, Oakland County, Michigan	10	\$1,451	331	\$14,716	89	0	0	0	0	4	5	2	14	46	26	14
Census Tract 1732, Oakland County, Michigan	10	\$1,471	67	\$14,277	1	0	0	0	1	95	3	0	0	19	36	45
Census Tract 1800, Oakland County, Michigan	10	\$1,669	88	\$16,333	0	0	0	0	3	93	4	0	11	26	25	38
Census Tract 1811, Oakland County, Michigan	10	\$1,561	149	\$15,982	4	0	0	0	0	95	0	0	3	47	29	22
Census Tract 1813, Oakland County, Michigan	10	\$1,580	318	\$15,923	7	0	3	0	1	88	1	0	25	24	31	20
Census Tract 1814, Oakland County, Michigan	10	\$1,658	158	\$16,716	10	0	0	0	1	88	1	0	15	26	38	21
Census Tract 1830, Oakland County, Michigan	10	\$1,565	133	\$15,327	12	0	1	0	2	84	0	0	0	20	45	36
Census Tract 1832, Oakland County, Michigan	10	\$1,384	141	\$13,508	6	0	1	0	1	91	1	0	5	20	26	48
Census Tract 1838, Oakland County, Michigan	10	\$1,586	150	\$15,842	2	0	1	0	1	95	1	0	23	21	25	31
Census Tract 1977.02, Oakland County, Michigan	10	\$982	42	\$9,549	2	0	10	0	6	81	1	0	11	9	16	64
Census Tract 5169, Wayne County, Michigan	10	\$1,054	227	\$10,442	92	0	0	0	0	5	3	0	24	32	38	6
Census Tract 5202, Wayne County, Michigan	10	\$1,214	236	\$12,200	23	0	37	0	4	32	2	2	5	9	48	38
Census Tract 5225, Wayne County, Michigan	10	\$1,172	453	\$11,899	83	0	0	0	0	12	3	2	17	33	25	25
Census Tract 5549, Wayne County, Michigan	10	\$2,694	94	\$25,814	60	0	1	0	1	38	0	0	9	17	61	13
Census Tract 5570, Wayne County, Michigan	10	\$2,532	48	\$24,418	6	0	2	0	1	89	2	0	10	22	48	20
Census Tract 5575, Wayne County, Michigan	10	\$2,231	78	\$22,586	0	0	2	0	0	98	0	0	4	32	32	32
Census Tract 5625, Wayne County, Michigan	10	\$1,412	84	\$14,226	7	0	0	0	0	92	1	0	12	28	35	24
Census Tract 5641, Wayne County, Michigan	10	\$1,522	225	\$14,544	13	0	14	0	0	68	4	0	12	21	31	36
Census Tract 5647, Wayne County, Michigan	10	\$2,073	77	\$19,884	13	6	3	0	0	54	23	0	1	52	16	32
Census Tract 5650.01, Wayne County, Michigan	10	\$1,957	129	\$19,701	6	1	16	0	0	76	2	0	9	13	41	38
Census Tract 5657, Wayne County, Michigan	10	\$2,081	130	\$21,530	7	0	14	0	0	78	1	0	5	22	34	40
Census Tract 5671, Wayne County, Michigan	10	\$1,614	251	\$15,401	11	0	0	0	1	83	3	1	16	41	32	10
Census Tract 5672.01, Wayne County, Michigan	10	\$2,272	208	\$22,880	1	0	0	0	1	97	1	0	3	38	42	17
Census Tract 5679, Wayne County, Michigan	10	\$1,885	164	\$19,200	10	0	1	0	2	87	1	0	9	33	37	21
Census Tract 5742.03, Wayne County, Michigan	10	\$1,772	188	\$18,226	4	0	1	0	1	88	5	0	3	33	21	42
Census Tract 5774, Wayne County, Michigan	10	\$2,105	272	\$20,693	4	0	0	0	10	72	4	11	25	36	35	4
Census Tract 5780, Wayne County, Michigan	10	\$1,637	308	\$15,610	6	0	0	0	3	88	2	1	6	49	43	2
Census Tract 5804, Wayne County, Michigan	10	\$1,620	155	\$15,855	0	0	0	0	0	99	0	0	7	31	47	15
Census Tract 5809, Wayne County, Michigan	10	\$1,663	228	\$16,616	2	0	0	0	1	92	5	1	20	36	40	4
Census Tract 5839, Wayne County, Michigan	10	\$1,721	451	\$16,771	39	0	8	0	0	53	0	0	24	41	32	3
Census Tract 2302, Macomb County, Michigan	9	\$2,203	111	\$23,331	0	0	1	0	0	99	0	0	13	20	46	21
Census Tract 2310, Macomb County, Michigan	9	\$2,403	148	\$27,342	0	0	1	0	0	98	0	0	13	30	38	19
Census Tract 2312, Macomb County, Michigan	9	\$1,724	135	\$19,666	2	0	9	0	0	89	0	0	11	39	33	16
Census Tract 2317, Macomb County, Michigan	9	\$2,026	352	\$22,526	1	7	2	0	0	88	1	0	24	23	28	25
Census Tract 2319, Macomb County, Michigan	9	\$2,141	187	\$23,317	1	0	3	0	0	96	1	0	16	13	44	26
Census Tract 2322, Macomb County, Michigan	9	\$1,792	354	\$19,833	12	0	6	0	0	82	0	0	14	34	29	23
Census Tract 2415, Macomb County, Michigan	9	\$1,571	187	\$17,056	10	0	0	0	0	89	1	0	16	42	29	12
Census Tract 2475, Macomb County, Michigan	9	\$1,291	211	\$14,035	13	0	0	0	0	87	0	0	15	49	27	9
Census Tract 2476.01, Macomb County, Michigan	9	\$1,273	237	\$13,479	32	0	0	0	0	68	0	0	7	24	63	6
Census Tract 2504, Macomb County, Michigan	9	\$1,750	62	\$20,250	7	0	0	0	3	88	2	0	4	22	60	14
Census Tract 2519, Macomb County, Michigan	9	\$1,706	129	\$19,134	1	0	0	0	1	96	3	0	8	23	54	15
Census Tract 2521, Macomb County, Michigan	9	\$1,614	107	\$17,811	3	0	0	0	1	96	0	0	9	21	39	31
Census Tract 2541, Macomb County, Michigan	9	\$1,500	292	\$17,588	7	0	0	0	1	91	1	0	9	41	42	9
Census Tract 2560, Macomb County, Michigan	9	\$1,929	126	\$21,208	8	0	0	0	0	91	1	0	11	46	37	7
Census Tract 2563, Macomb County, Michigan	9	\$1,775	139	\$19,343	31	0	0	0	1	67	1	0	7	42	38	12

Census Tract 2582, Macomb County, Michigan	9	\$1,944	214	\$21,354	39	0	0	0	0	61	0	0	31	26	35	7
Census Tract 2589, Macomb County, Michigan	9	\$2,271	138	\$24,596	60	0	0	0	0	37	2	0	33	25	36	5
Census Tract 2600, Macomb County, Michigan	9	\$1,900	138	\$20,394	5	0	2	0	1	87	5	0	5	46	37	12
Census Tract 2602, Macomb County, Michigan	9	\$1,765	120	\$20,337	3	0	0	0	4	93	0	0	8	36	43	14
Census Tract 2608, Macomb County, Michigan	9	\$1,931	168	\$21,186	4	0	3	0	1	91	1	0	20	29	40	11
Census Tract 2611, Macomb County, Michigan	9	\$1,619	485	\$17,271	22	0	5	0	1	71	1	0	20	22	34	24
Census Tract 2615, Macomb County, Michigan	9	\$1,538	220	\$16,403	16	0	5	0	3	75	0	0	10	38	42	10
Census Tract 2618, Macomb County, Michigan	9	\$1,825	87	\$20,183	7	0	17	0	0	75	1	0	5	40	37	19
Census Tract 2623, Macomb County, Michigan	9	\$1,536	240	\$17,098	10	0	26	0	0	64	0	0	17	32	35	16
Census Tract 2638, Macomb County, Michigan	9	\$1,940	239	\$22,556	50	0	4	0	4	39	2	0	18	40	41	1
Census Tract 2640, Macomb County, Michigan	9	\$1,893	205	\$20,527	52	0	5	0	0	30	12	0	14	39	35	11
Census Tract 1366.01, Oakland County, Michigan	9	\$1,456	140	\$17,002	2	0	2	0	3	87	7	0	1	29	23	47
Census Tract 1611, Oakland County, Michigan	9	\$969	226	\$10,695	72	0	1	0	1	24	2	0	17	17	43	22
Census Tract 1617, Oakland County, Michigan	9	\$1,933	101	\$22,438	70	0	0	0	1	14	14	0	6	18	24	52
Census Tract 1621, Oakland County, Michigan	9	\$1,047	281	\$12,069	97	0	0	0	0	2	1	0	14	25	46	15
Census Tract 1674, Oakland County, Michigan	9	\$1,437	327	\$15,615	38	0	0	0	2	59	1	0	2	20	58	20
Census Tract 1681, Oakland County, Michigan	9	\$1,525	124	\$16,846	11	0	1	0	2	85	0	0	0	76	11	13
Census Tract 1710, Oakland County, Michigan	9	\$1,343	361	\$14,736	28	0	3	0	0	65	2	1	7	40	28	26
Census Tract 1714, Oakland County, Michigan	9	\$1,825	521	\$20,111	68	0	0	0	0	30	2	0	4	19	40	38
Census Tract 1715, Oakland County, Michigan	9	\$1,661	317	\$17,663	95	0	0	0	0	3	2	0	16	22	47	15
Census Tract 1812, Oakland County, Michigan	9	\$1,455	343	\$16,306	5	0	4	0	0	90	2	0	16	30	37	18
Census Tract 1880.01, Oakland County, Michigan	9	\$1,725	55	\$18,723	1	0	0	0	0	96	2	0	0	15	24	61
Census Tract 1966, Oakland County, Michigan	9	\$1,992	7	\$21,170	0	0	21	0	0	78	0	0	0	6	14	80
Census Tract 1974, Oakland County, Michigan	9	\$1,365	163	\$15,450	1	0	14	0	0	85	0	0	46	16	18	20
Census Tract 5554.01, Wayne County, Michigan	9	\$1,952	103	\$22,069	82	0	1	0	2	15	1	0	22	16	35	28
Census Tract 5574, Wayne County, Michigan	9	\$2,471	37	\$29,055	1	0	0	0	0	95	4	0	1	16	16	67
Census Tract 5590, Wayne County, Michigan	9	\$2,672	55	\$28,747	5	0	0	0	1	93	1	0	1	31	44	24
Census Tract 5632, Wayne County, Michigan	9	\$1,515	179	\$17,069	14	0	1	0	0	78	8	0	0	52	30	18
Census Tract 5659, Wayne County, Michigan	9	\$1,799	58	\$21,108	12	0	3	0	1	84	0	0	18	32	38	11
Census Tract 5664, Wayne County, Michigan	9	\$1,929	42	\$21,921	44	0	0	0	1	55	0	0	4	48	33	15
Census Tract 5673, Wayne County, Michigan	9	\$1,742	195	\$18,598	6	0	1	0	2	90	1	1	12	35	46	7
Census Tract 5688, Wayne County, Michigan	9	\$1,083	324	\$12,715	62	0	10	0	2	24	1	1	31	36	22	12
Census Tract 5697, Wayne County, Michigan	9	\$1,991	178	\$21,505	5	0	0	0	0	91	4	0	18	32	44	7
Census Tract 5765, Wayne County, Michigan	9	\$2,038	82	\$23,518	0	0	1	0	1	84	12	1	5	31	47	17
Census Tract 5779, Wayne County, Michigan	9	\$1,765	388	\$18,841	4	1	0	0	2	87	1	5	23	36	37	5
Census Tract 5801, Wayne County, Michigan	9	\$1,492	155	\$17,163	3	0	1	0	5	88	2	2	13	27	48	12
Census Tract 5805, Wayne County, Michigan	9	\$1,830	106	\$19,432	0	0	0	0	1	98	0	0	7	19	48	26
Census Tract 5840, Wayne County, Michigan	9	\$2,170	229	\$23,465	17	0	0	0	0	82	0	0	4	25	69	3
Census Tract 5880.01, Wayne County, Michigan	9	\$1,134	196	\$12,460	31	0	1	0	0	68	0	0	4	14	44	39
Census Tract 5915.02, Wayne County, Michigan	9	\$1,599	100	\$18,509	5	0	9	0	1	85	0	0	6	41	45	8
Census Tract 2305.01, Macomb County, Michigan	8	\$1,520	401	\$18,500	2	0	1	0	0	89	2	6	14	31	39	16
Census Tract 2318, Macomb County, Michigan	8	\$2,100	203	\$25,239	2	0	4	0	0	94	1	0	24	17	28	31
Census Tract 2320, Macomb County, Michigan	8	\$2,230	63	\$29,479	4	0	2	0	0	94	0	0	15	29	38	18
Census Tract 2330, Macomb County, Michigan	8	\$2,217	159	\$26,506	2	0	0	0	0	98	0	0	9	20	40	31
Census Tract 2405, Macomb County, Michigan	8	\$2,061	108	\$24,251	3	0	0	0	0	95	2	0	3	15	70	13
Census Tract 2410, Macomb County, Michigan	8	\$1,322	293	\$16,724	44	0	2	0	0	54	0	0	9	38	48	4
Census Tract 2414, Macomb County, Michigan	8	\$1,387	123	\$18,222	2	0	0	0	0	98	0	0	12	42	42	5
Census Tract 2503, Macomb County, Michigan	8	\$1,578	153	\$20,720	5	0	0	0	3	91	1	0	6	45	25	24
Census Tract 2522, Macomb County, Michigan	8	\$1,122	187	\$13,252	2	0	1	0	1	96	1	0	5	15	46	35
Census Tract 2545, Macomb County, Michigan	8	\$1,327	371	\$15,785	2	0	0	0	0	97	0	0	19	36	33	12
Census Tract 2552, Macomb County, Michigan	8	\$1,254	348	\$15,392	36	0	1	0	0	57	3	3	5	37	49	9
Census Tract 2585, Macomb County, Michigan	8	\$1,862	65	\$22,469	44	0	0	0	0	50	4	1	23	28	33	17
Census Tract 2603, Macomb County, Michigan	8	\$1,697	187	\$20,786	3	0	5	0	0	91	1	0	9	33	38	20
Census Tract 2607, Macomb County, Michigan	8	\$1,726	145	\$20,715	5	0	12	0	0	79	3	0	6	43	30	22
Census Tract 2609, Macomb County, Michigan	8	\$1,915	166	\$23,985	2	0	37	0	1	59	0	1	4	36	27	34
Census Tract 2610, Macomb County, Michigan	8	\$1,610	199	\$19,772	35	0	8	0	1	56	0	0	15	34	36	16
Census Tract 2614, Macomb County, Michigan	8	\$1,998	150	\$23,657	5	0	7	0	3	83	1	2	12	40	31	18
Census Tract 2616.01, Macomb County, Michigan	8	\$1,874	39	\$24,653	4	0	5	0	2	88	0	0	19	37	29	16
Census Tract 2680, Macomb County, Michigan	8	\$1,402	419	\$18,177	12	0	3	0	1	81	2	0	20	40	33	6
Census Tract 1532, Oakland County, Michigan	8	\$1,349	15	\$16,542	0	0	0	0	0	99	0	0	50	2	4	44
Census Tract 1572, Oakland County, Michigan	8	\$2,052	248	\$26,606	31	0	1	0	0	62	6	0	21	32	28	19
Census Tract 1604, Oakland County, Michigan	8	\$1,052	408	\$12,613	89	0	2	0	0	8	1	0	15	12	49	25

Census Tract 1609, Oakland County, Michigan	8	\$1,205	159	\$15,418	56	0	1	0	0	41	1	0	11	27	26	36
Census Tract 1660, Oakland County, Michigan	8	\$1,645	95	\$20,305	29	0	8	0	0	61	1	0	6	24	27	43
Census Tract 1685, Oakland County, Michigan	8	\$1,187	193	\$14,198	27	0	2	0	1	69	1	0	17	17	24	42
Census Tract 1689.02, Oakland County, Michigan	8	\$1,232	142	\$14,492	29	0	34	0	5	32	0	0	4	4	50	42
Census Tract 1736, Oakland County, Michigan	8	\$1,734	62	\$20,746	7	0	0	0	4	84	5	0	6	20	33	41
Census Tract 1750, Oakland County, Michigan	8	\$1,534	285	\$18,374	9	0	0	0	0	88	3	0	20	33	36	12
Census Tract 1843, Oakland County, Michigan	8	\$1,735	42	\$20,680	5	0	0	0	1	91	2	0	1	33	33	33
Census Tract 1881, Oakland County, Michigan	8	\$1,814	19	\$21,724	2	0	1	0	1	96	0	0	0	6	14	80
Census Tract 5172, Wayne County, Michigan	8	\$754	67	\$9,579	62	10	5	0	1	12	1	10	1	27	43	29
Census Tract 5652, Wayne County, Michigan	8	\$1,333	226	\$17,700	39	0	4	0	2	53	0	1	10	38	43	9
Census Tract 5803, Wayne County, Michigan	8	\$1,660	228	\$20,901	0	0	0	0	1	96	2	0	10	31	50	9
Census Tract 5808, Wayne County, Michigan	8	\$1,426	82	\$17,752	1	0	0	0	3	95	0	0	9	57	31	3
Census Tract 2309.02, Macomb County, Michigan	7	\$1,273	215	\$17,921	12	0	0	0	0	86	3	0	1	34	56	10
Census Tract 2472.02, Macomb County, Michigan	7	\$2,010	72	\$29,716	2	0	0	0	0	89	2	7	10	15	60	15
Census Tract 2565, Macomb County, Michigan	7	\$1,950	81	\$26,670	26	0	0	0	1	71	2	0	6	22	66	6
Census Tract 2626, Macomb County, Michigan	7	\$1,163	257	\$15,626	17	0	10	0	1	71	0	1	17	45	21	16
Census Tract 1686.01, Oakland County, Michigan	7	\$1,324	9	\$18,835	10	0	21	0	0	69	0	0	0	0	1	99
Census Tract 1703, Oakland County, Michigan	7	\$1,676	33	\$22,411	2	0	0	0	1	93	2	1	7	15	42	36
Census Tract 1724, Oakland County, Michigan	7	\$881	245	\$12,367	52	0	2	0	0	45	0	0	16	24	41	20
Census Tract 5157, Wayne County, Michigan	7	\$726	667	\$10,463	87	0	0	0	0	9	2	2	11	25	38	26
Census Tract 5165, Wayne County, Michigan	7	\$828	145	\$12,723	74	0	2	0	1	21	0	2	9	19	55	16
Census Tract 5171, Wayne County, Michigan	7	\$826	59	\$11,102	75	0	1	0	0	22	2	0	13	8	51	28
Census Tract 5207, Wayne County, Michigan	7	\$759	265	\$10,859	49	1	4	0	0	37	2	7	14	27	29	30
Census Tract 5653.02, Wayne County, Michigan	7	\$948	517	\$13,644	34	0	1	0	1	64	0	0	62	8	15	15
Census Tract 5802, Wayne County, Michigan	7	\$1,332	316	\$19,115	0	0	0	0	1	96	2	1	5	66	26	3
Census Tract 2403, Macomb County, Michigan	6	\$1,530	267	\$24,409	2	0	0	0	0	71	27	0	13	37	42	8
Census Tract 2601, Macomb County, Michigan	6	\$1,298	196	\$21,389	16	0	7	0	5	71	0	1	10	41	31	19
Census Tract 1603, Oakland County, Michigan	6	\$801	582	\$12,979	79	0	1	0	0	19	1	0	16	19	42	23
Census Tract 1835, Oakland County, Michigan	6	\$1,276	229	\$22,474	73	0	1	0	0	25	0	0	7	12	68	13
Census Tract 1975, Oakland County, Michigan	6	\$1,263	83	\$20,129	1	0	47	0	1	50	0	0	21	5	14	60
Census Tract 1810.01, Oakland County, Michigan	5	\$789	505	\$15,540	27	0	6	0	0	59	8	0	15	20	30	35
Census Tract 9824, Wayne County, Michigan	2	\$296	2	\$15,546	100	0	0	0	0	0	0	0	0	0	100	0
Census Tract 9820.02, Macomb County, Michigan	0	\$0	12	\$0	0	0	0	0	0	0	0	0	0	0	0	0
Census Tract 9834, Wayne County, Michigan	0	\$0	8	\$55,861	0	0	0	0	0	100	0	0	0	0	100	0
Census Tract 9801, Macomb County, Michigan																
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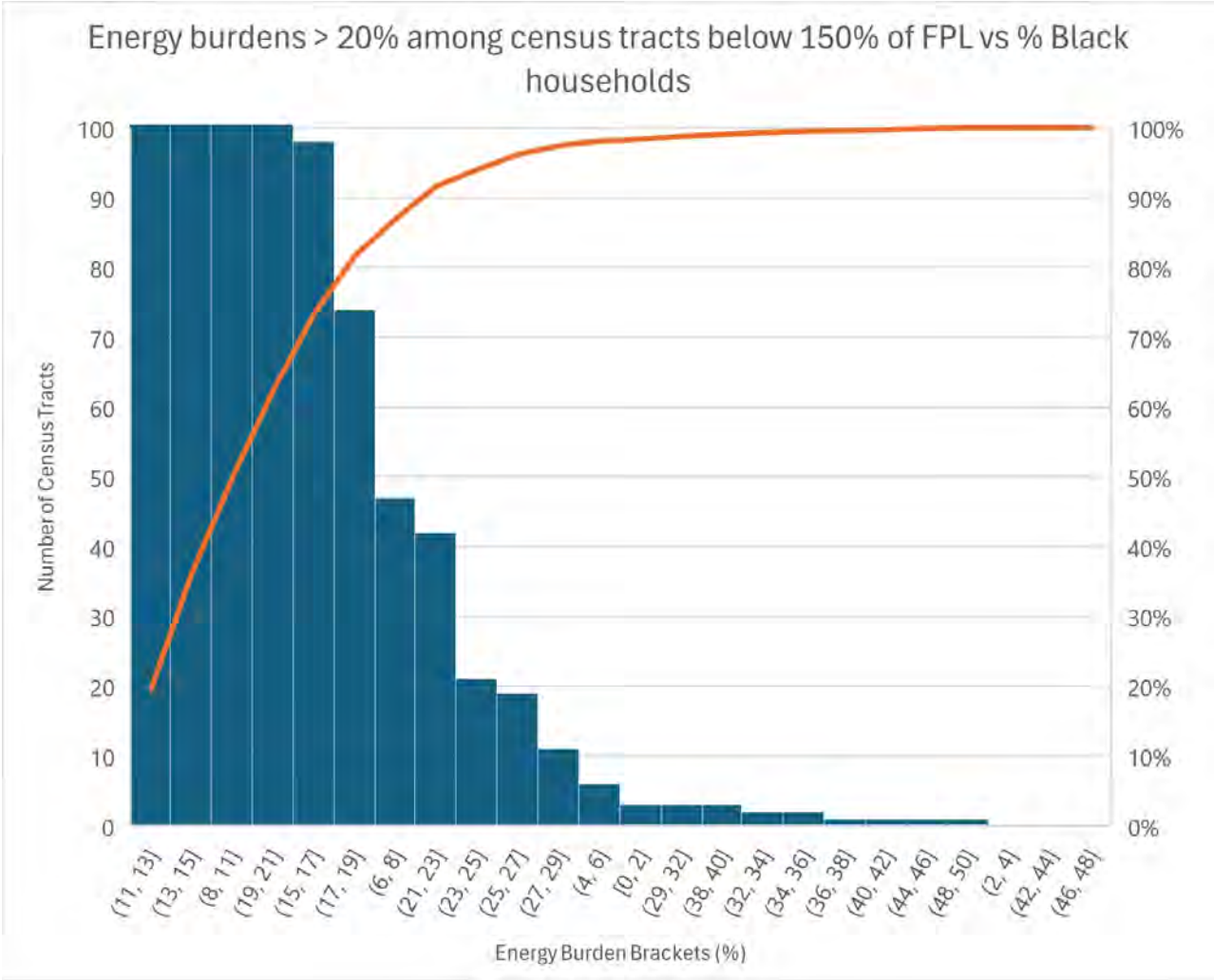
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OPEN

Unveiling hidden energy poverty using the energy equity gap

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Income-based energy poverty metrics ignore people's behavior patterns, particularly reducing energy consumption to limit financial stress. We investigate energy-limiting behavior in low-income households using a residential electricity consumption dataset. We first determine the outdoor temperature at which households start using cooling systems, the inflection temperature. Our relative energy poverty metric, the *energy equity gap*, is defined as the difference in the inflection temperatures between low and high-income groups. In our study region, we estimate the energy equity gap to be between 4.7–7.5 °F (2.6–4.2 °C). Within a sample of 4577 households, we found 86 energy-poor and 214 energy-insecure households. In contrast, the income-based energy poverty metric, energy burden (10% threshold), identified 141 households as energy-insecure. Only three households overlap between our energy equity gap and the income-based measure. Thus, the energy equity gap reveals a hidden but complementary aspect of energy poverty and insecurity.

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Energy poverty manifests itself in a high percentage of income spent covering energy bills, increased risk of electricity shutoffs, and a household's inability to maintain comfortable indoor temperatures or use desired services (e.g., air conditioning, heat, computers)^{1,2}. An often-overlooked space in energy poverty analysis lies in the cavity between metrics that measure financial stress (energy burden defined as energy expenditure over total income) and complete lack of energy services (utility shutoffs). Within this cavity are the households which limit their energy consumption to reduce financial strain. These households may appear to spend small amounts of their income on their energy bills while limiting enough energy to avoid having the utility cut their power supply. It is estimated that, annually, 1300 people die every year in the U.S. from extreme heat³. In 2009 and 2010 alone, over 8250 emergency room visits in the US were caused by heat stroke⁴, with low-income, minority, and elderly populations being disproportionately affected³. A large portion of these deaths may have been prevented if people could cool their homes properly. We acknowledge that proper cooling ability includes being able to acquire and sufficiently use an AC system^{5,6}.

As the effects of climate change manifest themselves in heatwaves⁷ and deep freezes, communities will need to adapt (i.e., reduce their risk of illness and death⁸) by creating comfortable indoor temperatures within their homes. However, this depends on whether they can rely on their resources for adopting energy-efficient heating and cooling systems, meaning many vulnerable households who limit their energy consumption, potentially putting themselves at risk of heatstroke or hypothermia, may not qualify for energy poverty alleviation under current programs.

For example, in the US, the two main energy assistance programs, the Low Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP), use an income threshold to determine eligibility^{9,10}. LIHEAP uses reduction in a household's energy burden, service loss prevention, and service restoration, to calculate the effectiveness of its assistance⁹. WAP is geared more towards homeowners with its performance based on the number of households weatherized and post-weatherization surveys for those receiving assistance, with questions including change in energy burden and change in forgoing other necessities like food to pay energy bills^{9,11}. This suggests that these programs make an implicit assumption that people meet or try to meet their energy needs first compared to other necessities like food or healthcare. Neither WAP nor LIHEAP takes into explicit account those who forgo energy consumption to pay for other necessities (i.e., energy limiting behavior), nor do they offer a clear definition of energy poverty⁹. The lack of consideration for households who forgo energy for other needs poses a limitation in identifying the multidimensional nature of poverty^{12,13} and reduces the options for policy intervention. In LIHEAP and WAP, spending patterns are viewed as adequate ways to measure the effectiveness of these energy assistance programs^{9,11}.

In a broader sense, energy poverty is defined as insufficient energy access due to lack of supply, low affordability, limited quantity, poor quality, unreliability, or a combination of these shortcomings. Existing energy poverty metrics fall into the following categories: A) primary or secondary, and B) relative or absolute, as seen in Fig. 1. Here we define each category combination and provide some examples of each. A primary metric is defined as a metric that directly utilizes consumer-level information. A secondary metric would require derivation to reach a conclusion. Secondary metrics include metrics that aggregate utility information or use weighted scoring for poverty indices. A relative metric compares the energy poverty status of two or more entities (i.e., country-to-country or household-to-household) or

one with oneself (i.e., progress over time for one country). Finally, an absolute metric will provide a strict threshold for energy poverty.

Relative-secondary metrics for energy poverty use summary statistics from the regional or local level (not individuals) and compare the progress of different regions to some benchmark. These are often used to describe progress in energy poverty reduction in developing countries. One example is an access-consumption matrix at a national level¹⁴. Access-consumption matrices portray shifts in a country's energy profile, mainly the change in fuel utilization and how many people use each fuel. If more people are gaining access to energy services in an under-developed country, and more people are shifting from dirtier to cleaner fuels in developing regions, energy poverty is reported as decreasing^{14,15}. Due to the fact that energy poverty in developing regions often means a lack of access to modern energy services, these national energy access metrics are best used for countries beginning their clean energy transition and expanding access to modern energy services^{14,15}.

Relative-primary metrics come directly from households or individuals, and benchmark feelings of energy poverty in comparison to others in the population. These can be scores from a survey asking questions on self-perception of energy poverty. For example, a survey done in Greece used indicators such as "inability to keep home adequately warm," "leakages, damp walls, mold," and "restriction of other essential needs" to solicit the subjective feeling of energy poverty^{16,17}. Compared with the 10% energy burden threshold, the study found that when a household is objectively categorized as energy-poor, they were more likely to respond "yes" for the subjective indicators. Another study explores the relationship between social relations and energy access, where a positive feedback loop exists between good social relations and higher quality energy access^{2,18}. However, drawbacks of survey-based metrics are long completion times and difficulty comparing the level of energy poverty experienced

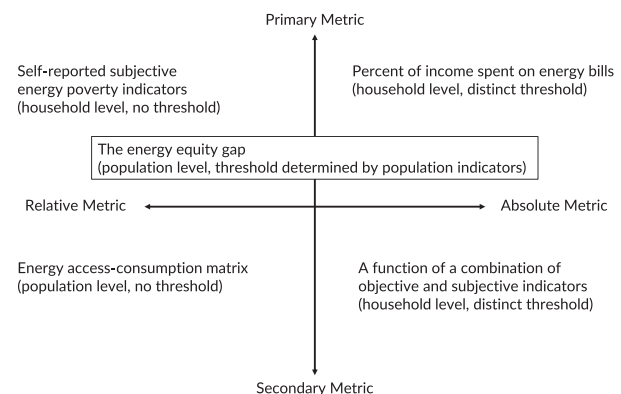


Fig. 1 Categories of energy poverty metrics. The X-axis represents relative or absolute metrics, or whether the metric has a distinct threshold for energy poverty. The Y-axis represents primary or secondary metrics, or whether a metric requires more than basic consumer-level data to calculate. A primary-absolute metric can be energy burden, or percent of income spent on energy bills; a primary-relative metric can be self-reported energy poverty indicators; a secondary-absolute metric can be a combination of the previous two, where an arbitrary score is calculated based on energy burden and survey results; and a secondary-relative metric can be an energy access-consumption matrix, often used to portray the progress of energy access in developing countries. The energy equity gap is a primary metric that can be both relative and absolute, where it can tell us the relative energy equity progress of a region, as well as household-level energy poverty.

between households. Although there are many survey studies on housing characteristics and perceived energy poverty^{16,19,20}, we find a lack of metrics which can quantify the amount of energy a household forgoes to alleviate financial burden (i.e., energy limiting behavior). Thus, there is a need to use surveys in combination with data driven approaches to elicit perceptions of energy limited behavior, while also determining the degree to which people actually limit energy consumption.

Absolute-secondary metrics compare information related to energy usage against some predetermined threshold. These metrics often combine income-based metrics with socio-demographic factors and housing conditions to calculate a weighted score to measure energy poverty^{2,18}. However, because these measures (income-based, survey, and combined) single out those currently experiencing energy poverty, they can miss distributional changes over time and the severity of the energy poverty experience relative to the rest of the population. Additionally, a limitation is that these metrics often focus on equality (i.e., all households reaching a certain status) but miss equity because they cannot identify how the energy-poor compare to the non-energy-poor. Achieving energy equality entails giving everyone the same tools to achieve a desired level of energy consumption. For example, providing households with a voucher to spend less than 10% of their income on their current energy bills. Achieving energy equity entails giving groups different types of tools such that they can equally take advantage of opportunities or reach a desired goal. For example, an energy equity policy could entail each person receiving enough assistance to cool or heat their homes to their desired comfortable temperature.

Absolute-primary metrics use individual or household information and measure energy usage and other information against some predetermined threshold. These metrics are often used to measure household-level energy burden (i.e., energy expenditure over income). The underlying theory is that the more significant percentage of income spent on energy, the more energy-poor one is, similar to Engel's Coefficient for food expenditure²¹. A common threshold for energy burden to indicate a household is energy poor (proposed in 1991) is 10%^{9,18}. Energy burden can depend on a number of factors such as electricity price, prices of other goods, and heating or cooling needs¹. The advantage of this threshold metric is that it indicates the economic burden of meeting energy needs and does not have a high computational burden. However, limitations of using the energy burden threshold metric include not distinguishing between gross (i.e., pre-tax) and disposable income (i.e., post-tax and other mandatory charges like mortgage and rent), not considering indoor comfort levels, and not considering local and current costs of living¹⁸. As a result, households may have the same pre-tax income level but have vastly different mortgage or rental costs, meaning that the 10% threshold on gross income may miss people who are spending more than 90% of their income on other basic necessities²².

Despite the recent development of new metrics to capture consumer behaviors (e.g., under-consumption of energy and choice of thermal comfort)^{3,8}, household-level energy poverty evaluation for government assistance programs in developed countries has been led by absolute-primary income-based metrics^{9,18,23,24}. While these income-based metrics are widely used, they have a few shortcomings. First, they are sensitive to energy prices and mask the degree to which households change their energy consumption behavior following a price shift¹⁸. Second, and perhaps more importantly, the energy burden metric does not capture vulnerable low-income households who forgo energy usage to reduce financial stress. Lastly, income-based metrics miss essential dimensions of energy poverty, such as the inability to use enough energy to cool or heat homes to comfortable, and/or safe temperatures²⁵.

Most papers investigating the inability to satisfy a household's desired energy demand focus on electricity supply and reliability constraints in developing countries^{26–28} and energy affordability in developed countries^{1,29,30}. Within developed countries (i.e., those with close to 100% electricity supply access)³¹, energy poverty and insecurity can manifest themselves in 1) electricity shutoffs resulting from nonpayment, 2) forgoing heating services due to financial strain and participating in unsafe practices (e.g., using the stove or oven for heat, unsafe uses of space heating technologies which lead to fires³²), 3) spending a large percentage of income on energy bills, and 4) difficulty adopting clean energy and efficient technologies^{17,33–35}. While multiple papers address the indicators of energy poverty^{9,36,37} and insecurity^{17,35}, we find a void of metrics that can identify energy-limiting households (i.e., those without comfortable indoor temperatures) who may put themselves at risk of heat-related illness, excess indoor moisture, mold growth, and other adverse health effects^{35,38,39} (e.g., respiratory illness and asthma).

In countries where the entire population has access to modern energy infrastructure, household-level energy poverty manifests itself as having inadequate energy services within the household, or an inability to consume energy at a desired level². Thus, a more holistic definition of energy poverty would include people who limit their energy consumption (i.e., display energy limiting behavior), and those who spend a large portion of their income on their energy bills (i.e., high energy burden). Our work fills this gap by creating a metric which can identify energy limiting behavior. We define energy limiting behavior as a household's inability or unwillingness to consume enough energy to reach a desired level of comfort. A household displays energy limiting behavior if they reduce their energy consumption significantly below another household within the same region that does not have a budget constraint for energy spending. For example, assume households A and B live in the same region and have similar preferences for their ideal indoor temperature, around 70 °F (21 °C). Household A is a low-income household (i.e., a budget constraint on energy spending), and Household B is a high-income household (i.e., no budget constraint). If Household B starts using their air conditioning unit when it is 70 °F (21 °C) outside, but Household A waits until it is 75 °F (24 °C) outside, then household A is displaying 5 °F (3 °C) of energy limiting behavior compared to Household B.

Here, we introduce a behavior-based energy poverty measure, the energy equity gap, which captures one critical aspect of energy poverty (i.e., energy-limiting behavior), providing a complementary metric to capture inequity within a region. We first determine the outdoor temperature at which households start using cooling systems, the inflection temperature. Then, our relative energy poverty metric, the energy equity gap, is defined as the difference in the inflection temperatures between low and high-income groups. In our study region, we estimate the energy equity gap to be between 4.7 °F (2.6 °C) and 7.5 °F (4.2 °C). In 2015–2016, within our sample of 4577 households, we found 86 energy-poor and 214 energy-insecure households. In contrast, the income-based energy poverty metric, energy burden, identified 141 households as energy insecure when the threshold is set to 10%, with only three households overlapping between our energy equity gap and the income-based measure.

Results

Quantifying residential electricity consumption patterns. To capture those households left behind by income-based energy poverty measures, we propose a different energy poverty metric: the energy equity gap. We illustrate its effectiveness for identifying households at risk for inability to reach comfortable indoor

temperatures, and possibly heat-related illness. Our study region in the US, Arizona, has long, high-heat summers and mild winters (see Supplementary Information Note 6). Arizona has a higher level of heat-related illnesses (2944 heat-related ER visits in 2019⁴⁰) compared to cold-related illnesses (495 cold-related ER visits in 2019⁴¹), leading us to focus our energy poverty analysis on the electricity sector due to this providing the bulk of cooling energy in the summer (air conditioning (AC) or fan usage). Identifying cooling system use is vital for addressing and planning for energy justice, which hinges on the proper distribution of benefits for a clean energy transition^{42–44} and an ability to mitigate the effect of heatwaves. We also introduce a tiered system for identifying and addressing the energy poverty needs of the most vulnerable households and contrast this with the existing income-based metric.

The energy equity gap is a measure that investigates how consumer electricity consumption behavior across income groups shifts with temperature (i.e., consumers' temperature response functions). Previous research has investigated how consumers' temperature response functions (modeling energy usage against temperature or other climate factors) change with climate^{45,46}, but have not incorporated these functions into energy poverty identification. The energy equity gap metric considers the effect of outdoor temperature on energy consumption and quantifies relative energy limiting behavior, where those with fewer constraints on their budget set the threshold for a desired level of energy consumption to maintain a comfortable indoor temperature in the region (see Methods). Using the energy equity gap, we measure electricity usage patterns between income groups within a metropolitan region, thus eliminating the effect of weather or outdoor temperature on electricity usage for different households, which might occur in large study areas. A benefit of our primary-relative energy poverty metric, energy equity gap, is that policymakers can have more targeted energy justice efforts by first identifying the outdoor temperature that places their region at risk for heat-related illnesses or energy limiting behavior. Once the threshold has been set, policymakers can then use our relative metric to identify energy insecure households that are dangerously close to sinking into energy poverty and create proactive measures for reducing their burden and increasing their ability to consume energy to increase their comfort. In addition to capturing household-level electricity consumption behavior, the energy equity gap allows for a cross-temporal comparison of population-level energy equity within a region.

The basis of the energy equity gap is household-level inflection temperatures. To best incorporate behavior into the metric, we define the inflection temperature as the outdoor temperature at which a household starts using its cooling system as it shifts from spring to summer temperatures, assuming there is no difference in comfort preference or need across income groups. To find the inflection temperature of each household, daily electricity consumption is modeled using average daily temperature, electricity pricing plan, holiday effects, and day-of-the-week and month-of-the-year fixed effects (see Methods). The minimum of the quadratic equation between electricity consumption and temperature after controlling for the covariates mentioned above is defined as the temperature at which people start using their cooling systems, the inflection temperature (Fig. 2). This assumption stems from 1) heating and AC systems being the largest energy consumer within a household⁴⁵, and 2) our study region having a warm and dry climate, with short, mild winters and long, high-heat summers. If the study region is in a colder climate or a climate with more distinct seasons, we recommend separating the year into two climate zones (i.e., spring-summer-fall and fall-winter-spring). To adapt the energy equity gap to identify heating system energy use, we would need to include

information from the gas and oil sector. We leave the heating sector analysis for future work. We hypothesize that low-income households are more likely to endure higher temperatures before they start cooling their homes in the summer to save money and will thus have higher inflection temperatures.

Redefining energy poverty and energy insecurity. The energy equity gap is defined as the difference between the highest and lowest median household inflection temperatures among all income groups (Fig. 3) of the study region, a metropolitan area in Arizona (see Methods). We chose to use the median instead of the mean to desensitize the measure from outliers. The energy equity gap indicates the disparity in energy use across the income spectrum for a region while eliminating the effect of climate and electricity pricing. Within our metropolitan region, we assume the climate is uniform for households in the sample data, and everyone has access to the same energy services. Therefore, a sign of reduced energy inequity would be a narrowing energy equity gap, indicating that households are converging to a similar inflection temperature, thus reduced energy inequity.

The distribution of household-level inflection temperatures across income groups is shown in Fig. 3. We see that the energy equity gap ranges from 4.7–7.5 °F (2.6–4.2 °C), highlighting that low-income groups are more likely to forgo cooling services until later in the summer than high-income groups (see Supplementary Info Note 5 for another sample analysis). Furthermore, there is a statistically significant difference between the median inflection temperatures between each income group for all years, meaning there is little chance that the inflection temperature differences occurred by chance, verified using the Mood's Median test (see Methods).

Figure 4 illustrates the change in the energy equity gap across income groups for the four years in our analysis. The higher inflection temperatures further show low-income households tend to wait longer to turn on their AC units, pointing to underlying constraints, budget or otherwise, restricting their access to cooling. When cooling is restricted, it has been shown that buildings are at a higher risk for increased rates of mold, allergens, and fungi growth^{47,48} and that when the degree of

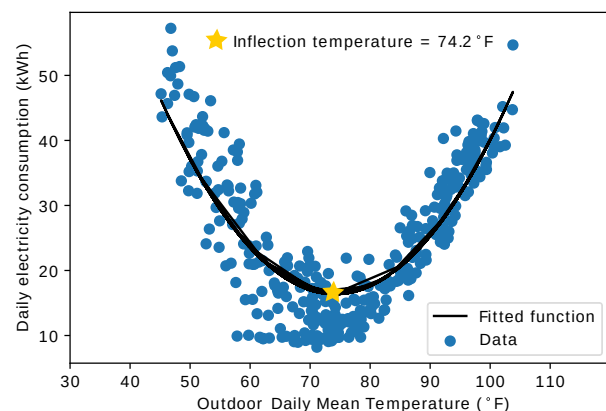


Fig. 2 Identifying the inflection temperature for daily electricity consumption and local daily mean outdoor temperature. This graph represents the daily electricity consumption of one household for one year ($N = 365$). The star marks the inflection temperature for this household for this year. We note that our true temperature response function includes electricity price, weekend, holiday, day of the week, and month of the year effects. The inflection temperature is the minimum of the quadratic temperature response function between the residuals after controlling for these factors and outdoor temperature.

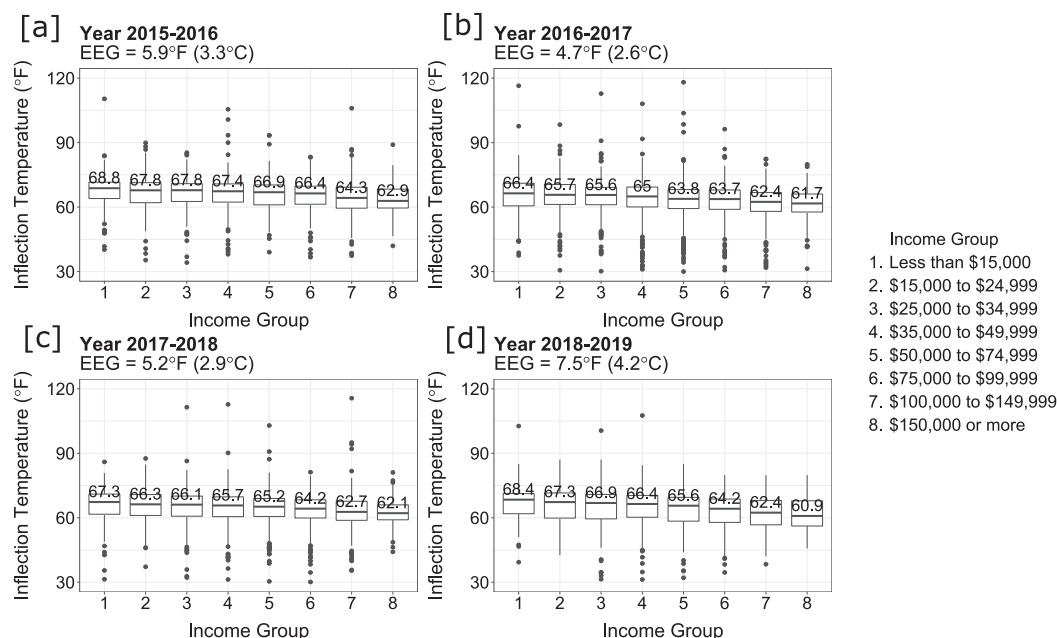


Fig. 3 The distribution of inflection temperature across income groups. The energy equity gap (EEG) for each year is calculated as the difference between the highest and lowest median inflection temperature (indicated by the middle bar and number) among all income groups in all four panels, income group 1 had the highest, and income group 8 had the lowest median inflection temperature. The energy equity gap (EEG) is shown at the top of each panel. **(a)** 2015-2016 $N = 4577$ households, **(b)** 2016-2017 $N = 4522$ households, **(c)** 2017-2018 $N = 3852$ households, **(d)** 2018-2019 $N = 2650$ households. Each box and whiskers plot indicates the minima and maxima of inflection temperatures of one income group for one year (the lower and upper bound of the whiskers), the first and third quartiles (the lower and upper bound of the box), and the median (the middle line). The outliers are shown as dots on either side of the whiskers. Source data can be found in our code repository.

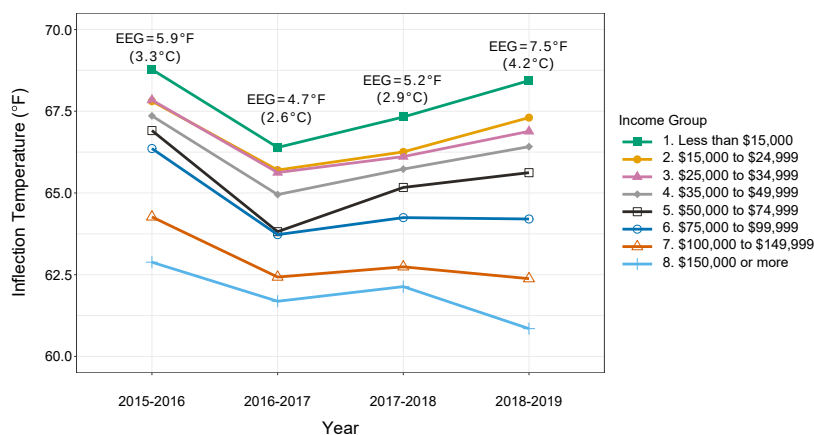


Fig. 4 Energy equity gap (EEG) and median inflection temperature changes across study years. Each line represents one income group. Each data point represents the median inflection temperature of the income group for that year.

discomfort becomes too great (high indoor temperature) populations are at a higher risk for heat stroke⁴⁹.

The energy equity gap shrinks and widens, resulting from low-income households first lowering then increasing their inflection temperatures while high-income households have a general trend of lowering their inflection temperatures across the years in our analysis. Thus, highlighting increasing energy inequity in the region.

The energy equity gap narrowed by 20.3% between the first two years of our study, but then widened by 10.6% and 44.2% in the last three years of our study, as seen in Table 1. We find that a change in cooling degree days or residential electricity price correlates to energy equity gap changes in the following year.

Between years one and two, there was a 2.4 % increase in residential electricity prices and a 3.6% increase in cooling degree days. This parallels with a 10.6% increase in the energy equity gap in year 3, most likely caused by low-income groups waiting longer to turn on their AC systems. This may signify a delayed price elasticity of demand effects in year-to-year residential electricity price changes and a warming climate. Between years two and three, the residential electricity price rose again by 2.7% and cooling degree days by 2.5%, which corresponds to a 44.2% increase in the year's energy equity gap. Thus, both a higher temperature and a higher electricity price can cause energy equity to deteriorate. Within our study population, low-income

Table 1 Temperature, electricity price, and energy equity gap shifts in Arizona.

Arizona metric	Change from year 1 to 2	Change from year 2 to 3	Change from year 3 to 4
Warmest Month Average Max outdoor temperature	1.0%	−0.2%	−0.2%
Cooling Degree Days (CDD)	3.6%	2.5%	−5.2%
Average residential electricity retail price (cents/kWh)	2.4%	2.7%	−2.7%
Energy equity gap	−20.3%	10.6%	44.2%

Warmest Month Average Max is the average maximum temperature of the hottest month in a year.

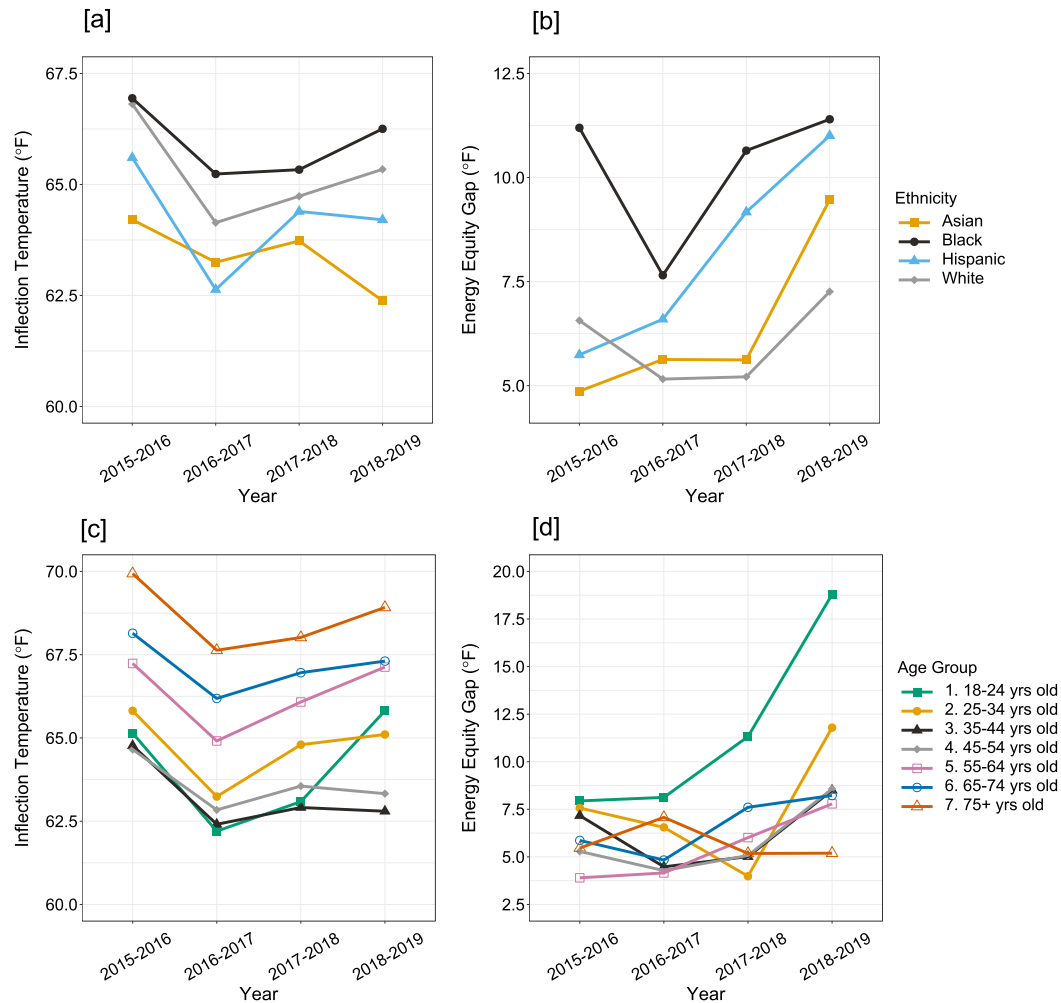


Fig. 5 Inter- and intra-group comparison of the inflection temperature and energy equity gap for ethnicity and age groups. Median inflection temperatures by (a) ethnicity and (c) age group show disparities across demographics. The energy equity gap highlights energy consumption behavior differences between high and low-income populations within their respective (b) ethnicity and (d) age groups. See Supplementary Information Notes 3 and 4 for more details.

households are more likely to live in older residences (see Supplementary Information Note 2), which can contribute to more significant energy needs and financial strain required to cool the home.

Price shifts will impact electricity consumption shifts within minority groups and those at the intersection of multiple vulnerable groups (e.g., low-income minority groups or low-income elderly populations) differently. Figure 5a, c show the median inflection temperature for each ethnicity and age group; Fig. 5b, d show the energy equity gap within each ethnicity and age group, respectively. Comparing Fig. 5a, b (assuming similar

temperature preference between ethnicities^{50,51}), we see that the overall inflection temperature is highest in the Black population. This combined with high energy equity gaps, indicates that the Black population is worse off and experiences high levels of inequity. In the Asian population, the overall median inflection temperatures are low yet there are wide energy equity gaps, indicating high income disparity within the group.

In the Black population, we see increasing disparity followed by the 2.4% electricity price increase from year 1 to 2, resulting in a 39% increase in the energy equity gap from year 2 to 3, earlier than the large price shock that affected the whole population.

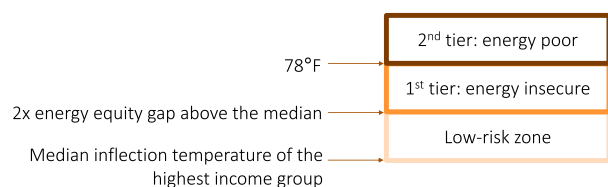


Fig. 6 Tier systems for energy poverty and insecurity identification using the energy equity gap. The darker the shade the more severe the level of energy poverty experienced by a household is.

This indicates that the Black population is disproportionately affected by price shifts compared to the other ethnicities. The white population most closely resembles the overall population trend because white populations account for the majority (>70%) of residents in our sample. In general, we find that even when a minority group's median inflection temperature is low, there can be a high disparity between low and high-income populations (see Supplementary Information Note 3), evident in the Asian population.

We also investigated energy poverty and equity across head of household age groups (Fig. 5c, d). There are statistically significant differences between median inflection temperatures across age groups ($p < 0.05$), as confirmed using the Mood's Median test (see Methods), indicating low probability that these variations occur solely due to chance. For the 18–24 age group, both the median inflection temperature ($>7^\circ\text{F}$, 3.9°C) and the energy equity gap increased sharply ($>14^\circ\text{F}$, 7.8°C) between 2018 and 2019, while for the older populations, the energy equity gap had little change across the years. From an energy poverty targeting standpoint, this highlights that within the elderly population, all residents should be targeted to reduce inflection temperatures, while for the youngest age groups, the most effective poverty eradication policy would be to target low-income groups.

For all age groups except for 75+, the later increase in the energy equity gap is from low-income households getting worse off and high-income households performing better, most evident in age groups 18–24 and 25–34. The difference in inflection temperatures between age groups may be attributed to each age group's different temperature comfort levels. Elders may prefer warmer indoor temperatures, and cooling air from an AC system may inflame arthritis⁵², but caution should be used when differentiating between a comfortably warm temperature and one that puts the resident at risk for a heat-related illness⁵³. Because there is a significant relationship between household income and inflection temperature, the high energy equity gap in younger age groups may be attributed to larger income inequality among young people.

We acknowledge that there is a chance that the inflection temperature and energy equity gap can be affected by indoor thermostat preferences. To account for varying preferences across ethnic and age groups, we investigate the inflection temperature disparities for different income groups within demographic distinctions (see Supplementary Information Note 3). For example, if one ethnic group preferred to turn on their AC units at a certain temperature, we expect to find a narrow vertical distribution for the inflection temperatures (i.e., the Hispanic population in Supplementary Information Note 3). On the other hand, if the different inflection temperatures represent inequity, we expect to find a wide vertical distribution (i.e., the Black and Asian population in Supplementary Information Note 3). Thus, the energy equity gap can highlight inequities across and within groups in a region. We present a more detailed discussion of the preference limitation in the Supplementary Information Note 3.

We introduce a tiered system (Fig. 6) to identify the households with the highest risk of heat-related illness and death. First, we assume the median inflection temperature of the highest income group is the ideal inflection temperature for this region. This assumption stems from the belief that the highest income groups are the least likely to constrain their budget and thus would initiate cooling systems earliest in the year. Similar to using a standard deviation, we define people with inflection temperatures between one and two energy equity gaps above the ideal inflection temperature to be in the low-risk zone. Next, households with inflection temperatures between two energy equity gaps and 78°F (25.6°C) are in the energy insecure zone. Within government buildings, it is recommended that 78°F degrees be the indoor set point⁵⁴, meaning this temperature setting may limit the risk for mold and allergen build-up, as well as heat-related illness and death. Finally, households with inflection temperatures higher than 78°F (25.6°C) are defined as energy poor. We use the indoor 78°F (25.6°C) comfort set point as our energy poverty threshold because households would need some degree of cooling above this outdoor temperature.

We acknowledge that there are multiple factors that can influence comfort levels and the health risk of occupants in high heat temperatures. Previous studies have shown that heat-mortality risk occurs when outdoor temperature rises above 90°F (32.2°C)⁵⁵. However, our goal is to identify households at risk for both health-related illness and death, which can result from a lower temperature threshold. We derive this lower threshold (78°F , 25.6°C) from recommended indoor AC setting for government buildings^{54,56}, as well as from recommendations of various utility companies^{57,58}. A key assumption in this threshold is that when the outdoor temperature is above this level, the indoor temperature would rise enough to warrant turning on the AC.

Using this tiered system, policymakers and utility companies can create more targeted weatherization aid programs. When we apply the tiers system to 2015–2016 data (Table 2), we identify 86 energy poor (1.9% of our sample) and 214 energy insecure households (4.7% of our sample).

Comparing the energy equity gap to income-based measures.

While US government assistance programs lack a clear definition for energy poverty, change in energy burden is often used to measure the outcome of these programs^{9,11}. Both LIHEAP and WAP use income limit by household size to determine eligibility^{59,60}, with some flexibility for states to determine what income level to set as the eligibility threshold. When using the 10% energy burden threshold to identify energy-insecure households in our study region, we found that less than 3% of households were defined as energy insecure (Fig. 7), of which over 70% reside in the lowest income group ($<\$15,000$) for all years in our study. Comparing the energy equity gap categorization with the energy burden measure of individual households, we find that few households (≤ 20) were identified as energy insecure or energy poor under both metrics (Table 2, also see Supplementary Information Note 7 for a visual representation). The energy burden metric categorizes more households as energy insecure, but our tiered system identifies more energy-poor households who may be placing themselves at risk by limiting cooling-associated energy use. The energy burden metric misses more than 95% of those with high inflection temperatures and, therefore, a higher risk of extreme heat exposure. Of that 95%, around half of the households are in one of the three low-income groups ($<\$35,000$). There are energy insecure households identified in the non-low-income groups, which hints that while some

Table 2 Comparing the energy equity gap (EEG) and financial-based energy assistance categories.

(Number of households in each category)	2015–2016	2016–2017	2017–2018	2018–2019
Total households	4577	4522	3852	2650
Energy equity gap (EEG) low risk zone	2719	2143	1889	1619
EEG 1 st tier: Energy insecure	214	631	484	42
EEG 2 nd tier: Energy poor	86	83	57	59
Households with energy burden $\geq 10\%$	141	135	111	88
EEG low-risk zone households with energy burden $\geq 10\%$	94	59	64	55
EEG 1 st tier households with energy burden $\geq 10\%$	6	16	9	1
EEG 2 nd tier households with energy burden $\geq 10\%$	3	4	1	2
EEG 1 st and 2 nd tier households with energy burden $< 10\%$	274	587	286	93
EEG 2nd tier households not eligible for LIHEAP	72	63	48	48
EEG 2nd tier households not eligible for WAP	53	37	33	29

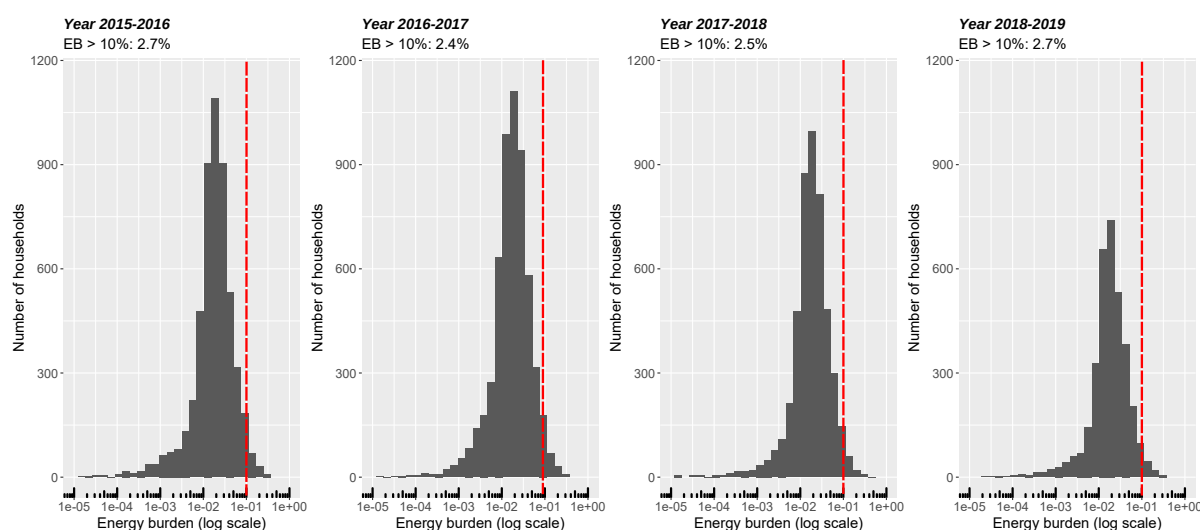


Fig. 7 Energy insecurity measured using the energy burden (EB) metric. The x-axis represents the percent of income a household spends on electricity. The red dotted line indicates the 10% income spending threshold, and EB10 details the proportion of households above the energy spending threshold. For example, in 2015–2016, 2.7% of households in our sample spent more than 10% of their income on electricity. The maximum amount of spending in our sample population is 35%.

households are not classified as low-income, they may have low disposable income (e.g., high mortgage or rent costs) and limit their financial burden by reducing their energy consumption. This further highlights the need for multiple energy poverty and insecurity measures to determine financial and behavioral energy consumption trends in energy-insecure households.

We also compared eligibility for LIHEAP and WAP and households in the 2nd tier of the energy equity gap metric. In our dataset of 6002 households, 871 qualified for LIHEAP and 1553 qualified for WAP using their respective income threshold⁹. We found that 48–72 households each year have high inflection temperatures but are not eligible for LIHEAP. Because WAP has a higher income threshold than LIHEAP, all households that qualify for LIHEAP also qualify for WAP, so this range reduces to 29–53 households when comparing the energy equity gap and WAP. Many of these missed households are just on the edge of the low-income threshold but have uncomfortably and sometimes dangerously high inflection temperatures, making them vulnerable without assistance.

Limitations of analysis and opportunities for future work. Energy poverty exists in multiple forms, leading to numerous

limitations in any quantification method. Here we present a discussion of the limitations of our methods and opportunities for future improvements. Uncertainties in using the iteration of the energy equity gap outlined in this paper include the lack of heating data from the natural gas provider. From the dataset provided by the electric utility, we gather that 60% of households in this study use electricity for both cooling and heating, while the remaining most likely use natural gas or oil for heating. However, we did not find the type of heating system to be a significant indicator of household inflection temperatures. Thus, the model used to calculate the inflection temperature still stands for this particular electricity-based dataset (see Methods), particularly for a high-heat area like Arizona where heat-related illness and death is significantly higher than cold-related ones^{40,41}.

Housing characteristics that relate to the energy efficiency of the home⁶¹ (e.g., number of windows, insulation, wall thickness, finishing material, the orientation of the home, etc.) were not included in the dataset but would be valuable additions to future utilities data collection effort. We did find a relationship between residence age and income group, where a large proportion of low-income households lived in older homes (see Supplementary Information Note 2), which could contribute to higher inflection temperatures and less overall household energy efficiency.

One limitation of this study is a lack of indoor thermostat data and an inability to quantify the actual indoor temperature of homes. Thermostat data could provide more information about the willingness of occupants to consume energy for cooling and heating needs. However, thermostat information would not reveal a consumer's true temperature comfort preferences. The inability of thermostat data to identify true household preferences results from household occupants adjusting their thermostat based on multiple factors such as spending limits (i.e., disposable income), comfort, and energy conservation habits. Thus, a person might deliberately keep their thermostats at non-ideal temperatures (i.e., energy limiting behavior), rather than their true comfortable temperature, to save money or energy. Another possibility is that the energy equity gap could be wider than our analyses suggest due to the urban heat islanding effect^{62,63}, with low-income households being more exposed to high heat due to less shading and vegetation in their urban environments.

In spite of these limitations, we believe this analysis provides a crucial first step in identifying energy limiting behavior in low-income households in a metropolitan region. A fruitful direction for future work would be to investigate actual temperature discrepancies within the home.

Discussion

The energy burden metric targets households who limit other necessities to meet energy needs but misses out on those who limit energy spending to meet other needs. The energy equity gap fills this void by identifying who chooses to endure higher temperatures in the summer and how their behavior may change due to price spikes and weather changes. The two types of metrics should be used in conjunction to identify households experiencing multiple forms of energy poverty: those who experience financial strain while satisfying their energy needs, and those who forgo energy consumption to reduce financial strain and satisfy other necessities. By considering behavior patterns in addition to spending patterns, policy makers will be able to better identify who is in need of energy assistance. As nations continue designing equitable and sustainable energy policies, regions need a straightforward method to evaluate the current level of energy poverty from an economic, consumption, and behavioral perspective.

By grouping households by income and energy equity gap severity, policymakers and utility companies can target the most at-risk households requiring urgent financial help with energy bills and weatherization. The value of the energy equity gap is that it creates the possibility of a sliding-scale energy poverty assistance program, which could set weatherization targets for the population based on their ability to adapt to extreme weather events (e.g., heatwaves) and how they are performing relative to others in the region. For example, if primary policies were designed to target households with an inflection temperature above 78 °F (25.6 °C) and those that spend more than 10% of their income on meeting their energy needs, this could reduce financial strain and risk of heat-related illnesses in the region. Secondary policy targets should focus on households with low income and above-average inflection temperatures. These households are likely to suffer from multiple forms of energy poverty and insecurity but are not at high risk for heat-related death.

On the other hand, high-income households with high inflection temperatures may be best suited for discounted weatherization programs. Despite having higher incomes, weatherization costs may still be too high for these households if they have limited disposal income. When adapting the energy

equity gap to other regions, electricity consumption may be sufficient for similarly high-heat regions. However, researchers and energy planners should consider gas, electric, and potentially other fuels used for heating to estimate total energy consumption for colder climates. Calculating the energy equity gap requires the same information for the traditional energy poverty metric, so the cost to compute and utilize the energy equity gap would be marginal.

In the ever-evolving discussion around equity, justice, and policy, we need to study and develop policy that answers the needs of those historically and systemically marginalized. We can start by identifying those falling through the policy cracks of economic-based poverty metrics by casting a finer net which also includes poverty displayed through energy consumption behavior. The energy equity gap contributes to the discussion of existing energy poverty metrics by capturing a region's relative progress while including the households that income-based metrics may have left behind. By targeting the population with higher-than-ideal inflection temperatures with equity-centered policies, regions will more effectively eradicate energy poverty and assist their residents in adapting to climate change.

Methods

Data. The data was provided by Salt River Project, a large utility company in Arizona. The dataset comprises two parts: first, hourly electricity consumption in kWh from May 2015 to April 2019 for 6000 households and the billing plan for each household; second, a comprehensive Residential Equipment and Technology Survey conducted in 2017 for those households. The survey included information on household sociodemographic information, and dwelling characteristics (e.g., residence age, size, and type). For summaries of demographics information please see Supplementary Information Note 1.

Salt River Project provides different billing packages from which customers can choose based on their preferences. Each billing package has its own pricing rules and condition. The billing packages can be categorized into Basic Rate Plan, Time-of-Use Plans, and Prepaid Plans. Pricing rules were integrated into the consumption dataset to account for energy consumption patterns based on electricity pricing, where a uniform weighted average electricity price is calculated across 24 h of the day.

The hourly electricity consumption was aggregated into daily consumption. Daily consumption information was then coupled with daily average temperatures for the study region, compiled from WeatherForYou.com⁶⁴.

Inflection temperature. The inflection temperature is defined as the outdoor temperature where a household shifts from using its heating system to its cooling system. We recognize that there may be a temperature range where the household uses neither heating nor cooling, and the base level energy consumption during that period would be temperature-independent⁴⁶. In this context, the inflection temperature is still an indicator of the shift in energy consumption behavior. A household's inflection temperature is calculated using a nonlinear regression model (Eq. (1)), which estimates daily electricity consumption of household i on day t (E_{it}) based on the following variables: daily average temperature (T_t), electricity price based on the billing plan of the household and season ($P_{t,s}$), dummy variables of whether day t is a holiday (H_t), day-of-the-week fixed effects (δ_t), and month-of-the-year fixed effects (μ_t). When modeling day-of-the-week and month-of-the-year dummy variables, Wednesday and March were dropped, respectively, to prevent collinearity.

$$E_{it} = \alpha + \beta_1 \times T_t + \beta_2 \times T_t^2 + \beta_3 \times P_{t,s} + H_t + \delta_t + \mu_t \quad (1)$$

The quadratic equation models the relationship between daily electricity consumption and daily average temperature. We chose a quadratic relationship because it best coincides with the shape of the electricity consumption and temperature data, and a median R^2 value of 0.8 for all households (Fig. 2). The convex shape of the curve confirms the notion that electricity consumption is highly correlated with temperature. The inflection temperature is the minimum electricity consumption point (Eq. (2)) and signifies the outdoor temperature a household must experience before initiating their AC units.

$$T_{\text{inf}} = T_t \text{ when } f'(E_{it}) = 0 \quad (2)$$

We acknowledge that in building literature there are studies that use a piecewise linear function to identify cooling and heating turn on points (often referred to as balance points)^{45,46,65–67}. We use the quadratic function over the piecewise linear function due to higher R^2 values, which is consistent with other studies⁶⁸ (see Supplementary Information Note 12 for more discussion).

The outliers of the inflection temperature model are defined as any household with an inflection temperature below 30 °F (−1.1 °C) or above 120 °F (48.9 °C), based on outdoor temperature limit ranges measured within the study region. An inflection temperature outside of this bound may indicate incomplete electricity consumption data. Within our study, we filtered out 0.5% in year one, 1.6% in year two, 1.2% in year three, and 0.2% in year four from our analysis due to their classification as outliers. There are a total of 6002 households across the four years of study, but not all households have complete data for all years, which is why the total number of households in Table 2 decreased. One reason for the incomplete data may be that households started or stopped service midway with this utility company.

Computing the energy equity gap. The energy equity gap quantifies the relative energy consumption behavior differences between low and high-income groups using the inflection temperatures. We hypothesized that lower-income households are more likely to have higher inflection temperatures due to financial limitations and a desire to delay cooling their homes to reduce their energy burden (i.e., percent of income spent on energy services). After calculating the inflection temperature (T_{inf}) for each household for one year, we group households by income. The energy equity gap for year y , G_y , is the maximum median inflection temperature ($\max(T_{inf,median})$) minus the minimum inflection temperature ($\min(T_{inf,median})$) among all income groups.

$$G_y = \max(T_{inf,median}) - \min(T_{inf,median}) \quad (3)$$

We hypothesized that lower-income households are more likely to have higher inflection temperatures. To test our hypothesis, we performed two-tailed Mood's Median tests, a nonparametric alternative to a one-way analysis of variance, for significance. A significant result from a Mood's Median test demonstrates that one sample stochastically dominates another, and the differences between sample medians are statistically different. Tests were also performed on median inflection temperatures of ethnicity and age groups, with P -values shown in Table 3. When we group the households by income, we see significant P -value results for all four years, which indicates that the difference in median inflection temperatures of income groups have a close to 0% chance of solely being random (i.e., they are statistically significant). We see similar results when we group the sample population by age, which means age may also be a strong indicator of inflection temperature. Therefore, we cannot rule out that age may play a role in electricity consumption habits (e.g., older people may prefer to turn on their AC at a higher temperature), which would affect the inflection temperatures seen across groups. That being said, when computed within an age or ethnicity group, the energy equity gap can highlight when members are experiencing worsening poverty (i.e., the gap is widening), or when members of the group are adapting to temperature changes in a similar fashion (i.e., the gap is narrowing). While the ethnicity p -values are not on the same order of magnitude as income or age groups, we find that there is less than a 1% chance that the variation between ethnic groups is solely due to chance for years one, two, and four, and less than 6% for year three, thus indicating high statistical significance.

We also considered the potential effects of type of residence (i.e., single-family home, multi-family home, condo, mobile home, townhouse), residence age, and residence size that can have on the household's inflection temperature. However, we find including these variables would introduce multicollinearity into the model because they are correlated with income. For more details see Supplementary Information Note 8.

Computing the traditional energy poverty metric. The traditional economic based energy poverty metric, energy burden, is defined as the percent of income a household spends on satisfying their energy (e.g., electricity) demand. We calculate the proportion of energy expenditure of each household for each year using income, residential electricity price, and energy consumption. For each household, the utility company provides the income bracket each household falls into. We use the midpoint of each income group to estimate the percent of income spent on energy consumption. For the lowest income group (<\$15,000), \$10,000 was taken as the midpoint; for the highest income group (>\$150,000), \$175,000 was taken as

the midpoint.

$$S_{i,y} = \frac{\sum E_{i,t} \times P_i}{I_{i,m}} \quad (4)$$

$S_{i,y}$ is the energy expenditure over income of household i in year y , $E_{i,t}$ is the daily electricity consumption of household i on day t , P_i is the average electricity price of the billing plan of household i , $I_{i,m}$ is the midpoint estimate of income for household i .

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The raw and processed electricity consumption data and the residential energy technology survey data are available under restricted access bound by a non-disclosure agreement, access can be obtained by upon reasonable request to the authors and with permission from the Salt River Project. Records of mean daily outdoor temperatures were retrieved from WeatherForYou.com by way of web scraping and can be accessed here. Source data for Fig. 3, Supplementary Information Figs. S3, S6, and S9 can be accessed here.

Code availability

All data and models are processed in Python 3.8.5. The figures are produced in PowerPoint and R studio (based on R 4.0.3). All custom code⁶⁹ is available on GitHub at <https://github.com/Pa223/The-Energy-Equity-Gap>.

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References

1. Sovacool, B. K. Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. *Energy* **93**, 361–371 (2015).
2. Primc, K., Slabe-Erker, R. & Majcen, B. Constructing energy poverty profiles for an effective energy policy. *Energy Policy* **128**, 727–734 (2019).
3. *Climate Change Impacts in the United States: The Third National Climate Assessment*. <https://nca2014.globalchange.gov/downloads> <https://doi.org/10.7930/J0Z31WJ2> (2014).
4. Wu, X., Brady, J. E., Rosenberg, H. & Li, G. Emergency department visits for heat stroke in the United States, 2009 and 2010. *Injury Epidemiol.* **1**, 8 (2014).
5. *Heat wave: a social autopsy of disaster in Chicago*, Klinenberg. <https://press.uchicago.edu/ucp/books/book/chicago/H/bo20809880.html> (2015).
6. Canouï-Poittrine, F. et al. Excess deaths during the August 2003 heat wave in Paris, France. *Rev. Epidemiol. Sante Publique* **54**, 127–135 (2006).
7. Baldwin, J. W., Dessy, J. B., Vecchi, G. A. & Oppenheimer, M. Temporally compound heat wave events and global warming: an emerging hazard. *Earth Future* **7**, 411–427 (2019).
8. Dong, W., Liu, Z., Liao, H., Tang, Q. & Li, X. New climate and socio-economic scenarios for assessing global human health challenges due to heat risk. *Clim. Change* **130**, 505–518 (2015).
9. Bednar, D. J. & Reames, T. G. Recognition of and response to energy poverty in the United States. *Nat. Energy* **5**, 432–439 (2020).
10. *Low Income Home Energy Assistance Program (LIHEAP) | The Administration for Children and Families*. <https://www.acf.hhs.gov/ocs/low-income-home-energy-assistance-program-liheap> (2022).
11. Rose, E. M. & Hawkins, B. A. Background Data and Statistics on Low-Income Energy Use and Burden for the Weatherization Assistance Program: Update for Fiscal Year 2020. <https://doi.org/10.2172/1761662> (2020).
12. Okushima, S. Gauging energy poverty: a multidimensional approach. *Energy* **137**, 1159–1166 (2017).
13. Duclos, J.-Y., Sahn, D. E. & Younger, S. D. Robust multidimensional poverty comparisons*. *Economic J.* **116**, 943–968 (2006).
14. Pachauri, S. & Spreng, D. Measuring and monitoring energy poverty. *Energy Policy* **39**, 7497–7504 (2011).
15. Culver, L. C. Energy poverty: what you measure matters. *The Stanford Natural Gas Initiative* (2017).
16. Middlemiss, L. et al. Energy poverty and social relations: a capabilities approach. *Energy Res. Soc. Sci.* **55**, 227–235 (2019).
17. Memmott, T., Carley, S., Graff, M. & Konisky, D. M. Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic. *Nat. Energy* **6**, 186–193 (2021).

Table 3 P -values from two-tailed Mood's Median tests on median inflection temperatures of income, ethnicity, and age groups.

Grouping	2015–2016	2016–2017	2017–2018	2018–2019
Income	5.36E–23***	6.85E–22***	2.50E–16***	2.05E–13***
Ethnicity	5.94E–03*	6.02E–05***	2.85E–01	1.73E–02
Age	2.30E–29***	1.61E–32***	8.91E–20***	7.36E–17***

Alpha = 0.05.

Signif. codes: "****" [0, 0.001] "***" [0.01, 0.05] "**" [0.05, 0.1] "*" [0.1, 1].

18. Romero, J. C., Linares, P. & López, X. The policy implications of energy poverty indicators. *Energy Policy* **115**, 98–108 (2018).
19. Spiliotis, E., Arsenopoulos, A., Kanellou, E., Psarras, J. & Kontogiorgos, P. A multi-sourced data based framework for assisting utilities identify energy poor households: a case-study in Greece. <https://doi.org/10.1080/15567249.2020.1739783> **15**, 49–71 (2020).
20. Memmott, T., Carley, S., Graff, M. & Konisky, D. M. Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic. *Nat. Energy* **2021** 6:2 **6**, 186–193 (2021).
21. USDA ERS. *Percent of income spent on food falls as income rises*. <https://www.ers.usda.gov/amber-waves/2016/september/percent-of-income-spent-on-food-falls-as-income-rises/> (2016).
22. Papada, L. & Kaliampakos, D. Measuring energy poverty in Greece. *Energy Policy* **94**, 157–165 (2016).
23. Liddell, C., Morris, C., McKenzie, S. J. P. & Rae, G. Measuring and monitoring fuel poverty in the UK: National and regional perspectives. *Energy Policy* **49**, 27–32 (2012).
24. Moore, R. Definitions of fuel poverty: Implications for policy. *Energy Policy* **49**, 19–26 (2012).
25. Herrero, S. T. Energy poverty indicators: a critical review of methods. *Indoor Built Environ.* **26**, 1018–1031 (2017).
26. Dagnachew, A. G., Lucas, P. L., Hof, A. F. & van Vuuren, D. P. Trade-offs and synergies between universal electricity access and climate change mitigation in Sub-Saharan Africa. *Energy Policy* **114**, 355–366 (2018).
27. Batinge, B., Kaviti Musango, J. & Brent, A. C. Perpetuating energy poverty: Assessing roadmaps for universal energy access in unmet African electricity markets. *Energy Res. Soc. Sci.* **55**, 1–13 (2019).
28. Karplus, V. J. & von Hirschhausen, C. Electricity access: an introduction. *Econ. Energy Environ. Policy* **8**, 1–18 (2019).
29. Higgins, L. & Lutzenhiser, L. Ceremonial equity: low-income energy assistance and the failure of socio-environmental policy. *Soc. Probl.* **42**, 468–492 (1995).
30. MURRAY, A. G. & MILLS, B. F. The impact of low-income home energy assistance program participation on household energy insecurity. *Contemp. Economic Policy* **32**, 811–825 (2014).
31. *Access to electricity (% of population)*, Data. <https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS> (2020).
32. Held, J. S. *Common causes of electric space heater fire examined*. <https://jsheld.com/insights/articles/common-causes-of-electric-space-heater-fires-methods-of-prevention> (2022).
33. Reames, T. G. Targeting energy justice: exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy* **97**, 549–558 (2016).
34. Reames, T. G. A community-based approach to low-income residential energy efficiency participation barriers. *Local Environ.* **21**, 1449–1466 (2016).
35. Hernández, D. & Siegel, E. Energy insecurity and its ill health effects: a community perspective on the energy-health nexus in New York City. *Energy Res. Soc. Sci.* **47**, 78–83 (2019).
36. Union of Concerned Scientists. *The energy burden: how bad is it and how to make it less bad*. <https://blog.ucsusa.org/joseph-daniel/how-to-make-energy-burden-less-bad> (2019).
37. Middlemiss, L. & Gillard, R. Fuel poverty from the bottom-up: characterising household energy vulnerability through the lived experience of the fuel poor. *Energy Res. Soc. Sci.* **6**, 146–154 (2015).
38. *Damp Indoor Spaces and Health. Damp Indoor Spaces and Health*, <https://doi.org/10.17226/11011> (National Academies Press, 2004).
39. Evans, J., Hyndman, S., Stewart-Brown, S., Smith, D. & Petersen, S. An epidemiological study of the relative importance of damp housing in relation to adult health on JSTOR. *J. Epidemiol. Community Health* **54**, 677–686 (2000).
40. *Heat-related illness by year emergency department visit inpatient admission (hospitalization)*. <https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/pubs/heat-related-illness-emergency-department-and-inpatient-admissions-in-arizona-by-year.pdf> (2021).
41. *Cold-related illness by year*. <https://www.azdhs.gov/preparedness/epidemiology-disease-control/extreme-weather/index.php#cold-home> (2021).
42. Jenkins, K., McCauley, D., Heffron, R., Stephan, H. & Rehner, R. Energy justice: a conceptual review. *Energy Res. Soc. Sci.* **11**, 174–182 (2016).
43. Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K. & Wlokas, H. New frontiers and conceptual frameworks for energy justice. *Energy Policy* **105**, 677–691 (2017).
44. Sovacool, B. K. & Dworkin, M. H. Energy justice: conceptual insights and practical applications. *Appl. Energy* **142**, 435–444 (2015).
45. Chong, H. Building vintage and electricity use: old homes use less electricity in hot weather. *Eur. Economic Rev.* **56**, 906–930 (2012).
46. Fazeli, R., Ruth, M. & Davidsdottir, B. Temperature response functions for residential energy demand - a review of models. *Urban Clim.* **15**, 45–59 (2016).
47. Tang, W., Kuehn, T. H. & Simcik, M. F. Effects of temperature, humidity and air flow on fungal growth rate on loaded ventilation filters. *J. Occup. Environ. Hyg.* **12**, 525–537 (2015).
48. Hirsch, D. J., Hirsch, S. R. & Kalbfleisch, J. H. Effect of central air conditioning and meteorologic factors on indoor spore counts. *J. Allergy Clin. Immunol.* **62**, 22–26 (1978).
49. Kilbourne, E. M., Choi, K., Jones, T. S. & Thacker, S. B. Risk factors for heatstroke: a case-control study. *JAMA: J. Am. Med. Assoc.* **247**, 3332–3336 (1982).
50. Lawes, M., Havenith, G. & Hodder, S. Ethnic differences: the influence of relative humidity on thermal perception. *CIEHF Publications* (2021).
51. Wang, L., Chen, M. & Yang, J. Interindividual differences of male college students in thermal preference in winter. *Build. Environ.* **173**, 106744 (2020).
52. Aikman, H. The association between arthritis and the weather. *Int. J. Biometeorol.* **40**, 192–199 (1997).
53. Oudin Åström, D., Bertil, F. & Joacim, R. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. *Maturitas* **69**, 99–105 (2011).
54. DDOE. *Energy tips for institutional and government buildings*. <https://doee.dc.gov/service/energy-tips-institutional-and-government-buildings> (2021).
55. Diaz, J. et al. Heat waves in Madrid 1986–1997: effects on the health of the elderly. *Int. Arch. Occup. Environ. Health* **75**, 163–170 (2002).
56. Department of Energy. *Thermostats*. <https://www.energy.gov/energysaver/thermostats> (2021).
57. *Thermostat settings: the ideal settings for summer & winter*. <https://valleyservice.net/blogs/thermostat-settings> (2020).
58. *Recommended thermostat settings for winter and summer*. <https://www.centralhtg.com/blog/recommended-thermostat-settings> (2018).
59. Benefits.gov. *Low Income Home Energy Assistance Program (LIHEAP)*. <https://www.benefits.gov/benefit/623> (2020).
60. Department of Energy. *How to apply for weatherization assistance*. <https://www.energy.gov/eere/wap/how-apply-weatherization-assistance> (2022).
61. Thomson, H., Simcock, N., Bouzarovski, S. & Petrova, S. Energy poverty and indoor cooling: an overlooked issue in Europe. *Energy Build.* **196**, 21–29 (2019).
62. Hsu, A., Sheriff, G., Chakraborty, T. & Many, D. Disproportionate exposure to urban heat island intensity across major US cities. *Nat. Commun.* **12**, 1–11 (2021).
63. Harlan, S. L. et al. In the shade of affluence: the inequitable distribution of the urban heat island. *Res. Soc. Probl. Public Policy* **15**, 173–202 (2007).
64. Phoenix Arizona Local Weather Forecasts and Conditions - WeatherForYou.com. <https://www.weatherforyou.com/reports/index.php?config=&pass=&dpp=&forecast=zandh&config=&place=phoenix&state=az&pands=phoenix,az&country=us> (2019).
65. Brown, M. A., Cox, M., Staver, B. & Baer, P. Modeling climate-driven changes in U.S. buildings energy demand. *Climatic Change* **134**, 29–44 (2015).
66. Hiruta, Y., Gao, L. & Ashina, S. A novel method for acquiring rigorous temperature response functions for electricity demand at a regional scale. *Sci. Total Environ.* **819**, 152893 (2022).
67. ASHRAE Guideline 14-2002 Measurement of energy and demand savings. ISSN 1049-894X (2002).
68. Kim, Y. J., Lee, S. J., Jin, H. S., Suh, I. A. & Song, S. Y. Comparison of linear and nonlinear statistical models for analyzing determinants of residential energy consumption. *Energy Build.* **223**, 110226 (2020).
69. Pa223. *Pa223/The-Energy-Equity-Gap*, <https://doi.org/10.5281/zenodo.6369436> (2022).

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Author contributions

D.N. conceived the research idea and designed and oversaw the research process. S.C. designed and performed the analysis. S.C. wrote and revised the initial draft of the paper. D.N. and Y.Q. reviewed and revised the paper. B.X. collected and cleaned the data. Correspondence and requests for materials should be addressed to D.N. or Y.Q.

Competing interests

The authors declare no competing interests.

Additional information

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HOME ENERGY AFFORDABILITY GAP

Fisher
Sheehan
& Colton
Public Finance &
General Economics



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Introduction

The objective was to quantify the gap between "affordable" home energy bills and "actual" home energy bills. We were successful.

In 2003, Fisher, Sheehan & Colton (FSC) introduced a model that calculated the dollar amount by which "actual" home energy bills exceeded "affordable" home energy bills on a county-by-county basis for the entire country. This is the "home energy affordability gap." Updated every year since then, the model has become an invaluable tool for research, legislative analysis, program-planning and advocacy. The analyses are used by individuals and organizations across the country. The 2012 Home Energy Affordability Gap, published in May 2013, introduces the 2nd Series of FSC's annual Affordability Gap analysis. While remaining fundamentally the same, several improvements have been introduced in both data and methodology in the Affordability Gap (2nd Series). Explore our site to learn more.

For Example **Connecticut's 5th Congressional District**

The aggregate 2012 Home Energy Affordability Gap for all households **at or below**

For Example **Marion County Oregon**

The 2013 Home Energy Affordability Gap for each household **at or below 50%** of the Federal Poverty Level was \$1,206. That was a home energy burden (bill as a

For Example **The Commonwealth of Pennsylvania**

The aggregate 2012 Home Energy Affordability Gap for all households **at or below 200%** of the Federal Poverty Level in

4/30/24, 12:38 PM

Home Energy Affordability Gap



200% of the Federal Poverty Level in Connecticut's 5th Congressional District was \$131,743,402. The gross 2012 LIHEAP allocation for the entire state was \$79,532,000.



percentage of income) of 22.9%. Housing analysts consider an energy burden of more than six percent (6%) to be unaffordable.



Pennsylvania was \$1,840,924,328. The 2012 "Gap" for each household was \$1,252 or \$104/month.

Fisher, Sheehan & Colton
Public Finance and General Economics

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February 15, 2024

Ms. Lisa Felice
Executive Secretary
Michigan Public Service Commission
7109 W. Saginaw Hwy
Lansing, MI 48917

Re: MPSC Case No. U-18120 – Rule 460.151

Dear Ms. Felice:

Attached are DTE Gas's and Electric's revised quarterly report for 1st, 2nd, and 3rd quarters of 2023. The revisions are to item A. total customer contacts. Revisions are shown in bold and italics. These revised reports supersede the reports filed previously. DTE is filing these revised report as directed by Michigan Public Service Commission Staff (MPSC Staff). In addition, DTE has unloaded this revised information to the MPSC's Quarterly report Salesforce. These reports are pursuant to the Consumer Standards and Billing Practices for Electric and Natural Gas Service Rule 460.151.

Sincerely,

Denise Diz Digitally signed by Denise Diz
Date: 2024.02.15 13:02:27
-05'00'

Denise Diz
Sr. Executive Consumer Affairs Consultant

Enclosure

1st Quarter Report
Complaints/Hearings
January - March 2023



	January 23	February 23	March 23	Total	Comments
Customer Service					
A. Total customer contacts (Res and Non-Res)	3,774,033	3,864,260	4,328,229	11,966,522	January and March have five weeks. Storms in February and March
B. Total customer complaints	1,730	2,143	2,670	6,543	
a. Billing	846	1,126	1,345	3,317	
b. Service	436	617	819	1,872	
c. Credit and Collection	182	131	158	471	
d. Other	266	269	348	883	January - HPP 52, Administrative 119, Claims 33, Property Restoration 55, Energy Waste Reduction/Renewables 7, Totals 266 February - HPP 27, Administrative 106, Claims 34, Property Restoration 82, Energy Waste Reduction/Renewables 20 Totals 269 March - HPP 40, Administrative 126, Claims 54, Property Restoration 120, Energy Waste Reduction/Renewables 8, Totals, 348
Freeform area, If complaint is not listed above, provide general description					
Customer Payment Performance					
C. Number of customers paid by the due date	2,502,344	2,496,067	2,493,023		Customers that are on an active payment arrangement that are current on their monthly payment amount are considered paid by the due date.
D. Number of customers delinquent 31-60 days or more	53,907	58,755	61,027		Data reported is for customers with oldest arrears in the 31-60 days past the due date bucket as of month end.
E. Number of customers delinquent 61-90 days or more	39,004	36,839	36,048		Data reported is for customers with oldest arrears in the 61-90 days past the due date bucket as of month end.
F. Number of customers delinquent 91 days or more	300,476	295,766	290,213		Data reported is for customers with oldest arrears in the >90 days past the due date bucket which includes customers with final arrears as of month end. Final arrears are written off 150 days after the final bill due date.
Payment Plans and Settlements					
G. Number of written settlement agreements	1	0	1	2	
H. Number of payment plan arrangements issued	3,952	3,949	5,689	13,590	
Winter Protection Plan (WPP)					
I. Total enrolled in program at the end of the month	1,256	1,305	961		The month end count is higher than the combined senior and low-income customers because DTE has additional customers enrolled in the program.
a. Number of low-income customers enrolled at end of month	997	1,033	731		
b. Number of seniors enrolled at end of month	232	233	196		
J. Number of defaults at end of month	229	423	420	1,072	
Alternative Shutoff Protection Plan					
K. Total enrolled in program at end of month	35,451	33,076	30,756		Non low-income and non-seniors are included in the month end count for Total enrolled in the program
a. Number of low-income customers enrolled at end of month	11,298	11,271	11,218		
b. Number of seniors enrolled at end of month	16,175	14,648	13,488		
L. Number of defaults at end of month	6,534	6,129	6,105	18,768	
Informal Hearings					
M. Number of hearings requested	2	2	1	5	
N. Number of hearings scheduled		1		1	
O. Total number of hearing determinations issued	0	1	0	1	
a. Hearings resolved in favor of customer				0	
b. Hearings resolved in favor of company		1		1	
c. Hearings resolved in compromise				0	
P. Reasons for the hearings		Billing		0	
Shutoff Information					
Q. Total discontinuation notices issued at end of month	231,338	242,323	219,324	692,985	
a. Electric	231,338	242,323	219,324	692,985	All customer types, and all products, electric, gas or combination
b. Natural Gas				0	
R. Total of customers physically discontinued due to non-payment	18,981	9,048	16,363	44,392	
a. Electric	18,129	8,083	15,618	41,830	
b. Natural Gas	852	965	745	2,562	
S. Total of customers physically discontinued due to unauthorized use	868	777	1300	2,945	
a. Electric	627	473	1,015	2,115	
b. Natural Gas	241	304	285	830	
T. Total of customers physically discontinued due to safety	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
U. Total of customers physically discontinued due to access	132	49	102	283	
a. Electric				0	
b. Natural Gas	132	49	102	283	
V. Total of customers physically discontinued due to "other" (*ADD new line for each reason)	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
W. Discontinuations prevented or restored due to "medical emergency"	42	36	54	132	
X. Discontinuations prevented or restored due to "critical care"	17	8	27	52	
Y. Total number of seniors identified	837,368	839,582	841,689		
Restoration Information					
Z. Total number of customers restored	14,642	6,691	12,334	33,667	
a. Electric	14,441	6,340	12,034	32,815	
b. Natural Gas	201	351	300	852	
AA. Total restored due to receiving assistance	443	282	719	1,444	
a. Electric	433	259	689	1,381	
b. Natural Gas	10	23	30	63	

2nd Quarter Report
Complaints/Hearings
April - June 2023



	April-23	May-23	June-23	Total	Comments
Customer Service					
A. Total customer contacts (Res and Non-Res)	2,975,688	2,946,978	3,885,764	9,808,430	
B. Total customer complaints	1,800	1,991	2,381	6,172	
a. Billing	892	978	1,082	2,952	
b. Service	331	258	605	1,194	
c. Credit and Collection	128	107	131	366	
d. Other	449	648	563	1,660	April - HPP 142, Administrative 82, Claims 58, Property Restoration 265, Energy Waste Reduction/Renewables 2, Totals 449 May - HPP 51, Administrative 94, Claims 97, Property Restoration 402, Energy Waste Reduction/Renewables 4, Totals 648 June - HPP 31, Administrative 153, Claims 108, Property Restoration 266, Energy Waste Reduction/Renewables 5, Totals 563
Freeform area, If complaint is not listed above, provide general description					
Customer Payment Performance					
C. Number of customers paid by the due date	2,495,343	2,485,640	2,486,490		Customers that are on an active payment arrangement that are current on their monthly payment amount are considered paid by the due date.
D. Number of customers delinquent 31-60 days or more	59,457	51,392	74,467		Data reported is for customers with oldest arrears in the 31-60 days past the due date bucket as of month end.
E. Number of customers delinquent 61-90 days or more	37,747	38,998	31,499		Data reported is for customers with oldest arrears in the 61-90 days past the due date bucket as of month end.
F. Number of customers delinquent 91 days or more	286,192	288,696	292,992		Data reported is for customers with oldest arrears in the >90 days past the due date bucket which includes customers with final arrears as of month end. Final arrears are written off 150 days after the final bill due date.
Payment Plans and Settlements					
G. Number of written settlement agreements	1	1	1	3	
H. Number of payment plan arrangements issued	4,465	5,251	4,925	14,641	
Winter Protection Plan (WPP)					
I. Total enrolled in program at the end of the month	690	525	425		The month end count is higher than the combined senior and low-income customers because DTE has additional customers enrolled in the program.
a. Number of low-income customers enrolled at end of month	497	355	269		
b. Number of seniors enrolled at end of month	143	121	107		
J. Number of defaults at end of month	156	91	89	336	
Alternative Shutoff Protection Plan					
K. Total enrolled in program at end of month	31,488	32,666	33,122		Non low-income and non-seniors are included in the month end count for Total enrolled in the program
a. Number of low-income customers enrolled at end of month	12,133	12,543	13,786		
b. Number of seniors enrolled at end of month	14,074	15,666	15,692		
L. Number of defaults at end of month	5,892	5,453	7,678	19,023	
Informal Hearings					
M. Number of hearings requested	1	0	1	2	
N. Number of hearings scheduled	0	0	0	0	
O. Total number of hearing determinations issued	0	0	0	0	
a. Hearings resolved in favor of customer				0	
b. Hearings resolved in favor of company				0	
c. Hearings resolved in compromise				0	
P. Reasons for the hearings				0	
Shutoff Information					
Q. Total discontinuation notices issued at end of month	251,193	238,306	201,394	690,893	All customer types, and all products, electric, gas or combination
a. Electric	251,193	238,306	201,394	690,893	
b. Natural Gas				0	
R. Total of customers physically discontinued due to non-payment	19,280	14,921	22,808	57,009	
a. Electric	17,725	13,247	21,450	52,422	
b. Natural Gas	1,555	1,674	1,358	4,587	
S. Total of customers physically discontinued due to unauthorized use	1,147	858	788	2,793	
a. Electric	1,031	659	553	2,243	
b. Natural Gas	116	199	235	550	
T. Total of customers physically discontinued due to safety	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
U. Total of customers physically discontinued due to access	183	117	105	405	
a. Electric				0	
b. Natural Gas	183	117	105	405	
V. Total of customers physically discontinued due to "other" (*ADD new line for each reason)	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
W. Discontinuations prevented or restored due to "medical emergency"	63	86	100	249	
X. Discontinuations prevented or restored due to "critical care"	19	25	23	67	
Y. Total number of seniors identified	843,260	844,505	845,664		
Restoration Information					
Z. Total number of customers restored	14,304	10,020	16,602	40,926	
a. Electric	13,897	9,693	16,377	39,967	
b. Natural Gas	407	327	225	959	
AA. Total restored due to receiving assistance	591	393	512	1,496	
a. Electric	545	365	499	1,409	
b. Natural Gas	46	28	13	87	

3rd Quarter Report
Complaints/Hearings
July - September 2023



	July 23	August 23	September 23	Total	Comments
Customer Service					
A. Total customer contacts (Res and Non-Res)	3,614,311	3,501,489	3,764,588	10,880,388	
B. Total customer complaints	2,429	3,100	2,671	8,200	
a. Billing	1,119	1,699	1,848	4,666	
b. Service	755	827	405	1,987	
c. Credit and Collection	104	154	91	349	
d. Other	451	420	327	1,198	July – HPP 13, Administrative 138, Claims 73, Property Restoration 220, Energy Waste Reduction/Renewables 7, Totals 451 August – HPP 15, Administrative 135, Claims 48, Property Restoration 210, Energy Waste Reduction/Renewables 12, Totals 420 September – HPP 21, Administrative 98, Claims 49, Property Restoration 150, Energy Waste Reduction/Renewables 9, Totals 327
Freeform area, if complaint is not listed above, provide general description					
Customer Payment Performance					
C. Number of customers paid by the due date	2,519,259	2,488,444	2,516,176		Customers that are on an active payment arrangement that are current on their monthly payment amount are considered paid by the due date.
D. Number of customers delinquent 31-60 days or more	65,500	60,363	67,872		Data reported is for customers with oldest arrears in the 31-60 days past the due date bucket as of month end.
E. Number of customers delinquent 61-90 days or more	45,481	37,126	37,566		Data reported is for customers with oldest arrears in the 61-90 days past the due date bucket as of month end.
F. Number of customers delinquent 91 days or more	293,537	306,814	301,103		Data reported is for customers with oldest arrears in the >90 days past the due date bucket which includes customers with final arrears as of month end. Final arrears are written off 150 days after the final bill due date.
Payment Plans and Settlements					
G. Number of written settlement agreements	0	0	1	1	
H. Number of payment plan arrangements issued	4,958	5,786	6,229	16,973	
Winter Protection Plan (WPP)					
I. Total enrolled in program at the end of the month	332	275	237		The month end count is higher than the combined senior and low-income customers because DTE has additional customers enrolled in the program.
a. Number of low-income customers enrolled at end of month	188	144	103		
b. Number of seniors enrolled at end of month	83	75	55		
J. Number of defaults at end of month	46	22	28	96	
Alternative Shutoff Protection Plan					
K. Total enrolled in program at end of month	32,400	33,136	34,093		Non low-income and non-seniors are included in the month end count for Total enrolled in the program
a. Number of low-income customers enrolled at end of month	14,546	16,349	17,594		
b. Number of seniors enrolled at end of month	15,011	14,517	14,302		
L. Number of defaults at end of month	6,579	6,780	9,558	22,917	
Informal Hearings					
M. Number of hearings requested	0	0	2	2	
N. Number of hearings scheduled			1	1	
O. Total number of hearing determinations issued	0	0	0	0	
a. Hearings resolved in favor of customer				0	
b. Hearings resolved in favor of company				0	
c. Hearings resolved in compromise				0	
P. Reasons for the hearings			Billing	0	
Shutoff Information					
Q. Total discontinuation notices issued at end of month	226,566	248,578	236,436	711,580	All customer types, and all products, electric, gas or combination
a. Electric	226,566	248,578	236,436	711,580	
b. Natural Gas				0	
R. Total of customers physically discontinued due to non-payment	19,669	20,390	20,668	60,727	
a. Electric	18,841	19,887	19,451	58,179	
b. Natural Gas	828	503	1,217	2,548	
S. Total of customers physically discontinued due to unauthorized use	766	1,112	850	2,728	
a. Electric	645	957	757	2,359	
b. Natural Gas	121	155	93	369	
T. Total of customers physically discontinued due to safety	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
U. Total of customers physically discontinued due to access	42	57	68	167	
a. Electric				0	
b. Natural Gas	42	57	68	167	
V. Total of customers physically discontinued due to "other" (*ADD new line for each reason)	0	0	0	0	
a. Electric				0	
b. Natural Gas				0	
W. Discontinuations prevented or restored due to "medical emergency"	107	120	74	301	
X. Discontinuations prevented or restored due to "critical care"	35	27	22	84	
Y. Total number of seniors identified	846,958	848,910	850,711		
Restoration Information					
Z. Total number of customers restored	15,898	16,144	15,971	48,013	
a. Electric	15,798	16,082	15,870	47,750	
b. Natural Gas	100	62	101	263	
AA. Total restored due to receiving assistance	452	408	325	1,185	
a. Electric	444	402	316	1,162	
b. Natural Gas	8	6	9	23	
Electric Only - Customer Service					
BB. Average customer call answer time (seconds)	46	60	57		All customer types, and all products, electric, gas or combination
CC. Percentage of the call blockage factor	0%	0%	0%	0	All customer types, and all products, electric, gas or combination
DD. Percentage of the complaint response factor	100%	100%	100%	1	

MPSC Case No: U-21291

Requester: FLO

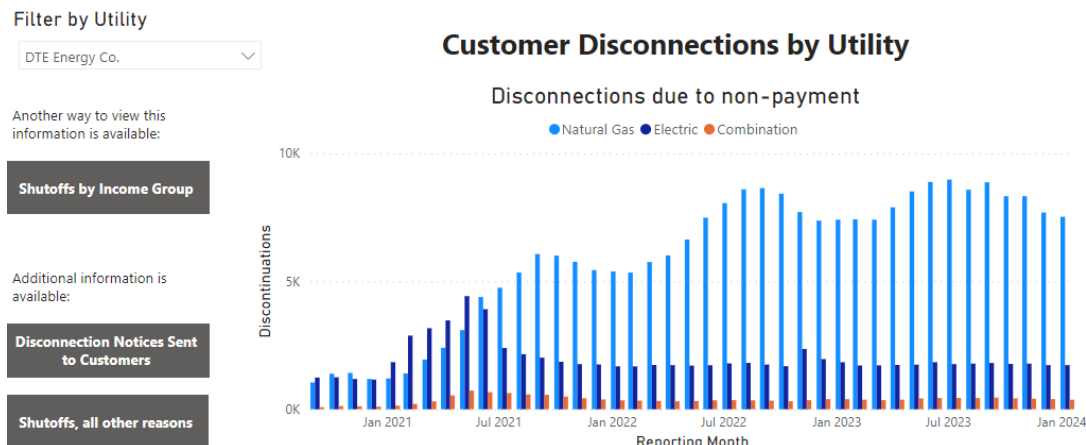
Question No.: FLOGD-1.3

Respondent: J. E. Sparks

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Question: 3. The MPSC aggregates disconnection and shutoff notice information on its “Utility Customer Data” webpage, using data provided by DTE and other utilities. Utility Customer Data, MICH. PUB. SERV. COMM’N, <https://www.michigan.gov/mpsc/regulatory/reports/other/utility-customer-data>. According to the data (reproduced below in Figure 1), it appears that gas-only disconnections have increased each year since September 2020. At the same time, according to the data (reproduced below in Figure 2), it appears that gas-only shutoff notices have remained relatively consistent each year since September 2020, following a seasonal pattern that does not appear to exceed 25,000 disconnection notices in a given month. Please explain why shutoff notices have remained relatively consistent during this period while actual shutoffs have increased each year. In this description, please list factors the Company believes relevant to account for the higher rate in actual shutoffs relative to shutoff notices received.

Figure 1: Customer Disconnections by Utility (DTE)



<https://www.michigan.gov/mpsc/regulatory/reports/other/utility-customer-data>

MPSC Case No: U-21291

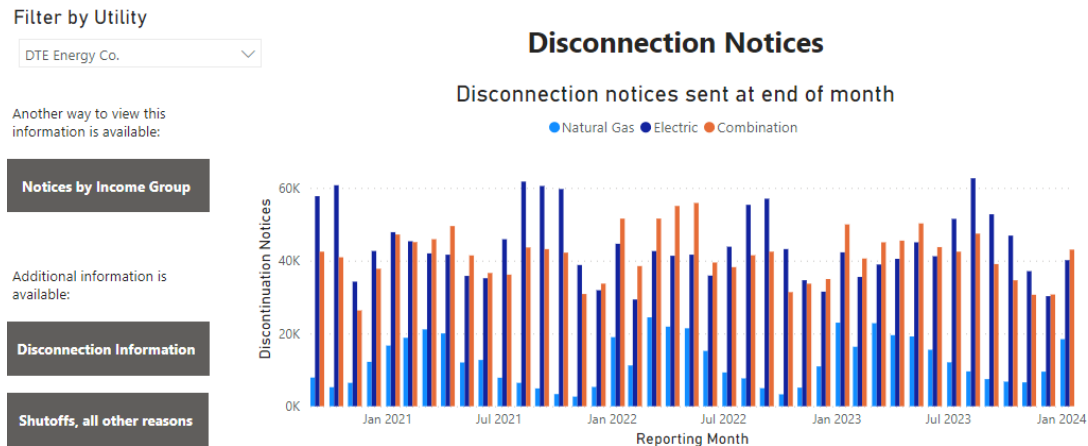
Requester: FLO

Question No.: FLODG-1.3

Respondent: J. E. Sparks

Page: 2 of 3

Figure 2: Customer Disconnection Notices (DTE)



<https://www.michigan.gov/mpsc/regulatory/reports/other/utility-customer-data>

Answer: The Utility Customer Data website displays information as provided in the Company's monthly U-20757. The gas disconnects information referenced is a total number of residential premises that were disconnected from 11/1/2019 to the last day of the reporting month that have not been restored. It is not the number of residential disconnects for any given month. The displayed screenshot from the website will align with the January 2024 report submitted by the Company. See attachment for the U-20757 report submitted for January 2024 and explanations of the data.

MPSC Case No: U-21291

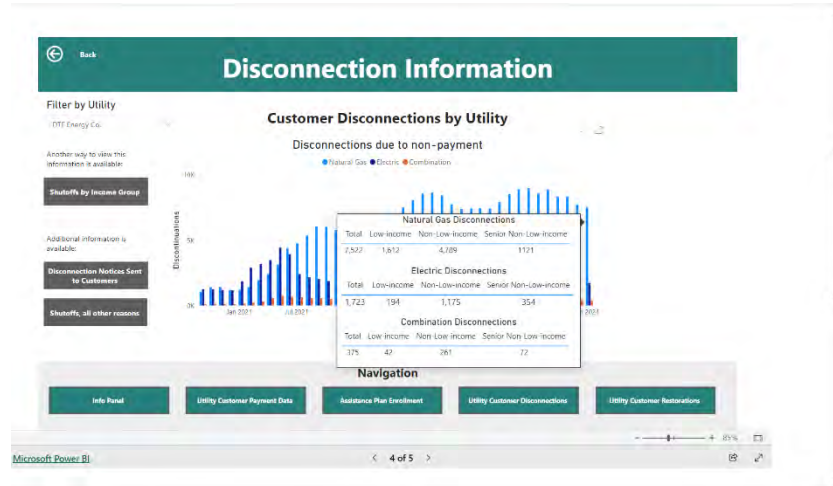
Requester: FLO

Question No.: FLODG-1.3

Respondent: J. E. Sparks

Page: 3 of 3

Figure 1 MPSC Customer Disconnections by Utility (DTE)



Attachment: U-21291 FLODG-1.3-01 U-20757 January 2024 2-12-24 Report

Lights Out: Profitable Utility Company Shut Off Electricity to Homes Hundreds of Thousands of Times

by Sarah Alvarez, Outlier Media, with data analysis by Agnel Philip, ProPublica

March 18, 2022, 6 a.m. EDT

Three months into the pandemic, Michigan's largest power company, DTE Energy, began ramping up power shut-offs for customers behind on their bills. A regulatory system built to prioritize investors, not affordability, let it happen.



Rebecca Mock for ProPublica

Co-published with [Outlier Media](#)

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During the early stages of the pandemic, Michigan's largest power company leaned in to a chance to show its charitable side, helping buy laptops for Detroit's public school children and publicizing that it would not disconnect the gas and electric service of people who could not pay their bills. DTE Energy said it was on "high alert to help those customers whose lives are being disrupted."

But the relief from the threat of a shut-off ended quickly for DTE's customers, who pay some of the highest electricity rates in the country. DTE's moratorium on disconnections lasted just over three months.

An analysis by ProPublica and Outlier Media shows the extent to which one of the nation's poorest cities and other communities across Southeast Michigan have been impacted by electric service disconnections since the COVID-19 pandemic began. DTE disconnected customers 80,600 times in 2020 and more than doubled that number in 2021. Its 178,200 disconnections for nonpayment last year were its highest annual total since 2016.

The shut-offs reflect an unrelenting reality in Detroit and surrounding areas, where low-income residents have long struggled to keep their lights on while avoiding crushing debt tied to a basic service. It's a problem rarely discussed except among activists and advocates, as regulators and legislators have focused on other issues, like reliability of service.

DTE has more than 2 million customers, but size alone does not explain its shut-off numbers, nor does the level of poverty within the company's service area. The analysis by ProPublica and Outlier is the first to examine DTE's disconnections and compare them to shut-offs by other Michigan utilities.

During the pandemic, DTE's rate of electricity shut-offs — disconnections as a proportion of customers — outpaced the six other utilities in Michigan that are owned by private investors and have their prices regulated by the state. DTE's rate was twice as high as the state's second largest utility, Consumers Energy, which serves areas with a similar share of low-income residents, according to an analysis of U.S. Census Bureau data.

Prior to the COVID-19 emergency, from 2013 — the earliest year for which data was available — through 2019, DTE disconnected electric accounts 1.2 million times. That represented 47% more shut-offs than Consumers during those years, adjusted for the number of customers each utility had. (Both utilities also provide gas service and combine those costs into one bill for many customers, but electricity is the more expensive of the two.)

DTE responded to the findings of Outlier and ProPublica in interviews and through email. The utility said that in most cases, customers have service restored within 48 hours. DTE spokesman Christopher Lamphear stressed that the utility works with customers to help arrange affordable payment plans or get financial assistance and contributes millions of dollars annually to a range of programs for low-income communities and customers. He said DTE forgave \$2.6 million in debt for struggling customers in 2020.

But DTE, which told state regulators it has half a million customers living in poverty, has acknowledged the struggles faced by customers who can't afford electricity. In recent testimony before state regulators, DTE described how some people build up significant debt on their monthly bills and then see the problem exacerbated by late fees, shutoffs and security deposits required for reconnection.

Many of the customers who experience shut-offs "are stuck in a repeated cycle of disconnects and reconnects" and must "make tough choices about which monthly bills get paid, and which ones don't," a company representative testified.

Outlier Media helps Detroit residents access useful and verified information via an automated text messaging system monitored by reporters who will follow up with them. This winter, Outlier heard from hundreds of DTE customers who were looking for resources to help pay their bills.

Of those, 136 said they had had their power shut off or owed money to DTE. Another 343 said they needed help to pay their current DTE bill. Among their comments:

"I was diagnosed with covid and stuck in bed so I missed my notice."

"Insurmountable debt owed to DTE. I live in an apartment which has very little insulation, thereby causing my heating charges to be extreme."

"My service was shut off due to nonpayment just last month. I had to come up with \$135 to get my service restored."

One Detroit man who responded to Outlier was shut off earlier this year and reconnected the same day. His bill shows he currently owes more than \$2,500 to DTE. In an interview, the recent widower described the stress of not knowing if he could keep the electricity on for his children so they could use the internet for school.

"I open the door and I'm just hoping that my service is not off," said the man, who didn't want to be named in the story to protect his family's privacy. "When the power is off, that stops the kids from being able to go to school." DTE confirmed that his account had been shut off.

Even though many customers routinely scramble to pay their bills, the state's utility regulators are not empowered by state law to directly consider affordability when setting prices. Echoing a dynamic seen

across the country, Michigan's regulators focus primarily on keeping utilities profitable enough to satisfy investors and on ensuring customers receive power without unexpected blackouts.

"There's not sort of a clear place in Michigan law where it gets to 'And also can customers afford to pay for it?'" said Dan Scripps, chair of the entity charged with overseeing utilities, the Michigan Public Service Commission.

Over the last decade, the MPSC has granted DTE a regular series of price hikes worth billions of dollars in revenue to the company.

The state has rules prohibiting shut-offs during extreme weather and requiring notices before disconnection, but it's often up to utilities to decide how much leniency to show customers.

DTE's Lamphear said in an email that it has "an obligation to all customers" to manage unpaid bills in a cost-effective way, so that lost revenue doesn't result in higher costs for all.

"Given these challenges we continue to advocate for additional financial support from federal and state sources to provide a safety net for the most vulnerable people we serve," Lamphear wrote.

Federal data shows that DTE's price, as measured in cost per kilowatt-hour, is the second highest among investor-owned utilities in Michigan, behind the Upper Peninsula Power Company, a utility with only about 50,000 customers in Northern Michigan. Consumers' rate, meanwhile, is about 10% lower than DTE's.

DTE's price per kilowatt-hour is also higher than the price charged by the largest utility in each of the other Great Lakes states of Illinois, Indiana, Minnesota, Ohio and Wisconsin.

Despite the rate it charges, DTE said, its average monthly bill is on par with the national average, in large part because Michigan residential customers use less electricity than the average American customer.

Outlier and ProPublica employed the same methodology used by DTE to compare its average bills to those of the largest utilities in those five Great Lakes states. DTE's average bill turned out to be the second most expensive among that group in 2020, the most recent year with full data.

Researchers have developed another way to measure affordability called "energy burden," which accounts for price and income by calculating the share of customers' monthly earnings that goes toward utility costs. A recent study of 25 large metropolitan regions determined that the burden for low-income Detroit residents was particularly severe.

Michigan regulators don't require utilities to disclose where shut-offs happen or which communities are most affected, and DTE declined to provide that information to an Outlier reporter. But advocates in Detroit's low-income neighborhoods and researchers say Black communities are significantly impacted. The percentage of Black residents in DTE's service area is nearly three times as high as Consumers', according to a ProPublica and Outlier analysis of census data.

Jeremy Lark of Greenpath Financial Wellness, a nonprofit that helps customers to access payment plans for DTE debt, said more than 60% of people working with Greenpath to manage their DTE debt are Black.

"The customers that come to us," he said, "it's pretty common that past due bills are in the thousands of dollars."

High Prices and Oversight That Favors Utilities

Thomas Edison grew up in Port Huron, Michigan, before going on to help develop electric power generation. One of his first licensees for generating electricity was the Detroit Edison Company; it was reorganized into DTE Energy in 1996.

In the early part of the 20th century, as industry and ordinary households demanded more electricity, governments across the country didn't have the funds, expertise or will to build a brand new electric grid. Instead, they struck deals with large power companies to supply and distribute power; the utilities would be subject to government oversight but also would be insulated from future competition.

These "investor-owned utilities" — some, like DTE, with publicly traded stock — provide utility service for the majority of Americans and often need government approval to set prices.

The Michigan Public Service Commission, which negotiates these rates through an administrative proceeding, is not empowered to reject rates on the grounds they're too expensive for low-income customers. Instead, it "has an obligation under Michigan law to set rates based on whether the investments proposed are reasonable and prudent and then allowing for the opportunity to earn a profit on those that are," said Scripps, chair of the commission.

He added: "Affordability is always a front-of-mind issue, but it's not tied to how we evaluate utility investments."

Similar dynamics are at play across the country. Two recent exceptions can be found in Oregon and Massachusetts, where recent legislation gave regulators power to take customers' ability to pay into consideration when setting gas or electric rates.

Since 2011, the MSPC has approved six rate increases for DTE, each for amounts that were about half of what the company had requested. Over that same time period, according to the commission, DTE's revenues have increased by several billion dollars, due in part to those rate increases. DTE is currently asking for a seventh rate increase, worth an additional \$388 million in annual revenue.

Nationally, the rate DTE charges residents ranks in the top 5 percent of all investor-owned, public and cooperative electric suppliers, according to government data analyzed by Outlier and ProPublica.

In DTE's service area, the increases in residential rates stand in contrast to what's happened with businesses and industry. The commercial rates businesses pay have been relatively stable in recent years, while industrial users saw their rates decline between 2010 and 2019, according to federal data analyzed by the Citizens Utility Board of Michigan, a state-funded consumer advocate.

Amy Bandyk, executive director for CUB of MI, said her organization — and by extension residential ratepayers — is outspent by the utility companies, which can afford more lawyers and experts to argue their side in rate cases.

"DTE and Consumers have lots of lobbyists and lawyers and analysts all focused on getting a better return for their shareholders," she said. "I like to think our arguments are good, but the utilities are just very well-funded."

She'd like to see the state move toward a billing structure that caps bills at a percentage of income for those who might otherwise struggle to pay, a reform that is popular with advocates nationally.

The MPSC has urged DTE and Consumers Energy to take some steps in this direction, and both companies have taken steps to test this approach. DTE's pilot program, which began in January, caps bills at 10% of income for some households who use DTE for both gas and electric service, with the company absorbing the rest of the cost. The program will last two years for no more than 2,000 customers living at or below 200% of poverty.

Even as Bandyk observes what's happening with the MPSC, she would like to see more urgency.

"There are so many people that need help right now," she said. "High utility rates affect everyone, and, obviously, there are specific groups of customers hit especially hard."

Donald Lutas is one of those customers. A retiree on a fixed income, he has tried to make his 105-year-old Detroit home more energy-efficient by adding insulation in its attic and replacing windows. But his house

is still large and drafty, and he has problems keeping up with his gas and electric bills, especially in winter when he's seen monthly charges of more than \$500.



Donald Lutas in the entry hallway of his home in Detroit Nick Hagen for ProPublica

“Right now I have to make a choice between paying my part of Medicare or paying for utilities,” said Lutas, who used to run a residential care facility for people with mental health challenges. “I couldn’t afford both. I had multiple shut-off notices last winter, and I couldn’t allow myself to get disconnected.”

Lutas said he chose to forgo his primary care visits and only keep his hospitalization insurance in order to afford to pay DTE. As he struggles to make payments, Lutas can’t help but think about how DTE continues to thrive financially.

“It is a problem which is more glaring considering that DTE is constantly posting a profit, a major profit,” he said.

Even as the pandemic upended lives in the Detroit area, DTE saw strong earnings in 2020 and 2021. Cash dividends paid out to investors in the electric company, bolstered by rate hikes, rose 76% from 2010 to 2020, to \$539 million. DTE’s financial success is important to everyone in the region, the utility argues, because it allows DTE to attract additional investors and borrow money at a lower financing cost.

Beyond its investor dividends, the health of the company’s finances is reflected in the pay of its top executive. CEO Jerry Norcia received a salary of \$1.2 million as part of total compensation of \$9.7 million in 2020, his first full year on the job. In every other year since 2017, the company’s compensation package for its CEO has topped \$10 million.

DTE Shut-offs Outpace Other Utilities’

When the pandemic began in 2020, causing a wave of medical and financial hardship, 34 states directed utilities to stop shutting off customers’ service, according to the National Association of Regulatory Utility Commissioners. But Michigan was not one of those, relying instead on voluntary pauses by the state’s utilities.

DTE’s shut-off moratorium was shorter than those put in place by the largest utilities in Illinois, Indiana, Minnesota, Ohio and Wisconsin.

MPSC chair Scripps defended the utility’s decision to limit its self-imposed moratorium to only three months in a [commentary](#) published in the Detroit Free Press in December 2020. Citing experience from Michigan’s recession in the early 2000s, Scripps said people who stop paying their bills during a longer moratorium might be unlikely to ever catch up. He argued that focusing instead on aggressively distributing assistance dollars would have more long-term benefit.

Consumers Energy, meanwhile, voluntarily extended its shut-off moratorium to eight months for most residential customers, through October 2020. The longer moratorium did not lead to more shut-offs once it ended, according to data filed by the company with the MPSC. Consumers' shut-offs in 2021 were the third fewest for any year since 2013. Only 2016 and 2020 had fewer.

Looking back on its moratorium, Consumers said it did the right thing for its customers. "We believe our approach was the right one," the utility said in an email, "as we did not want to add additional stress onto our customers during an already stressful time."

The MPSC has required utilities to file frequent reports on shut-off numbers during COVID-19, every two weeks for the first few months of the pandemic and then every month since. But those reports only tally the number of people who remain shut off from electric, gas or both services at the end of each month-long period. Because these reports don't account for shut-offs where service was later reconnected, they underrepresent the true problem.

But Michigan utilities also file quarterly reports with the MPSC tallying every disconnection for nonpayment. Through examining these, a more complete picture of the breadth of shut-offs during the pandemic emerges.

The analysis by ProPublica and Outlier found that from April 2020 through December 2021, the last month for which data is available, DTE disconnected accounts 208,000 times for nonpayment. These reports contain numbers for both residential and commercial disconnections, but the preponderance are residential.

Because of the way the MPSC collects its data, the analysis could calculate the total number of shut-offs, not the number of customers affected. A single customer might be disconnected more than once during a period of time. DTE, for instance, said that its 80,600 shut-offs in 2020 "represented approximately 66,000 unique customers."

ProPublica and Outlier asked both DTE and Consumers for their company policies on what triggers a shut-off notice. Again, there was a clear difference.

DTE said it can begin the shut-off notification process after customers miss just one payment and fall more than \$100 behind on a bill. State law requires a shut-off notice be sent at least 10 days before an account is disconnected. In order to avoid shut-off, customers can pay their entire past due balance, agree to a payment plan or apply for assistance, which includes a shut-off hold during the application process.

"We offer them a range of options based on their circumstances: affordable payment plans, senior protections, medical holds and low-income assistance," DTE said in an email. It added: "DTE acts leniently wherever possible within the MPSC's rules."

Consumers Energy said it also can start its notification process after customers miss just one bill, but only if they have fallen at least \$200 behind. If a late customer gets their balance owed below \$75, Consumers said, it won't go through with the disconnection.

Both companies require customers who get disconnected for nonpayment to provide a deposit before getting reconnected. The deposit can be significant. Under Michigan regulations, the deposit can equal up to twice a customer's average monthly bill; the fee is waived for anyone receiving utility assistance from the state to help them reconnect.

In 2020, aided by an influx of federal COVID-related assistance, the state helped more than 341,000 people across Michigan with energy costs ranging from bills to furnace repairs.

However, more than 40% of individuals who applied that year were rejected, usually because of income requirements, when they applied for that help. Some of the state's relief programs also require a shut-off notice to qualify.

Detroit's Heavy Burden

Cassia Haywood, who lives on Detroit's West Side with her 11-year-old daughter, is quite familiar by now with what DTE shutoff notices look like: a letter marked by several thick red lines and plenty of bold red type.

For years, those letters have forced her to scramble to avoid losing electricity and gas-powered heat. In that very basic sense, her efforts were a success in 2021.

Thanks to payment plans with DTE and intermittent help from social service agencies, Haywood has managed to keep her electricity on. Payment plans can give people more time to pay off money owed to the company in affordable chunks, but some plans still allow the total debt to grow.

Her debt to DTE, built up over several years of gas and electric charges, now totals \$8,000, part of which will be added to her bill each month until she has paid it all down. It's a debt she fears she may never pay off.

Haywood has an auto-assembly job but is only getting sporadic hours. "I'm just not getting ahead with it," she said.

The financial pressures bearing down on Haywood and others reflect the energy burden faced by many Detroit residents: a household's energy costs, both electric and gas, divided by its income. Researchers and policy makers largely agree that an energy burden over 6% is unaffordable.

Haywood said she uses about \$200 of energy each month, making her burden about 10%. Because she also needs to pay hundreds of dollars toward her debt with DTE each month, the actual burden of her DTE bill is about 34% of her income.

Sometimes a DTE bill for electricity and gas can rival housing costs.

"We pay so much, even on the payment plan," said Germaine Iwu, who lives with her husband and four children on the East Side of Detroit. Their typical monthly bill this year has been \$326 through their plan. "Our mortgage is only like \$400," she said.

A recent study by the American Council for an Energy Efficient Economy, a national nonprofit, put the median energy burden in the Detroit metro area at 10% for low-income families. That's higher than the national average and the third-highest among the metropolitan areas it studied, behind Baltimore and Birmingham.

This research found that 43% of Black and 38% of Latinx households in the Detroit metro area have an unaffordable energy burden. Researchers cite a combination of factors for these percentages, including higher energy usage because of older housing stock that is not energy-efficient.

A separate survey of more than 350 Detroit families — conducted over the winter of 2020 by Detroit nonprofit We Want Green Too and Kate Hutchens, a University of Michigan researcher— found their average energy burden was close to 16%, higher than that of the overall metro area.



Gloria Lowe in her home in Detroit. Lowe runs We Want Green Too, a nonprofit that studied the energy burden in Detroit. Nick Hagen for ProPublica

Addressing the problem in Detroit won't be easy.

The National Consumer Law Center, which has extensively studied utility prices and regulation, advocates that states develop payment plans that are based on a percentage of income, eliminate deposits for reconnection and prohibit shut-offs for low-income households that include infants or people who are elderly or disabled. To get a clearer view of who is being impacted, the center also wants utility companies to provide more data about who is affected by shut-offs.

In Michigan, the MPSC has pushed utilities to experiment with percentage-of-income plans for some, but there seems to be little momentum for bigger changes. State Sen. Jeff Irwin, a Democrat from Ann Arbor, said regulators and legislators have been overly responsive to the utilities' desires for reliable investor payouts. For instance, Democrats have pushed legislation limiting shut-offs of water but not electricity.

Irwin said the legislature is too responsive to industry and "blind to the needs of residential affordability.

"The very specific conversation about helping people who can't pay their bills does not get a lot of play," he said.

DTE is currently pushing a different idea: a prepaid option it said would help low-income customers. Its reference in state filings to the struggles of customers who face shut-offs came as it urged the MPSC to endorse that proposal.

Under DTE's plan, people would prepay into an energy account, and if that account runs dry, the company would then use a "remote disconnect feature." Customers would need to make a minimum payment of \$40 to get their power restored, and the process would begin again.

"That is the thing that brings me closest to feeling like I'm living in a post-apocalyptic world," said Margrethe Kearney, a lawyer with the Environmental Law & Policy Center, which opposes the plan and has intervened in the still-undecided MPSC case.

"DTE has lots of reasons for wanting to do this. And they say, 'Well, you know, it'll help people manage their energy use. It'll keep people from racking up these \$3,000 bills.' But at the same time, it's like, what happens when it's the middle of a heatwave? And you don't have any money to put in your account?"

Some activists want to fundamentally challenge the way low-income communities must rely on DTE. Advocacy from Soulardarity, an environmental justice group, has led to a pilot program, endorsed by MPSC, that will give hundreds of low-income residents in Highland Park, Detroit and River Rouge access to solar power and credits on their bills.

Shimekia Nichols, the group's executive director, considers that a small step, if an insufficient one, toward a larger goal of independence from DTE's monopoly.

“That is what energy democracy is about,” she said. “It’s what we have to do, because otherwise people are just going to keep needing help.”

About the Data: How We Analyzed Shut-off Rates and Service Area Demographics

Outlier Media and ProPublica collected quarterly reports from the Michigan Public Service Commission that cataloged total disconnections of electric customers for nonpayment by month since 2013. The shut-off numbers do not separate out residential and non-residential customers. The news organizations then calculated average monthly shut-off rates during the pandemic by averaging the disconnections from April 2020 through the end of 2021, which was the most recent data available, and divided that by the average number of electric customers (residential and non-residential) reported by Michigan’s investor-owned utilities to MPSC for 2020. Customer counts for 2021 were not available at the time of publication. We followed a similar method for calculating the average shut-off rate from 2013 through 2019, averaging the monthly customer count figures reported for each year as our base.

For our analysis of the customer demographics for Michigan’s largest two utilities, we re-created an MPSC map of the electric service areas for DTE and Consumers Energy at the Census tract level, using 2010 boundaries. We then matched these tracts to Census data and calculated the percent of residents in each service area who are Black and the percent who are low-income, using the 2015-2019 five-year American Community Survey. We defined low-income percentage as the number of people at or below the poverty line divided by the total population, for each service area. We excluded tracts where the utilities appeared to only serve a portion of the total area.

Comparisons of average bills and rates per kilowatt-hour were based on data from the U.S. Energy Information Administration.

Erin Smith, Alyssa Johnson and Alex Mierjeski contributed research.

Update, March 18, 2022: This story was updated to include the name of Chris Lamphear, a DTE spokesman.

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Center for Energy and Environmental Policy Research

Social Norms and Energy Conservation

by
Hunt Allcott

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Social Norms and Energy Conservation

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MIT and NYU

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Abstract

This paper evaluates a large-scale pilot program run by a company called OPOWER, previously known as Positive Energy, to mail home energy use reports to residential utility consumers. The reports include energy conservation information as well as social comparisons between a household's energy use and that of its neighbors. Using data from a randomized natural field experiment at 80,000 treatment and control households in Minnesota, I estimate that the monthly program reduces energy consumption by 1.9 to 2.0 percent relative to baseline. In a treatment arm receiving reports each quarter, the effects decay over the months between letters and increase again upon receipt of the next letter. I provide evidence to suggest that at least some of this effect is because consumers' attention is malleable and non-durable. I show that "profiling," or using a statistical decision rule to target the program at households whose observable characteristics predict larger treatment effects, could substantially improve cost effectiveness in future programs. The results provide additional evidence that non-price "nudges" can substantially affect consumer behavior.

JEL Codes: C44, D03, L94, Q41.

Keywords: Social norms, attention, energy demand, randomized field experiments, statistical treatment rules, profiling.

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1 Introduction

Climate change has emerged as one of the most pressing issues of the early 21st century, and many consider energy efficiency to be a promising approach to reducing energy demand and thus abating greenhouse gas emissions. Historically, economists and policymakers have had the intuition that relative prices are the primary driver of adoption of energy efficient technologies and behaviors. As a result, subsidies for energy efficient capital goods draw the vast majority of federal and state energy efficiency funding (Gillingham, *et al*, 2006).

Perhaps spurred by an increasing general interest in behavioral economics, there has been a recent surge in the appeal of non-price interventions that "nudge" consumers to conserve energy. Non-price interventions are typically inexpensive to implement relative to subsidies, and as demonstrated by Bertrand, *et al*, (2010) in the context of consumer finance, carefully-crafted psychological cues can have effects on consumer behavior that are comparable to large changes in relative prices¹. A principal challenge, however, is to craft interventions that are scalable and have large effects in a representative population.

This paper econometrically evaluates a large-scale energy conservation program run by a company called OPOWER, previously known as Positive Energy, for an electric utility in Minnesota. The OPOWER program is implemented as a randomized controlled natural field experiment, allowing an unbiased estimate of average treatment effects in the eligible population. The treatment involves mailing to residential consumers Home Energy Reports with two principal features. The first feature is an Action Steps Module that provides information, specifically targeted to each household, on strategies to conserve energy. The second is a Social Comparison Module that details the household's electricity consumption and compares it to that of its one hundred nearest geographical neighbors in houses of comparable size.

This social comparison feature was motivated by academic work showing that normative comparisons can significantly affect individual behavior. Empirical work by psychologists and political scientists has shown that information on social norms can induce people to conserve energy (Goldstein, Cialdini, and Griskevicius 2008), vote (Gerber and Rogers 2009), or stop littering (Cialdini, Reno, and Kallgren 1990). This social influence literature has developed alongside work by economists on social learning² and conditional cooperation in the private provision of public goods³.

The effects of Positive Energy's program are of practical interest for two reasons. First, independent estimates of the energy use reductions caused by the Home Energy Reports are important

¹For their study, Bertrand, *et al*, partnered with one of the largest banks in South Africa to offer new loans to existing clients, via letters that varied both the interest rate offer and other psychological cues. They varied the number of different potential loans that were presented (to test whether greater choice could overload decision-making), how the interest rate was compared to some market benchmark, the race and gender of the person in a photo on the offer letter, the expiration date of the offer, whether the offer is combined with a promotional giveaway, and whether the letter mentions suggested uses for the loan. Consistent with economic theory, they found that consumers that had been offered lower interest rates were much more likely to take up the loans. They also found, however, that any one psychological cue could affect takeup by almost as much as a one to two percentage point change in the monthly interest rate. See Allcott and Mullainathan (2009a and 2009b) for further discussion of applications of non-price approaches to energy conservation suggested by recent research in psychology and economics.

²This literature includes Banerjee (1992), Beshears, *et al*, (2009), Conley and Udry (Forthcoming), Duflo and Saez (2002, 2003), Foster and Rosenzweig (1995), Mobius, Niehaus, and Rosenblat (2005), and others. In these settings, agents make a choice under uncertainty and draw inference from others' behavior because others may have distinct and useful information.

³Recent work on conditional cooperation includes Fischbacher, Gächter, and Fehr (2001), Shang and Croson (2004), Frey and Meier (2004), Alpizar, Carlsson, and Johansson-Stenman (2008), and others. These studies demonstrate that people are more likely to contribute to public goods when informed that others are contributing more.

per se. The program has been covered in the New York Times (Kaufman 2009), the Atlantic (Tsui 2009), National Public Radio, and other popular media outlets. It has been introduced at 20 utilities, including six of the largest ten in the United States, and by the end of 2009 nearly two million households will be involved nationwide. Other utilities are considering adopting the program, and credible documentation of the magnitude of its effects will affect the disposition of millions of dollars in potential investment.

Second, the success or failure of the OPOWER program is also of more conceptual interest. Whether this program is perceived as successful will influence whether future energy efficiency programs are influenced by findings from behavioral science and evaluated via randomized controlled trials⁴. If the program has economically significant effects, it would be a remarkable illustration of the effectiveness of non-price interventions compared to the existing large rebates for energy efficient durables.

The point estimates of the Average Treatment Effect (ATE) of OPOWER's monthly Home Energy Reports for the households served by this Minnesota utility range from a 1.9 to a 2.0 percent reduction in electricity consumption relative to the control group. The 95 percent confidence intervals in the four primary specifications span a range from 1.52 to 2.31 percent. Because of the large sample size and randomized control group, the estimated ATEs are highly robust to alternative specifications of fixed effects and control variables. The effects appear to vary depending on the envelopes in which they are delivered, the time elapsed since the beginning of the treatment, and the season.

The point estimate of the cost effectiveness of the existing Minnesota program is 5.25 cents of program cost per kilowatt-hour saved. This number, which could differ substantially by geographic region and by the scale of the program⁵, compares favorably to the price-based approaches of traditional energy efficiency programs. A principal general-interest result of this analysis is the demonstration that a low-cost, non-price intervention - simply sending a letter - can significantly affect consumer behavior. This adds to the growing empirical literature on the power of behavioral interventions, or "nudges," in a variety of domains, including Bertrand, *et al*, (2010), Benartzi and Thaler (2004), Ashraf, Karlan, and Yin (2006), and others.

The experiment was designed to test the efficacy of the overall treatment, not to provide evidence on the mechanisms underlying the effects. The existing data do provide suggestive evidence, however, of several behavioral issues at play. Program households were randomly assigned to groups that would receive Reports every month versus every quarter. Interestingly, the Quarterly group treatment effects decay in the months between receiving Reports, then increase again with the receipt of the next Report, then decay again. The decay is economically significant, as it constitutes almost half of the treatment effect. Survey evidence indicates that an important result of the Reports is to increase day-to-day energy conservation behaviors, such as turning off lights and unplugging appliances, that households *already knew* could save energy. This suggests that the decay in the Quarterly group is the result of a cycle in which receiving a letter reminds or motivates the

⁴OPOWER's Home Energy Reports are but one example of a wide variety of energy efficiency programs that utilities operate to satisfy regulatory requirements, including information campaigns, energy audits and weatherization, and rebates for purchasing energy efficient durable goods such as lightbulbs, air conditioners, and water heaters. The causal effects of these programs are typically estimated using the "deemed savings approach": multiply the number of participants by ex-ante "engineering estimates" of the energy savings per participant relative to some counterfactual. While those in industry have long questioned the accuracy and precision of deemed savings and other approaches (e.g. Nadel and Keating (1991)) and are aware of the conceptual benefits of randomized controlled trials, there is no consensus on how the effects of energy efficiency programs should be measured.

⁵Allcott and Mullainathan (2009a, 2009b) calculate a cost effectiveness of 2.9 cents/kilowatt-hour for a nationwide OPOWER program using a simple profiling rule.

household to change behaviors, the attention fades over time, and it is re-engaged upon receiving the next quarter's Report.

The attention channel would be consistent with part of the "Focus Theory of Normative Conduct" in psychology, which originally motivated OPOWER's social comparisons (Cialdini, Reno, and Kallgren 1990). One element of this theory applies bounded attention to social norms, arguing that social norms affect behavior only when at top of mind and suggesting that this attention can dissipate over time. This effect would also be similar to the "Two Steps Forward, One Step Back" dynamic in consumer credit, where credit card fees remind consumers to avoid triggering fees in the future, but that reminder effect decays over months (Agarwal, Driscoll, Gabaix, and Laibson 2006). More generally, the suggestion of bounded and malleable attention is consistent with a growing theoretical and empirical literature in economics, including Chetty, Looney, and Kroft (2009), Finkelstein (2009), Gabaix and Laibson (2006), and others.

Econometric results also show that households that were high energy consumers before the treatment conserve substantially more than households whose baseline consumption was low. This is consistent with models in which low-consumption households have higher marginal costs of energy conservation or are already better informed. Alternatively, this finding is also consistent with one of the chief concerns in providing information on social norms: while individuals worse than the norm may improve, a "boomerang effect" might cause those better than the norm to regress (Clee and Wicklund 1980, Ringold 2002).

This finding of heterogeneous treatment effects also implies that "profiling," or targeting future treatment toward units with highest Conditional Average Treatment Effects, could raise the Average Treatment Effect on the Treated and thus improve the program's cost effectiveness. The final section of the paper builds on this insight to develop a statistical treatment rule under which a decisionmaker who wishes to treat some share of the population in a future program allocates treatment to maximize the expected treatment effect. The routine draws on a recently-growing literature⁶ on using the results of randomized experiments to develop statistical decision rules for future treatments. Dehejia (2005), for example, shows that a program that would not be implemented based on examining the ATE alone would increase welfare if implemented in subgroups that have higher Conditional Average Treatment Effects. I show that if the OPOWER program were to be administered to half of the eligible population, profiling would improve its cost effectiveness by a factor of two relative to random assignment. This demonstration of the potential usefulness of profiling is an additional general-interest economic result of the present analysis.

This paper proceeds by providing background on OPOWER's pilot experiment in Minnesota. Section 3 details the econometric strategy, and Section 4 presents results. Section 5 details the statistical treatment rule and gains from profiling, and Section 6 concludes.

2 Experiment Overview

2.1 Motivating Literature

Social scientists have long been aware that social norms can affect individual behavior. There is a large experimental literature in psychology that shows that providing people with information on social norms can have powerful influence (Cialdini 2003, Goldstein, Cialdini, and Griskevicius 2008, Gerber and Rogers 2009, Cialdini, Reno, and Kallgren 1990). This could occur for a number

⁶This literature includes Berger, Black, and Smith (2000), Dehejia (2005), Graham, Imbens, and Ridder (2009), Hirano and Porter (2006), Imai and Strauss (2009), and Manski (2004, 2009)

of reasons. We might emulate the norms of high status people to signal high status (Veblen 1899, Pesendorfer 1995). We might conform to customs due to social penalties for noncompliance (Akerlof 1980). We might follow a subgroup norm to signal horizontal type (Levy 1959, Wernerfelt 1990) or because of intrinsic utility from conforming to an identity (Akerlof and Kranton 2000). We might conform to a norm of prosocial behavior to signal benevolent underlying preferences (Bernheim 1994) or to otherwise receive social acclaim (Becker 1974). Finally, we might follow others because their choices are informative when we have imperfect information (Banerjee 1992). The explanations for conformity depend most importantly on whether the action taken is observed or unobserved and whether we are considering consumption of private goods or private provision of public goods.

There are three pathways through which information on neighbors' electricity consumption would most likely affect a household's quantity of electricity demanded. First, the Reports could induce households to conserve if individuals derive utility from being shown to be more frugal than their neighbors. Second, because some externalities, primarily from power plant greenhouse gas emissions, are not internalized in electricity prices, many consumers perceive that energy conservation helps provide a public good (more moderate global climate). A literature on "conditional cooperation," including Alpizar, Carlsson, and Johansson-Stenman (2008), Axelrod (1984), Cialdini (2003), Fischbacher, Gächter, and Fehr (2001), Frey and Meier (2004), and Shang and Croson (2004), has shown that people are more likely to contribute to public goods when informed that others are contributing.

Third, the information in the Home Energy Reports may facilitate social learning, as in Conley and Udry (Forthcoming), Duflo and Saez (2002, 2003), Foster and Rosenzweig (1995), Mobius, Niehaus, and Rosenblat (2005), and other applications. Electricity costs the average household about \$1000 per year, but households may not be very knowledgeable about the amount of electricity they consume or what factors influence consumption. Given this uncertainty, new information on neighbors' consumption might induce the household to re-optimize around the level of household energy services or the efficiency with which energy input is transformed into energy services. For example, a household that learns that comparable households are using much less energy might infer that they themselves have low-cost opportunities to conserve.

All of these channels suggest that revealing the social norm should affect high consumption households more than low consumption households. Importantly, the second and third channels suggest that learning that they consume less than normal would induce low consumption households to conserve *less*. This has been called the "boomerang effect" (Clee and Wicklund 1980, Ringold 2002). In a pilot study of electricity conservation that influenced the design of OPOWER's Home Energy Reports, Schultz, Nolan, Cialdini, Goldstein, and Griskevicius (2007) found that revealing the social norm did indeed cause low consumption households to increase consumption. Their solution was to add "injunctive social norms," which label others' behavior as good or bad, along with the "descriptive social norms," which simply describe others' behavior.

There is also a large body of existing work on how information provision and behavioral interventions can induce households to conserve energy. Giving consumers feedback on their consumption, providing information on energy savings opportunities, comparing their use to their neighbors' use, facilitating public or private goal setting, and structuring commitment devices have caused households to reduce energy consumption by 5-20 percent. Abrahamse, et al, (2005), Darby (2006), Fischer (2008), Shippee (1980), and Stern (1992) provide reviews of this literature. Many of these approaches, however, have been tested only in the lab, or in field experiments with small or unrepresentative groups. Furthermore, even if effective in field experiments, many of these academic

interventions have been too labor-intensive to be used as a large-scale energy efficiency program.

OPOWER intentionally designed its pilot programs to exploit this existing body of knowledge. While the randomization into treatment and control will allow an unbiased estimate of the overall effect of the Reports, because the entire Treatment group received the social comparisons, historical consumption information, and energy efficiency tips, it will not be possible to determine what aspect of the Reports drives that treatment effect. As in Benartzi and Thaler (2004), I can evaluate the overall efficacy of the program motivated by behavioral science, but I cannot test more refined hypotheses about the channels through which the program works. Although popular media outlets have concluded it is the peer comparison feedback in particular that reduces households' electricity usage, the treatment arms of the pilot program itself provide no evidence that this is actually true. What's interesting about the OPOWER pilot experiments is that they take an existing body of scientific knowledge and test whether they are effective at scale, in a natural field experiment in the general population.

2.2 Experimental Design

As of October 2009, OPOWER is operating pilot projects for utilities in California, Minnesota, Washington, Illinois, Colorado, and Virginia. This paper evaluates their program at an electric utility called Connexus Energy, which serves customers in seven counties in central Minnesota near Minneapolis and St. Paul⁷. Minnesota's New Generation Energy Act of 2007 requires that utilities run conservation programs that reduce energy demand by 1.5 percent each year. Although in many states, utilities have little financial incentive to reduce their own sales, such Energy Efficiency Resource Standards have been the primary reason why utilities have contracted with OPOWER.

Connexus Energy has approximately 96,000 households in its service territory. The households eligible for the Connexus Energy pilot experiments were those with a full one year of electricity bill history as of January 2009, as historical consumption data were required to construct the social comparisons. From the 78,492 eligible households, approximately half (39,217) were randomized into a Treatment group, which would receive Home Energy Reports, and the rest were randomized into a Control group, which would not. Some utility staff were automatically enrolled in the reports and are therefore excluded from the analysis. The experiments are still ongoing.

The Reports are several-page letters with two key components. The first, which is illustrated in Figure 9.1 and appears at the top of the letter's first page, is the Social Comparison Module. This compares the household's electricity consumption over the past twelve months to the mean of its comparison group and the 20th percentile. In an attempt to address the potential boomerang effect, the "Efficiency Standing" on the right side of the Social Comparison Module adds injunctive messages: it labels low- and moderate-consumption households as "Great" and "Good" and adds "smiley face" emoticons.

The Report's second key component is the Action Steps Module. As illustrated in Figure 9.2, this suggests both changes to the household's stock of energy-using durable goods and to the use of that capital stock. These suggestions are targeted to different households based on historical energy use patterns and demographic characteristics. For example, households whose energy use was relatively high the previous summer were more likely to receive suggestions to purchase new energy efficient air conditioners.

⁷Positive Energy carries out internal statistical evaluations, and independent evaluations of their pilot programs in Puget Sound and Sacramento are carried out by Ayres, Raseman, and Shih (2009) and Violette, Provencher, and Klos (2009).

The mechanics of the billing and report mailing process are as follows. The utility sends a worker to read each household's electricity meter approximately once per month, records the consumption over the period, and sends the consumer its monthly bill. Meanwhile, the meter readings are sent electronically to OPOWER, where each household's social comparison is computed. The Home Energy Report is printed by an outside contractor, sent via U.S. Mail, and at some point is opened at the household. The time between meter reading and the arrival of the Report is typically about three weeks. For almost all households, the first round of Reports were constructed after each household's meter reading in January 2009, although a small handful of households were randomized into Treatment and Control groups over the next few months. Sixty percent of Treatment group households were randomly assigned to receive the letters after every monthly meter reading, while 40 percent received them only once a quarter⁸.

2.3 Data and Baseline Characteristics

I observe the 1,540,403 electricity bills for all Treatment and Control households between January 2008 and August 2009, including the date of meter reading and consumption between that reading and the previous. I also observe OPOWER's social comparison information for every household, including whether they were rated as "Below Average," "Good," or "Great," and how far they were from the cutoffs to be in each of the other categories. I observe both the social comparisons that the Treatment group did receive and what the Control group would have received. For each billing period, I also observe the number of Heating Degree-Days or Cooling Degree-Days, which are correlated with the amount of electricity that should be required to keep a house at a comfortable temperature⁹.

Table 8.1 displays the baseline observable characteristics for the Treatment and Control group. Baseline Usage, which is the average across all meter reads in 2008, is 27.7 kilowatt-hours per day for both the Treatment and Control groups. For households ever in the "Great," "Good," or "Below Average" groups, average Baseline Usage is 16.5, 25.0, and 40.7 kilowatt-hours per day, respectively. Although the household sizes are similar by construction, the "Great" group is poorer, has fewer household members, and has houses that are worth less.

For context, consider that a medium-sized (75 watt) lightbulb used four hours each day consumes 0.3 kilowatt-hours. A typical window air conditioner running at its highest setting for five hours uses 5 kilowatt-hours. As illustrated in Figure 9.3, heating and cooling are the primary uses of household electricity in the United States: over half of annual electricity consumption is for refrigerators, air conditioners, and space and water heating. In the most recent available data,

⁸Two other variations in the treatment should be noted. After the second Report, the normative messaging was made more "Gentle" for a randomly selected half of the Treatment group. In the "Gentle" condition, the "Below Average" efficiency group no longer saw that there were "Great" and "Good" categories; they instead simply see the message that "You used more than average - Turn the report over to find ways to save." Positive Energy also experimented with sending different envelope types. Because the different envelope types and "Gentle" treatment do not have sharp economic interpretation, and because the estimated effects of these treatments are not substantially different, the treatment effects presented in this paper combine the different envelopes and the Gentle and non-Gentle treatments into one Average Treatment Effect.

⁹More precisely, Heating Degree-Days is the sum, over all of the days in the billing period, of the maximum of zero and the difference between the day's average temperature and 65 degrees. A day with average temperature 95 has 30 HDDs, while a day with average temperature 60 has zero HDDs. Cooling Degree-Days is the sum, over all the days in the billing period, of the maximum of zero and the difference between 65 degrees and the day's average temperature. A day with average temperature 95 has zero CDDs, while a day with average temperature 60 has five CDDs.

computers, televisions, and lighting combined account for only 15 percent of electricity use (US Energy Information Administration 2001).

Connexus has provided demographic data for each account number in the dataset¹⁰, including characteristics of the house (Age, an indicator for Gas Heat, Value, an indicator for Rental, Single Family, and Square Footage) and of the occupants (Age of household head, Household Size, and Income). On Baseline Usage, as well as on all other observable characteristics, the Treatment and Control groups are strikingly well-balanced. One of the ten baseline characteristics, the age of the head of household, is statistically different with 90% confidence; the Treatment and Control averages differ by less than 0.2 years. As would be expected in a randomized experiment, an F test fails to reject that the two groups are identical on observables.

2.4 Attrition

The pilot program experienced two forms of attrition, account closure and opting out. Consumers close accounts when they move to a different house; 1.25 and 1.24 percent of Treatment and Control households, respectively, close accounts during the first six months of 2009. Households that close accounts tend to be younger, use less electricity, and have lower incomes, but are statistically indistinguishable on other observed characteristics. There is no statistical difference between the Treatment and Control groups in either the rate of account closure or the correlations between account closure and observable characteristics. The accounts that closed after Treatment began are included in the base specifications during the period when their consumption is observed, although excluding them has no discernible influence on the results.

The second form of attrition is by households that asked to opt out of receiving the Home Energy Reports. In the first six months of 2009, 247 households (0.6 percent of the Treatment group) opted out, likely because they perceived the reports as undesired junk mail. These consumers are statistically different: they are slightly older, have lower incomes, use less electricity, and are less likely to live in single family homes. Although they opted out of receiving Reports, their electricity bills are still observed.

3 Empirical Strategy

3.1 Average Treatment Effects

This section details the straightforward approach to estimate the Population Average Treatment Effect of the Home Energy Reports in the population of eligible households. Simply put, the preferred specification will estimate energy consumption as a function of whether the household is assigned to treatment, conditional on other controls, after removing household fixed effects.

To arrive at that specification, I begin with the standard Rubin Causal Model (Rubin 1974, Imbens and Wooldridge 2009). Each household i has two *potential outcomes* for the energy consumption outcome for the meter read t : one if it were assigned to the Treatment group ($T_i = 1$) and one if it were assigned to the Control ($T_i = 0$). Of course, only one of those outcomes can actually be observed:

¹⁰ Any missing observations were imputed using conditional mean imputation.

$$Y_{it} = Y_{it}(T_i) = Y_{it}(0)(1 - T_i) + Y_{it}(1)(T_i) = \begin{cases} Y_{it}(0) & \text{if } T_i = 0 \\ Y_{it}(1) & \text{if } T_i = 1 \end{cases} \quad (1)$$

The quantity of interest is the Average Treatment Effect, $\tau = E[Y_{it}(1) - Y_{it}(0)]$. The "treatment" here is defined as "being mailed the Home Energy Reports or actively opting out." As discussed above, some Treatment households opted out, so the treatment is not simply "being mailed the Home Energy Reports." An alternative potential estimand would be the Intent-to-Treat (ITT) Effect of being sent the Report, for the population that did not opt out; this is simply my ATE divided by the fraction of the population that did not opt out. Since that fraction is very close to 1, the ATE and ITT Effect differ only by a negligible amount. The treatment is also not "opening Home Energy Reports." It is difficult to measure letter open rates, and thus it would be difficult to estimate that second form of ITT Effect.

I define the treatment effect in this way because it is a useful estimand from a policy perspective. OPOWER, and the utilities that contract with them and policymakers that regulate them, want to know the aggregate electricity conservation possible from applying the program to a population. For the population from which the experimental households were drawn, this quantity of interest can be derived simply by multiplying the ATE by the population size¹¹.

Each household has a different meter reading schedule. Let $t \in \{t_{\min}, \dots, t_{\max}\} = \{-12, -11, \dots, 0, 1, 2, \dots\}$ index bill numbers beginning one year before the treatment began; for each household, each bill number is associated with a particular day, month, and year. Most of the first set of Reports were sent in mid-January, immediately after a meter read at time t_{i0} . As I will show, little substantive or statistical effect is observed until the second meter reading after the January round. All meter reads t more than 40 days after t_{i0} , which for nearly all households is simply the second subsequent monthly meter read, are therefore considered "post-treatment."

The variable P_{it} is a post-treatment indicator variable for household i 's meter reading at date t . Denote by Y_{it} the average daily electricity consumption for period ending at t . So that this can later be interpreted as a percentage change, the variable is normalized by control group consumption in the post-period. The variable Q_i denotes whether household i was assigned to the Quarterly group, in either Treatment or Control state. Random assignment to Treatment and Control implies that unobservable factors ε_{it} that influence electricity consumption are uncorrelated with T and Q . This allows an unbiased estimate of the ATE for both the Monthly and Quarterly Groups with the following equation:

$$Y_{it} = (\tau + \tau_Q Q_i) \cdot T_i P_{it} + \beta \cdot P_{it} + \mu_{my} + v_i + \varepsilon_{it} \quad (2)$$

This specification includes month-by-year dummy variables μ_{my} and household fixed effects v_i ; alternative arrangements of fixed effects and controls will also be presented. This is estimated in OLS using the standard fixed effects estimator, using Huber-White ("robust") standard errors, clustered by household. As discussed by Bertrand, Duflo, and Mullainathan (2004), these standard errors are consistent in the presence of any correlation pattern in the errors ε_{it} within household over time.

¹¹To determine cost-effectiveness, the cost estimates must be adjusted to account for the fact that some households will opt out.

3.2 Decay of Effects in Quarterly Group

After estimating the Average Treatment Effects, I move to an empirical test of whether these effects decay in the Quarterly group over the three bills observed in each quarter. Intuitively, we would like to test whether the Quarterly group conserves more on the first and second bills after receiving a Report (the second and third bills after the one on which the report was based) compared to on the third bill of the quarter. This must control for bill-to-bill (i.e. month-to-month) variation in the average treatment effect in the Monthly group, which could be driven by seasonal weather changes. I estimate the following equation:

$$Y_{it} = Q_i T_i P_{it} \cdot (\tau_{Q12} B_{12it} + \tau_Q) + \sum_{b=t_{\min}}^{t_{\max}} 1(t=b) \cdot \{\beta_{1b} T_i + \beta_{2b}\} + v_i + \varepsilon_{it} \quad (3)$$

The variable B_{12it} is an indicator for whether bill t is the first or second bill after receiving a Report. The first term compares the treatment effects τ_{Q12} in the Quarterly group when $B_{12it} = 1$ to the baseline quarterly treatment effect τ_Q . If the treatment effects decay, τ_{Q12} will be more strongly negative (or less positive) than τ_Q . The second term of the equation controls for underlying treatment effects and consumption levels for each bill number, ranging from $t_{\min} = -12$ at the beginning of the data to the most recent bill observation $t_{\max}$.

4 Results

4.1 Treatment Effects

Table 8.2 presents the estimates of the Average Treatment Effect in the eligible population. The top row is the ATE for the Monthly group, while the second row is the difference between that and the Quarterly group ATE. The first specification is the simple unconditional difference-in-differences estimator. The latter four primary specifications include different configurations of fixed effects, month-by-year dummies, and weather controls; specification III is the exact specification detailed in the Empirical Strategy section. The point estimates of ATEs center around negative 1.9-2.0 percent and 1.5 percent for the Monthly and Quarterly treatments, respectively, and are not statistically different between the five specifications.

Table 8.3 displays two "alternative approaches" to evaluating these pilot programs. The first two columns reflect the approach that would need to be taken if the program did not have a randomized experimental control group. These specifications use only the Treatment group data and implement a difference estimator to estimate the treatment effect. The first column is a simple before-after comparison, without accounting for weather or season, and the results are not encouraging: $\hat{\tau}$ differs from the experimental estimate by almost an order of magnitude. After including fourth-order polynomials in Heating and Cooling Degree-Days and 12 month-of-year dummies in the second column, however, the estimated treatment effect is -2.53 percent. This is comparable to but still statistically different from the experimentally-estimated effect with more than 95 percent confidence.

Perhaps the clearest way to emphasize the possible bias from time-varying unobservables is to replicate this regression with the Control group only. In this placebo regression, we expect to see

no effects of the treatment. The third column of table 8.3 shows that we estimate a statistically-significant treatment effect on the control group of -0.57 percent. These results underscore the importance of randomized experimentation when results must be measured with precision. Related to the discussion of Lalonde (1986) and Dehejia and Wahba (1999), however, the approximate similarity of the experimental and non-experimental results does suggest that observable time and weather covariates are useful in this setting in controlling for effects on the outcome variable that may be correlated with treatment.

The fourth specification in Table 8.3 presents a cautionary tale about using the logarithmic function. It replicates Specification III from Table 8.2, except after logging the dependent variable. In principle, both coefficients are interpreted as percents and should be comparable. In practice, the estimated Monthly and Quarterly ATEs in the log specification are 36 and 23 percent lower, respectively, than in the comparable specification in levels. This difference is both economically significant, in that it would make a noticeable difference in the estimated cost effectiveness, and statistically significant. This difference between the percentage ATEs in logs and levels is relatively constant across (unreported) different specifications, and it is not driven by the 307 observations of the dependent variable that are equal to zero.

Intuitively, this difference is driven by Jensen's Inequality. The treatment effect of interest is the average reduction in kilowatt-hours resulting from the program. The percent changes reported in Table 8.2 are that quantity, normalized by Control group consumption in the post-treatment period to generate a percent change. The log specification is fundamentally different: it is the average of the percent reductions across households, instead of the percent of baseline that the average reduction represents. It turns out that the percentage treatment effect is larger (in absolute value) for households with higher consumption, and substantially higher for the most consumptive households. Taking the log of the household's consumption, and then taking the average across households, understates the ATE (in absolute value) relative to taking the average change in level across households and then normalizing into a percent.

4.2 Decay of Effects in Quarterly Group

Figure 9.4 illustrates the estimated Average Treatment Effect on meter reads over time, separately for the households receiving quarterly and monthly reports. The omitted meter read, number 0, is the meter reading t_{i0} upon which the first reports were based, which was in January or the first few days of February. For the 12 reads before that, the treatment and control group consumption levels are substantively and statistically identical. This is still the case on the first meter read after t_{i0} . By the second meter read, however, there is a noticeable Average Treatment Effect. That affect grew between February and August, perhaps both because the response to the Reports may grow in the early phases of the program and because the effects may be stronger in the summer months.

Although the standard errors are wide, the figure suggests that the Quarterly group's ATE is higher in month 2, the first meter read where we would expect to see effects from a Report generated from the month 0 meter read, and then decays in months 3 and 4. A second quarterly report was generated from meter read number 3, and the Quarterly group's treatment effect again increases (in absolute value) in months 5 and 6. The point estimate then decreases again in absolute value in month 7.

Table 8.4 presents the formal econometric test, described in the Empirical Strategy section, of whether the effects are stronger for the first two meter reads after receiving a Report (2, 3, 5, and 6) relative to the third (meter reads 4 and 7). Specification I includes separate dummies for the

first (and second) bill after receiving the report, which on the graph are reads 2 and 5 (and 3 and 6). Specification II is identical to Specification I except that it combines the dummy variables for the first and second bills.

In this latter specification, the effect of a Quarterly Report relative to the Monthly Report for the first or second bill after the report arrives is -0.15%. The baseline Quarterly variable, which captures the relative effect in the third bill of the quarter, is 0.56%. This is a difference of 0.71%, which is economically substantial: it is nearly half of the Quarterly group's treatment effect. The results for Specification I similarly show that the ATEs for the first and second bills after receiving a Report are stronger than the effect in the third bill of the quarter; they are different with better than 95 percent confidence in a two-sided test.

Three factors could explain this result. First, the information contained in the Reports - or gathered in response to the Reports - has value that varies by season. OPOWER targets a set of between 100 and 200 tips to households, and while some have effects that would vary negligibly by season ("Buy an energy efficient refrigerator"), others are capital stock or usage changes that are fundamentally seasonal ("Replace your heater" or "Cover your pool"). Second, perceiving oneself as a "frugal" consumer of energy could enter consumers' utility functions directly, and one could model that the marginal utility of conservation could depend on how recently a Report arrived. Third, the Reports could remind households of opportunities that they already knew about to conserve energy, and that reminder effect could decay over time due to bounded attention.

OPOWER has collected surveys of the treatment group in one of their pilot programs that provide some further evidence on this issue. Treatment group households were asked to self report what they had changed as a result of receiving the Home Energy Reports. Some of the reported effects were indeed seasonal changes to household capital stock, including weather-stripping windows, improving insulation, or servicing the air conditioner. Many of the most frequently reported changes, however, were day-to-day usage behaviors: turning off lights, unplugging electronics, adjusting thermostats, and closing window blinds. Importantly, these behaviors are activities that most consumers likely *already knew* could save them energy¹².

With these data, it is not possible to definitively parse out the information and attention explanations. If day-to-day behavior changes constitute a substantial portion of the treatment effects, however, it is more likely that the decays in the Quarterly group ATEs are part of a cycle in which the Reports remind or motivate households to conserve, and this attention decays over time.

4.3 Effects as a Function of Baseline Usage

Figure 9.5 illustrates the treatment effects by deciles of the distribution of baseline usage, again normalized by Control group average consumption in the post-treatment period. These effects range from almost zero for the bottom two deciles of baseline usage to 6.4 percent in the top ten percent. In general, the more electricity a household used before the treatment, the more that it conserved post-treatment. This could be because the most consumptive households had low-cost energy conservation opportunities, and the tips contained in the Reports made them aware of this. This result is also consistent with the "boomerang effect" model, under which previously

¹²OPOWER is gathering further evidence on both information and behaviors using an improved survey of both treatment and control groups, and these results can be formally presented in the next revision of this paper to strengthen this argument.

low-consumption households might not conserve - or might even consume more - after receiving information that they are less consumptive than their peers.

Some readers may have noticed that the design of the normative categorizations could allow the use of a Regression Discontinuity design to estimate their causal relative effects. Those households just below the cutoff between being categorized "Good" and "Great" are in the limit identical to those households just above, but they received different normative categorizations. This provides a natural experiment that could allow the estimation of the relative effects, for households near the cutoff, of being in the three different categorizations. In practice, the Regression Discontinuity estimator does not offer enough power to either estimate a statistically significant effect of the categorizations or to compute a "tightly-estimated zero" by rejecting reasonably small hypothesized effects. See Appendix 7.1 for more details.

5 Profiling and Cost Effectiveness

Regardless of the mechanism that drives the variation in treatment effects across households with different baseline usage, the heterogeneity in treatment effects as a function of an observable characteristic suggests that there could be substantial gains from targeting the program towards the most responsive households. Furthermore, because we observe a larger set of household characteristics that might be correlated with the treatment effect, a more comprehensive approach to "profiling" could be useful. My approach builds on the literature detailing the use of existing information on heterogeneous treatment effects to allocate future treatments. This literature dates to Wald's (1950) work on statistical decision theory and has grown recently with work by Berger, Black, and Smith (2000), Dehejia (2005), Graham, Imbens, and Ridder (2009), Hirano and Porter (2006), Imai and Strauss (2009), and Manski (2004, 2009).

Compared to much of the recent literature, the present problem is straightforward, as the objective function will be unambiguous and the decisionmaker can be modeled as risk-neutral. I focus on perhaps the simplest case of profiling: the OPOWER program is to be allocated to a given proportion of the population, and we want to target the program such as obtain the largest expected treatment effect¹³ conditional on the information from a previous randomized trial. The decision variable is which subset of its customer population, defined by observable characteristics, will be assigned to treatment.

The constraint of targeting less than the entire population could arise because the electric utility has limited resources to treat its entire customer base. It could also arise if the Energy Efficiency

¹³While we would in principle want to maximize welfare, the utility in practice minimizes cost from its own perspective, with no consideration for the change in consumer welfare. Given that costs are constant across individuals, minimizing the cost of achieving a given reduction is equivalent to maximizing the expected treatment effect of treating a given number of people. In designing this system, regulators presumably hope that the solutions to the cost minimization and welfare maximization problems are similar. One example of why this distinction can be important is the case of rebates for energy efficient appliances. If these rebates are entirely inframarginal (an example of what energy industry analysts call the "free rider problem," not to be confused with the traditional free rider problem in the provision of public goods), their cost effectiveness would be infinite. Given that inframarginal rebates are simply transfers, the efficiency losses in the simplest model would be zero.

In practice, and in this analysis in particular, this simplification must be made because while it is easy to observe electricity consumption, it would be quite costly to observe the actions that households take in response to the Reports. It is possible, for example, that the Reports induce some households to buy more energy efficient lightbulbs or appliances. Since the change in treatment group demand for these other goods is unobserved, we cannot compute welfare. This concern is quite general in evaluating energy efficiency programs; one resulting benefit here is that focusing on cost effectiveness keeps this analysis consistent with a previous body of work.

Resource Standard, the state regulation requiring a given amount of energy conservation relative to baseline, could be satisfied by treating only a portion of the population with the Home Energy Reports. As discussed earlier, state-level Energy Efficiency Resource Standards are the primary reason why utilities contract with OPOWER to reduce the demand for their product.

The decisionmaker seeks a statistical treatment rule $\delta : \mathcal{X} \rightarrow \{0, 1\}$ that maps individuals with characteristics X to the treated or control states for a future OPOWER program. Denote by Δ the space of possible treatment rules. The scalar $\delta_i = \delta(X_i) \in \{0, 1\}$ is the choice of treatment for individual i with characteristics X_i . The decisionmaker has information Θ from the existing randomized experiment in a representative sample of larger population $\mathcal{P}$. Recall that, as defined earlier in the paper, the heterogeneous Conditional Average Treatment Effect $\tau(X_i)$ is typically less than zero, meaning that we wish to assign treatment to units with expected treatment effects that are more negative.

The utility's objective is to maximize the expected (negative) treatment effect conditional on the information from the past experiment, given that they are to treat H households from the population:

$$\max_{\delta \in \Delta} E \left[\sum_{i \in \mathcal{P}} -\tau(X_i) \cdot \delta_i | \Theta \right] \quad s.t. \quad \sum_{i \in \mathcal{P}} \delta_i = H \quad (4)$$

Imagine ordering the households in the population by expected treatment effect conditional on their X_i . Denote by R^* the H th-strongest expected treatment effect. Given the assumption of no spillovers between treatment units, the optimal statistical decision rule collapses to assigning OPOWER treatment to the H households with expected treatment effects more negative than R^* :

$$\delta_i^* = 1(E[-\tau(X_i)|\Theta] \geq -R^*) = 1(\widehat{-\tau(X_i)} \geq -R^*) \quad (5)$$

While recent related applications such as Dehejia (2005) and Imai and Strauss (2009) have used Bayesian estimators to construct a distribution of possible outcomes, I use the frequentist approach more familiar to program evaluation in economics. As suggested in the first line of the above equation, I use the heterogeneous Conditional Average Treatment Effects estimated in OLS, $\widehat{\tau_i(X_i)}$ to construct $E[\tau(X_i)|\Theta]$. A remaining challenge is to determine which conditioning variables will be used to estimate the heterogeneous treatment effects and to assign future treatment. Including a large set of conditioning variables could allow treatment to be targeted at smaller subgroups that might have particularly large treatment effects. In a finite sample, however, including a larger set of covariates increases the likelihood of overfitting, which could cause the program to be targeted at groups that idiosyncratically appeared to have large treatment effects only in the experimental data.

Appendix 7.2 details a procedure, based on the work of Imai and Strauss (2009), to determine the optimal set of conditioning variables Z^* . I first define the set of possible conditioning variables Z , which are the observed demographics X plus all interactions and squares of the continuous demographic variables. I then place these potential conditioning variables in order of "prescriptiveness," which refers to the amount by which conditioning on each individual increases the expected

ATE of a future program. Third, I use cross-validation to generate out-of-sample predictions of the expected ATE while adding progressively less-prescriptive variables to the set of conditioning variables. Fourth, I select the set of conditioning variables that has the largest expected ATE.

This procedure indicates that the optimal set of conditioning variables in this application Z^* actually has only one element: the household's pre-program baseline electricity usage. Conditioning on additional variables causes the model to overfit, reducing the future expected ATE.

5.1 Profiling and Cost Effectiveness: Results

Table 8.5 presents the results of heterogeneous treatment effects regressions for the entire sample, as in Step 2a. The covariates are normalized to mean zero, standard deviation 1, meaning that a one standard deviation increase in Baseline Usage is associated with an increase in the ATE (in absolute value) of 1.73 to 2.12 percentage points. The first specification interacts the treatment indicator with the optimal Z^* , the baseline consumption variable.

The second and third regressions represent two alternative "rules of thumb" or selecting prescriptive variables. The second column interacts the treatment indicator variable with all ten available demographic characteristics. Conditional on the other interactions, houses with gas heat have higher treatment effects in absolute value, while houses with larger square footage have lower treatment effects. No other observable characteristics are statistically significantly associated with the strength of the treatment effect. The third column interacts the treatment indicator only with the three characteristics on which the treatment effect varies with 95 percent confidence in the first specification. The final column is simply the homogeneous treatment effect estimation, where the treatment effect represents the combination of Monthly and Quarterly treatment arms.

Table 8.6 presents the expected ATEs $\tilde{\tau}(\delta_Z(X))$ when treatment is assigned to one half of the population based on three sets of conditioning variables Z : the optimal set Z^* and two "rule of thumb" conditioning procedures. These ATEs, which pool the effects from the Quarterly and Monthly groups and are computed via the cross validation procedure discussed in Appendix 7.2, are compared to assigning to treatment the entire population or a randomly selected sample thereof. The table shows that profiling doubles the ATE for the treated half of the population. This is remarkable: energy efficiency programs, as well as job training programs, health interventions, and any number of other programs, devote continual effort to incrementally improve their efficacy. These results show that profiling can immediately double the expected average impact.

Interestingly, the expected treatment effects on the treated populations are very similar across the three profiling procedures. In this particular application, the "rules of thumb" for determining covariates on which to condition assignment are nearly as useful as the optimal rule.

The table's second row displays the average annual electricity bill savings for the treated group under the four different assignment mechanisms, based on Connexus Energy's average residential electricity price¹⁴. The average household saves \$18 per year on electricity bills as a result of the changes caused by being sent monthly Home Energy Reports.

Using the ATE for the program to date and an estimate of cost per letter sent, I find that the cost effectiveness of the existing Connexus program is 5.25 cents per kilowatt-hour saved. This compares reasonably well to recent point estimates of the average cost of other utility energy efficiency programs, which range from 4.7 to 13.3 cents per kilowatt-hour in a study by Auffhammer,

¹⁴This is available from <http://www.connexusenergy.com/resrates.htm>.

Blumstein, and Fowlie (2008)¹⁵ and from 1.6 to 3.3 cents per kilowatt-hour in a study by Friedrich, *et al.* (2009)¹⁶. As shown in Table 8.6, using profiling to target treatment at the most responsive half of the population would cut the cost per kilowatt-hour in half, to 2.68 cents-kilowatt-hour¹⁷.

The reader should bear in mind that the ATE, and therefore the cost effectiveness, could vary substantially across utilities and geographic areas, by electricity demand, as determined by season and the mildness of the weather, and as a function of the duration the program has been in effect. For a nationwide rollout of the Home Energy Reports, Allcott and Mullainathan (2009a, 2009b) calculate a somewhat better cost effectiveness, given that program costs would be lower at scale. Some utilities also report that the program affects customer satisfaction, an additional effect that this calculation does not consider. Finally, it is important to re-emphasize that we do not observe how the program changes households' choice of energy services such as comfort from heating and cooling, nor do we observe how their expenditures change for energy-using goods. As a result, we can say little about the welfare effects of the intervention.

6 Conclusion

This paper evaluates the effects of the OPOWER Home Energy Reports, which give households feedback on past energy consumption, compare them to their neighbors, and provide energy conservation tips. The program is a remarkable departure from traditional energy efficiency programs in that it is designed with direct insight from behavioral science and is implemented using randomized controlled trials. The perceived success or failure of these pilot programs will directly affect millions of dollars of future investment and will more generally influence how future energy efficiency programs are designed and evaluated.

I find that the Average Treatment Effect in the population of eligible Minnesota households is between 1.9 and 2.0 percent below baseline. In the group receiving quarterly Reports, this effect decays somewhat in the months between Reports, either because the information decays seasonally or because the attentional effects of a Report decay over time. I also show that the intervention's effects are strongest for households that have highest baseline consumption. This is consistent with (but not causal evidence of) a "boomerang effect" in which learning the social norm can fail to motivate households with low baseline consumption or even cause them to increase consumption.

Although the OPOWER experiment was carried out in a specific domain and requires a general-interest reader to digest some institutional detail, this analysis has two important and generalizable economic implications. First, the analysis adds to a recently-growing appreciation of how "profiling," the targeting of social programs with heterogeneous treatment effects toward individuals with high expected effects, can improve a program's welfare implications. If a utility were limited to

¹⁵I write "point estimate" because there are various forms of uncertainty around this comparison, including not just the statistical uncertainty in the point estimate conditional on the data, but also uncertainties such as regarding the durability of energy savings, the generalizability across different regions, and the quality of the underlying data used to compute the costs of these other programs.

¹⁶The Friedrich, *et al.* (2009) analysis is based on electric utilities' estimates of cost effectiveness, which are typically based on the "deemed savings" measurement approach. Many analysts believe that these estimates could be biased toward zero.

¹⁷Note that this example is not a reasonable basis for an argument to limit the application of the program: given the low cost of Positive Energy's program, even applying the program households where the treatment effect is smaller than the median can be more cost effective than some existing alternative programs. This does, however, show that if the program must be limited to some subset of the population due to budget constraints, there are gains to targeting it towards the most responsive subset.

implementing the OPOWER program for half of its residential population, I estimate that profiling could make the program twice as cost effective.

Second, this analysis adds to recently-growing appreciation of how non-price interventions can affect consumer behavior. Economists in general, and energy efficiency program managers in particular, have historically focused on how prices and subsidies affect demand. The idea that simply sending a letter - a treatment that has no effect on relative prices and may have limited effects on information sets - can cause measurable changes in demand is remarkable. From the utility's perspective, the cost effectiveness of the OPOWER program compares favorably to the traditional large subsidies for energy efficient durable goods. Perhaps the most important conclusion, therefore, is that some combination of information, attention, and social norms can cause substantive changes in consumer behavior at population scale.

References

- [1] Abrahamse, Wokje, Linda Steg, Charles Vlek, and Talib Rothengatter (2005). "A Review of Intervention Studies Aimed at Household Energy Conservation." *Journal of Environmental Psychology*, Vol. 25, No. 3 (September), pages 273-291.
- [2] Agarwal, Sumit, John Driscoll, Xavier Gabaix, and David Laibson (2006). "Two Steps Forward, One Step Back: The Dynamics of Learning and Backsliding." Working Paper, Harvard University (July).
- [3] Aigner, Dennis (1984). "The Welfare Econometrics of Peak-Load Pricing for Electricity." *Journal of Econometrics*, Vol. 26, No. 1-2, pages 1-15.
- [4] Akerlof, George (1980). "A Theory of Social Custom, of which Unemployment May Be One Consequence." *Quarterly Journal of Economics*, Vol. 94, No. 4 (June), pages 749-775.
- [5] Akerlof, George, and Rachel Kranton (2000). "Economics and Identity." *Quarterly Journal of Economics*, Vol. 115, No. 3 (August), pages 715-753.
- [6] Allcott, Hunt (2009). "Rethinking Real Time Electricity Pricing." MIT Center for Energy and Environmental Policy Working Paper 2009-015 (October).
- [7] Allcott, Hunt (2009a). "Attention, Social Norms, and Energy Conservation." Working Paper, Massachusetts Institute of Technology (June).
- [8] Allcott, Hunt, and Sendhil Mullainathan (2009a). "Behavioral Science and Energy Conservation." Working Paper, Massachusetts Institute of Technology (July).
- [9] Allcott, Hunt, and Sendhil Mullainathan (2009b). "Behavioral Science and Energy Policy." Working Paper, Massachusetts Institute of Technology (August).
- [10] Alpizar, Francisco, Fredrik Carlsson, and Olof Johansson-Stenman (2008). "Anonymity, Reciprocity, and Conformity: Evidence from Voluntary Contributions to a National Park in Costa Rica." *Journal of Public Economics*, Vol. 92, pages 1047-1060.
- [11] Andreoni, James, and Ragan Petrie (2004). "Public Goods Experiments Without Confidentiality: A Glimpse Into Fund-Raising." *Journal of Public Economics*, Vol. 88, pages 1605-1623.
- [12] Ashraf, Nava, Dean Karlan, and Wesley Yin (2006). "Tying Odysseus to the Mast: Evidence from a Commitment Savings Product in the Philippines." *Quarterly Journal of Economics*, Vol. 121, No. 2, pages 673-697.
- [13] Aubin, Christophe, Denis Fougere, Emmanuel Husson, and Marc Ivaldi (1995). "Real-Time Pricing of Electricity for Residential Customers: Econometric Analysis of an Experiment." *Journal of Applied Econometrics*, Vol. 10 (December), pages S171-S191.
- [14] Axelrod, Robert (1984). *The Evolution of Cooperation*. New York: Basic Books.
- [15] Banerjee, Abhijit (1992). "A Simple Model of Herd Behavior." *Quarterly Journal of Economics*, Vol. 107, No. 3 (August), pages 797-817.
- [16] Barbose, Galen, Charles Goldman, and Bernie Neenan (2004). "A Survey of Utility Experience with real time pricing." Working Paper, Lawrence Berkeley National Laboratory, December.
- [17] Becker, Gary (1965). "A Theory on the Allocation of Time." *Economic Journal*, Vol. 75, pages 493-517.
- [18] Becker, Gary (1974). "A Theory of Social Interactions." *Journal of Political Economy*, Vol. 82, No. 6 (November), pages 1063-1093.
- [19] Benabou, Roland and Jean Tirole (2003). "Intrinsic and Extrinsic Motivations." *Review of Economic Studies*, Vol. 70, pages 489-520.
- [20] Benartzi, Schlomo, and Richard Thaler (2004). "Save More Tomorrow: Using Behavioral Economics to Increase Employee Saving." *Journal of Political Economy*, Vol. 112, No. 1 (February), pages S164-S187.

- [21] Berger, Mark, Dan Black, and Jeffrey Smith (2000). "Evaluating Profiling as a Means of Allocating Government Services." Working Paper, Syracuse University (September).
- [22] Bernheim, Douglas (1994). "A Theory of Conformity." *Journal of Political Economy*, Vol. 102, No. 5(October), pages 847-877.
- [23] Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan (2004). "How Much Should We Trust Difference-in-Differences Estimates?" *Quarterly Journal of Economics*, Vol. 119, No. 1, pages 249-275.
- [24] Bertrand, Marianne, Dean Karlan, Sendhil Mullainathan, Eldar Shafir, and Jonathan Zinman (2010). "What's Advertising Content Worth? Evidence from a Consumer Credit Marketing Field Experiment." *Quarterly Journal of Economics*, forthcoming.
- [25] Beshears, John, James Choi, David Laibson, Brigitte Madrian, and Katherine Milkman (2009). "The Effect of Providing Peer Information on Retirement Savings Decisions." Working Paper, Harvard University (March).
- [26] Bitler, Marianne, Jonah Gelbach, and Hilary Hoynes (2006). "What Mean Impacts Miss: Distributional Effects of Welfare Reform Experiments." *American Economic Review*, Vol. 96, No. 4 (September), pages 988-1012.
- [27] Blumstein, Carl, Seymour Goldstone, and Loren Lutzenheiser (2000). "A Theory-Based Approach to Market Transformation." *Energy Policy*, Vol. 28, No. 2 (February), pages 137-144.
- [28] Boisvert, Richard N., Peter Cappers, Charles Goldman, Bernie Neenan, and Nicole Hopper (2007). "Customer Response to RTP in Competitive Markets: A Study of Niagara Mohawk's Standard Offer Tariff." *The Energy Journal*, Vol. 28, No. 1 (January), pages 53-74.
- [29] Chetty, Raj, Adam Looney, and Kory Kroft (2009). "Salience and Taxation: Theory and Evidence." *American Economic Review*, Vol. 99, No. 4 (September), pages 1145-1177.
- [30] Cialdini, Robert (2003). "Crafting Normative Messages to Protect the Environment." *Current Directions in Psychological Science*, Vol. 12, pages 105-109.
- [31] Cialdini, Robert, Linda Demaine, Brad Sagarin, Daniel Barrett, Kelton Rhoads, and Patricia Winter (2006). "Managing Social Norms for Persuasive Impact." *Social Influence*, Vol. 1, pages 3-15.
- [32] Cialdini, Robert, Raymond Reno, and Carl Kallgren (1990). "A Focus Theory of Normative Conduct: Recycling the Concept of Norms to Reduce Littering in Public Places." *Journal of Personality and Social Psychology*, Vol. 58, pages 1015-1026.
- [33] Clee, Mona, and Robert Wicklund (1980). "Consumer Behavior and Psychological Reactance." *Journal of Consumer Research*, Vol. 6, pages 389-405.
- [34] Conley, Timothy and Christopher Udry (Forthcoming). "Learning About a New Technology: Pineapple in Ghana." *American Economic Review*.
- [35] Darby, Sarah (2006). "The Effectiveness of Feedback on Energy Consumption." Working Paper, Oxford Environmental Change Institute (April).
- [36] Davis, Lucas (2008). "Durable Goods and Residential Demand for Energy and Water: Evidence from a Field Trial." *RAND Journal of Economics*, Vol. 39, No. 2 (Summer), pages 530-546.
- [37] Dehejia, Rajeev (2005). "Program Evaluation as a Decision Problem." *Journal of Econometrics*, Vol. 125, pages 141-173.
- [38] Dehejia, Rajeev, and Sadek Wahba (1999). "Causal Effects in Nonexperimental Studies: Reevaluating the Evaluation of Training Programs." *Journal of the American Statistical Association*, Vol. 94, No. 448 (December), pages 1053-1062.
- [39] Duflo, Esther, and Emmanuel Saez (2002). "Participation and Investment Decisions in a Retirement Plan: The Influence of Colleagues' Choices." *Journal of Public Economics*, Vol. 85, pages 121-148.

- [40] Dufllo, Esther, and Emmanuel Saez (2003). "The Role of Information and Social Interactions in Retirement Plan Decisions: Evidence from a Randomized Experiment." *Quarterly Journal of Economics*, Vol. 118, No. 3 (August), pages 815-842.
- [41] Fischbacher, Urs, Simon Gächter, and Ernst Fehr (2001). "Are People Conditionally Cooperative? Evidence from a Public Goods Experiment." *Economic Letters*, Vol. 71, pages 397-404.
- [42] Finkelstein, Amy (2009). "E-ZTAX: Tax Salience and Tax Rates." *Quarterly Journal of Economics*, Vol. 124, No. 3 (August), pages 969-1010.
- [43] Foster, Andrew, and Mark Rosenzweig (1995). "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture," *Journal of Political Economy*, Vol. 103, No. 6 (December), pages 1176-1209.
- [44] Frey, Bruno, and Felix Oberholzer-Gee (1997). "The Cost of Price Incentives: An Empirical Analysis of Motivation Crowding-Out." *American Economic Review*, Vol. 87, No. 4 (September), pages 746-755.
- [45] Frey, Bruno, and Stephan Meier (2004). "Social Comparisons and Pro-Social Behavior: Testing 'Conditional Cooperation' in a Field Experiment." *American Economic Review*, Vol. 94, No. 5 (December), pages 1717-1722.
- [46] Friedrich, Katherine, Maggie Eldridge, Dan York, Patti Witte, and Marty Kushler (2009). "Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved through Utility-Sector Energy Efficiency Programs." ACEEE Report No. U092 (September).
- [47] Gabaix, Xavier, David Laibson (2006). "Shrouded Attributes, Consumer Myopia, and Information Suppression in Competitive Markets." *Quarterly Journal of Economics*, Vol. 121, No. 2 (May), pages 505-540.
- [48] Gerber, Alan, and Todd Rogers (2009). "Descriptive Social Norms and Motivation to Vote: Everybody's Voting and So Should You." *Journal of Politics*, Vol. 71, pages 1-14.
- [49] Gillingham, Kenneth, Richard Newell, and Karen Palmer (2006). "Energy Efficiency Policies: A Retrospective Examination." *Annual Review of Environment and Resources*, Vol. 31, pages 161-192.
- [50] Goldstein, Noah, Robert Cialdini, and Vidas Griskevicius (2008). "A Room with a Viewpoint: Using Norm-Based Appeals to Motivate Conservation Behaviors in a Hotel Setting." *Journal of Consumer Research*, Vol. 35, pages 472-482.
- [51] Graham, Bryan, Guido Imbens, and Geert Ridder (2009). "Complementarity and Aggregate Implications of Assortative Matching: A Nonparametric Analysis." NBER Working Paper 14860 (April).
- [52] Grinblatt, Mark, Matti Keloharju, and Seppo Ikäheimo (2008). "Social Influence and Consumption: Evidence From the Automobile Purchases of Neighbors." *Review of Economics and Statistics*, Vol. 90, pages 735-753.
- [53] Gunter, Lacey, Ji Zhu, and Susan Murphy (2007). "Variable Selection for Optimal Decision Making." *Artificial Intelligence in Medicine*, Vol. 4594 (August), pages 149-154.
- [54] Graham, Bryan, Guido Imbens, and Geert Ridder (2009). "Complementarity and Aggregate Implications of Assortative Matching: A Nonparametric Analysis." NBER Working Paper 14860 (April).
- [55] Hirano, Keisuke, and Jack Porter (2006). "Asymptotics for Statistical Treatment Rules." Working Paper, University of Wisconsin (August).
- [56] Houwelingen, Jeannet, and Fred van Raaij (1989). "The Effect of Goal-Setting and Daily Electronic Feedback on In-Home Energy Use." *Journal of Consumer Research*, Vol. 16, No. 1 (June), pages 98-105.
- [57] Hutton, Bruce, Gary Mauser, Pierre Filiatrault, and Olli Ahtola (1986). "Effects of Cost-Related Feedback on Consumer Knowledge and Consumption Behavioral: A Field Experimental Approach." *Journal of Consumer Research*, Vol. 13, No. 3 (December), pages 327-336.

- [58] Imai, Kosuke, and Aaron Strauss (2009). "Planning the Optimal Get-out-the-vote Campaign Using Randomized Field Experiments." Working Paper, Princeton University (May).
- [59] Imbens, Guido, and Jeffrey Wooldridge (2009). "Recent Developments in the Econometrics of Program Evaluation." *Journal of Economic Literature*, Vol. 47, No. 1 (March), pages 5-86.
- [60] Imbens, Guido, and Karthik Kalyanaraman (2009). "Optimal Bandwidth Choice for the Regression Discontinuity Estimator." IZA Discussion paper No. 3995 (February).
- [61] Kaufman, Leslie (2009). "Utilities Turn Their Customers Green, With Envy." *The New York Times*, January 30.
- [62] Lalonde, Robert (1986). "Evaluating the Econometric Evaluations of Training Programs." *American Economic Review*, Vol. 76, No. 4 (September), pages 604-620.
- [63] Lee, David, and Thomas Lemieux (2009). "Regression Discontinuity Designs in Economics." NBER Working Paper 14723 (February).
- [64] Levitt, Steven D. and John A. List (2009). "Field Experiments in Economics: The Past, the Present, and the Future." *European Economic Review*, forthcoming.
- [65] Levy, Sidney (1959), "Symbols for Sale." *Harvard Business Review*, Vol. 37 (July-August), pages 117-124.
- [66] List, John, and Michael Price (2008). "The Role of Social Connections in Charitable Fundraising: Evidence from a Natural Field Experiment." *Journal of Economic Behavior and Organization*, Vol. 69, No. 2 (February), pages 160-169.
- [67] Lutzenhiser, Loren (1993). "Social and Behavioral Aspects of Energy Use." Annual Review of Energy and the Environment, Vol. 18 (November), pages 247-289.
- [68] Manski, Charles (2004). "Statistical Treatment Rules for Heterogeneous Populations." *Econometrica*, Vol. 72, No. 4 (July), pages 1221-1246.
- [69] Manski, Charles (2009). "Diversified Treatment Under Ambiguity." Working Paper, Northwestern University.
- [70] Meer, Jonathan (2009). "Brother Can You Spare a Dime? Peer Effects in Charitable Solicitation." Working Paper, Stanford Institute for Economic Policy Research (March).
- [71] Mobius, Markus, Paul Niehaus, and Tanya Rosenblat (2005). "Social Learning and Consumer Demand." Working Paper, Harvard University (December).
- [72] Munshi, Kaivan, 2004. "Social Learning in a Heterogeneous Population: Technology Diffusion in the Indian Green Revolution." *Journal of Development Economics*, Vol. 73, pages 185-215.
- [73] Munshi, Kaivan, and Jacques Myaux (2006). "Social Norms and the Fertility Transition." *Journal of Development Economics*, Vol. 80, pages 1-38.
- [74] Nadel, Steven, and Kenneth Keating (1991). "Engineering Estimates versus Impact Evaluation Results: How Do They Compare and Why?" in *Energy Program Evaluation: Uses, Methods, and Results*. Proceedings of the 1991 International Energy Program Evaluation Conference.
- [75] Nolan, Jessica, Wesley Schultz, Robert Cialdini, Noah Goldstein, and Vidas Griskevicius (2008). "Normative Influence is Underdetected." *Personality and Social Psychology Bulletin*, Vol. 34, pages 913-923.
- [76] Pesendorfer, Wolfgang (1995). "Design Innovation and Fashion Cycles." *American Economic Review*, Vol. 85, No. 4 (September), pages 771-792.
- [77] Reiss, Peter, and Matthew White (2005). "Household Electricity Demand, Revisited." *Review of Economic Studies*, Vol. 72, No. 3 (July), pages 853-883.
- [78] Reiss, Peter, and Matthew White (2008). "What Changes Energy Consumption? Prices and Public Pressure." *RAND Journal of Economics*, Vol. 39, No. 3 (Autumn), pages 636-663.

- [79] Ringold, Debra Jones (2002). "Boomerang Effects in Response to Public Health Interventions: Some Unintended Consequences in the Alcoholic Beverage Market." *Journal of Consumer Policy*, Vol. 25, No. 1 (March), pages 27-63.
- [80] Rubin, Donald (1974). "Estimating Causal Effects of Treatments in Randomized and Non-Randomized Studies." *Journal of Educational Psychology*, Vol. 66, No. 5, pages 688-701.
- [81] Schultz, Wesley, Jessica Nolan, Robert Cialdini, Noah Goldstein, and Vidas Griskevicius (2007). "The Constructive, Destructive, and Reconstructive Power of Social Norms." *Psychological Science*, Vol. 18, pages 429 –434.
- [82] Shang, Jen, and Rachel Croson (2004). "Field Experiments in Charitable Contribution: The Impact of Social Influence on the Voluntary Provision of Public Goods." Working Paper, University of Pennsylvania.
- [83] Shippee, Glenn (1980). "Energy Consumption and Conservation Psychology: A Review and Conceptual Analysis." *Environmental Management*, Vol. 4, No. 4, pages 297-314.
- [84] Stern, Paul (1992). "What Psychology Knows about Energy Conservation." *American Psychologist*, Vol. 47, No. 10, pages 1224-1232.
- [85] Tsui, Bonnie (2009). "Greening With Envy." *The Atlantic*, Vol. 304, No. 1 (July/August), pages 24-25.
- [86] US Energy Information Administration (2001). "Residential Energy Consumption Survey." <http://www.eia.doe.gov/emeu/recs/recs2001>.
- [87] Veblen, Thorstein (1899). The Theory of the Leisure Class: an economic study of institutions. New York, NY: The Macmillan Company.
- [88] Violette, Daniel, Provencher, Bill, and Mary Klos (2009). "Impact Evaluation of Positive Energy SMUD Pilot Study." Boulder, CO: Summit Blue Consulting (May).
- [89] Wald, Abraham (1950). Statistical Decision Functions. New York, NY: John Wiley & Sons.
- [90] Wernerfelt, Birger (1990). "Advertising Content When Brand Choice Is a Signal." *Journal of Business*, Vol. 63, No. 1, Part 1 (January), pages 91-98.
- [91] Wolak, Frank (2006). "Residential Customer Response to Real-time Pricing: The Anaheim Critical Peak Pricing Experiment." Center for the Study of Energy Markets Working Paper 151 (May).

7 Appendices

7.1 Regression Discontinuity

In this Appendix, which need not be included for publication, I briefly discuss a Regression Discontinuity specification that could in principle be used to estimate the relative effects of the different normative categorizations Social Comparison Module in the Home Energy Reports. These effects should be observed two meter reads after the meter read upon which the categorization was based.

In keeping with the tradition of graphical analysis of RD designs (Lee and Lemieux 2009, Imbens and Wooldridge 2009), Figure 9.8 illustrates the treatment group's consumption as a function of distance from the household-specific comparison group's mean consumption, which is the cutoff between being categorized as "Good" vs. "Below Average." The Usage variable on the y-axis, which as before is normalized by Control group post-treatment consumption, is residual of degree-day polynomials and month-by-year controls, but not of household fixed effects. The line is upward sloping, as households that consume less compared to their peers on a given bill also tend to have lower residual usage on future bills. Figure 9.9 is the analogous illustration near the 20th percentile of the household-specific comparison group, which is the cutoff between being categorized as "Great" vs. "Good."

What's apparent from both graphs is that the two-sided 95 percent confidence interval around any estimated effects at this bandwidth is approximately four percent of Control group post-treatment consumption, which is more than double the overall ATE from the Reports. Any differences in ATEs from being placed in one or the other normative category, however, would likely be much smaller. I attempted the RD estimation including household fixed effects and other controls to reduce residual variance, and also added data from one of OPOWER's other pilot programs. This does not sufficiently reduce the variance around the estimated RD treatment effect to estimate a statistically significant effect of the categorizations or to compute a "tightly-estimated zero" by rejecting reasonably small hypothesized effects.

7.2 Variable Selection

This Appendix details the procedure for selecting a vector of observables and interactions to condition on when estimating $\tau_i(X_i)$ in the profiling procedure. The discussion of this problem and my approach to addressing it draw heavily on previous work by Imai and Strauss (2009) and, somewhat less directly, on Gunter, Zhu, and Murphy (2007).

While there is a large literature on how to select "predictive" variables that are correlated with the outcome, there is no consensus on the choice of "prescriptive variables" that help assign units to treatment. Predictive variables are by definition correlated with the outcome and therefore may be useful for reducing residual variance, i.e. improving the efficiency of the estimator. However, if a predictive variable has the same correlation with the outcome in treatment and control, meaning that it is not correlated with the treatment effect, this variable would not be useful for generating a statistical decision rule.

Most fundamentally, a powerful prescriptive variable is one that increases the efficacy of the targeted program in a future implementation when profiling is conditioned on that variable. Intuitively, one approach to choosing the set of prescriptive variables is to try conditioning on all possible covariates and subsets thereof, generating assignment rules based on each potential set of covariates, then running a future program based on that assignment rule and measuring the effects. Because these theoretical future programs differ only in the rules used to assign treatment, the future program with the highest ATE is the one with the best assignment rule.

The actual approach is designed to mimic that process, while addressing two concerns. First, we of course cannot try many different future implementations. We can, however, mimic that process with the data from the existing program: we can partition the data, use the "first" part to generate the treatment rule and the "second" part to test its efficacy. If we then reverse the partition - use the "second" part to generate the treatment rule and the "first part" to test efficacy, we will have then exploited all of the data available while still cross-validating the assignment mechanism outside of the sample that generated it.

A second problem with the intuitive approach is that it would be very computationally intensive to try all possible sets of covariates. Instead, using a procedure developed by Imai and Strauss (2009), we can rank the individual covariates based on their "prescriptiveness." In this context, "prescriptiveness" means how much conditioning and assigning based on that one covariate increases the expected treatment effect relative to random assignment of treatment.

Imagine ordering the variables from most to least prescriptive. Beginning with the most prescriptive variable, one can progressively add the next-most prescriptive variable to the set of conditioning variables. Conditioning assignment on additional covariates should for some time increase the future treatment effect of the future targeted program, but the overfitting effect will eventually dominate and the future treatment effect will decrease. This procedure of sequentially adding variables in order of prescriptiveness ensures that we have the most prescriptive set of variables at the apparent maximum. This ordering procedure simplifies the problem from one of selecting the optimal *set* of covariates to selecting the optimal *number* of covariates. Because of the ordering, the optimal number will also tell us the optimal set (Imai and Straus 2009).

7.2.1 Specifics of the Variable Selection Algorithm

The goal is to select the optimal set of covariates Z^* , drawn from some set of possible covariates $\mathcal{Z}$, such that a statistical treatment rule conditioning on Z^* maximizes the expected treatment effect in a future implementation of the program. The variables Z are functions of household observable characteristics X . Denote by $\delta_Z(X)$ the treatment rule using variables Z , and denote by $\tilde{\tau}(\delta_Z(X))$ the expected treatment effect of a future program using that rule. Consistent with the maximization problem introduced above, that treatment effect is conditioned on including some set of people such that the minimum treatment effect is above some threshold R^* . For simplicity, in this part of the problem, I assume that $\tilde{\tau}(\delta_Z(X))$ reflects the treatment effect when one-half of the population is to be treated. The maximization problem is:

$$Z^* = \arg \max_{Z \in \mathcal{Z}} E[-\tilde{\tau}(\delta_Z(X)) | \Theta] \quad (6)$$

Following Imai and Strauss (2009), I implement a four-step procedure.

Step 1: Define the possible set of prescriptive variables. In principle, the possible set of prescriptive variables $\mathcal{Z}$ could be all levels of interactions of the 10 observable household characteristics, plus polynomial series of the continuous variables. To speed computation, I use only the variables themselves, interactions of each pair, and squares of the continuous variables. This gives a set $\mathcal{Z}$ of $J = 62$ possible covariates, which are indexed $j = 1, \dots, J$.

Step 2: Order the set of variables by prescriptiveness. In this step, the set of J possible covariates is ordered by "prescriptiveness": the amount by which conditioning on that one variable Z_j increases the expected future treatment effect $\tilde{\tau}(\delta_{Z_j}(X))$.

For each of the J possible covariates Z_j , the procedure is:

Step 2a: Use the entire dataset to estimate the average treatment effect, combining Monthly and Quarterly treatment arms, and the amount by which the ATE changes with a change in Z_j :

$$Y_{it} = (\tau_0 + \tau_1 \cdot Z_j) \cdot T_i P_{it} + \beta \cdot P_{it} + \mu_{my} + v_i + \varepsilon_{it} \quad (7)$$

Step 2b: For both the Treatment and Control groups, fit each individual i 's $\widehat{\tau(X_i)} = \hat{\tau}_0 + \hat{\tau}_1 \cdot Z_{ji}$ from the above regression.

Step 2c: Treatment rule $\delta_{Z_j}(X)$ assigns treatment to the one-half of households with the most negative fitted treatment effects.

Step 2d: Using the half of the original randomized Treatment and Control groups assigned to treatment by this potential rule, estimate the treatment effect $\tilde{\tau}(\delta_{Z_j}(X))$.

After computing these expected average treatment effects for each Z_j , these effects are ordered from the largest negative treatment effect to smallest. This gives a new ordering of the set $\mathcal{Z}$ from most to least prescriptive, such that $-\tilde{\tau}(\delta_{Z_j}(X)) \geq -\tilde{\tau}(\delta_{Z_{j+1}}(X)), \forall j$. The double solid line in Figure 9.6 illustrates this ordering for $j = 1, \dots, 62$. The most prescriptive variable is Baseline Usage, followed by interactions of Baseline usage with the Single Family and Rent indicator variables.

Step 3: Determine the expected ATE for each combination of prescriptive variables.

For each combination of prescriptive variables with effectiveness greater than or equal to that of j , cross validation is now used to predict the expected treatment effect of profiling on that combination in assigning treatment for a future program. First, the sample is randomly divided into $K = 5$ subsets for K-fold cross validation.

For each value of j from 1 to J , which are now ordered from most to least prescriptive, the procedure is:

Step 3a: Define $Z_{1,\dots,j}$ as the set of variables such that $-\tilde{\tau}(\delta_{Z_i}(X)) \geq -\tilde{\tau}(\delta_{Z_j}(X))$. This set contains all the variables, including j , that have at least as prescriptive as j . For each of the K cross-validation sets, estimate the heterogeneous treatment effects equation using the $K - 1$ "training sets" excluding k . In set k , which is out of sample, then determine the treatment rule $\delta_{kZ_{1,\dots,j}}(X)$.

Step 3b: After using cross validation to determine the treatment rule $\delta_{Z_{1,\dots,j}}(X)$ for all Treatment and Control observations in the data, then use the original randomization into Treatment and Control to estimate the ATE for those units that would be assigned to treatment, $\tilde{\tau}(\delta_{Z_{1,\dots,j}}(X))$.

Step 4: Determine the optimal number of variables. The single solid line appearing on the lower portion of Figure 9.6 illustrates the $\tilde{\tau}(\delta_{Z_{1,\dots,j}}(X))$ computed via cross validation when profiling based on an increasing number of covariates Z . The optimal set of covariates Z^* is determined by the point on that line with the largest (negative) treatment effect:

$$j^* = \arg \max_j E[-\tilde{\tau}(\delta_{Z_{1,\dots,j}}(X))|\Theta] \quad (8)$$

In this case, the most negative treatment effect is at the far left of Figure 9.6, meaning that $j^* = 1$. In this application, the optimal statistical treatment rule assigns treatment based only on Baseline Usage.

8 Tables

8.1 Baseline Household Characteristics

	<i>Treatment</i>	<i>Control</i>	<i>T-C</i>	<i>Great</i>	<i>Good</i>	<i>Below Av</i>
<i>Mean:</i> Baseline Usage (kwh/day)	29.74	29.69	0.053	16.52	25.04	40.67
<i>SD (and SE):</i>	(16.44)	(16.17)	(0.117)	(8.05)	(9.68)	(17.89)
Consumer Age	49.98	49.82	0.161	52.57	50.05	48.45
	(12.18)	(12.18)	(0.087)*	(12.99)	(12.34)	(11.38)
1(Gas Heat)	0.92	0.92	-0.0013	0.94	0.93	0.90
	(0.28)	(0.27)	(0.0020)	(0.24)	(0.25)	(0.30)
Household Size	2.61	2.62	-0.010	2.23	2.57	2.84
	(1.22)	(1.23)	(0.009)	(1.07)	(1.18)	(1.28)
House Age	31.57	31.40	0.166	32.07	30.99	31.59
	(28.03)	(27.96)	(0.200)	(28.06)	(27.68)	(28.24)
House Value	393.9	394.7	-0.792	369.6	385.5	414.5
	(139.4)	(139.4)	(0.995)	(121.7)	(132.6)	(150.6)
Income (1000s)	86.18	86.19	-0.010	75.59	84.42	92.85
	(37.86)	(37.60)	(0.269)	(33.52)	(36.48)	(39.52)
1(Rent)	0.022	0.023	0.000	0.019	0.023	0.024
	(0.14)	(0.14)	(0.001)	(0.11)	(0.14)	(0.15)
Single Family	0.96	1	-0.001	0.97	0.96	0.95
	(0.21)	(0)	(0.001)	(0.18)	(0.20)	(0.22)
Square Footage	1660	1659	1.41	1614	1637	1703
	(454)	(449)	(3.22)	(442)	(441)	(464)
<i>F-Test p-Value</i>			0.384			
1(Account Closed)	0.012	0.013		0.023	0.011	0.010
	0.11	0.11		0.15	0.10	0.10
Number of Households	39217	39275		14,055	33,016	30,913
Number of Bill Obs	769299	771083		276,922	650,671	609,982

*, **, ***: Different from zero with 90%, 95%, and 99% confidence, respectively.

"Number of Households" by normative categorization reflects the number of treatment or control households that were at any point in that category. The sum of these numbers across the three categories therefore is greater than the number of households in the experiment.

8.2 Treatment Effects

	I	II	III	IV	V
T x Post	-0.0152 (0.0045)***	-0.0192 (0.0019)***	-0.0191 (0.0019)***	-0.0197 (0.0018)***	-0.0189 (0.0019)***
T x Quarterly x Post	-0.0019 (0.0055)	0.0045 (0.0024)*	0.0045 (0.0024)*	0.0044 (0.0022)**	0.0043 (0.0024)*
Post	-0.0919 (0.0022)***	-0.0841 (0.0011)***	-0.0453 (0.0058)***	-0.0870 (0.0050)***	-0.0058 (0.0058)
Degree-Day Polynomial					Yes
Month x Year Dummies			Yes	Yes	Yes
House Fixed Effects		Yes	Yes		Yes
House x Month Fixed Effects				Yes	
Observations (thousands)	1,540	1,540	1,540	1,540	1,540
R ²	0.0041	0.0041	0.0453	0.0000	0.0485
F Statistic	4159	4284	7053	3391	3018

*, **, ***: Different from zero with 90%, 95%, and 99% confidence, respectively.

Dependent variable is the household's average daily electricity consumption (kilowatt-hours), normalized by average control group consumption in the Post period.

8.3 Alternative Empirical Approaches

	Treatment Only	Treatment Only	Control Only	In Logs
T x Post				-0.0122 (0.0016)***
T x Quarterly x Post				0.0009 (0.0021)
Post	-0.1033 (0.0015)***	-0.0253 (0.0017)***	-0.0057 (0.0016)***	-0.0430 (0.0039)***
Quarterly x Post	0.0045 (0.0024)*	0.0043 (0.0024)*	-0.0045 (0.0023)**	-0.0373 (0.0009)***
Degree-Day Polynomial		Yes	Yes	
Month Dummies		Yes	Yes	
Month x Year Dummies				Yes
House Fixed Effects	Yes	Yes	Yes	Yes
Observations (thousands)	769	769	771	1540
R ²	0.0047	0.0479	0.0484	0.0553
F Statistic	3675	1249	1252	13362

*, **, ***: Different from zero with 90%, 95%, and 99% confidence, respectively.

Dependent variable for the first three specifications is the household's average daily electricity consumption (kilowatt-hours), normalized by average control group consumption in the Post period. For the fourth specification, it is the log of that value.

8.4 Decay of Quarterly Treatment Effects

	I	II
T x Quarterly x Post	0.0056 (0.0034)	0.0056 (0.0034)
T x Quarterly x Post (1st Bill)	-0.0009 (0.0032)	
T x Quarterly x Post (2nd Bill)	-0.0021 (0.0024)	
T x Quarterly x Post (1st or Second Bill)		-0.0015 (0.0025)
Degree-Day Polynomial		
T x Bill Number Dummies	Yes	Yes
Bill Number Dummies	Yes	Yes
House Fixed Effects	Yes	Yes
Observations (thousands)	1,456	1,540
R ²	0.0431	0.0431
F Statistic	3795	3883

*, **, ***: Different from zero with 90%, 95%, and 99% confidence, respectively.

Dependent variable is the household's average daily electricity consumption (kilowatt-hours), normalized by average control group consumption in the Post period.

8.5 Heterogeneous Treatment Effects

	I	II	III	IV
T x Post	-0.0172 (0.0015)***	-0.0168 (0.0014)***	-0.0172 (0.0015)***	-0.0173 (0.0016)***
T x Post x Baseline Usage	-0.0173 (0.0036)***	-0.0212 (0.0039)***	-0.0209 (0.0038)***	
T x Post x Consumer Age		-0.0018 (0.0015)		
T x Post x Gas Heat		-0.0063 (0.0024)***	-0.0061 (0.0024)**	
T x Post x Household Size		0.0020 (0.0017)		
T x Post x House Age		0.0004 (0.0016)		
T x Post x log(House Value)		-0.0012 (0.0015)		
T x Post x log(Income)		-0.0009 (0.0019)		
T x Post x 1(Rent)		-0.0006 (0.0014)		
T x Post x Single Family		-0.0003 (0.0013)		
T x Post x Square Footage		0.0053 (0.0019)***	0.0043 (0.0017)**	
Post	-0.0470 (0.0060)	-0.0438 (0.0060)***	-0.0447 (0.0060)***	-0.0453 (0.0058)***
Month x Year Dummies	Yes	Yes	Yes	Yes
House Fixed Effects	Yes	Yes	Yes	Yes
Post x (X Variable) Controls	Yes	Yes	Yes	-
Observations (thousands)	1,540	1,540	1,540	1,540
R ²	0.0040	0.0041	0.0040	0.0453
F Statistic	8506	4769	7216	7374

*, **, ***: Different from zero with 90%, 95%, and 99% confidence, respectively.

Dependent variable is the household's average daily electricity consumption (kilowatt-hours), normalized by average control group consumption in the Post period.

The ATE represents combination of Monthly and Quarterly groups.

Specification I: Optimal set of conditioning variables Z^* : Baseline Usage only.

Specification II: "Rule of thumb" conditioning variables: All observed demographic variables

Specification III: "Rule of thumb" conditioning variables: Only demographic variables statistically significantly associated with the treatment effect.

Specification IV: No conditioning variables.

8.6 Profiling and Cost Effectiveness

Assignment Mechanism	<i>All</i>	<i>I</i>	<i>II</i>	<i>III</i>
Expected ATE (percent)	-0.0173 (0.0016)	-0.0338 (0.0033)	-0.0322 (0.0032)	-0.0328 (0.0032)
Electricity Bill Savings (dollars/household-year)	18.42 (1.74)	36.05 (3.49)	34.32 (3.44)	34.89 (3.45)
Cost Effectiveness (cents/kwh saved)	5.25 (0.50)	2.68 (0.26)	2.82 (0.28)	2.77 (0.27)
Percent of Households Assigned Same as II	0.497	0.678		
Percent of Households Assigned Same as III	0.497	0.690	0.717	

ATE is in percent of Control group usage in the post-treatment period.

The ATE represents combination of Monthly and Quarterly groups.

Assignment Mechanism "All": Assign to treatment all households, or a randomly-selected subset.

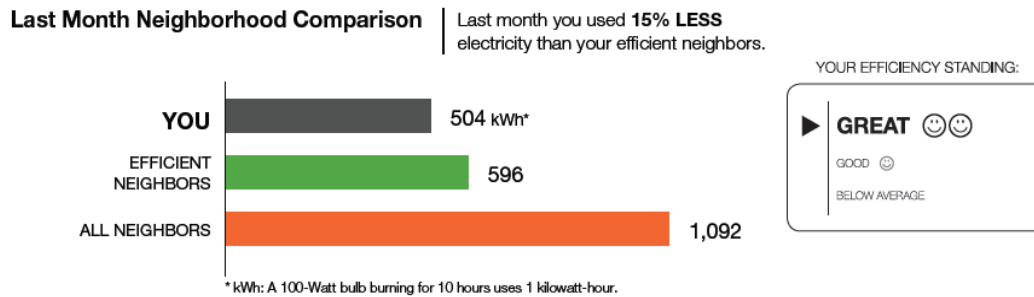
Assignment Mechanism I: Optimal set of conditioning variables Z^* : Baseline Usage only.

Assignment Mechanism II: "Rule of thumb" conditioning variables: All observed demographic variables

Assignment Mechanism III: "Rule of thumb" conditioning variables: Only demographic variables statistically significantly associated with the treatment effect.

9 Figures

9.1 Home Energy Reports: Social Comparison Module



9.2 Home Energy Reports: Action Steps Module

Action Steps | Personalized tips chosen for you based on your energy use and housing profile

Quick Fixes
Things you can do right now

☐ **Adjust the display on your TV**
New televisions are originally configured to look best on the showroom floor—at a setting that's generally unnecessary for your home.

Changing your TV's display settings can reduce its power use by up to 50% without compromising picture quality. Use the "display" or "picture" menus on your TV: adjusting the "contrast" and "brightness" settings have the most impact on energy use.

Dimming the display can also extend the life of your television.

SAVE UP TO \$40 PER TV PER YEAR

Smart Purchases
Save a lot by spending a little

☐ **Install occupancy sensors**
Have trouble remembering to turn the lights off? Occupancy sensors automatically switch them off once you leave a room—saving you worry and money.

Sensors are ideal for rooms people enter and leave frequently (such as a family room) and also areas where a light would not be seen (such as a storage area).

Wall-mounted models replace standard light switches and they are available at most hardware stores.

SAVE UP TO \$30 PER YEAR

Great Investments
Big ideas for big savings

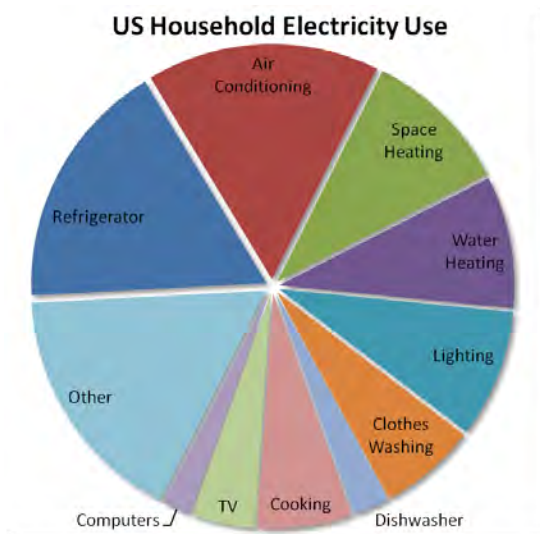
☐ **Save money with a new clothes washer**
Washing your clothes in a machine uses significant energy, especially if you use warm or hot water cycles.

In fact, when using warm or hot cycles, up to 90% of the total energy used for washing clothes goes towards water heating.

Some premium-efficiency clothes washers use about half the water of older models, which means you save money. SMUD offers a rebate on certain washers—visit our website for more details.

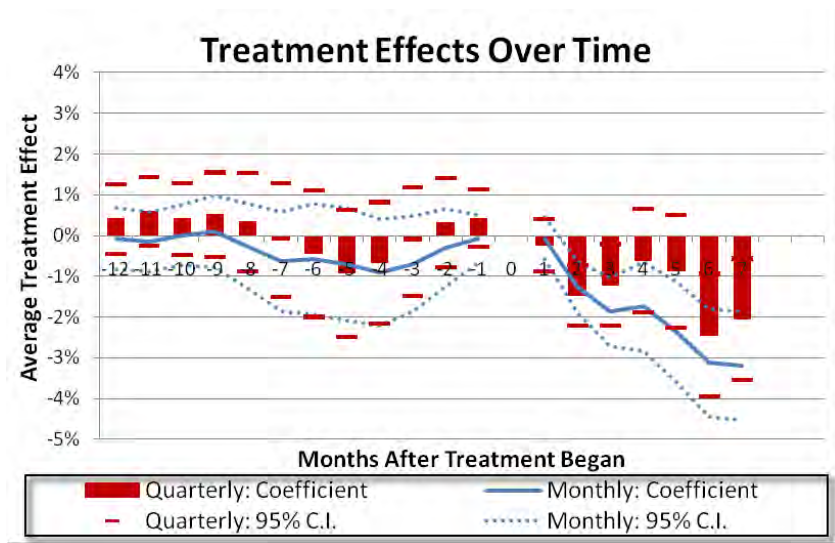
SAVE UP TO \$30 PER YEAR

9.3 US Household Electricity Use

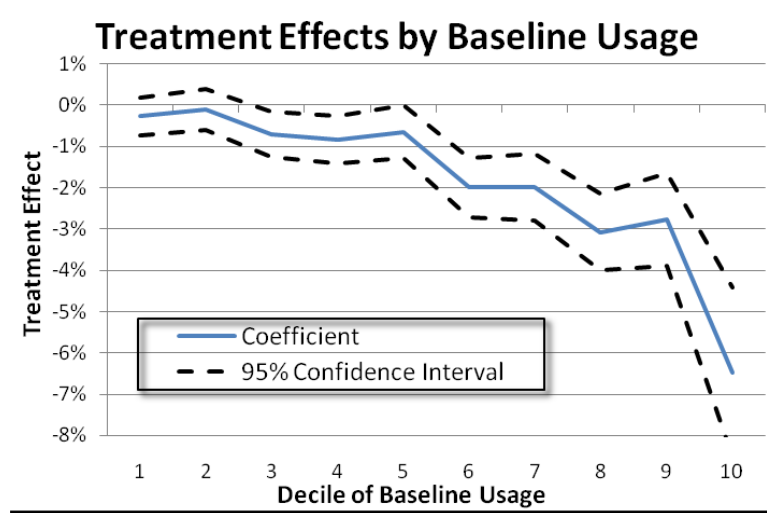


Source: US national average from 2001 Residential Energy Consumption Survey (US Energy Information Administration 2001).

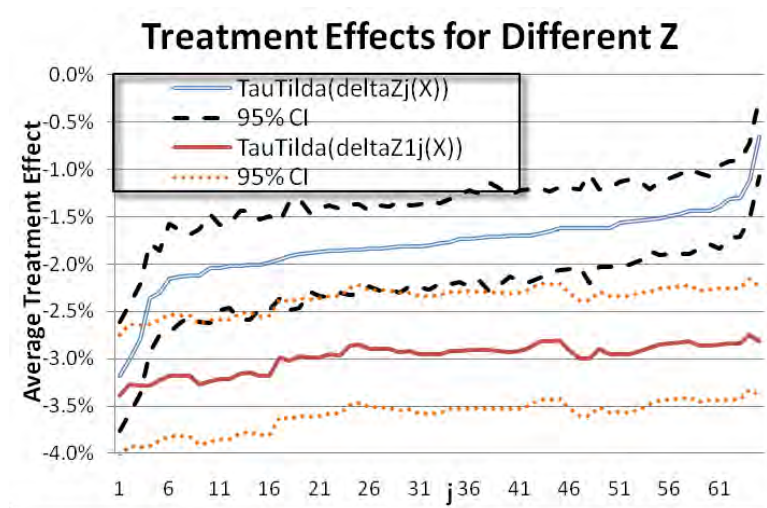
9.4 Treatment Effects Over Time



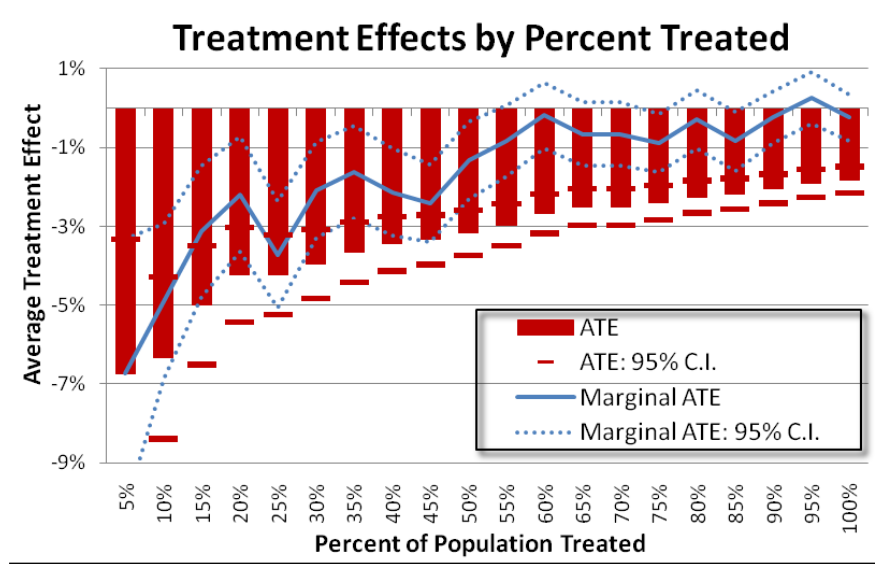
9.5 Treatment Effects by Decile of Baseline Usage



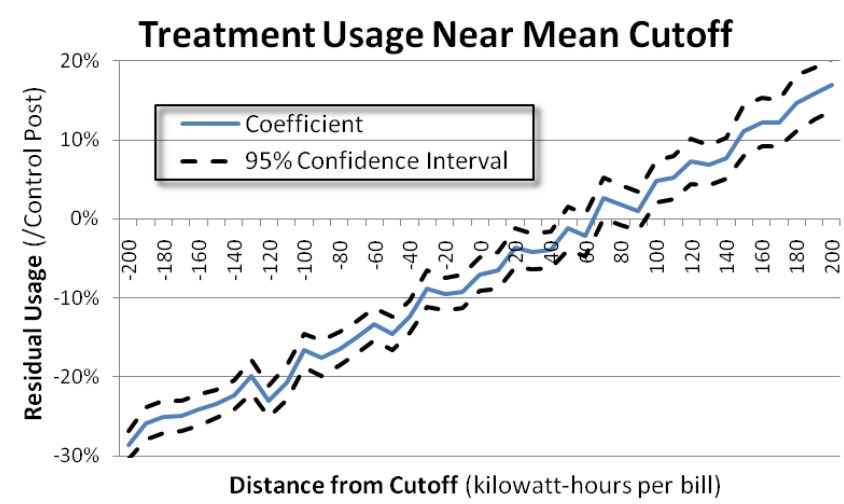
9.6 Profiling: Treatment Effects for Different Z_j



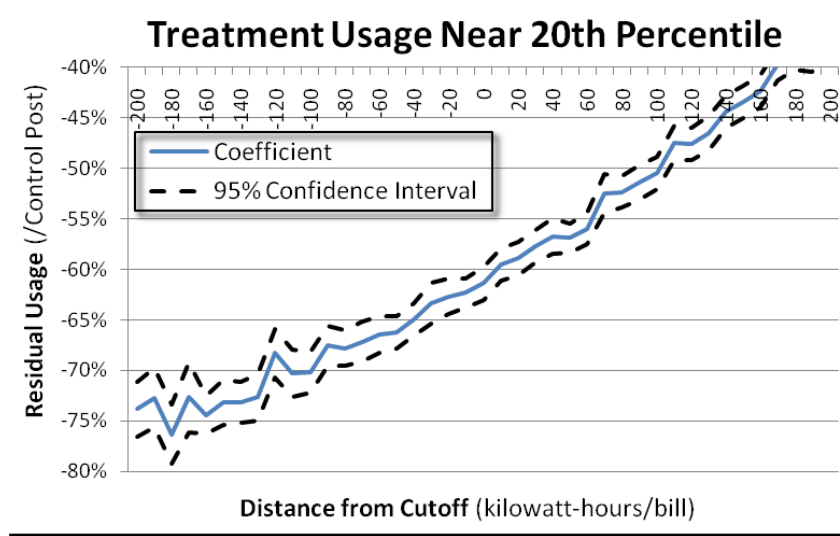
9.7 Gains from Profiling



9.8 Treatment Group Near Mean Comparison Cutoff



9.9 Treatment Group Near 20th Percentile Cutoff



Evaluation of the U.S. Department of Energy's Weatherization Assistance Program: Impact

Results

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Abstract

This paper presents the results of two impact evaluations of the U.S. Department of Energy's Weatherization Assistance Program (WAP). This comprehensive weatherization program provides grants to U.S. states, which then provide grants to local weatherization agencies to weatherize income-eligible low-income homes. The program treats single family and mobile homes, and multifamily buildings in all climate zones. The impact evaluations focused on Program Years (PYs) 2008 and 2010. The latter fell during the American Recovery and Reinvestment Act (ARRA) period. The program supported the weatherization of 98,000 units in PY 2008 and 332,000 units in PY 2010. It is estimated that the program saved 2.3 trillion Btus in PY 2008 and 7.6 trillion Btus in PY 2010. These savings achieve \$420 million in energy cost savings with respect to PY 2008 and \$1.2 billion in savings in PY 2010. Environmental and health and household related benefits add \$267 million and \$1.2 billion and \$694 million and \$3.8 billion of co-benefits to the energy cost savings benefits. The average total benefit per unit weatherized in PY 2008 is \$22,000 versus an average total cost of \$4,700. These results for PY 2010 are \$20,000 and \$6,800, respectively.

Keywords: low-income weatherization, energy savings, emissions reductions, health benefits, cost-effectiveness

1.0 Introduction

This paper presents impact results from two evaluations of the U.S. Department of Energy's Weatherization Assistance Program (WAP). One is known as the retrospective evaluation and focused on WAP Program Year 2008. The other is known as the ARRA Period evaluation and focuses on one Program Year, 2010, that falls within the American Recovery and Reinvestment Act of 2009 (ARRA)

time frame. Reported below are estimated energy savings, non-energy benefits, and cost effectiveness for those two program years.¹

Briefly, WAP was created by Congress in 1976 under Title IV of the Energy Conservation and Production Act. The purpose and scope of the Program as currently stated in the Code of Federal Regulations (CFR) 10 CFR 440.1 is “to increase the energy efficiency of dwellings owned or occupied by low-income persons, reduce their total residential energy expenditures, and improve their health and safety, especially low-income persons who are particularly vulnerable such as the elderly, persons with disabilities, families with children, high residential energy users, and households with high energy burden.” (Code of Federal Regulations, 2011)²

WAP provides grants, guidance, and other support to Grantees: weatherization programs administered by each of the 50 states, the District of Columbia, territories and several Native American tribes. The Grantees, in turn, oversee a network of 900+ local weatherization agencies (Subgrantees): community action agencies, nonprofit organizations, and local government agencies that are eligible to receive weatherization funding from DOE. These weatherization agencies qualify eligible households, assess their homes’ energy efficiency opportunities, install energy-saving measures, and inspect the work. The work performed includes air sealing, insulation upgrades, furnace repair/replacements, and other dwelling-specific measures found to be cost-effective, as well as home improvements needed to ensure the health and safety of household occupants. The work is done at no cost to the eligible participants. WAP weatherizes single-family homes (SF), mobile homes (MH) and multifamily buildings, both small (2-4 units) (SMF) and large (5+ units) (LMF) buildings, regardless of home heating fuel (e.g., natural gas (NG), electricity, fuel oil). WAP procedures are adaptable to all climate zones.³

In February 2009, the U.S. Congress passed and the President signed ARRA (also referred to as the Recovery Act) into law. Included in the hundreds of billions of dollars of programs, initiatives, and investments was \$5 billion for WAP. Annually, this funding represents about six times more per year

¹ Tonn et al. (2014c) and Tonn et al. (2015a) are reports that summarize all aspects of the retrospective and ARRA period evaluations, respectively. All reports from the evaluations can be found at: <http://weatherization.ornl.gov>

² For a comprehensive treatment of the population eligible for WAP, please see Carroll et al. (2014b).

³ To learn more about WAP through a series of case studies, please see Tonn, Rose and Hawkins (2014a).

than Congress had been typically appropriating for WAP. The huge increase in funding was based on the assumption that weatherization was a ‘shovel ready’ program, capable of quickly ramping up production and, most importantly given a major goal of ARRA, employing significant numbers of individuals to weatherize low-income homes. The national weatherization network was given approximately three years to spend these funds.

Preparations for what came to be known as the retrospective evaluation were well underway by the time ARRA was passed. It was decided to also evaluate WAP as administered during the Recovery Act for several reasons. One was to meet the accountability and transparency goals for efforts funded by ARRA. Also, the Recovery Act also included several provisions specifically related to WAP and it was decided that an evaluation could provide insights into the impacts and effects of those provisions on the program. The most important provisions in the Recovery Act pertaining to WAP are these:

- The income eligibility threshold for the program was raised from 150% of the Federal Poverty Level to 200%, though the 60% or less of the state medium income threshold remained the same;
- The average DOE funding that could be spent per weatherized unit was raised from \$2,500 to \$6,500; and
- WAP Grantees and Subgrantees had to adhere to the provisions of the Davis-Bacon Act with respect to prevailing wages and paperwork reporting.

Section 2.0 presents descriptive statistics about the number, types and locations of units weatherized using WAP funds during the program years of interest and presents a summary of DOE and leveraged funds expended (Section 2.1). Also described in this section is how WAP was similar and dissimilar in PYs 2008 and 2010 and how these factors may have influenced program outcomes. Section 3.0 presents the impact results, beginning with a summary of the research design (Section 3.1), then the energy savings impacts (Section 3.2), with summaries of the non-energy impacts (Section 3.3), and cost-effectiveness estimates (Section 3.4). The paper concludes in Section 4.0 with observations about program operation and effectiveness.

2.0 WAP During the Recovery Act

2.1 Production and Funding⁴

During the ARRA period, WAP's funding and production levels were unprecedented. Figure 1 presents the number of units weatherized by quarter the national weatherization network using DOE funds from 2008 through 2014. One can see that the production supported by ARRA funds spiked in the fourth quarter of 2011 at 90,000 units. In entire PY 2008, WAP only supported the weatherization of 98,000 units. The figure also shows that units weatherized with formula funds (i.e., normal Congressional appropriations) declined to fall below pre-ARRA levels. Ramp up and ramp down of employment in low-income weatherization matches these curves.

[Figure 1]

Table 1 documents the number and types of units weatherized in PY's 2008 and 2010. Most of the units weatherized by WAP are owner occupied, single family site built homes. The program has been increasing its efforts to weatherize units in large multi-family buildings and the buildings themselves. Some progress along those lines is seen in PY 2010. Table 2 indicates in which climate zones homes were weatherized in PYs 2008 and 2010 (see Figure 2 for the map of climate zones used in this research). There is a much bigger difference in where homes were weatherized during the Recovery Act than what types of homes were weatherized. This is because according to the WAP authorizing legislation, the funding formula used to distribute WAP funding to the Grantees changes when the annual appropriation exceeds \$275 million to allocate a higher percentage of funding to hot climate states. The hot humid states of the U.S. Southeast were particular beneficiaries of this formula change. Weatherizing more homes in the hot climates also increases the percentage of home heating with electricity and decreased the number heated with fuel from PY 2008 to PY 2010.

Table 4 summarizes funding received by the Grantees and Subgrantees in PY 2010 and PY 2008 for low-income weatherization. The Congressional appropriation for WAP in PY 2008 was \$236 million.

⁴ A more complete characterization of WAP during the Recovery Act can be found in Tonn, Rose and Hawkins (2015c).

This funding was used to leverage another \$486 million in non-DOE funding. Most of the leveraged funding came from states deciding to allocate some of their Low Income Home Energy Assistance Program (LIHEAP) funding to low-income weatherization.⁵ State public benefit funds and utility companies were other important sources of leveraged funding. \$224 million of the leveraged funding was braided with DOE/WAP funding to weatherize homes. Generally, the leveraged funding invested in DOE homes followed DOE/WAP guidelines, but this is not always the case. The remaining leveraged funding was spent in whatever ways dictated by the source of the leveraged funding. The two evaluations reported on herein only included homes that had DOE weatherization funds invested in them.

2.2 Recovery Act Influences on Program Impacts

In many ways, WAP during the Recovery Act resembled WAP as implemented just before the Recovery Act in PY 2008. For example, WAP did not change appreciably during the Recovery Act period with respect to these characteristics:

- Frequency of use of various diagnostic procedures (e.g., blower door tests were used with the same frequency).
- Approaches to and topics covered for client education purposes (e.g., most client education was again delivered during the in-home audit and the most popular topics were thermostat usage, insulation and lighting).
- Approaches for weatherization measure selection (e.g., frequency of Subgrantees using priority lists versus computerized audits was about the same).
- Measures installed (e.g. air sealing was again the most frequently installed measure).
- Use of various training venues (e.g., National Weatherization Program Conference was again a preferred training option).

⁵ LIHEAP is also a federal program, though administered by the U.S. Department of Health and Human Services.

- Weatherization program marketing efforts were at the local level (e.g., mailings to clients, radio ads were most popular again).
- Leveraged funding was approximately the same (\$700 million in PY 2010 versus \$600 million in PY 2008) though available leveraged funding per unit was substantially lower.

In some ways, though, WAP as implemented during the Recovery Act was different. For example, the income eligibility requirements were adjusted from being 150% of the federal poverty level to 200% and the average amount of DOE funds that could be invested in a home was increased from \$2500 to \$6500. In part because of these changes, households that received weatherization services had higher incomes and fewer vulnerable individuals in residence. Because more homes were weatherized in the hot climates, on average the homes that were weatherized were smaller, newer, less likely to use bulk fuels (e.g., fuel oil), and were more likely to use supplemental fuels (e.g., electric space heaters).

The Grantees and Subgrantees were under an enormous amount of pressure to ramp-up their programs. Among the challenges faced by Grantees and Subgrantees were these:

- Davis-Bacon Act provisions delayed production ramp-up and increased operations and administrative costs for the Subgrantees.
- Federal and Grantee oversight increased for Subgrantees, which, increased administrative costs.
- Both Grantees and Subgrantees had to deal with increased media and political attention focused on their weatherization programs.
- Subgrantees were faced with rapidly increasing and training the new workforce.
- In part, because of these challenges and increased costs, the estimated cost effectiveness of the program during the ARRA period was lower than estimated for the retrospective period.

Before discussing the program's energy savings estimates, it is important first to summarize factors encountered by the national weatherization network during the ARRA period that could have led to differences in energy savings and cost effectiveness observed during the retrospective evaluation.

- An inexperienced weatherization workforce may have missed some energy savings opportunities.
- More units were weatherized in hot climates where per unit energy savings are generally lower.
- Increased costs reduced the number of measures that could pass SIR test.
- The average number of major measures installed per unit was lower in the ARRA period than in the retrospective, thereby reducing average energy savings potential.
- Increased oversight in some cases may have increased work quality, which, in turn, may have increased energy savings.

Additionally, one could argue that many factors impacted cost effectiveness of the national WAP, including:

- Davis Bacon increased weatherization costs through increases in wages for weatherization staff and administrative costs for manpower for to handle the extra paperwork.
- Increased oversight increased administrative costs.
- Drags on administration efficiency were caused by bureaucratic reorganization, organizational attention to ramp-up and ramp-down processes, and media and political scrutiny.
- Economies of scale attributable to larger programs were reported by some Subgrantees.

3.0 Estimates of WAP Impacts

3.1 Research Design⁶

⁶ The plans for the retrospective and ARRA period evaluations of WAP are found in Ternes et al. (2007) and Tonn et al. (2011).

WAP was implemented by close to 900 Subgrantees in PY 2008 and 1000 Subgrantees in PY 2010. A probability proportional to size (PPS) sampling approach was used to randomly select 400 agencies in PY 2008 to provide information on homes weatherized in PY 2008 and for a comparison group, homes weatherized in PY 2009.⁷ Size was measured by DOE funding received by the agencies in PY 2008. This approach was augmented by two additional parameters. One, at least one Subgrantee in every state was included in the sample. Two, the largest Subgrantee in terms of funding was included in the sample with a probability of 1.0. The same approach was used to create the sample of Subgrantees for PY 2010. New Subgrantees in PY 2010 were added to the pool for possible selection.⁸

The sampled Subgrantees were asked to provide lists of units weatherized for each year under study and the following year. To build the sample of units for energy analyses of single family (SF), mobile home (MH), and small multi-family buildings (SMF) approximately one-third of the units from each list submitted by a Subgrantee were randomly selected to be in the energy savings analysis sample. Then, the Subgrantees were asked to provide NG and/or electric utility account information for the sampled units. The evaluation team then contacted the requisite NG and electric utilities to collect the billing histories. Bills were collected for periods of 12 months pre-weatherization and 12 months post-weatherization. For the PY 2010 analyses, the SMF units have been grouped with the SF homes into a site built homes (1-4 units) category. This was done because from a building science perspective the units in SMF buildings behave, are weatherized, and respond to weatherization in the same manner as SF homes. A PRISM-focused approach was used to screen billing histories for analysis and estimate energy savings.⁹

With respect to the retrospective period analysis, 379 out of 395 Subgrantees returned clients lists (96%). From those lists, a total of 22,134 units were sampled with the intention of collecting natural

⁷ We believe that homes weatherized the following year provides an excellent control group. Subgrantees have substantial waiting lists (642 in PY08 and 544 in PY10) and homes wait many months for weatherization services (27 months in PY08 and 18 months in PY10). This steady pipeline of homes in the queue suggests that the characteristics of homes weatherized do not change much from one PY to the next.

⁸ One major difference between PY 2008 and PY 2010 is that 450 Subgrantees were included in the sample. The sample size is larger because the project team needed to include all Subgrantees that received Sustainable Energy Resources for Consumers (SERC) grants (~92) in the sample so that billing histories for homes that received weatherization and SERC technologies could be collected as part of the national billing history collection process.

⁹ PRISM stands for Princeton Scorekeeping Method. For more information, see <http://www.marean.mycpanel.princeton.edu>

gas and electric utility bills. Table 5 presents the beginning sample sizes and attrition for billing histories for SF, MH, and SMF units.

With respect to the ARRA period analysis, 438 out of 448 Subgrantees returned clients lists (98%). From those lists, a total of 39,115 units were sampled with the intention of collecting natural gas and electric utility bills. Table 6 presents the beginning sample sizes and attrition for billing histories for SF, MH, and LMF units for PY 2010.

About 25 percent of weatherized homes are heated with delivered fuels—fuel oil, propane, kerosene, and wood. An oil metering study was implemented in seven states in the Northeastern United States during the 2010/2011 heating season to help estimate energy savings attributable to weatherizing homes that use fuel oil. The study involved installing devices to track heating system operation in 52 treatment homes and 35 comparison group homes. The results of this study were used to estimate fuel oil savings in both retrospective and ARRA period homes. Energy savings in homes heated with propane and kerosene were assumed to be similar to natural gas energy savings in homes heated with natural gas. Electricity savings in these homes were also assumed to be similar to electricity savings in homes heated with natural gas (Blasnik 2014d).

Large multi-family buildings (LMF) were handled differently. In PY 2008, the project team was only able to collect billing histories for LMF weatherized in New York City, though it should be noted that this was the first time that billing history analysis was done on such a large number of low-income LMF buildings. The sample of LMF buildings started at 243, with 13,467 units, weatherized during PYs 2007, 2008 and 2009. After visiting all 243 buildings, 223 met the criteria for inclusion in the study and the team was able to collect information on 223 of these buildings. The Evaluation Team attempted to collect building-level heating fuel information (both natural gas and fuel oil), common area electric data, and unit-level electric data for all eligible buildings. The response rates by fuel type were:

- Fuel Oil Data - Fuel oil companies furnished data for 50 of the 101 buildings that used fuel oil as a main heating fuel (50%).
- Natural Gas Data – Gas companies furnished data for 72 of the 90 buildings that used natural gas as a main heating fuel (80%).
- Common Area Electric Data – Electric companies furnished common area electric data for 152 of the 220 buildings (69%).
- Unit-Level Electric Data – Electric companies furnished unit-level electric data for 53 of the 220 buildings (24%); those buildings included 629 of the 12,128 units in eligible buildings.

On a positive note, NYC accounted for one-third of LMF units weatherized in PY 2008. Billing histories were sufficient to estimate energy savings for 3,764 units in LMF buildings heated with natural gas, 1,738 units in buildings heated with fuel oil. Common area electricity bills were collected for 147 accounts and 251 separate apartment units. Gross rather than net energy savings were estimated for the LMF sector.

A national occupant survey instrument was developed and administered, in part, to assess changes in household energy behaviors post-weatherization. The approximately 45 minute phone survey also contained a set of questions that pertained to health, safety and well-being. The occupant survey was conducted in two phases. In phase 1, a random sample of households close to receiving their energy audits were surveyed, along with a random sample comparison group of households that had been weatherized one-year previously. In phase 2, these same households from both groups were sampled one year to eighteen months later. The survey was implemented as follows:

- From the subset of 400 Subgrantees mentioned above, 220 were randomly sampled to participate in the occupant survey;

- In 2010, these Subgrantees were asked to furnish lists of single family and mobile homes scheduled for audits at the time of the request and for lists of types of homes weatherized one year previously;¹⁰
- Homes were randomly selected from aggregated lists for the treatment and comparison groups;
- A computer-assisted telephone survey (CATI) was implemented, with a 70% response rate;
- The samples sizes for the treatment (pre-weatherization) and comparison homes (one year post-weatherization) were 665 and 803, respectively; and
- These same homes were re-surveyed in 2013, yielding 398 responses from the treatment homes and 430 from the comparison homes.¹¹

Lastly, it should be noted that 290 households surveyed to be part of the pre-weatherization treatment group had not had their homes weatherized by the time they were contacted to be part of the client satisfaction portion of the occupant survey. It is assumed that weatherization was deferred for these homes.

3.2 Estimated Energy Savings¹²

Table 7 presents the aggregate and per unit energy savings estimates by house type for PYs 2008 and 2010. One can see that the substantial increase in the number of units weatherized more than tripled the total energy savings achieved in the site built home sector. On the other hand, for many of the reasons cited above, the energy savings per unit decreased somewhat from 2008 to 2010 in the site built category, from 29.3 MMBtu to 26.6 MMBtu. The unit savings for the MH category increased somewhat during the ARRA period. The LMF savings per unit dropped when buildings outside of

¹⁰ Households living in large multi-family buildings were not included in the survey because weatherization of these buildings is quite different. For example, as LMF weatherization job that replaced an old central boiler and a similarly old central hot water heater may not include many if any measures in the individual units.

¹¹ For more information on the national occupant survey, see Retrospective Evaluation report Carroll et al. (2014a).

¹² Documentation for the energy savings and cost effectiveness estimates by housing type can be found in Blasnik et al. (2014a, 2014b, 2014c, 2014d) for the retrospective evaluation and Blasnik et al. (2015a, 2015b) and Carroll et al. (2015a) for the ARRA period evaluation. All of these reports report confidence intervals for energy savings by fuel type and other variables.

New York City were added to the sample.¹³ For comparison purposes, the per unit natural gas savings for weatherized site built homes in PY 1989 was 17.6 MMBtu (Brown et al. 1994).

Figure 3 presents the estimated energy savings for site built homes for five program years, 2007 to 2011 by climate zone. The first panel presents NG savings for homes heated with NG. The second panel presents estimated electricity savings for those homes. The third panel presents electricity savings in homes heated by electricity. Estimated energy savings were only done nationally for PYs 2007, 2009, and 2011. Net energy savings are presented for every year except the last, PY 2011, which are gross energy savings.

Overall, the pattern of results meets expectations. The percentage of energy savings is higher for NG in NG heated homes than for electricity in homes heated with electricity. Baseload electricity savings are lower than NG savings as a percentage in homes heated with NG. NG savings are quite a bit lower in homes located in the hot-dry climate zone. Energy savings are higher in the cold climate zone than in the very cold climate zone for homes heated with NG because it is assumed that the latter are built tighter than the former. As hypothesized in the previous section, energy savings in site built homes dropped from 2008 to 2010, possibly due to many factors associated with the Recovery Act period. But then again, the savings rebounded in PY 2011, possibly due to the national weatherization network meeting the challenges of the Recovery Act period. Additionally, electricity saved in homes heated with NG and homes heated with electricity were higher in the Recovery Act years than in PY 2008. The national averages for energy savings in the three panels cluster around 17%, 7.5%, and 10.5%, respectively. For comparison purposes, the previous national evaluation of WAP estimated natural gas savings in homes heated with natural gas to be 13% (Brown et al. 1994) and a meta-evaluation of evaluations done by states between 1993 to 2005 estimated savings at 23% (Schweitzer 2005).

¹³ To clarify, the retrospective evaluation's large multifamily impact study only had billing data for buildings weatherized in New York City (See Blasnik et al. 2014c).

A topic frequently addressed by energy program evaluators is the rebound effect (Greening et al. 2000; Galvin 2014). The evaluations collected four sets of data that suggest that there is a negligible rebound effect. This is surmised from these findings:

- A nationally representative sample of 500 homes treatment and comparison monitored for temperature during a heating season as part of a larger national Indoor Air Quality study found that the indoor temperature increased only 0.27oF post-weatherization (Pigg et al. 2014). These monitored temperature results are consistent with the findings of several other studies done over the years (e.g., Ternes et al. 1991; Levins and Ternes 1994; McCold et al. 2008);
- The evaluation team visited over 100 homes flagged as having saved more or less energy than estimated and found with respect to the latter that household demographic changes, changes in supplemental heating, and repair or replacement of non-functioning heating systems explained the findings. Homes that did change their thermostat settings lowered them in the winter because their homes were more efficient (Pigg 2014);
- The national occupant survey asked respondents about thermostat setting in the day and night during winter and summer and there were no statistical significant differences from pre- to post-weatherization (Tonn et al. 2015b); and
- The same survey inquired about a large number of energy behaviors and no pattern was found to indicate that the households changed their behaviors to increase or decrease energy use (Tonn et al. 2015b).

Table 8 presents estimates of the energy cost savings by housing type by program year. The SF and SMF estimates have been combined in PY 2008 for this analysis and as mentioned previously are referred to collectively as site-built homes. The decrease in dollars saved per site built homes from PY 2008 to PY 2010 is expected given the factors identified above in Section 2.2. The dollars saved per MH weatherized did not change appreciably from one period to the next. The large decrease in the average energy costs savings per unit in the LMF sector is explainable: a very large percentage of

weatherized LMF buildings in New York City use very expensive fuel oil for their heating fuel. This expensive energy source is rarely used outside of the Northeast.

3.3 Non-Energy Benefits

In addition to producing energy savings and energy cost savings, a sizable set of non-energy benefits can be attributable to low-income weatherization. Figure 4 illustrates the framework developed to organize the assessment of non-energy benefits. The framework has three main categories: societal benefits, ratepayer benefits, and household benefits. Investments in weatherization create direct societal economic benefits (i.e., produce jobs and income multiplier effects). Reductions in energy use resulting from physical changes in the home result in environmental benefits (e.g., reductions in the emissions of harmful air pollutants), which are included in the societal bucket. Weatherization, through energy cost savings, directly impacts household income. Health and safety measures, combined with improvements in disposable income, impact the health and well being of household members (e.g., by reducing instances of thermal stress, reducing asthma symptoms and increasing households' ability to afford prescriptions). Improved health outcomes can lead to societal benefits through decreases in expenses to public and private medical insurance plans. Ratepayers can benefit from decreases in subsidies to Percentage of Income Payment Programs (PIPPs), for example. The balance of this section addresses: emissions benefits, and household health and other household-related benefits.¹⁴

3.3.1 Emissions Reductions

One benefit of WAP is that reducing the amount of energy used in clients' homes reduces the emissions associated with the production and consumption of energy. Values for emissions reductions are estimated for: carbon, particulate matter, sulfur dioxide, nitrogen oxide, and volatile organic compounds. The environmental emissions benefit estimation procedure involves four steps:

1. Energy Usage Reductions (State-Level) – The program evaluation estimated energy savings per weatherized unit for each type of energy used in clients' homes (e.g., NG, electricity) for each building type (i.e., SF, MH, and MF).

¹⁴ For an estimation of the macro-economic impacts of WAP expenditures in PY 2008, please see Burton and Bray (2014).

2. Quantity of Avoided Emissions (State-Level) – Published data sources were used to estimate the avoided greenhouse gases, sulfur dioxide, nitrogen oxide and particulate matter emissions associated with the energy usage reductions for each type of energy. The analysis developed estimates of the average avoided emissions per housing unit at the state level and the aggregate avoided emissions per state.
3. Value of Avoided Emissions (State-Level) – The dollar value of avoided greenhouse gas emissions was computed using guidance from Office of Management and Budget (OMB) and sulfur dioxides, nitrogen oxides, particulate matter, and volatile organic compounds was computed using the Air Pollution Emission and Policy Analysis Model (APEEP) as recommended by the National Research Council (NRC) in their 2010 Report to Congress.¹⁵ The analysis developed estimates of the average emissions benefit per housing unit at the state level and the aggregate emissions benefit per state.
4. National Averages and Aggregates – Using the state-level data, the analysis developed a weighted average avoided emissions and benefits per housing unit served by the program and aggregate avoided emissions and benefits for the overall program. The avoided emissions are expressed as avoided CO₂ equivalents in metric tons, and average short tons of avoided for SO_x, NO_x, PM, and VOCs.

One important reason for developing estimates at the state level in Steps 1 and 2 is because environmental emissions rates for electricity generation vary by region. The valuation procedure done in Step 3 was conducted at the state level because the APEEP model estimates damages at the county level based on pollution sources and population. In addition, this approach furnishes data that can be useful to states for their own planning purposes. The lifetime CO₂ emissions reductions are over 7 million metric tons and over 17 thousand short tons for criteria pollutants in PY 2010, as indicated in Table 9.

¹⁵ National Research Council, 2010. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. The National Academies Press, Washington, DC. It should be noted that since this research was conducted, the discount rate to estimate the social cost of carbon has increased from 3% to 7%.

Table 9 also presents the results of monetizing the present value of environmental emissions benefits by emissions type and housing type.¹⁶ The present value of these benefits for units weatherized in PY 2010 is \$645,000,000. This and the individual values by housing type and emissions type are about three to four times higher than the estimates for PY 2008 because of the higher number of units weatherized in PY 2010. These results are sensitive to the value of a metric ton (CO₂) or short ton of emissions reduced. For example, the value of a short ton of SO₂ emissions reduced is much higher than the value for a metric ton of CO₂ (i.e., \$38 versus \$95,000), primarily because studies that monetize the values of reductions of the criteria pollutants incorporate the human health benefits related to reducing exposures to outdoor air pollutants. The monetary values associated with reducing the criteria air pollutants by weatherizing LMF buildings are relatively larger because these buildings generally are located in areas with higher population densities and therefore, relatively speaking, more individuals benefit from the reduced emissions.

3.3.22 Health and Household-Related Non-Energy Benefits¹⁷

As described in Sect. 3.1, WAP recipients were surveyed pre- and post-weatherization. Numerous questions in the survey pertained to health, budget, and other related issues (Liddell and Morris 2010; IEA 2014; Howden-Chapman et al. 2008; Gilbertson et al. 2012). Table 10 presents descriptive statistics for a selected set of health-related questions. Results presented in the first three rows indicate that weatherization reduced asthma symptoms and accompanying visits to emergency departments and hospitals of the main respondents. That weatherization can reduce asthma symptoms is not unexpected because many routine weatherization measures can produce this co-benefit (Krieger 2010). For example, air sealing a home can reduce the infiltration of outdoor allergens as well as insects and other pests. Insulating homes makes homes them comfortable to live in in the winter and summer. In some cases, occupants are less likely to need medical assistance post-weatherization

¹⁶ See Carroll et al. (2014c) and Carroll and Bausch (2015) for more information on the environmental emissions benefits study.

¹⁷ A comprehensive discussion of the health benefits of low-income weatherization and the survey results is found in Tonn et al. (2014b).

because now their homes are not too hot or too cold.¹⁸ General reports of physical and mental health improved post-weatherization due to a multiple of influences of weatherization (e.g., more comfortable, less drafty homes; less infiltration of outdoor noise into the home (Brink 2013)).

Fuel poverty is an issue facing low-income homes in the U.S. (Hernandez 2013; Power 2006) and internationally (Boardman 2010; Ormandy 2009). The survey contained several questions pertaining to the household's budget. As indicated in Table 11, weatherization reduced the frequency of difficult budget tradeoffs, though did not eliminate budget problems. For example, many fewer households found it difficult to pay their energy bills post-weatherization though over 50% reported still facing this issue post-weatherization. Fewer households faced tradeoffs involving food and being able to afford prescriptions.

Monetization of health and household-related benefits provides a way to combine these benefits with the energy cost savings and emissions benefits to develop a fuller picture of the total benefits versus costs of WAP. Twelve categories of health and household-related benefits were monetized as part of this evaluation.¹⁹ They are listed in Table 8. Here are several points to be considered with respect to these estimates:

- The methodologies used to estimate these benefits are based on a national survey of occupants (with a comparison group) and data collected on measures installed in homes by WAP, and on cost estimates for medical treatment were mined from national medical databases²⁰;
- Household benefits are limited to financial benefits accruable directly to the households;

¹⁸ Thermal stress from heat is forecast to increase due to climate change, all things being equal (Wu et al. 2014).

¹⁹ Methodologies used to generate the monetary estimates listed in Table 3.10 can be found in Tonn et al. (2014b).

²⁰ Hospitalization and emergency department costs were retrieved from an online database provided by the Department of Health and Human Services (DHHS) sponsored by the Agency for Healthcare Research and Quality (AHRQ). These data were collected through the Medical Expenditure Panel Survey (MEPS). The costs for a physician office visit were retrieved from a collection of databases sponsored again by AHRQ referred to as the Healthcare Cost and Utilization Project (HCUP).

- Financial benefits due to improved health, for instance, that benefit health insurance plans (e.g., Medicaid and Medicare) are accrued to society in this framework;
- The value of lives saved is considered societal;
- The benefits are accruable immediately (e.g., weatherizing a home can immediately begin to protect occupants from thermal stress);²¹ and
- The present values are calculated over a ten-year time frame using the 2013 discount rate published by OMB.²²

Table 12 presents the estimates of the monetary value for twelve non-energy benefits for households residing in single family and mobile homes.²³ These estimates are grouped into three tiers according to the strength of the methodologies and data underlying the estimates. Tier 1 estimates can be considered to have the least amount of uncertainty, followed by the Tier 2 and Tier 3 estimates. The per unit estimates are the same as reported for PY 2008; however, the aggregate total for the WAP program accounts for the number of units weatherized in PY 2010 to capture the valuation of non-energy benefits for WAP during the ARRA period, which was nearly \$4 billion.

The highest benefit accrues from preventing instances of thermal stress from exposure to extreme cold indoor temperatures. This benefit has a high value because in a few cases, weatherization can prevent thermal stress that can lead to death and preventing a death was valued at \$7.5 million in this analysis. Preventing deaths also weighed heavily in the benefits estimated for preventing other instances of thermal stress (i.e., from exposure to extreme hot indoor temperatures), CO poisoning, and home fires.

²¹ Impacts that may take many years to be realized are not included in this analysis.

²² The discount rates were taken from OMB Circular A-94 Appendix C, 2013 OBM Real Treasury interest rates (See <https://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist.pdf>). An exception was made for installing CO monitors, where present value was calculated over a 5-year period as the lifespan of CO monitors generally remains effective for an average of five years.

²³ SMF and LMF homes were not included in these analyses because clients living in these types of homes were not included as part of the national occupant survey and because weatherization of LMF buildings focuses more on central heating and water heating systems and common areas and less on individual units, which is hypothesized to have a very different impact on health and household-related non-energy benefits.

3.4 Cost-Effectiveness Estimates

Table 13 presents a summary of the cost-effectiveness analyses by housing type for PY 2010 and PY 2008. The present values of the energy cost savings were calculated based on expected measure lifetimes, U.S. Energy Information Administration (EIA) estimates of future energy prices, and OMB discount rates for 2013. Only total measure installation costs are included in these analyses. The largest difference in cost-effectiveness between PY 2008 and PY 2010 falls in the LMF building category. In this category, the PY 2010 analyses include LMF outside of NYC. The large reduction in the percentage of LMF in the PY 2010 sample that heat with fuel oil explains the preponderance of the difference in savings to investment ratios for this sector. As noted above, the formula used to allocate WAP ARRA funds to the Grantees increased the proportion of funds flowing to hot climate regions of the U.S. Since these regions do not use expensive fuel oil and offer lower energy savings per unit, the lower SIRs for single family and mobile homes in PY 2010 are not unexpected. Under these assumptions, overall the programs benefit-cost ratio was 1.59 in PY 2008 and 0.98 in PY 2010.

Table 14 presents a summary of the total program benefits and costs for WAP for PY 2010 for all weatherized units. The average cost per unit weatherized is \$6,812, which includes all funding leveraged to invest in DOE units and all programmatic costs (i.e., measure costs, administrative costs, training and technical assistance). The average energy cost savings is \$3,681. Because numerous households whose homes were weatherized participate in utility administered PIPPs that are subsidized by ratepayers, approximately 22% of the energy cost savings accrue to ratepayers. The combined present value of the energy and non-energy benefits per unit is approximately \$22,000.²⁴ Accounting for the units weatherized in PY 2010, the total present value of the benefits exceeds \$5.7 billion. It should be noted that there are uncertainties in all of these estimates. However, the total estimates are conservative in several manners. First, the health and household-related benefits do not

²⁴ This study assumes there is no free-rider issue. In other words, none of the households whose homes were weatherized would have undertaken weatherization without WAP. This assumption is justified given that all homes in the program are low-income and the national occupant survey documents problems these households have in paying everyday bills. It should be noted that these estimates also do not include spillover benefits, despite the fact that spillover was documented by the Social Network Study (Rose et al. (2015b)).

take into account subjective benefits enjoyed by households with respect to comfort, improved health and other factors. Second, these non-benefits were not estimated for the large multifamily component of WAP.

Lastly, numerous other non-energy benefits were not monetized by the evaluation, including potential health impacts of refrigerator replacement (i.e., as related to the prevention of food poisoning), health benefits attributable to minor home repairs (e.g., reducing trips and falls), increased home value resulting from the value of the weatherization investments, reduced interest payments on late payments of utility bills, reduced forced mobility, reduced emissions of heavy metals, improvements in national security, and the value of free training provided to weatherization staff. Ratepayer benefits not addressed include: lower bad debt write-off, reduced carrying costs on arrearages, fewer notices and customer calls, fewer emergency gas service calls, reduced transmission and distribution costs, and reduced peak electricity demands.

4.0 Conclusion and Policy Implications

WAP is an energy-efficiency program created to benefit low-income households in the United States. Its funding supports the weatherization of single family, mobile and multifamily buildings (from small to the very large in places like New York City) in all climate zones across the country. The impact results presented herein indicate that WAP is effective at saving energy, though its effectiveness varies by house type, climate zone, and heating fuel type. It is also evident that WAP produces substantial co-benefits for households and society. These co-benefits are very important to garner continued support for low-income energy efficiency programs nationwide because often these programs are not as cost effective, strictly speaking, as non-low income and commercial and industrial programs.

A unique opportunity was presented to evaluate WAP under two quite different situations. The retrospective evaluation considered a program that had been operating in approximately the same fashion at approximately the same funding level for about the previous decade. The ARRA period evaluation was conducted during a time of unprecedented funding and production and under different

regulatory guidelines. The impact analyses showed that the program saved substantially more energy and benefitted many more low-income households during the latter period but at a cost of reduced cost effectiveness, though even during the ARRA period the combined benefits exceeded the combined costs.

The program is quite adept at weatherizing the most typical homes that come into the program, single family homes heated with natural gas. More progress is needed to improve energy savings in mobile homes, which can, in part, be addressed through continuing to improve training and technical assistance with respect to this home type. The large multifamily sector is an altogether different challenge. Building types differ greatly as do approaches for weatherization (e.g., weatherizing a large multifamily building with 10+ stories that has central heating and hot water is much different than weatherizing a sprawling garden apartment complex). WAP also needs to gain property owner contributions to the weatherization effort, a process that takes time and patience.

There is no lack of future research directions. For example, it would be valuable to know how persistent energy savings are over time. Also, as indicated, numerous co-benefits were not included in this impact analysis. With respect to estimating health benefits, consideration could be given to conducting a ‘big data’ study that would link databases of weatherization recipients and appropriate comparison homes to their use of Medicaid, Medicare, and other health insurance. Future research project should also involve the direct collaboration of the health care sector and agencies that have human health missions.

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REFERENCES

Bensch, I., Keene, A09., Cowan, C., and Koski, K. 2014. National Weatherization Assistance Program Characterization: Describing the Pre-ARRA Program. ORNL/TM-2013/188, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April.

Berger, J., Lenahan, T., and Carroll, D. 2014. National Weatherization Assistance Program Process Field Study: Findings from Observations and Interviews at 19 Local Agencies Across the Country. ORNL/TM-2014/304, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Blasnik, M., Dalhoff, G., Carroll, D., Ucar, F., Bausch, D., and Johnson, D. 2015a. National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Mobile Homes (ARRA), ORNL/TM-2014/558, Oak Ridge National Laboratory, Oak Ridge, TN, July.

Blasnik, M., Dalhoff, G., Carroll, D., Ucar, F., and Bausch, D. 2015b. National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Single Family Homes (ARRA), ORNL/TM-2014/582, Oak Ridge National Laboratory, Oak Ridge, TN, July.

Blasnik, M., Dalhoff, G., Carroll, D., and Ucar, F. 2014a. Energy Impacts for Mobile Homes. ORNL/TM-2014/84, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November.

Blasnik, M., Dalhoff, G., Carroll, D., and Ucar, F. 2014b. Energy Impacts for Small Multifamily Homes. ORNL/TM-2014/325, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Blasnik, M., Dalhoff, G., Carroll, D., and Ucar, F. 2014c. Energy Impacts for Large Multifamily Homes. ORNL/TM-2014/332, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Blasnik, M., Dalhoff, G., Pigg, S., Mendyk, A., Carroll, D., and Ucar, F. 2014d. Energy Impacts for Single Family Homes. ORNL/TM-2015/13, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Boardman, B. 2010. Fixing Fuel Poverty: Challenges and Solutions. Earthcan. London.

Brink, Mark 2013. Noise-Induced Sleep Disturbances and Long-Term Health Risks. Environment and Health – Bridging South, North, East and West, Basel, Switzerland, August 19-23.
<http://www.ehbasel13.org/>

Brown, M., Berry, L., and Kinney, L. 1994. Weatherization Works: Final Report of the National Weatherization Evaluation. ORNL/CON-395, Oak Ridge National Laboratory, Oak Ridge, TN, September.

Burton, M. and Bray, L. 2014. Macro-economic Impacts of the Weatherization Assistance Program for PY 2008. ORNL/TM-2014/98, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Carroll, D. and Bausch, D. 2015. Environmental Nonenergy Benefits Working Paper: ARRA Period. ORNL/TM-2015/127, Oak Ridge National Laboratory, Oak Ridge, TN, July.

Carroll, D., Dalhoff, G., Johnson, D., Bausch, D., and Blasnik, M. 2015a. National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Large Multifamily (ARRA), ORNL/TM-2014/583, Oak Ridge National Laboratory, Oak Ridge, TN, July.

Carroll, D., Berger, J., Miller, C., and Driscoll, C. 2014a. National Weatherization Assistance Program Impact Evaluation - Baseline Occupant Survey: Assessment of Client Status and Needs. ORNL/TM-2015/22, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October.

Carroll, D., Kim, C., and Driscoll, C. 2014b. National Weatherization Assistance Program Impact Evaluation: Eligible Population Report. ORNL/TM-2014/212, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Carroll, D. et al. 2014c. Working Paper: National Weatherization Assistance Program Impact Evaluation: Environmental Emissions. ORNL/TM-2014/411, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Galvin, R. 2104. Making the ‘Rebound Effect’ More Useful for Performance Evaluation of Thermal Retrofits of Existing Homes: Defining the ‘Energy Savings Deficit’ and the ‘Energy Performance Gap’. *Energy and Buildings*, 69, 515-524.

Gilbertson, J. et al. 2012. Psychosocial Routes From Housing Investment to Health: Evidence from England’s Home Energy Efficiency Scheme. *Energy Policy*, Vol. 49, 122-133.

Greening, L., Greene, D., and Difiglio, C. 2000. Energy Efficiency and Consumption – The Rebound Effect – A Survey. *Energy Policy*, Vol. 28, 389-401.

Hernandez, D. 2013. Energy Insecurity: A Framework for Understanding Energy, the Built Environment, and Health Among Vulnerable Populations in the Context of Climate Change. *American Journal of Public Health*, Vol. 103, No. 4, e32-e34.

Howden-Chapman, P. et al. 2008. Effects of Improved Home Heating on Asthma in Community Dwelling Children: Randomised Controlled Trial. *British Medical Journal*, Vol. 337, 852-855.

International Energy Agency 2014. Capturing the Multiple Benefits of Energy Efficiency. Paris, France.

Krieger, J. 2010. Home is Where the Triggers Are: Increasing Asthma Control by Improving the Home Environment. *Pediatric Allergy, Immunology, and Pulmonology*, Vol. 23, Issue 2, 139-145.

Levins, W. and Ternes, M. 1994. Impacts of the Weatherization Program in Fuel-Oil Heated Houses. ORNL/CON-327, Oak Ridge National Laboratory, Oak Ridge, TN, 1994, October.

Liddell, C. and Morris, C. 2010. Fuel Poverty and Human Health: A Review of Recent Evidence. *Energy Policy*, Vol. 38, Issue 6, 2987-2997.

McCold, L., Goeltz, R., Ternes, M., and Berry, L. 2008. Texas Field Experiment: Performance of the Weatherization Assistance Program in Hot-Climates, Low-Income Homes. ORNL/CON-499, Oak Ridge National Laboratory, Oak Ridge, TN, April.

Ormandy, D. (Ed.) 2009. *Housing and Health in Europe: the WHO LARES Project*. Oxford. Routledge. UK.

Pigg, S., Cautley, D., Francisco, P. with Hawkins, B., and Brennan, T. 2014. Weatherization and Indoor Environment Quality: Measured Impacts in Single-Family Homes Under the Weatherization Assistance Program. ORNL/TM-2014/170, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Pigg, S. 2014. A Field Investigation of Apparent Low and High Savers. ORNL/TM-2014/308, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October.

Power, M. 2006. Fuel Poverty in the USA: The Overview and the Outlook. *Energy Action*, Vol. 98, March.

Rose, E., Hawkins, B., Tonn, B., Paton, D. and Shah, L. 2015a. Exploring the Potential of Weatherization and Healthy Homes Interventions on Asthma-related Medicaid Claims and Costs in a Small Cohort in Washington State. ORNL/TM-2015/213, Oak Ridge National Laboratory, Oak Ridge, TN, July.

Rose, E., Hawkins, B., Tonn, B., Conlon, B., Treitler, I. 2015b. Assessing the Potential of Social Networks as a Means for Information Diffusion – the Weatherization Experiences (WE) Project. ORNL/TM-2014/405, Oak Ridge National Laboratory, Oak Ridge, TN.

Schweitzer, M. 2005. Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005. ORNL/CON-493, Oak Ridge National Laboratory, Oak Ridge, TN, September.

Ternes, M., Schweitzer, M., Tonn, B., Schmoyer, R., and Eisenberg, J. 2007. National Evaluation of the Department of Energy's Weatherization Assistance Program (WAP): Program Year 2006 Experimental Plan. ORNL/CON-498, Oak Ridge National Laboratory, Oak Ridge, TN, February.

Ternes, M., Hu, P., Williams, L., and Goewey, P. 1991. The National Fuel End-Use Efficiency Field Test: Energy Savings and Performance of an Improved Energy Conservation Measure Selection Technique. ORNL/CON-303, Oak Ridge National Laboratory, Oak Ridge, TN, March.

Tonn, B. and Goeltz, R. 2015. National Weatherization Assistance Program Evaluation: Assessment of Refrigerator Energy Use. ORNL/TM-2015/150, Oak Ridge National Laboratory, Oak Ridge, TN, March.

Tonn, B., Carroll, D., Rose, E., Hawkins, B., Pigg, S., Blasnik, M., Eisenberg, J., Cowan, C., and Conlon, B. 2015a. "Weatherization Works II - Summary of Findings from the ARRA Period Evaluation of the U.S. Department of Energy's Weatherization Assistance Program," ORNL/TM-2015/139, Oak Ridge National Laboratory, Oak Ridge, TN, August.

Tonn, B., Rose, E., and Hawkins, B. 2015b. Survey of Recipients of Weatherization Assistance Program Services: Assessment of Household Budget and Energy Behavior Pre- to Post-Weatherization. ORNL/TM-2015/64, Oak Ridge National Laboratory, Oak Ridge, TN, March.

Tonn, B., Rose, E., and Hawkins, B. 2015c. National Weatherization Assistance Program Characterization Describing the Recovery Act Period. ORNL/TM-2014/593, Oak Ridge National Laboratory, Oak Ridge, TN, March.

Tonn, B., Rose, E., and Hawkins, B. 2014a. Weatherization – Beyond the Numbers: Case Studies of Fifteen High-Performing Weatherization Agencies - Conducted May 2011 – July 2012. ORNL/TM-2014/317, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Tonn, B., Rose, E., Hawkins, B., and Conlon, B. 2014b. Health and Household-Related Benefits Attributable to the Weatherization Assistance Program. ORNL/TM-2014/345, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Tonn, B., Carroll, D., Pigg, S., Blasnik, M., Dalhoff, G., Berger, J., Rose, E., Hawkins, B., Eisenberg, J., Umar, F., Bensch, I., and Cowan, C. 2014c. Weatherization Works – Summary of Findings from the Retrospective Evaluation of the U.S. Department of Energy’s Weatherization Assistance Program. ORNL/TM-2014/338, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September.

Tonn, B., Rose, E., Schmoyer, R., Eisenberg, J., Ternes, M., Schweitzer, M., and Hendrick, T., 2011. Evaluation of the National Weatherization Assistance Program During Program Years 2009-2011 (American Recovery Act and Reinvestment Period). ORNL/TM-2011/87, Oak Ridge National Laboratory, Oak Ridge, TN, December.

Wu, J et al. 2014. Estimation and Uncertainty Analysis of Impacts of Future Heat Waves on Mortality in the Eastern United States. *Environmental Health Perspectives*, Vol. 122, Issue 1, 10-16.

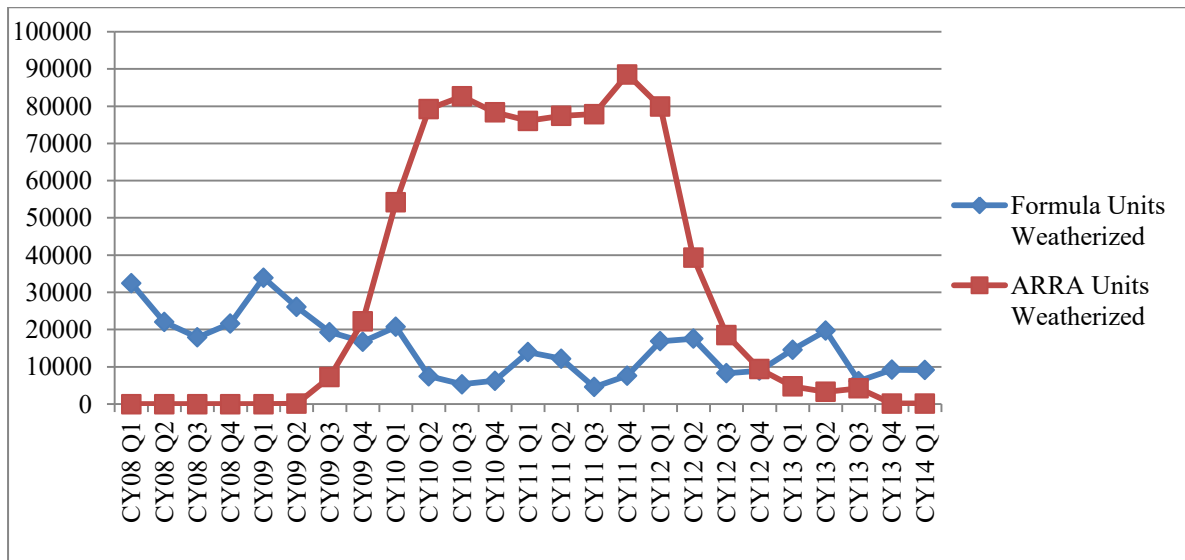


Figure 1. Units Weatherized With WAP Funds During the Recovery Act Period

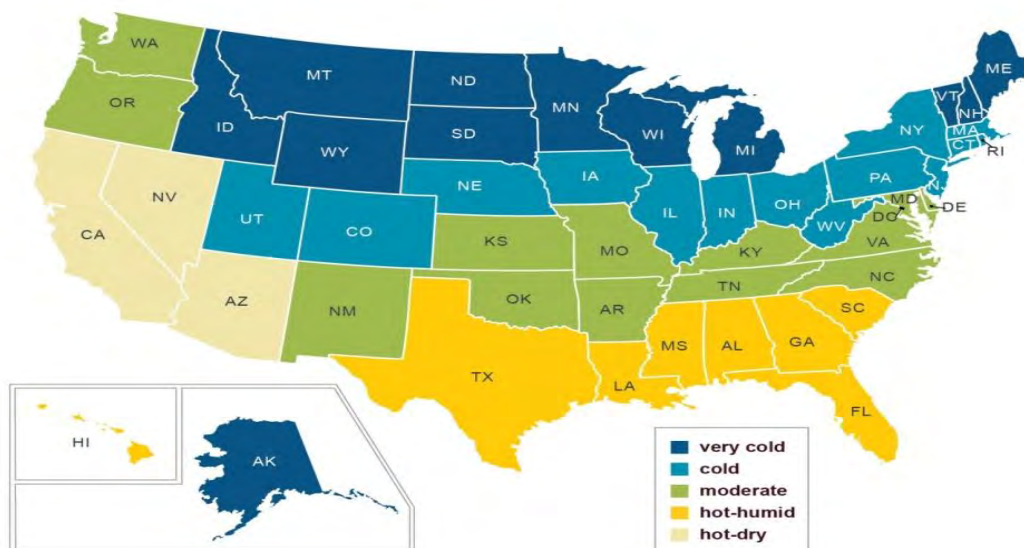


Figure 2. Climate Zones

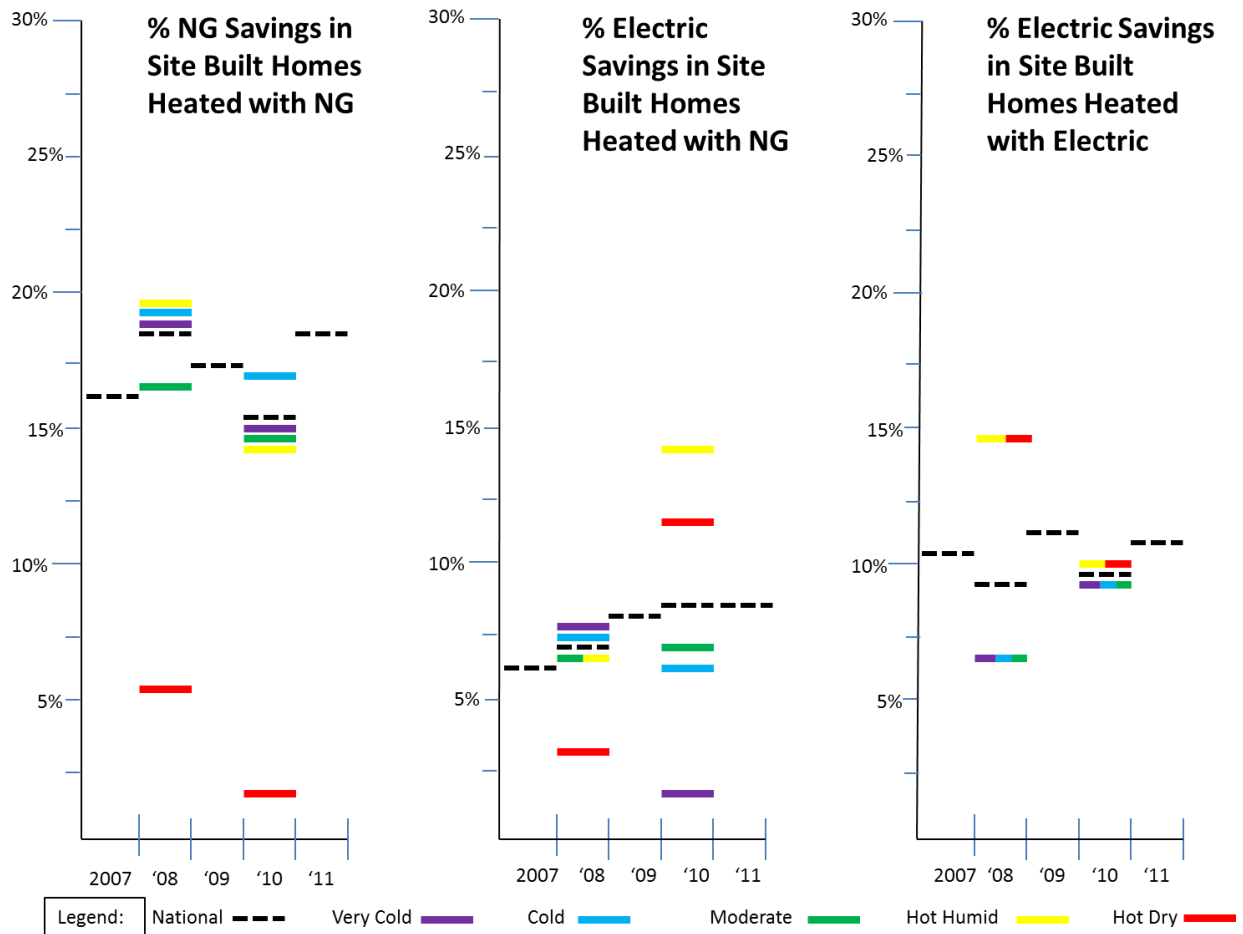


Figure 3. Estimated Energy Savings by House Type, Heating Fuel Type, and Climate Zone

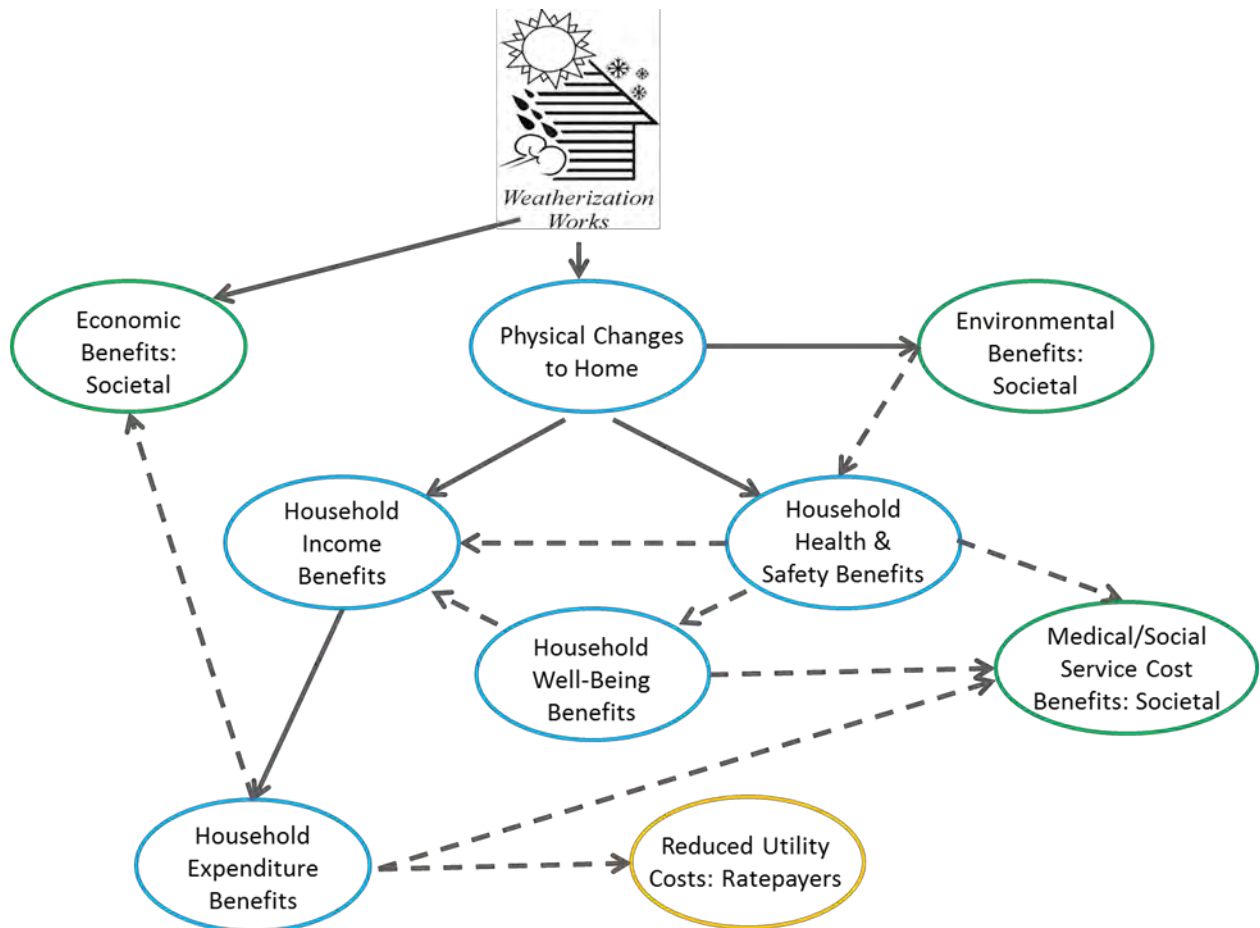


Figure 4. Framework for Understanding Non-Energy Benefits (solid lines represent direct, or first-order, pathways; dotted lines represent indirect, or second-order, pathways)

Table 1. Weatherized Units in Program Years 2008 and 2010 by Housing Type				
Housing Type	2008 Units	2008 by %	2010 Units	2010 by %
Site Built Homes (1-4 units)	62,835	64%	215,445	65%

Mobile Homes	17,754	18%	48,267	14.5%
Large Multi-family Units (5+)	17,376	18%	68,153 ²⁵	20.5%
Total	97,965	100%	331,865	100%

Table 2. Weatherized Units in Program Years 2008 and 2010 by Climate Zone

Climate Zone	2008 Units	2008 by %	2010 Units	2010 by %
Very Cold	24,749	25%	58,584	18%
Cold	42,233	43%	127,386	38%
Moderate	18,794	19%	56,006	17%
Hot/Humid	6,390	7%	55,157	17%
Hot/Dry	5,799	6%	34,732	10%
Total	97,965	100%	331,865	100%

Table 3. Weatherized Units in Program Years 2008 and 2010 by Heating Fuel Type (%)

Heating Fuel Type	All Units PY 2008	Single Family PY 2008	Mobile Home PY 2008	All Units PY 2010	Single Family PY 2010	Mobile Home PY 2010
Natural Gas	58%	60%	35%	56%	62%	31%
Electric	17%	14%	35%	25%	19%	40%
Fuel Oil	14%	14%	10%	9%	9%	7%
Propane	9%	9%	18%	8%	8%	18%
Other	3%	3%	2%	2%	2%	3%

Table 4. DOE and Leveraged Weatherization Funding in PY 2010 and PY 2008 (\$ millions)

	2010				2008			
	Grantees		Sub-grantees		Grantees		Sub-grantees	
	N	\$	N	\$	N	\$	N	\$
DOE	51	\$2,008	-	-	51	\$236	-	-
LIHEAP	43	\$401	5	\$1	46	\$319	11	\$3
State Public Benefit	5	\$46	52	\$19	8	\$83	50	\$9
Other State Programs	6	\$37	104	\$21	10	\$31	145	\$27
Utilities	13	\$24	268	\$94	14	\$21	174	\$52
PVE and Other Fed. Programs	8	\$10	78	\$17	9	\$12	90	\$30
Program Income, In-kind, Non-profit, 3rd Party, Other	3	\$22	171	\$14	4	\$20	106	\$6
Total		\$2,548		\$167		\$722		\$128

²⁵ Excluded in this number are multifamily units that were reported weatherized about which the evaluation team had no information and it also excludes weatherized shelters.

State Retained	\$138	\$50
Pass Through to Subgrantees	\$2,409	\$672
Total Program Funding	\$2,715	\$850
Amount Spent on DOE units	\$2,316	\$460
Number of DOE units	340,158	97,965

Table 5. Samples Sizes and Attrition in Billing Histories PY 2008

Sampled Units	Single Family Site Built 11,328			Mobile Homes 2,957			Small Multifamily Buildings 1,171		
	NG/NG	Elect/NG	Elect/Elect	NG/NG	Elect/NG	Elect/Elect	NG/NG	Elect/NG	Elect/Elect
Utilities Providing Data	428 (74%)	310 (72%)	428 (74%)	243 (76%)	124 (69%)	243 (76%)	74 (70%)	59 (69%)	74 (70%)
Starting Sample	7,547	7,547	1,111	1,245	1,245	819	793	793	NA
No Usage Data	2,831	2,987	492	567	610	124	132	165	
Available Insufficient Data/Poor Model Fit/Outlier	1,531	1,414	327	256	298	68	378	361	
Total Usable Sample Cases	3,185	2,725	292	422	337	260	283	267	
Non- Sampled Cases	313	266	14	194	156	16	0	0	
Total Usable Cases	3,498	2,991	306	616	493	276	283	267	

Table 6. Samples Sizes and Attrition in Billing Histories PY 2010

Sampled Units	Single Family Site Built 27,330			Mobile Homes 5632			Large Multifamily Buildings 6,134		
	NG/NG	Elect/NG	Elect/Elect	NG/NG	Elect/NG	Elect/Elect	NG/NG	Elect Baseload	FO/FO
Utilities Providing Data	373 (82%)	289 (84%)	373 (82%)	251 (70%)	137 (86%)	251 (70%)	120 (86%)	77 (85%)	31 (66%)
Starting Sample	16,985	16,985	5,317	1896	1896	2499	4,376	4,879	400
No Usage Data	7,005	7,053	2,800	818	876	1312	2,782	2,495	100
Available Insufficient Data/Poor Model Fit/Outlier	3,387	2,660	1,225	372	325	491	540	1,164	216
Total Usable Sample Cases	6,593	7,272	1,292	706	695	696	1,054	1,220	84
Non-	0	0	0	0	0	0	58	336	9

Sampled Cases									
Total Usable Cases	6,593	7,272	1,292	706	695	696	1,112	1,556	83

Table 7. Estimated Energy Savings by House Type for PY 2008 and 2010

Program Year/Home Type	2008	2008	2010	2010
	Total MMBtu Saved	MMBtu/ Unit Saved	Total MMBtu Saved	MMBtu/ Unit Saved
Site Built Homes (1-4 units)	1,8400,000	29.3	5,730,000	26.6
Mobile Homes	284,000	16.0	790,000	16.4
Large Multi-family	144,000 (NYC LMF)	26.9	1,086,554	15.9
Total	2,268,000		7,609,628	

Table 8. Summary of Energy Cost Savings by House Type and Program Year

	2008	2008	2010	2010
	Total \$ Saved	\$ Saved/ Unit	Total \$ Saved	\$ Saved/ Unit
Site Built (1-4 units)	\$331,300,000	\$5,200	\$963,000,000	\$4,468
Mobile Homes	\$54,200,000	\$3,053	\$143,000,000	\$2,957
Large Multifamily	\$34,500,000 (NYC LMF)	\$6,460 (NYC LMF)	\$117,000,000	\$1,710
Total	\$420,000,000		\$1,223,000,000	

Table 9. Emissions Reductions Attributable to WAP for PY 2008 and PY 2010

PY 2008	Thousands of Metric (CO ₂)/Short Tons (lifetime of measures)					Monetized Benefit (PV millions 2013 dollars)					Total Monetized Benefit (millions \$)
	CO ₂	SO ₂	NO _x	PM	VOC	CO ₂	SO ₂	NO _x	PM	VOC	
Single Family	1633	2.2	1.3	0.08	.05	\$62	\$59	\$11	\$4	\$0.4	\$136
Mobile Homes	302	0.4	0.2	0.02	.009	\$12	\$10	\$2	\$0.7	\$0.05	\$25
Small Multifamily	132	0.2	0.1	.006	.004	\$5	\$3	\$1	\$0.3	\$0.04	\$9
Large Multifamily	178	0.4	0.1	.005	.003	\$7	\$68	\$5	\$2	\$0.1	\$82
Total -- Aggregate	2246	3.3	1.8	0.1	0.07	\$85	\$139	\$19	\$8	\$0.6	\$252
PY 2010	CO ₂	SO ₂	NO _x	PM	VOC	CO ₂	SO ₂	NO _x	PM	VOC	
Single Family*	5583	7.9	4.4	0.3	0.2	\$213	\$194	\$37	\$15	\$1.3	\$460

Mobile Homes	888	1.6	0.7	0.06	0.02	\$34	\$34	\$4	\$3	\$0.1	\$75
Large Multifamily	912	1.0	0.7	0.03	0.03	\$35	\$58	\$11	\$4	\$0.6	\$109
Total -- Aggregate	7382	10.5	5.8	0.4	0.2	\$282	\$287	\$52	\$22	\$2	\$645

* Single-family category includes the small multifamily building category in PY 2010.

Table 10. Selected Health and Safety Impacts of Low-Income Weatherization

Health & Safety Impact	Pre-Wx	Post-Wx	Change
Asthma Symptoms (< 3 months since last) (%yes)	70.5%	58.7%	-11.8%
Asthma Emergency Department Visits (%yes)	15.8%	4.3%*	-11.5%
Asthma Hospitalizations (%yes)	13.7%	10.6%	-3.1%
Kept home at unsafe temperature past year (1=almost every month, 4=never)	3.69	3.91***	0.22
Medical attention too hot (%yes)	2.4%	1.5%*	-0.9%
Medical attention too cold (%yes)	3.2%	1.5%	-1.7%
Number of days previous month physical health not good	10.3	5.4***	-48%
Number of days previous month mental health not good	7.1	3.7***	-48%
Number of days previous month did not get enough rest or sleep	11.7	6.6***	-44%

*** p<.001; ** p <.01; * p<.05

Table 11. Selected Household Budget Impacts of Low-Income Weatherization

Trade Offs	Pre-Wx	Post-Wx	Change
How hard is it to pay your energy bills (1= very hard, 5= not at all hard)	2.18	2.88***	0.70
How often not purchased food to pay energy bills past year (1= every month, 3= every few months, 6= never)	5.00	5.23**	0.23

How often not paid energy bills to purchase food past year (1= every month, 3= every few months, 6= never)	5.31	5.55**	0.24
Household member went without food (past 4 weeks) (%yes)	7%	5%	-2%
Worried household members wouldn't have nutritious food (past 4 weeks) (%yes)	23%	18%**	-5%
Received food stamps or WIC assistance past year (%yes)	56%	50%	-6%
Needed to see doctor but could not because of cost (%yes)	32%	24%**	-8%
Household members had trouble paying medical bills) (1= yes, 0= no)	.41	.32**	-9%
Household member needed prescription medicines but couldn't afford (1= yes, 0= no)	.33	.22***	-11%
How often didn't fill prescription/took less to pay utility bill (1=every month, 3= every few months, 6= never)	5.28	5.51**	0.23

*** p<.001; ** p <.01; * p<.05

Table 12. Present Value of Per Unit and WAP Program Health-Related Benefits of Weatherization

	Total	Total (Value of Life Excluded)	Tier 1		Tier 2		Tier 3	
			Societal	Household	Societal	Household	Societal	Household
Asthma	\$2,009	-	\$1,852	\$157				
Thermal Stress-Cold	\$3,911	\$172	\$3,892	\$19				
Thermal Stress-Heat	\$870	\$85	\$855	\$15				
Food Assistance		-						
Reduction	\$832		\$832					
Reduction in Missed Days at Work	\$201	-	\$40	\$161				
CO poisoning	\$154	\$7			\$153	\$1		

Improve ment in Prescrip tion		-				-		
Adheren ce	\$1,929				\$1,929			
Reducti on in								
Use of		-			-			
Short- Term								
Loans	\$71					\$71		
Home Fires	\$831	\$175					\$768	\$63
Increase d								
Producti vity at Work		-						-
Due to								
Improve d Sleep	\$1,813						\$1,813	
Increase d								
Producti vity at Home		-					-	
Due to								
Improve d Sleep	\$1,329							\$1,329
Reducti on in								
Low- Birth Weight								
Babies from		-						-
Heat-or- Eat								
Dilemm a	\$198						\$198	
Total by Tiers			\$7,471	\$352	\$2,082	\$72	\$2,779	\$1,392
(Present Value	\$14,148	-						
Per Unit)			\$7,823		\$2,154		\$4,171	
Total by Tiers			\$600,33	\$28,29	\$167,31	\$5,766,8	\$223,324,	\$111,878,
(Present Value			3,094	5,957	0,541	63.04	724.16	910.72
WAP	\$1,136,88	-						
Progra m)	3,221							
			\$628,629,051		\$173,077,404		\$335,176,766	

Table 13. Energy Cost Savings, Efficiency Measure Costs, and Cost-Effectiveness by Building and Fuel Type (2013 Dollars)

	PY 2008			PY 2010		
	PV Energy Cost Savings	Measure Costs	Savings to Investment Ratio (90% C.I)	PV Energy Cost Savings	Measure Costs	Savings to Investment Ratio
Single Family*	\$5,337	\$3,096	1.72 (1.35 - 2.26)	\$4,468	\$3,990	1.12 (0.82 - 1.53)
Mobile Home	\$3,053	\$2,961	1.03 (0.83 - 1.32)	\$2,957	\$3,737	0.79 (0.66 - 0.97)
Small Multifamily	\$4,618	\$2,878	1.60 (1.23 - 2.16)	--	--	--
Large Multifamily**	\$6,460	\$3,336	1.82 (2.32 - 5.33) ⁺	\$1,996	\$2,976	0.67 (0.55 - 0.84)
All types	\$4,890	\$3,070	1.59	\$3,681	\$3,745	0.98

* SF category includes SMF in PY 2010

** LMF category only includes buildings weatherized in New York City in PY 2008

+ Buildings heated with fuel oil.

Table 14. Total Benefits and Costs for WAP PY2008 & PY 2010

	Present Value Per Unit PY 2008	Present Value Program PY 2008	Present Value Per Unit PY 2010	Present Value Program PY 2010
Energy Cost Savings	\$4,890*	\$420,000,000	\$3,681	\$1,233,000,000
Accrued to Households	\$3,814	\$327,800,000	\$2,872	\$962,000,000
Accrued to Ratepayers	\$1,075	\$92,000,000	\$809	\$271,000,000
Environmental & Water Benefits	\$3,118	\$266,945,000	\$2,130	\$694,000,000
Emissions Tier 1	\$2,932	\$252,000,000	\$1,944	\$645,000,000
Water Savings Tier 3	\$186	\$14,945,000	\$186	\$49,000,000
Health & Household-related Benefits**	\$14,148	\$1,137,000,000	\$14,148	\$3,731,000,000
Tier 1	\$7,823	\$657,000,000	\$7,823	\$2,156,000,000
Tier 2	\$2,154	\$174,000,000	\$2,154	\$570,000,000
Tier 3	\$4,171	\$335,000,000	\$4,171	\$1,100,000,000
Total Benefits	\$22,156	\$1,852,945,000	\$19,959	\$5,753,000,000
Total Costs ¹	\$4,695	\$481,000,000	\$6,812	\$2,320,000,000
DOE	\$2,295	\$235,000,000	\$5,926	\$2,018,400,000
Leveraged Funds	\$2,400	\$246,000,000	\$886	\$301,600,000

* – Excludes LMF outside of NYC

** – Excludes LMF

Highlights

- This paper presents estimates attributable to the Weatherization Assistance Program
- Energy savings were estimated by home type and climate zone
- Environmental emissions and health and household non-energy impacts were estimated
- The total benefits attributable to WAP are greater than the total program costs

DAAO Workpaper JS 5 - Customer Late Fees

Description: This workpaper is an adaptation of discovery response DAAODE-1.1 - 1.5 provided by J.E. Sparks. Columns F&G and rows 19&20 added by Witness Schott are highlighted in bold. No original formatting or data from the discover response has

Michigan Public Service Commission
DTE Electric Company
Customer Service

Case No: U-21534
Discovery Request DAAODE-1.1 - 1.5
Witness J.E Sparks
Page 1 of 1

Electric Residential Customers

Columns F&G Added

Billing Year	Customer Type*	Number of Customers	Reconnect Fees**	Late Fees**	Late Fee Percentage	Per customer	Bill Doc Total Sales (kWh)	Bill Doc Amount Excl Tax	Service Charge	Power Supply Charge	Distribution Charge	Bill Doc Tax Amount
2021	LI	149,740	\$439,680	\$4,902,463	2.3%	\$ 32.74	1,247,037,135	\$211,261,023	\$14,045,676	\$119,662,702	\$77,552,645	\$12,128,316
2022	LI	153,379	\$801,160	\$5,818,833	2.8%	\$ 37.94	1,214,277,574	\$208,145,778	\$14,414,713	\$119,809,599	\$73,921,466	\$12,638,571
2023	LI	160,946	\$604,160	\$6,623,751	3.2%	\$ 41.16	1,135,213,626	\$206,907,055	\$16,597,629	\$119,178,582	\$71,130,844	\$12,874,966
2021	Non LI	1,834,183	\$919,580	\$9,427,742	0.3%	\$ 5.14	15,136,465,100	\$2,725,317,826	\$173,160,977	\$1,442,587,548	\$1,109,569,301	\$114,779,865
2022	Non LI	1,838,520	\$1,415,580	\$10,609,248	0.4%	\$ 5.77	14,594,741,273	\$2,694,212,173	\$175,262,686	\$1,430,156,944	\$1,088,792,543	\$114,159,329
2023	Non LI	1,840,589	\$1,387,260	\$10,784,018	0.4%	\$ 5.86	13,384,788,565	\$2,645,366,629	\$197,044,912	\$1,402,790,319	\$1,045,531,399	\$113,006,694
Totals (added from original)			\$5,567,420	\$48,166,054								
Total late + reconnection fees, 2021-2023				\$53,733,474								

*LI defined as customers having an active low income profile (at or below 200% FPL) at any time during the corresponding billing year

**Reconnect and Late Fees dataset are fees that were assessed and not necessarily collected

Surcharges are included in the power supply and distribution charge

DAAODE-1.1 - 1.3					DAAODE-1.4	
	Number of Customers	Bill Doc Total Sales (kWh)	Bill Doc Amount Excl Tax	Avg. Use per month (kWh)		Avg. Bill (excluding tax)
LI	160,946	1,135,213,626	\$206,907,055	587.8		107.13
Non LI	1,840,589	13,384,788,565	\$2,645,366,629	606.0		119.77
Total	2,001,535	14,520,002,191	\$2,852,273,684	604.5		118.75
Percent LI	8.0%					

Michigan Public Service Commission
DTE Electric Company
Customer Service

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Witness J.E Sparks
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Electric Residential Customers

Billing Year	Customer Type*	Number of Customers	Reconnect Fees**	Late Fees**	Bill Doc Total Sales (kWh)	Bill Doc Amount Excl Tax	Service Charge	Power Supply Charge	Distribution Charge	Bill Doc Tax Amount
2021	LI	149,740	\$439,680	\$4,902,463	1,247,037,135	\$211,261,023	\$14,045,676	\$119,662,702	\$77,552,645	\$12,128,316
2022	LI	153,379	\$801,160	\$5,818,833	1,214,277,574	\$208,145,778	\$14,414,713	\$119,809,599	\$73,921,466	\$12,638,571
2023	LI	160,946	\$604,160	\$6,623,751	1,135,213,626	\$206,907,055	\$16,597,629	\$119,178,582	\$71,130,844	\$12,874,966
2021	Non LI	1,834,183	\$919,580	\$9,427,742	15,136,465,100	\$2,725,317,826	\$173,160,977	\$1,442,587,548	\$1,109,569,301	\$114,779,865
2022	Non LI	1,838,520	\$1,415,580	\$10,609,248	14,594,741,273	\$2,694,212,173	\$175,262,686	\$1,430,156,944	\$1,088,792,543	\$114,159,329
2023	Non LI	1,840,589	\$1,387,260	\$10,784,018	13,384,788,565	\$2,645,366,629	\$197,044,912	\$1,402,790,319	\$1,045,531,399	\$113,006,694

*LI defined as customers having an active low income profile (at or below 200% FPL) at any time during the corresponding billing year

**Reconnect and Late Fees dataset are fees that were assessed and not necessarily collected

Surcharges are included in the power supply and distribution charge

DAAODE-1.1 - 1.3 DAAODE-1.4

	Number of Customers	Bill Doc Total Sales (kWh)	Bill Doc Amount Excl Tax	Avg. Use per month (kWh)	Avg. Bill (excluding tax)
LI	160,946	1,135,213,626	\$206,907,055	587.8	107.13
Non LI	1,840,589	13,384,788,565	\$2,645,366,629	606.0	119.77
Total	2,001,535	14,520,002,191	\$2,852,273,684	604.5	118.75

STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the application of **DTE
ELECTRIC COMPANY** for authority to
increase its rates, amend its rate schedules
and rules governing the distribution and
supply of electric energy, and for
miscellaneous accounting authority

Case No. U-21534

ALJ Sally Wallace

PROOF OF SERVICE

I, Mark N. Templeton, certify that an electronic copy of the Official Exhibits DAO-117 to DAO-140 sponsored by Justin Schott (Part 3 of 10) on Behalf of Soulardarity and We Want Green, Too was served on the following on September 12, 2024.

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The statements above are true to the best of my knowledge, information, and belief.

UNIVERSITY OF CHICAGO LAW SCHOOL
ABRAMS ENVIRONMENTAL LAW CLINIC
Counsel for Soulardarity and
We Want Green, Too

Date: September 12, 2024

Sincerely,



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