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TOPICAL REVIEW

High energy burden and low-income energy affordability: conclusions from a literature review

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Abstract

In an era of U.S. energy abundance, the persistently high energy bills paid by low-income households is troubling. After decades of weatherization and bill-payment programs, low-income households still spend a higher percent of their income on electricity and gas bills than any other income group. Their energy burden is not declining, and it remains persistently high in particular geographies such as the South, rural America, and minority communities. As public agencies and utilities attempt to transition to a sustainable energy future, many of the programs that promote energy efficiency, rooftop solar, electric vehicles, and home batteries are largely inaccessible to low-income households due to affordability barriers. This review describes the ecosystem of stakeholders and programs, and identifies promising opportunities to address low-income energy affordability, such as behavioral economics, data analytics, and leveraging health care benefits. Scalable approaches require linking programs and policies to tackle the complex web of causes and impacts faced by financially constrained households.

1. The energy poverty problem

Energy drives the U.S. economy and impacts nearly every dimension of modern society; it is an imperative to 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 1970s when the U.S. Congress authorized the creation of the Weatherization Assistance Program (WAP) and the Low-Income Home Energy Assistance Program (LIHEAP), the nation's largest low-income energy programs, the nature of household energy consumption has evolved. For decades, the energy consumed by a typical household increased as suburbanization and sprawl allowed 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 often stayed put in the older core of American cities, following the concentric zones of American cities first identified by Park and Burgess (1925), in the first theory developed to explain the distribution of social groups in American cities.

Over time, these trends have reversed. Increasingly, congested urban areas have motivated the gentrification of inner cities, re-densifying older neighborhoods, 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. Innovations have continued to transform home energy use, most recently with the proliferation of increasingly efficient appliances, smart thermostats, solid state lighting, low-emissivity windows, foam insulation, and heat pumps, slashing the intensity of the average home's energy use. Rooftop

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solar panels have reached 'grid parity' in some parts of the U.S.,[6] and soon home energy storage systems and electric vehicles will enable households to arbitrage their energy assets.

In the midst of this transformation and in a new era of energy abundance—as the U.S. becomes a net energy exporter (U.S. Energy Information Administration (EIA) 2018), it is time to review what we know about the energy consumption and energy bills paid by 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 stakeholders across the U.S.—chiefly utilities and federal and state agencies, but also non-profits and religious organizations as well as cities and community organizations—work to save energy and reduce the energy costs of low-income households. Yet energy bills as a percent of household incomes (that is, household 'energy burden') remains persistently high among low-income populations across the U.S. (Drehobl and Ross 2016).

The paper begins by characterizing the magnitude, causes, correlates, and impacts of the energy burden currently experienced by low-income households in the U.S. It then describes the complex web 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 existing 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). We end with conclusions about opportunities to scale up such efforts so that the energy-poverty cycle in the U.S. can be broken.

1.1. The energy equity lens

Issues of equity permeate the transition to a smarter and greener energy economy (Sovacool *et al* 2016, Valentine *et al* 2019). The nature and location of energy financing and infrastructure investments can cause low-income households to benefit or lose. For example, few low-income households participate in energy-efficiency, solar, and electric vehicle programs, but these programs are financed by raising the electric rates of all customers (Johnson *et al* 2017, Sigrin and Mooney 2018, Monyei *et al* 2019). While such inequitable impacts of electricity and natural gas tariffs can be offset by modest low-income energy assistance programs (Borenstein and Davis 2012), few utilities provide such compensation. Overall, the U.S. is experiencing a growing wealth disparity between low-income households and more affluent Americans (Curti *et al* 2018), and living in minority communities often means more limited access to resources (Reames 2016, Sunter *et al* 2019). This intersection of race, ethnicity and class can lead to problems of procedural, distributive and intergenerational equity (Curti *et al* 2018, Carley 2020a, 2020b).

1.1.1. Procedural equity

Procedural equity is the idea of fairness and transparency of the processes that allocate resources and resolve disputes. Connected to the desire for due process, one aspect of procedural equity relates to administrative and legal proceedings. Inclusive and authentic engagement in the process to develop, implement, and adjudicate programs or policies is key to procedural equity (Curti *et al* 2018, p 9).

Economically disadvantaged communities across the country are amplifying their voices to ensure that the clean energy transition considers their needs. For example, the Future Energy Jobs Act (FEJA) in Illinois materialized with the help of a coalition of interest groups, increasing investment in energy efficiency and targeting economically disadvantaged communities (Goldberg and Mckibbin 2018). Similarly, a coalition of advocates in Pennsylvania organized a collaborative multidisciplinary movement that drove improvements to low-income energy-efficiency policy across the State (Grevatt *et al* 2018).

1.1.2. Distributive equity

Distributive equity refers to fairness in the allocation of rights or resources, arguing that one's place of birth, social status, and family influences are matters of luck that should not unduly influence the benefits we receive in life (Rawls 1971). 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, and prioritizing those with the greatest need (Curti *et al* 2018, p 9).

[6] www.greentechmedia.com/articles/read/gtm-research-20-us-states-at-grid-parity-for-residential-solar#gs.7enug2.

Numerous clean energy programs fail tests of distributive justice, including many energy-efficiency programs, special rates for electric vehicles, and net metering of rooftop solar installations. Such programs are typically paid for in part by low-income ratepayers who do not receive commensurate benefits (Chant and Huessy 2018, Carley *et al* 2018).

1.1.3. 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 (Williams-Rajee 2015). Most clean energy programs do work to reduce CO_2 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.

1.2. The context: multiple stakeholders in the low-income housing market

Numerous decision-makers and stakeholders influence the energy integrity of low-income housing. 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. Local NGOs and community-based organizations are also key stakeholders based on this tally, while at the other extreme, property and building managers are not mentioned in the 183 abstracts. This figure 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.

1.3. Scope and structure of literature review

Our literature review began with a formal and systematic search of the peer-reviewed published literature and the associated grey literature of more informal documents. For the peer reviewed literature, the Web of Science bibliography was searched using a syntax of keywords that included synonyms of three attributes: low-income household status, energy efficiency and solar energy, and evaluation and data analysis. All three dimensions were required, at least one author had to be from the U.S., and the papers had to be published in the 2010–2018 timeframe. The resulting 270 peer-reviewed publications were culled for out-of-scope citations and also 'mined' for additional as the citations embedded in the original 270 publications were examined. This produced a curated set of 171 publications.

We then used a Delphi approach (i.e. consulting with experts in the field) to ensure our inclusion of the important grey literature—including conference proceedings and reports of trade associations, government agencies, and NGOs. An extensive review process by the U.S. Department of Energy resulted in 12 additional documents, bringing the final annotated bibliography to 183 references (Lapsa *et al* 2020). Because energy efficiency, PV systems, electric vehicles, home storage, and microgrids can all influence energy burdens, the technology scope of this bibliography and our review is quite broad. In 2020, Oak Ridge National Laboratory (ORNL) published a meta-review of these articles, and the results of that review are summarized in this paper following further assessment and consideration of the findings (Brown *et al* 2020).

2. The energy burden of low-income households: a persistent problem

Low-income households in the U.S. are diverse, as are their patterns of energy consumption. Perhaps it is therefore not surprising that multiple measures of energy burden are used to describe their energy consumption patterns, how these patterns have changed over the past decade, and the causes and effects of high energy burden among low-income households (figure 1).

2.1. Variable and inconsistent metrics

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 ORNL (Eisenberg 2014) and the non-profit agency, Economic Opportunity 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

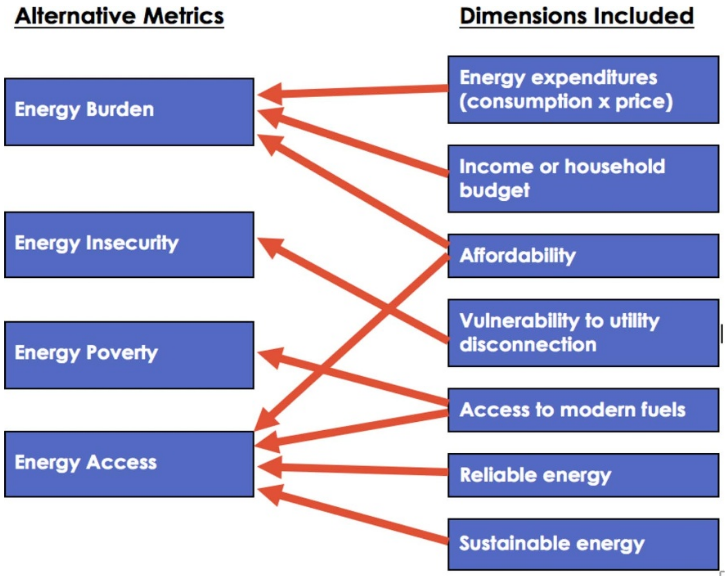

Figure 1. Alternative metrics and definitions. (Source: authors.)

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 total income or household budget. Energy expenditure is usually measured by looking at the total spending on household utility bills for heating, cooling, and other home services (Berry *et al* 2018). Most energy burden studies do not analyze household spending on transportation energy or water expenditures, nor do they examine or include different sources of financial support as household income. Based on data from 2013–2014, 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).

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 (2018) 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%. Based on this study, approximately 11% of Colorado residents were energy impoverished in 2015. In 2017, the same metric is 12% for Georgia (Cox 2019).

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 (Verclas and Hsieh 2018). Elnakat *et al* (2016) and Ross *et al* (2016) document that the incidence of energy security varies by region with the highest rates in the South; there are also strong correlations with gender, age, and level of education.

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 (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 (EIA 2000, Begay 2018b).

In the international literature, 'energy access' is a common term, and is the basis of the United Nation's Sustainable Development Goal (SDG) 7 as adopted in 2015. 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, but many groups face high energy burdens.

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 for program managers and policy analysts because the extent and nature of the energy burden problem depends on the definition used (Berry *et al* 2018, Lin 2018b). With inconsistent definitions, it is difficult to compare results across studies and derive lessons learned. Nevertheless, consequential conclusions are broadly substantiated.

First and foremost, low-income households spend a higher proportion of their income on energy bills than any other income group (Eisenberg 2014, Drehobl and Ross 2016, Berry *et al* 2018). This is true, even though low-income households consume less energy per capita and they spend less on energy per square foot of living space than other households (Drehobl and Ross 2016).

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

Third, energy security is significantly more problematic for low-income households than for other income groups. Davis (2015)[7] estimates that 40% of households with income below $50 000 find it difficult to pay their energy bills at least 'once in a while.' 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, but they appear 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).

Fourth, the energy consumption patterns of low-income households depend on the gender, age, race, education, occupation, and geography of their members (Elnakat *et al* 2016). Kontokosta *et al* (2019) examined an extensive database describing 3122 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. 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. Household energy patterns range widely across highly urbanized areas (Porse *et al* 2016), suburbs (Verclas 2018), and rural and remote locations (Souba and Mendelson 2018, Lin 2018b, Ross *et al* 2018, Begay 2018a, 2018b). 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 low-paying professions, while others are unskilled or semi-skilled, working in low-wage jobs in retail, hospitality, and health services (Schwartz 2014).

2.2. Causes and correlates of high energy burden

The underlying causes of high energy burden can be divided into five main categories—location and geography, housing characteristics, socio-economic situation, energy prices and policies, and behavioral factors (table 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 pay higher-than-average bills for both electricity and heating fuels (Shoemaker *et al* 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).

At the other extreme, low-income households in the nation's largest cities are home to higher-than-average energy burdens (Drehobl and Ross 2016). Fox (2016) and Brown (2018) document the problem of low-income burdens in Southeastern cities, where poverty rates are high, and households consume significant amounts of energy for both heating and cooling to keep their old and leaky homes livable. Further, HVAC systems in the South tend to be electric whereas heating in most other regions is dominated by natural gas, which tends to be more affordable.

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 burdens (Langevin *et al* 2013, Berkland *et al* 2018). These housing units usually have inefficient

[7] http://defgllc.com/news/article/how-well-are-you-reading-your-low-income-customers/.

Table 1. Causes and correlates of high energy burden.

Location and Geography	Housing Characteristics	Socio-economic Situation	Energy Prices and Policies	Behavioral Factors
• Rural, urban, remote community, Native American, island territory • Climate • Population density • Urban morphology (affecting access to jobs and efficient appliances)	• Characteristics of the building (manufactured, multifamily or single-family) • Rental and public housing • Type of appliances used • Type of thermostat: WiFi, smart, programmable, touch screen	• Income • Ethnicity and race • Immigrant vs native-born • Number of occupants, children, elderly, and handicapped	• Energy prices and 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 multi-family homes) • Lifestyle cultural factors • Lack of control over energy bills • High non-monetary costs

insulation and older appliances, further adding to the energy burden (Cabeza *et al* 2014). In addition, residents of rental housing often do not have control over their energy bills; for example, building management may control the heating and cooling settings, resulting in both a lack of control and thermal discomfort. 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, socioeconomic characteristics determine a household's ability to afford energy-efficiency retrofits and more energy-efficient appliances (Thorve *et al* 2018). For decades, de facto and de jure segregation pushed minorities, especially African Americans, into less-desirable lower quality housing.[8] Interestingly, Hernández *et al* (2016) find that while immigrant families and African Americans both have high housing costs, the utility costs are higher for African American families due to differences in energy related behavior. 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 hours when it matters most.

The fourth category of cause for energy burden are energy prices and policies. For example, high fixed components in power bills or reconnection fees are important barriers to reducing energy bills. Inter-regional comparisons of energy rates and energy burdens have not identified a correlation (Drehobl and Ross 2016), presumably because of autocorrelations with other regionally diverse factors. For instance, southern cities tend to have lower electricity rates, but higher energy burden. Where rates are low, the return-on-investment in energy efficiency is more challenging, which has resulted in less efficient housing in the South than compared to other regions (Brown *et al* 2014).

The fifth category covers behavioral determinants of energy consumption. Despite the stated willingness of households to conserve energy and invest in energy-efficient appliances, there is often incongruity between the values and actual behavior of customers based on their various internal and external determinants including liquidity and few nearby vendors of energy-efficient equipment (Brown and Sovacool 2018, Reames *et al* 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 working with local community agencies that already offer a variety of human services and have people with completed income qualification paperwork for other programs (food, housing, medical care, etc.). This is particularly valuable for a program like WAP since its administrative costs are generally capped at 10%.

Lack of knowledge is another hurdle to participation and energy-efficiency investments. It is especially evident in rental apartments where tenants do not have control over appliance choices and insulation but have to pay the bills (a type of 'split incentive' problem) (Brown 2001). Landlords know more than tenants about the energy integrity of their units, leading to uninformed housing choices by tenants and excessive energy use (Brown and Wang 2015, Berkland *et al* 2018). In general, low-income households are often unaware of the effect their energy choices have on bills and the possible ways of reducing consumption. This

[8] Rothstein 2017. The Color of Law: A Forgotten History of How Our Government Segregated America. Liveright Publishing.

asymmetry of information leads tenants to make uninformed housing decisions, rendering them 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).

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 (Hernández *et al* 2016, Camprubí *et al* 2016). These trade-offs create a negative feedback loop that traps families in an enduring cycle f poverty. For example:

- Low-income families unable to pay their high energy bills become vulnerable to utility shut-offs and evictions (see section 5.2).
- 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 difficult (Levy and Sledge 2012, Tonn *et al* 2015, Brown 2018).

Adverse health effects of high energy burdens can span a range of illnesses and conditions. These include thermal discomfort and respiratory problems such as asthma (Fabian *et al* 2014, Wells *et al* 2015, Chen *et al* 2017), and exposure to lead and indoor air pollution (Fabian *et al* 2012). The fear of not being able to pay bills and the possibility of losing electricity service altogether can stress mental health problems. There are also health effects related to the inefficient energy usage and poorly insulated buildings that are amplified for families with young children, the elderly, and African Americans—groups that often have limited adaptive capacity because of fewer resources (Hernández *et al* 2016, Massetti *et al* 2017).

3. The ecosystem of low-income energy programs and policies

Across the U.S., many programs and policies help to reduce the energy burden of low-income households (Brown and Wang 2015, Berg *et al* 2018). 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. 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.[9] 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 green energy transition. 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).

This complex ecosystem of energy policies does not target the needs of low-income households. Indeed, there is a growing body of literature that questions the fairness of policies that promote the clean energy transition when they are largely inaccessible to low-income households due to affordability barriers. 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.

[9] Database of State Incentives for Renewables & Efficiency (DSIRE) Financial Incentives for Energy Efficiency (2012).

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 this U.S. ecosystem are numerous and diverse energy programs and policies that do target low-income households, which are summarized in tables 2 and 3, 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 non-profit organizations. Program types distinguish between utility bill assistance, financial incentives, energy information, and regulations. Gilleo *et al* (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.

In recent years, approximately 80% (or about $6.3 billion) of low-income energy funding has been spent on bill payment assistance, 14% ($1.17 billion) on energy efficiency, and 5% ($38 million) on unspecified support (Cluett *et al* 2016, p 7) (figure 2). Utilities are the single largest source of funding for low-income energy programs: providing 41% of ratepayer-funded low-income bill assistance and 10% of the total for ratepayer-funded low-income energy efficiency. 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 WAP). In 2016, the block grant allocation to LIHEAP was $3.3 billion, re-allotment funds were $1.2 million, and funds carried over from previous year was $167 million.[10] State and local contributions at 3% and non-profit organizations at 2% complete the picture.[11]

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.[12]

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.[13]

Over the past decade, annual expenditures on low-income energy-efficiency programs have ranged widely between about $1 and $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 about 1000 Subgrantees. With leveraging, the national weatherization network expenditures rose to $2.7 billion[14] (Tonn *et al* 2015). In the post-ARRA period, WAP has been operating at approximately the pre-ARRA Congressional appropriation level, increasing to $254 million in 2019 and $308.5 million in 2020.[15]

3.1. Electric and gas utility programs and policies

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

10 https://liheappm.acf.hhs.gov.

11 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.

12 http://neada.org/state-tribal-programs/state-energy-assistance-directors/.

13 www.ncoa.org/wp-content/uploads/Alternative-Sources-of-Energy-Assistance.pdf.

14 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 *et al* 2015).

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

Table 2. 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

and 34% of residential natural gas efficiency spending, while the target segment of the population accounts for roughly one-third of total households (U.S. Census Bureau 2018).[16]

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 (Frank and Nowak 2015).[17] Utility

16 www.census.gov/quickfacts/fact/table/US/PST045217#PST045217.
17 https://beccconference.org/wp-content/uploads/2015/10/presentation_frank.pdf.

Table 3. Summary of benefits from DOE weatherization assistance program in 2008 and 2010.

Program Wide Benefits for All Housing Types		
	2008	2010
Total Homes Weatherized	97 965	340 158
Average Cost per Weatherized Home	Total Cost: $4695 DOE Investment: $2301	Total Cost: $6812 DOE Investment: $5926
Average Energy Measure Costs	$2899	$3545
Energy Savings Per Household (Present Value)	$4243	$3190
Total Energy Savings (Present Value)	$340 million	$1.2 billion
Savings-to-Investment Ratio	1.4[a]	0.98[a]
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)

[a] 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.(Sources: Tonn *et al* 2014, DOE 2015, Tonn *et al* 2018)

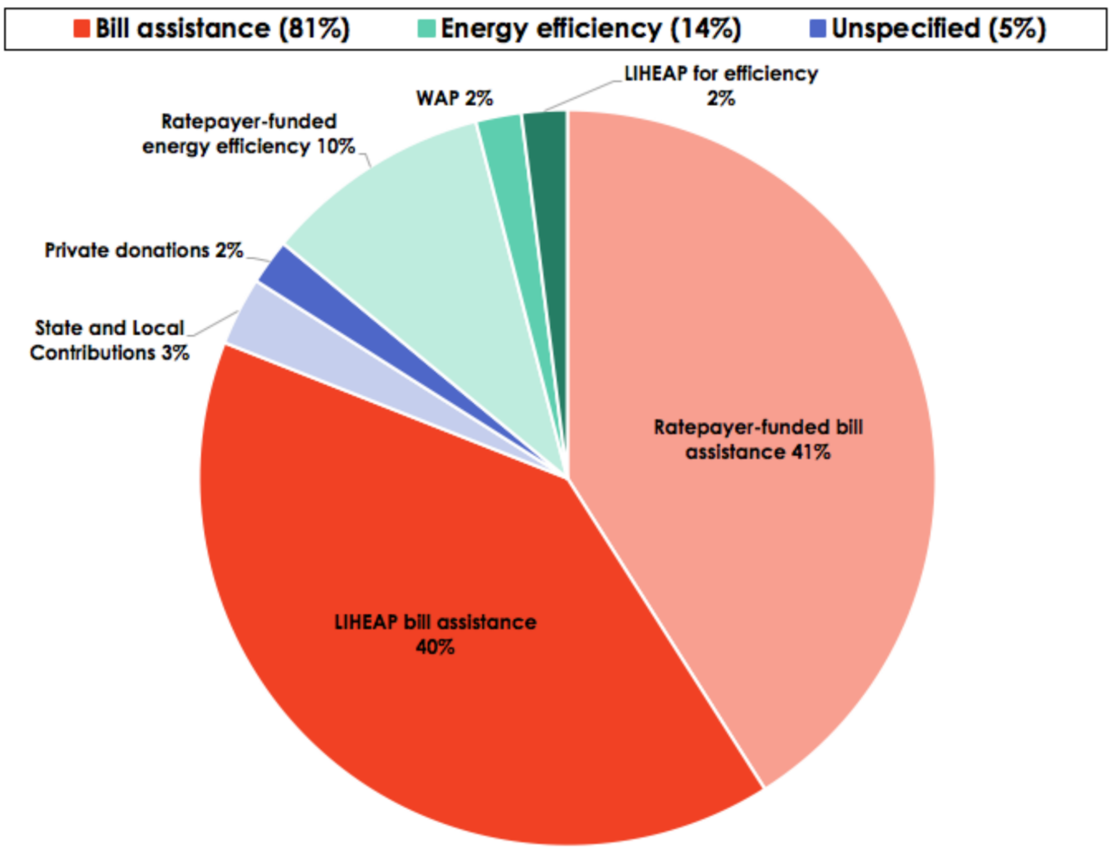

Figure 2. Expenditures on low-income energy programs in 2013–2017 (Note: excludes solar energy programs). (Source: authors, based on data from Hoffman *et al* (2018) and Cluett *et al* (2016).)

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 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, because they often require up-front costs to participate.[18]

The nation's 51 largest electric utilities spent 8.93% of their total energy-efficiency program funds on low-income programs, saving on average 5.29 kWh of electricity per low-income customer in 2016. However, the low medians for both of these statistics (6.23% of total spending and 2.80 kWh of savings per low-income customer), suggest 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 (Relf *et al* 2017).

A similar pattern of spending and accomplishment was reported in a survey of the largest electric and natural gas utilities serving the nation's 51 largest metropolitan statistical areas (MSAs). In 2015, 49 MSAs were served by a low-income electricity efficiency program, and 32 were served by a low-income natural gas efficiency program. Of the low-income customers served by these utilities, only 1.2% participated in electricity efficiency programs and only 1.5% participated in natural gas efficiency programs. Further, the amount spent, and savings achieved are highly variable across programs and fuels (Drehobl and Castro-Alvarez 2017):

- An average of $1538 was spent and 1377 kWh was saved per participating household.
- Per low-income customer, these averages drop to $3 and 22 kWh.
- For natural gas, slightly more ($2002) was spent per estimated low-income participant, and 135 therms were saved.
- Per low-income customer, these averages drop to $23 and 3 therms.

Of this sample, the cities served by utilities with the largest expenditures per low-income customer were Boston, San Antonio, Providence, San Francisco, and Hartford (figure 3). But in terms of kWh of electricity savings per low-income customer, the cities with the most impactful utilities were Boston, Hartford, San Antonio, Hartford, Providence, and Louisville, which each saved >50 kWh per low-income customer. 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.

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 suggest that the Pay-as-You-Save approach offers an effective approach. In Arkansas, 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.

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, offer payment plans, and implement alternatives to shutting off services. They can also eliminate late fees and interest payments 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.[19]

Utility companies and their customers can both benefit from assistance with arrearages 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.

3.1.1. 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

[18] www.cee1.org/annual-industry-reports.

[19] www.nclc.org/issues/prepaid-utility-service.html.

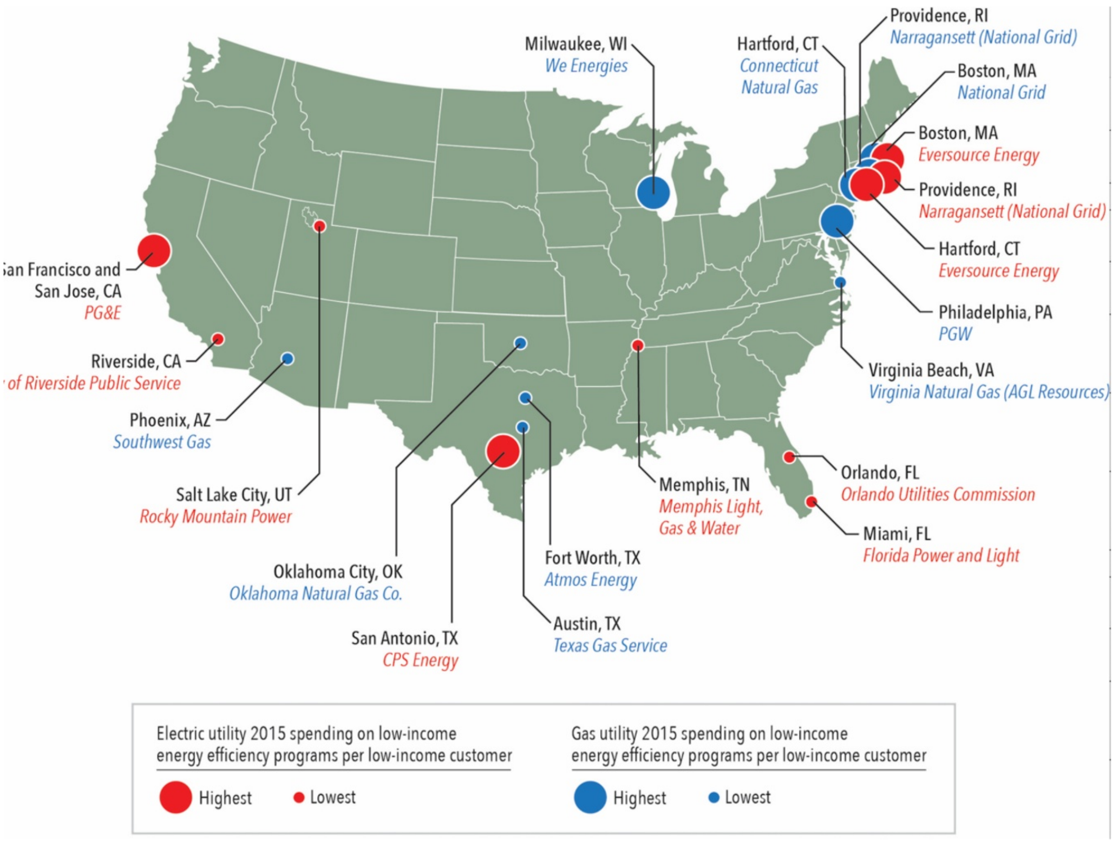

Figure 3. Electric and gas utility spending on low-income energy-efficiency programs per low-income customer in 2015. (Source: authors, based on data from Drehobl and Castro-Alvarez (2017).)

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 800 old homes (20 years +) located in lower-income communities served by seven local power companies; each pilot had an electric energy usage reduction target of 25% per home.[20] To assess future options to address energy equity, TVA created the Energy Efficiency Information Exchange. One of their key recommendations was adopted: to integrate TVA's eScore technology platform & training systems with WAP in order to streamline multiple aspects of WAP implementation to build capacity and serve more customers.[21]

Local power companies can also initiate program and project proposals, which are then reviewed by Utility Commissions and 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 (RIM) (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. The inverse of this is also true: the more weight the RIM test is given, the less likely that low-income energy efficiency programs will be approved (Brown and Wang 2015).

3.1.2. Residential on-bill lending 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 that are repaid through utility bills. Such loans can help overcome the liquidity and budget constraints of low-income households. Tying repayment to

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

[21] https://annualmeeting.naseo.org/Data/Sites/1/events/Annual-Meeting/2017/presentations/Cripps-TVA-Low-Income-Program-Highlights.pdf.

utility bills, allows households to consider energy upgrades as an operational savings rather than a capital expenditure (Gillingham *et al* 2009). While these programs require the participation of a utility, they also often 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). Energy saving performance contracts also address the problem of up-front financing.[22]

Two types of designs are currently used. On-bill loans create consumer debt that is tied to the borrower and is paid back through the bill. Alternatively, on-bill tariffs are tied to the meter and therefore are transferred to subsequent renters or owners of the property (Ross *et al* 2018). The tariff design helps to address split incentive barriers that renters may face, as the investment stays with the property and not the tenant.

Pay as You Save® (PAYS®) financing is the most prominent on-bill financing program; it uses a tariff design (Lin 2018a). 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 non-payment 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.

Based on an early assessment of on-bill financing, defaults are uncommon (Bell *et al* 2011). While on-bill loans would appear to be promising for owner-occupied housing, they may not be a good fit for building owners who take on the liability for the debt, but whose tenants typically have responsibility for the energy bills (Brown and Wang 2015). Also, property lien can have negative consequences. For example, households with liens on properties in Atlanta, Georgia, were deemed ineligible for accessing a tax relief fund for legacy residents.[23]

3.1.3. 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. 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.’[24]

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-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 non-profit 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 non-profit organizations in the seven counties the cooperative serves.[25] 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 totaling more than $100 000 each year since 2016.

[22] https://www4.eere.energy.gov/seeaction/publication/energy-efficiency-financing-low-and-moderate-income-households-current-state-market.

[23] Source: Erin Rose, Three Cubed, personal communication, August 2019.

[24] https://legiscan.com/TN/text/SB0308/2019.

[25] www.ngemc.com/ORU.

3.1.4. 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 postpaid 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 passed a resolution advising utilities that 'Rates for prepaid service are lower than rates for comparable credit-based service,…'[26] Data on the adoption of prepaid service and its impact on rates and disconnection times are difficult to obtain.

3.1.5. 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 since customers do not see seasonal or monthly variations in cost (Treadway 2018). Getachew *et al*[27] estimates that BB increases energy consumption by 3.8% to 4.7%, on average. Sexton (2015) found that automatic bill payments (ABP) and BB 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.[28]

3.1.6. Disconnection alterntives

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).

[26] http://nasuca.org/nwp/wp-content/uploads/2014/01/NASUCA-2011-3.pdf.

[27] https://beccconference.org/wp-content/uploads/2017/10/sadhasivan_presentation.pdf.

[28] 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.

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 households earning less than $25 000,[29] 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).[30]

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.'[31] 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.[32] 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.

3.2. Federal programs and policies

The dominant low-income federal programs and policies are the WAP operated by DOE and the 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) are also described because of their pertinence to low-income households.

3.2.1. DOE weatherization assistance

DOE's WAP 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-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 *et al* 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

[29] www.statista.com/statistics/203183/percentage-distribution-of-household-income-in-the-us/.
[30] https://supreme.justia.com/cases/federal/us/436/1/.
[31] Mathews v. Eldridge, 424 U. S. 319. Pp. 436 U. S. 16–19.
[32] https://supreme.justia.com/cases/federal/us/436/1/.

- 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 WAP 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.'[33] Hundred percent 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.

In 2015, utilities and states supplemented DOE funding by providing an additional $883 million, or $4.62 for every dollar invested by DOE.[34] 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.[35]

3.2.2. LIHEAP bill assistance

LIHEAP is a federally-funded program that helps low-income households meet their immediate home energy needs. LIHEAP began in the 1970s in response to increasing energy prices that made it difficult for low-income families to pay their utility bills.

HHS operates LIHEAP in every state and the District of Columbia, as well as on most tribal reservations and U.S. territories. Congress established the formula for distributing funds to Grantees based primarily on each state's weather, fuel prices, and low-income population. Grantees can use funds for heating and/or cooling costs as well as up to 15% of their funding (or 25% with a waiver) for weatherization assistance. The parameters on how these households are assisted are very broad, but the majority of the funds are used for two-party checks between the bill payer and the utility company.

According to the National Energy Assistance Director's Association, 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).

Collaboration between LIHEAP and WAP has proven 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.[36] 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 Statute requires that Grantees receive a state waiver to increase the maximum from 15% to 25%. NASCSP tracks the leveraging of each state. 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).

HHS requires Grantees to have a plan for 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. LIHEAP weatherization investments must be for cost-effective, residential weatherization measures or other energy-related home repairs that do not constitute construction.

[33] https://nascsp.org/wp-content/uploads/2017/09/WAP_ProgramOverviewFactSheet_3.16.17.pdf.
[34] https://nascsp.org/wp-content/uploads/2017/09/WAP_ProgramOverviewFactSheet_3.16.17.pdf.
[35] https://liheappm.acf.hhs.gov/data_warehouse/index.php?report\protect$\relax=$homepage.
[36] www.rd.usda.gov/programs-services/energy-efficiency-and-conservation-loan-program.

3.2.3. 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 EECLP operated by the USDA and the LIHTC tax credit monitored by the Internal Revenue Service. 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.[37] 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 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. LIHTC was authorized in the Tax Reform Act of 1986; it has supported more than 2 million housing units to date.[38] 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.

3.3. State programs and policies

Many State Energy Offices play active roles in extending energy-efficiency benefits and other energy services to low-income customers. State and regional resources that fund these initiatives include the Regional Greenhouse Gas Initiative, State Energy Program, Qualified Energy Conservation Bonds, state revolving loan funds, state treasure funding, general obligation bonds, utility ratepayer funds, and environmental settlements funds.

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, including (1) goals that specify minimum levels of expenditure or savings and (2) cost-effectiveness testing that gives extra credit for improving low-income energy efficiency. Nearly half of states have spending requirements for their low-income energy-efficiency programs, but only Pennsylvania and California have low-income savings requirements (Berg and Drehobl 2018). For example, the Illinois FEJA directed utilities to implement designated levels of low-income energy efficiency. In addition, Ameren Illinois Corporation was required to spend at least $8.35 million per year (Simms and Casentini 2018).

Adders to 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 often not held to the same cost-benefit requirements or thresholds as other types of residential efficiency programs.

3.4. 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 livable-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 a value chain approach to design such programs for communities in upstate New Hampshire.

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

[37] www.rd.usda.gov/programs-services/energy-efficiency-and-conservation-loan-program.

[38] https://betterbuildingssolutioncenter.energy.gov/sites/default/files/PP_Incorporate%20EE%20RE%20Standards%20as%20a%20Criterion%20in%20Tax%20Credits_FINAL_3.pdf.

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.[39] The Bristol Energy Efficiency Assistance Program partnered with an existing program in the City of Bristol that provided housing repair assistance 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.

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.[40]

NGOs operate energy and affordable housing initiatives at all scales from the local to the international. For example, the National Center for Healthy Housing, 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.[41] 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.

4. The impacts and cost-effectiveness of low-income energy programs 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 WAP 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

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). 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.

4.1.2. DOE weatherization assistance program

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 $4243 and energy measure costs of $2899, 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

[39] 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.
[40] www.greenenergytimes.org/2018/12/17/weatherize-campaigns-spread-across-new-hampshire/.
[41] https://nchh.org/information-and-evidence/learn-about-healthy-housing/healthy-homes-principles/.

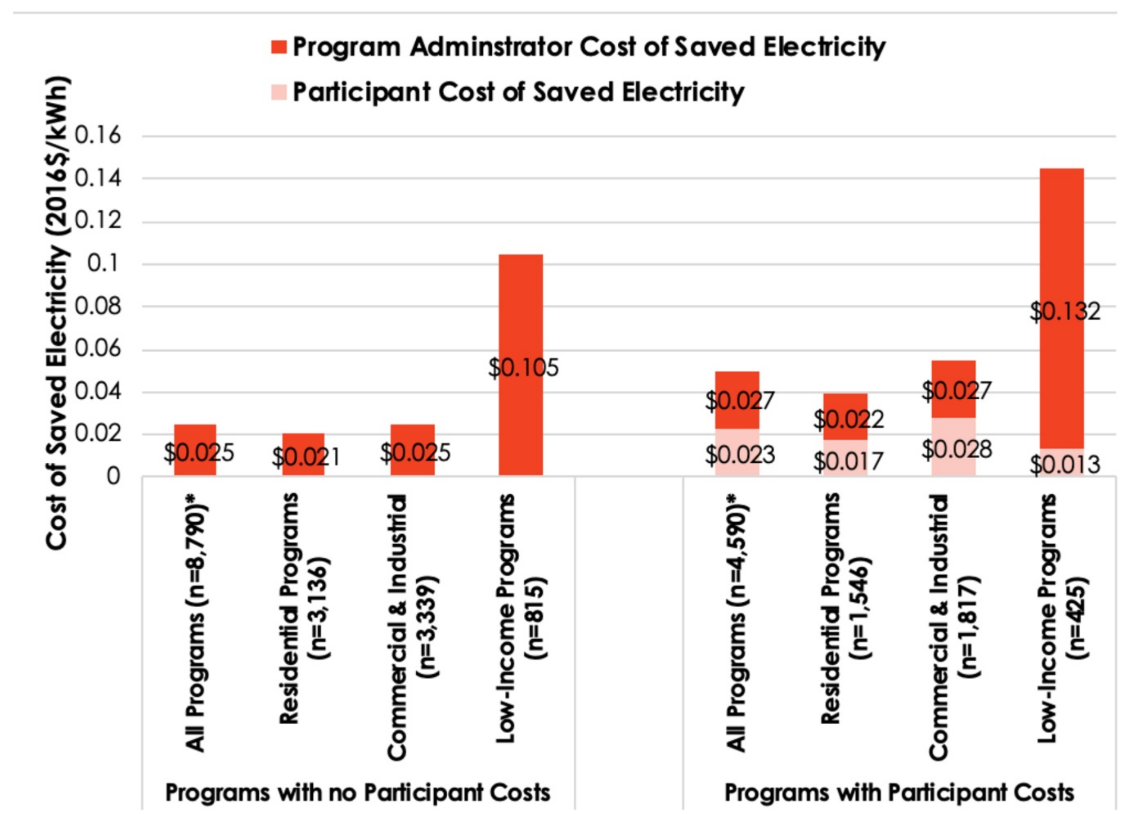

Figure 4. Cost of saving electricity in utility energy-efficiency programs. (Source: authors, based on data from Hoffman *et al* (2018).)

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.

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. 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 WAP 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: multi-family and rental markets, rural communities, and manufactured and mobile homes.

Multifamily buildings are home to nearly 25% of the U.S. population and more than half of low-income households (Frey *et al* 2015, Hernández *et al* 2016, Corso *et al* 2017). For a variety of reasons including high land values, cities and urban areas have a disproportionate number of multifamily buildings (Hernandez and Phillips 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 challenges (Fabian *et al* 2012, Waite *et al* 2018) At the same time, these households are often underserved by traditional energy-efficiency programs (Ross *et al* 2016, Berkland *et al* 2018).

These markets have been hard to reach by traditional utility and government programs (Henderson 2015, Corso *et al* 2017). A major reason is that when tenants pay the energy bills, the building owner may not be motivated to invest in improvements since the bill savings accrue to occupants (Reina and Kontokosta 2017). Similarly, tenants may not be incentivized to save if they are not paying the bill, as in master-metered buildings (Brown 2001, Inskeep *et al* 2015).

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 (Henderson 2015, Frey *et al* 2015, Chant *et al* 2016). Further, government control over multifamily units that form part of public housing make it easy 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 *et al* 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 *et al* 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 *et al* 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).

Low-income households in **rural communities** often spend as much as a quarter of their income on energy (Ross *et al* 2018), due partly to the low-density built environment enabled by lower land values. Lower densities can make it difficult to access energy-efficiency programs resulting in high program implementation costs (Shoemaker *et al* 2018). Rural communities also have high gas pipeline construction costs, making it difficult for residents to convert from electricity, fuel oil, kerosene and other fuels to natural gas, which is often the least-cost fuel for home heating (Ross *et al* 2018). As a result, their fuel mix is distinct, as are their regulatory structures.

Native American reservations also have similar trends and account for some of the highest rates of energy poverty in the U.S. Their off-grid homes span the contiguous United States and Alaska (Begay 2018a). Connecting to the grid to bring electric services 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 local resources could help rejuvenate the economies of rural communities (De Silva *et al* 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 on-grid electric power.

Several programs have been piloted and rolled out to reduce energy burdens and increase access in these communities over time. They 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 the challenge of split incentives. Similarly, community-based programs where partnerships with NGOs are 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).

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. 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.[42]

4.3. Technologies and measures installed

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 5). 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 *et al* (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.

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. This study highlights the importance of thoughtful consideration of weatherization program goals when selecting cities or regions to prioritize because different goals suggest different approaches.

4.4 The energy saving potential of low-income households in the U.S

In a study of the 48 largest cities in the country, Drehobl 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 FPL 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.

[42] https://aceee.org/blog/2016/08/mobile-homes-move-toward-efficiency.

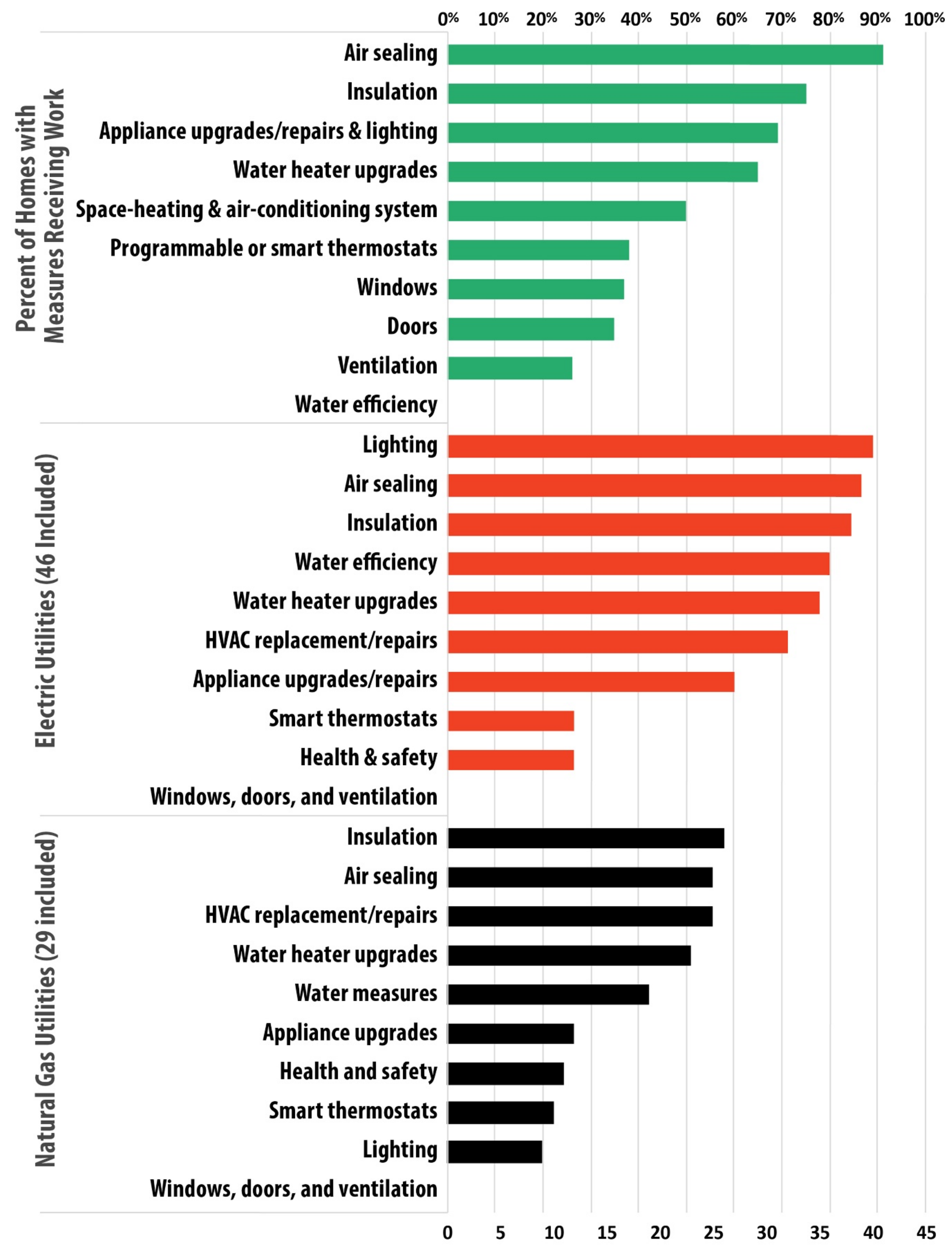

Figure 5. Measures installed in low-income programs. (Source: authors, based on data from Tonn *et al* (2014), Drehobl and Castro-Alvarez (2017).) Note: the top graph refers to measures installed by the Weatherization Assistance Program in 2008. The middle graph refers to measures installed in low-income programs operated by electric utilities in 2015. The bottom graph refers to measures installed in low-income programs operated by gas utilities in 2015.

5. Promising practices

Several practices appear to be particularly promising as effective ways to reduce low-income energy burdens—behavioral economics, data analytics, solar energy, advanced information and communications, and leveraging health care benefits.

5.1. 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 behavior. Well established concepts in behavioral and experimental economics on principal agent problems, information asymmetry, and bounded rationality inform this research (Simon 1976, Brown 2001, Gillingham *et al* 2009, Allcott and Rogers 2014). 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 (Sunstein and Reisch 2014, Allcott and Taubinsky 2015, Chetty 2015). Behavioral motivations may include monetary gains, information campaigns, education programs, audits and energy reports (Drehobl *et al* 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 (Sunstein and Reisch 2014, Allcott and Taubinsky 2015, Chetty 2015). As noted earlier, the incongruence between households' values and intrinsic and extrinsic factors can limit their ability to invest in energy saving activities. This gap is especially relevant for low-income households, which generally have lower energy literacy than other income groups.[43]

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 (Craig 2016, Drehobl *et al* 2018, Simms and Casentini 2018). Most low-income adults (and especially women and homeowners) are interested in learning about ways they can save on their electric or heating bills and avoid paying late fees and reconnection charges (Treadway 2018).

Some studies indicate there may also be high non-monetary costs associated with participation in a weatherization program that affect participation (Hirshfield and Iyer 2012, Fowlie *et al* 2015). 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 energy initiatives have the advantage of knowing and being more closely in touch with their local target market. 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. Further, designing a marketing model of local programs that takes 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 *et al* (2014) also note the potential for increasing energy efficiency by integrating technology that provides information on energy usage to low-income households. In-home displays, energy-efficiency coaching, and providing usage information have all been successful strategies (Donovan *et al* 2014).

5.2. Data analytics

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 All,[44] and NREL ResStock[45] 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 (Wierzba *et al* 2011, Hosgoer and Fischbeck 2015, Nahmens *et al* 2015, Porse *et al* 2016, Reina and Kontokosta 2017, Long *et al* 2018, 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 the energy sector on consumers. For example, Johnson *et al* (2017) use data from the PJM markets to estimate the effect of high solar PV

43 https://nef1.org/wp-content/uploads/2018/11/NEF-National-Energy-Literacy-Survey-White-Paper-181115.pdf.
44 https://maps.nrel.gov/solar-for-all/?aL=6m-d90%255Bv%255D%3Dt&bL=clight&cE=0&lR=0&mC=38.870832155646326%2C-98.34521484375001&tour=splash&zL=5.
45 www.osti.gov/biblio/1436972.

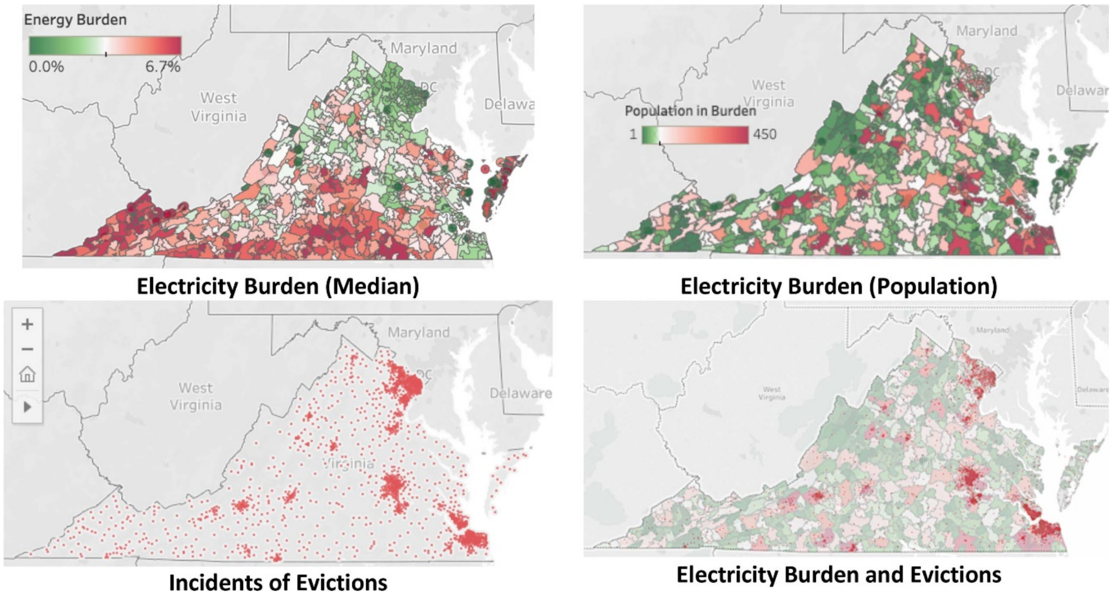

Figure 6. Data analytics of energy burden and evictions across zip codes in Virginia.[46]

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 programs and project designs (Hoffman 2017); 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 6).

Integrating new technology for collecting, generating data 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).

5.3. Solar energy for low-income households

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. Solar energy can significantly reduce energy burdens in targeted areas today, while also generating living-wage jobs and displacing pollution from fossil fuels, which can mitigate historic environmental injustices (Franklin and Osborne 2017). 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 in the U.S. to tackle energy poverty among its 35 000 remote off-grid tribal members, living in vast and rugged terrain, with dispersed housing, where solar PV rooftop systems are overcoming this rural electrification dilemma (Begay 2018b).

Programs are emerging that target barriers to solar installations for low-income households. They include rooftop solar and community solar initiatives.

Rooftop solar programs include 'Solarize' and 'Solar for All' campaigns.

[46] www.thegreenlinkgroup.com/energy-equity.

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 6000 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.[47]

Another sizeable community-led solar aggregation and energy efficiency program is targeting low-to-moderate-income residents of Northern Manhattan (Roundtree Jr. 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 (MASH) 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. 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 *et al* 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 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 (2018) 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 pilot program (Verclas 2018), and Vermont has also hybridized all three types of measures—energy efficiency, solar, and electric vehicles—with home energy storage.

Recent studies have also found evidence that despite high solar rooftop potential, many LMI communities might not be able to leverage the benefits for a variety of reasons such as income, demographic characteristics, language proficiency, age of the housing stock, and internet access (Reames 2020). As such, understanding local conditions and 'dynamics', and accounting for disparities along social and cultural characteristics can help design equitable and more successful programs.

Community solar helps low-income households take advantage of utility-scale 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

[47] https://doee.dcgov/solarforall.

Table 4. Favorite way to receive daily account information from local electric utility.

	Number of Households	Age		Household Income	
		18–54	55 +	<$25 K	$25 K to $49
Total Respondents with HH Income	(534)	(364)	(170)	(232)	(302)
Less than $50 000	%	%	%	%	%
Email	45	42	53[a]	41	48[a]
Text message	15	16	12	19[a]	12
Mobile app notification	12	15[a]	4	8	15[a]
More than one channel (phone, text message, email or app)	10	11	10	10	11
Recorded phone call	4	4	5	6[a]	3
Do not 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.
[a] Indicates figure is significantly higher than other sub-group at a 95% confidence level. The Russell Omnibus was conducted via the Internet among 1092 adults 18 years of age or older from October 21–24, 2016.(Source of Data: Treadway 2018)

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 from will not reach underserved communities (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 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 MASH in California which is utility-sponsored, co-op power in New York which is a non-profit, and the Maryland PSC pilot program that is Utility Sponsored. Like many Solarize programs, Solarize Mass-Somerville is a community shared 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, program 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 *et al* 2017, Cook and Shah 2018, 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, 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 for the future of community solar is that utilities are motivated to develop it not only to satisfy consumer demand or meet regulatory requirements for renewable energy, but also to alleviate revenue losses related to residential solar PV (Funkhouser *et al* 2015). 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. As the community solar models get adopted widely, it is pertinent to remain cognizant of the definition of communities and avoid any potential 'community washing' (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 (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.

5.4. Advanced information and communication technologies (ICT)

Digital, market-based programs are being used to educate, incentivize, incentivize and 'nudge' consumers to purchase energy-efficient products (Niederberger 2018). Adopting market-based and behavioral strategies supported by data to target online marketing and incentives 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 increasingly 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 (along with enabling resources to invest in upgrades), 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 and the use of a mobile app were viewed as the preferred information mechanism by 15% and 12% of respondents, respectively (table 4). Consistent with the digital divide, older and lower-income households are less likely to prefer the use of mobile apps (Treadway 2018).

One way for households to easily access and recognize their energy consumption is through the use of smart meters and thermostats (Brown *et al* 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.[48]

'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 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.[49]

5.5. 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 venting can exacerbate asthma and other respiratory problems for occupants (Batterman *et al* 2012, Doll *et al* 2016). Bad 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 (Hernández *et al* 2016).

The physical and mental health benefits of energy-efficiency upgrades are well documented (Fabian *et al* 2012, 2014, Frey *et al* 2015, Camprubí *et al* 2016, Leventis *et al* 2017, Coombs *et al* 2018). Surveys and case studies of residents systematically identify favorable health effects (Hernandez and Phillips 2015, Hernández *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 exceeds those of its energy benefits (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 providing healthy low-income housing, and the energy industry often cannot invest in energy-efficiency measures or install solar PV 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

[48] Nest Thermostat Real Savings. (n.d.). Retrieved April 22, 2018, from https://nest.com/thermostats/real-savings/.
[49] https://vandebron.nl/about; https://arena.gov.au/assets/2017/10/Final-Report-MHC-AGL-IBM-P2P-DLT.pdf.

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 and 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).

6. Conclusions

In the midst of a rapidly transforming energy system, this paper reviews the literature to assess how low-income 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.

The last decade has produced a large and expanding literature on low-income energy burden. This literature supports several broad conclusions with equity implications.

- Energy burden is higher among low-income households than other income groups.
- Low-income energy burden 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.
- 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 several 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 equity through program design and implementation

A majority of 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 (Cluett *et al* 2016, Hoffman *et al* 2018, Bednar and Reames 2020).
- 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 home owners, 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.

- 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 policy 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.
- The SIR 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 stakeholders. A coordinated approach to home energy, health, safety, and housing could reduce low-income energy burden while delivering numerous other benefits. 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 efficiently. At the same time, the expansion of home working, schooling, exercising, and cooking during the COVID-19 pandemic—made easier by advances in on-line and real-time computing—may portend a future with more home-based activities and higher home energy bills. Thus, the home environment may increasingly determine society's health and prosperity, underscoring the need for effective programs to help low-income households cope and adapt.

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