

Findings from a Pilot Led Bulb Exchange Program at a Neighborhood Scale

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Abstract

In the U.S. 44% of low-income households struggle to pay their utility bills, affecting their ability to afford necessities such as food and health expenses. Several government and utility funded energy efficiency programs exist to assist those experiencing energy insecurity. In Salt Lake City, Utah, there is a high demand for, but low availability of, energy efficiency services in underserved neighborhoods creating an opportunity for creative community-based programs to fill this inherent gap. This pilot project, involving the exchanging of LED bulbs in Salt Lake City, highlights the development of a community-based energy efficiency program that aims to bring energy savings to a uniquely targeted portion of the city and determines its feasibility in addressing energy insecurity at a larger scale. Through the 8-month project duration, 1,432 bulbs were exchanged at 23 events reaching 181 households in low-income areas. Through a year of use, these bulbs are estimated to save residents approximately \$18,219 in electricity bills and reduce CO₂ emissions from power plants by 122.23 metric tons, in addition to a savings of \$4,400 in social cost of carbon as defined by the U.S. Environmental Protection Agency. Since this pilot reached less than 1% of households, we extrapolated a reach of 2%, 5%, and 7.5% and found substantial potential decreases in power plant emissions and financial savings. As this project is ongoing and being expanded, we discuss relevant findings that will help shape future community-based models so that they are appropriately deployed and more effective in alleviating local energy insecurity.

Keywords

LED lighting; energy efficiency; electricity consumption; social cost of carbon; CO₂ emissions; community programs

1. Introduction

1.1 Motivation

1.1.1 Air quality in SLV

Salt Lake City (SLC), Utah's capital city with a population of 200,000, lies within Salt Lake County (SLCo), and is located at the heart of the Wasatch Front (Figure 1). The Wasatch Front is the main metropolitan area of the state of Utah with approximately 35% of the state's population residing in Salt Lake County alone (Kem C. Gardner Policy Institute, 2017). The Salt

Lake Valley (SLV) is bounded by the Wasatch Mountain Range to the east, Oquirrh Mountain Range to the west, the Traverse Mountains to the south, and the Great Salt Lake to the Northwest, resulting in a topographical bowl of mountains that almost completely surround the SLV.

This unique geography has serious implications on local air quality and makes Salt Lake County especially vulnerable to both wintertime and summertime air pollution issues. SLCo is especially susceptible to winter inversions that trap ground-level particulate matter in the valley. During the winter, elevated fine particulate matter (PM_{2.5}) results from a combination of increased local urban emissions due to heating demands and atmospheric inversion events. Much like the majority of the Western U.S., the SLV faces elevated ozone levels due to large amounts of solar radiation and high elevation, in addition to emissions from fossil fuel combustion.

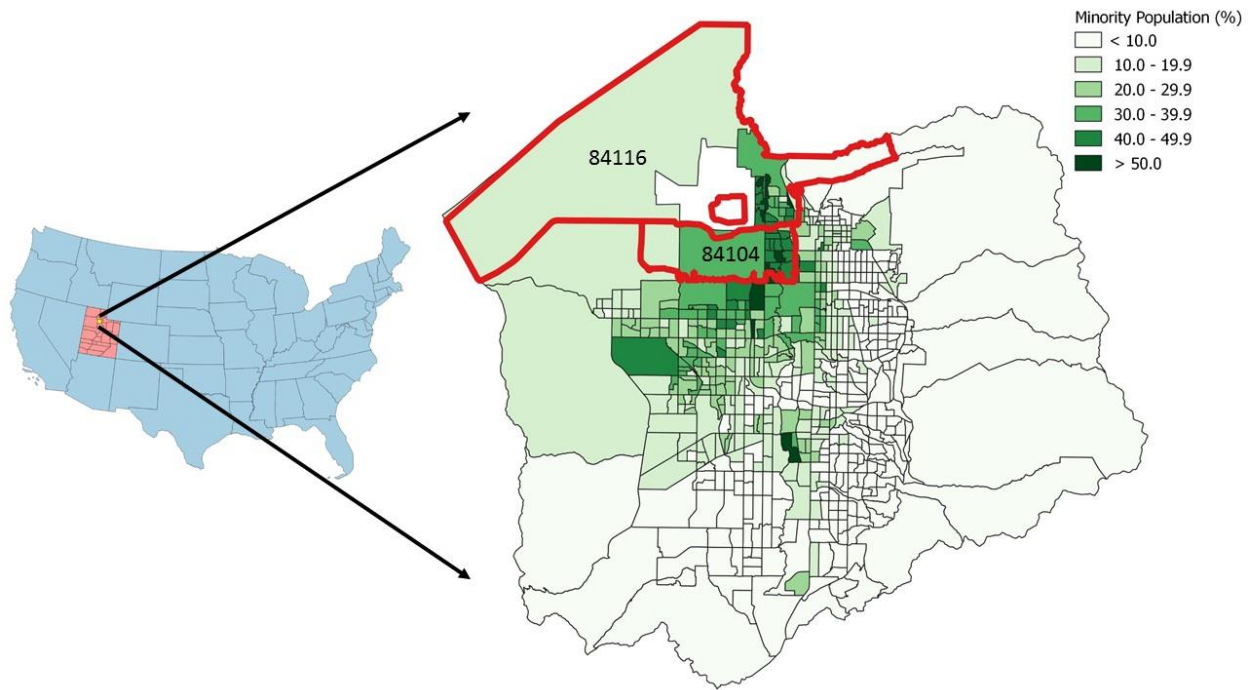


Figure 1. Study area showing the location of ZIP Codes 84104 and 84116 (outlined in red) within Salt Lake County, Utah, along with average household income.

These seasonal periods of poor air quality in the SLV are significant enough to warrant national attention. In 2018, the American Lung Association’s annual “State of the Air” report recognized the Salt Lake City metro area (SLC/Provo/Orem) as one of the “most polluted” cities for short-term particle pollution - number 8 on the list (American Lung Association, 2018). Additionally, the U.S. Environmental Protection Agency designated Salt Lake County—along with six other counties in Utah—as a “serious nonattainment” area for failing to meet the National Ambient Air Quality Standards (NAAQS) for short term (24-hour) particulate pollution for PM_{2.5}, particulates that are 2.5 microns in diameter or smaller (Utah Department of Environmental Quality, 2017). The average amount of winter days when air quality exceeds unhealthy levels, also known as red air days, is between 15-20 a year, and individual pollution events last between 5 and 7 days.

Several studies have focused on the wintertime elevated $PM_{2.5}$ (Baasandorj et al., 2017; Bares et al., 2018) and summertime elevated ozone (Horel et al., 2016; Lareau et al., 2012) levels in the Salt Lake Valley. Using a state-of-the-art mobile observation platform that includes instrumentation mounted on light rail trains (Mitchell et al., 2018) and a news helicopter (Blaylock, Horel, & Crosman, 2017), large spatial and temporal gradients in pollutant concentrations have been observed across Salt Lake County. The health impacts of poor air quality in Utah range from high incidences of pneumonia (Pirozzi et al., 2018), to increased hospitalizations due to respiratory issues (Horne et al., 2018). Furthermore, emerging associations between poor air quality and negative health outcomes such as pre-term births (Hackmann & Sjöberg, 2016) and suicides (Bakian et al., 2015) have been found in the Salt Lake Valley and Utah, furthering the importance of pollutant reduction strategies.

1.1.2 Socioeconomic divide & air quality implications

While the entire Salt Lake Valley is prone to experiencing severe air pollution, certain parts of the city are more likely to experience elevated levels of $PM_{2.5}$. These areas are largely concentrated in the commonly defined “West Side” of Salt Lake City that lies west of I-15. Substantial spikes in air particulates on SLC’s West Side are largely attributable to its numerous industrial facilities that include the airport, railways, refineries, as well as heavily trafficked highways (Figure 2). The combination of industrial polluters and significant vehicle emissions contribute to an air quality landscape that contains larger and more instances of emissions sources than other parts of the SLV.

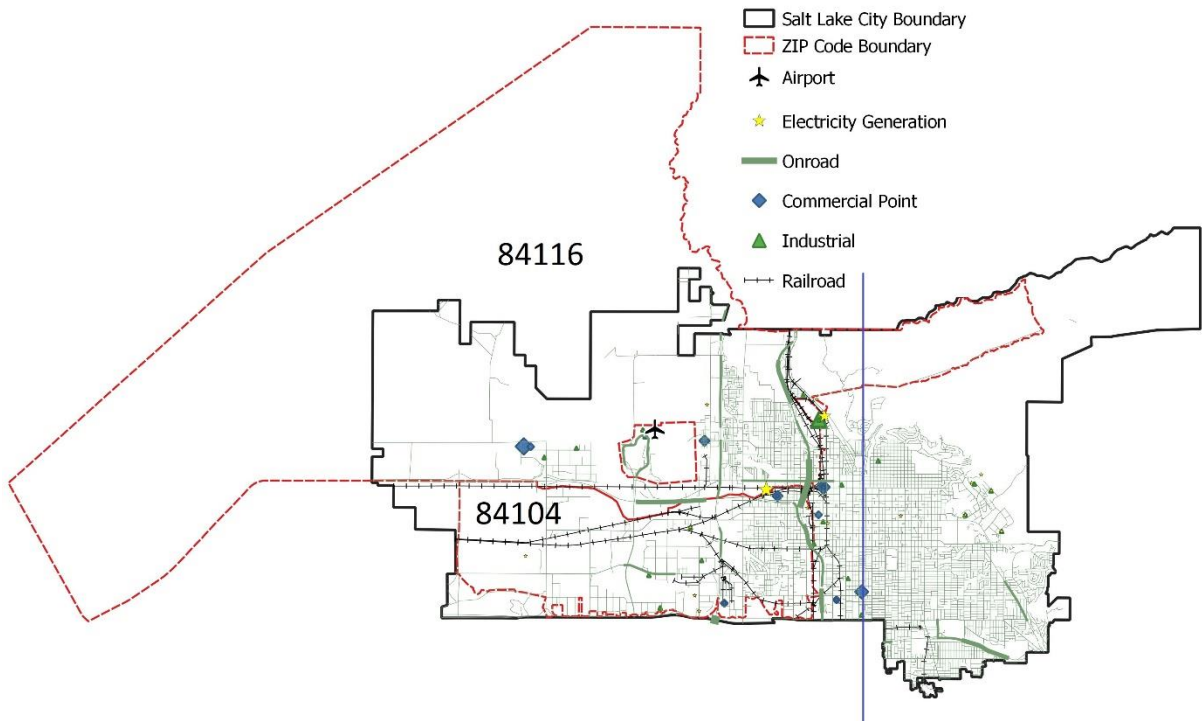


Figure 2. Emission sources in Salt Lake City and North-South vertical line located on State Street, dividing the East from the West Side. Symbol size is associated with relative emission magnitude.

In addition to differences in air quality, the West Side of SLC also has a lower median household income than other parts of the city (U.S. Census Bureau; American Community Survey, 2018) and is the most culturally and ethnically diverse part of Utah. The combination of these factors poses challenges to the West Side to overcome the air quality burdens it faces. Residents of this area are also more likely to speak a language other than English, which makes many utility and advocacy group messages relating to air quality, relayed predominantly in English, unhelpful to the population. Additionally, West Side residents of lower socioeconomic status are unlikely to possess the financial resources necessary to make home improvements that protect their health and simultaneously lower energy bills.

1.1.3 Socioeconomic divide & energy insecurity

The West Side's lower median household income compared to the rest of SLC also makes its population more vulnerable to experience energy insecurity. Energy insecurity (also often referred to as energy poverty or fuel poverty), is the inability to afford to pay monthly utility bills to support proper heating, cooling, and other energy needs in the home (T. G. Reames, 2016). This issue is pervasive in the United States: nearly half (44%) of low-income households struggle to pay their utility bills (Cluett, Amann, & Ou, 2016). A study conducted by Dreihobl and Ross (2016), found that the median energy burden on the average American household was 3.5% of income, while the median energy burden on the average low-income household was more than twice as high, at 7.2% of income. Following low-income households, other vulnerable demographics that face a greater energy burden include African Americans (5.4%), Latinos (4.1%) and renters (4%) (Dreihobl & Ross, 2016). Households with high energy burdens often have to choose between paying for necessities, such as food and medical expenses, and adequate heating, cooling, and lighting. As a result, households with a high energy burden may be improperly heated or cooled, and maintain inadequate lighting (Dreihobl & Ross, 2016). These conditions can increase incidences of physical and psychological ailments. Research has shown that higher rates of asthma, respiratory problems, heart disease and stress may result from this unhealthy home environment (Dreihobl & Ross, 2016; Hernández & Bird, 2010; Heyman, Harrington, Heyman, & The National Energy Action Research, 2011; Liddell & Morris, 2010; Wright, 2004). What's more, Salt Lake County families who fall below 50% of the federal poverty level (i.e. those who have an annual income of \$24,600 for a family of 4) spend a staggering 21% of their income on energy (\$1,698/year or \$141/month) (Boyce & Wirfs-Brock, 2016).

Energy insecurity is a distributional justice issue, which concerns the equitable social distribution of a good or service. Distributional justice surrounding energy insecurity is primarily caused by income inequality, discrepancies in energy prices, and inconsistencies in housing stock and energy efficiency (T. G. Reames, 2016). Addressing energy justice requires an understanding of the three main components of the "justice framework". First, how environmental hazards are distributed throughout society; second, the distribution of benefits, such as affordable access to energy, throughout society; and third, equitable representation in decision-making (Sovacool, Heffron, McCauley, & Goldthau, 2016). Social perception also contributes to the injustice surrounding the provision of energy. In the U.S. there is an expectation of an energy-intensive standard of living with a low cost for utility services (Sovacool, 2009). This, coupled with a

general lack of knowledge about the intensity of energy use or how energy is produced, creates obstacles in alleviating the effects of energy injustice (Sovacool, 2009).

1.1.4 Local sustainability goals and activities that impact energy and air quality

Local communities are actively working to safeguard public health by making policy changes and sponsoring programs that are designed to reduce pollution. In November 2016, the Salt Lake City Council adopted a joint resolution to transition the Salt Lake City community to 100% renewable electricity by 2032 and to reduce greenhouse gas emissions by 80% by 2040 (Salt Lake City, 2016). This city-wide goal is intended to reduce carbon dioxide emissions associated with Salt Lake City's residential and commercial electricity usage, as 62% of the city's electricity is generated by burning coal (Rocky Mountain Power, 2015). The Salt Lake City government has pursued a multifaceted approach to reach these ambitious emissions reduction goals. In addition to programs and goals related to reducing emissions from energy use, Salt Lake City also seeks to incorporate social equity issues into its sustainability, energy, and air quality efforts. For example, in the approved 2017-2018 fiscal year budget, Salt Lake City's Mayor, Jackie Biskupski, proposed an appropriation of \$200,000 to develop City-level programming to assist low-income households with implementing energy efficiency improvements, "bringing increased equity to [the City's] goals" (Salt Lake City, 2017). In early 2018, these funds were committed to a competitive request for proposal process seeking the development of a Community Energy Engagement program that sought to improve energy efficiency among residents in Salt Lake City, including underserved residents, and to increase the number of energy efficiency actions implemented by small businesses. Other Salt Lake City initiatives designed to improve efficiency and reduce emissions include the adoption of a local ordinance developed to reduce emissions from municipal and large, private, non-residential buildings, and a joint community energy planning process between the City and utility Rocky Mountain Power to source one hundred percent renewable electricity ("Commercial Building Benchmarking and Transparency," 2017; Salt Lake City Corporation Department of Sustainability & Rocky Mountain Power, 2017; SLCgreen, 2017).

1.2 Existing Energy Efficiency Programs

1.2.1. Federal and Utility Energy Efficiency Programs in SLC

Two federal and state government programs that serve to address energy inequality are the Weatherization Assistance Program (WAP) (Department of Energy, 2018) and the Low-Income Home Energy Assistance Program, which in Utah is known as the Home Energy Assistance Target (HEAT) program (Stoltzfus, 2003). WAP is a Department of Energy program that assists income-qualifying households facing a high energy burden with safety, comfort, and efficiency improvements to their homes. Qualifying participants for this program must fall at or below 200 percent of the federal poverty line (Department of Health and Human Services, 2017) and are assisted through the provision of energy efficiency updates to homes to decrease home energy burdens. The HEAT program is another federally funded income-qualifying program that provides services to high energy-burden households in the form of utility bill and energy crisis assistance for households with incomes at or below 150 percent of the federal poverty level. Localized networks of government agencies and nonprofits distribute the funds for these programs.

While these essential programs aim to address injustices caused by energy disparity, they also undergo challenges in meeting the great need of services. Areas of difficulty in program execution are seen in the distribution of funds, variability in effectiveness of energy cost savings, and split-incentive issues. Bird and Hernández (2012) defined split incentives as "a circumstance of when the flow of investments and benefits are not properly rationed among the parties to a transaction, impairing investment decisions". WAP and HEAT programs receive federal funding through block grants, which are then distributed by local organizations (Kaiser & Pulsipher, 2006). Effective programs must achieve long-term energy savings by making the most energy-intensive sources in the home more efficient, but not all WAPs result in similar energy savings. Several factors, including fuel type, climate zone, and structure type vary cost-savings outcomes for program participants (Tonn, Rose, & Hawkins, 2018). A review of state WAPs by Dreihobl and Ross (2016) found that most commonly, weatherization efforts include lighting, insulation, and air sealing upgrades, but do not address electrical components or smart thermostat installation. Despite variability in state programs, the non-monetary benefits of program participation, such as increased health and safety factors, are not negligible (Cluett et al., 2016). WAPs provide services to vulnerable populations, including renters, who have the greatest need for such services. Renters often bear a greater burden in terms of split incentives, as they are at the mercy of their landlords' decisions to supply appliances, which carry little incentive to be energy efficient since utility bills are often paid by renters. There is a second, temporal component in split incentive problems. Renters typically have limited knowledge of how long they will reside in their residence, making high-capital cost efficiency investments risky if they do not remain in the unit long-term (Bird & Hernández, 2012).

In addition to government funded assistance programs, many utilities also offer low-income financial support and energy efficiency upgrade programs. Despite these programs, there is high demand for, but low availability of, energy efficiency services in underserved communities throughout Salt Lake City and surrounding areas. Two utilities serve Salt Lake City: Dominion Energy (natural gas) and Rocky Mountain Power (electric), both of which offer assistance programming. But these utility-sponsored programs fall short of the vast demand, with low-income households occupying a small proportion of spending for demand-side management programs. One study has examined utility and municipality low-income program spending in 51 US cities, including Salt Lake City, finding that both Dominion Energy and Rocky Mountain Power hold some of the lowest expenditures on low-income programs. Rocky Mountain Power was within the five lowest spending electric utilities, allocating \$0.30 per low-income customer. In contrast, the highest spending electric utility, serving Boston, allocates over \$90 per low-income customer (Dreihobl & Castro-Alvarez, 2017). In addition to low spending levels of low-income energy efficiency programs, the study also found that both Rocky Mountain Power (spending \$209 per participant) and Dominion Energy (spending \$721 per participant) fell into the list of the five lowest spenders on energy efficiency program funding per participant across U.S. utilities. For example, Rocky Mountain Power's low-income efficiency budget in 2015 was \$60,000 out of a total budget of close to \$62 million (Rocky Mountain Power, 2016). Weatherization service provision also fall short of meeting vast need, as WAPs in the entire state of Utah only served an average of 540 (average of 28 in Salt Lake City) homes between 2014 and 2016. This is cause for creative, community-based solutions for addressing energy efficiency on a widespread scale.

1.2.2 Strategies for Inclusive Energy Efficiency Program Development

One strategy to increase the participation of underserved groups in energy efficiency programming is to develop partnerships with non-energy related community organizations that work directly with low-income households (Cluett et al., 2016). Community-based energy efficiency projects can empower and encourage members of a community to take action collectively while surpassing individual barriers to energy efficiency upgrades and education (T. G. Reames, 2016). Using a community-based approach allows organizations and communities to hold productive conversations about the connections of energy access and social justice issues (T. G. Reames, 2016). This framework encourages the development of programs that provide assistance to communities of color, renters, and low-income groups through trusted networks of existing organizations.

In order to develop equitable energy efficiency programs that are also more cost-effective and scalable than traditional weatherization service, programs can focus on the provision of residential lighting upgrades, at no cost to the resident, instead of whole-house retrofits, which are inherently limited in terms of scale. LED bulbs provide an excellent opportunity to deliver immediate savings in a low-cost, non-invasive way that is appealing to both renters and homeowners alike. LED light bulbs use 75% less energy than traditional incandescent bulbs, and can last up to twenty-five times longer (T.G. Reames, Reiner, & Stacey, 2018). Additionally, they require minimal effort to install, making them a great first step towards implementing energy efficiency measures. However, the higher capital cost of bulbs and limited availability can be a barrier for low-income communities (T.G. Reames et al., 2018). This has motivated the development of programs that distribute or exchange old, inefficient light bulbs for energy efficient LEDs.

1.2.3 Community Residential Energy Efficiency Program Models

An examination of low-income and efficiency programs reported in published literature and white papers found five programs, varied in scope and geographic location, that focus on distribution and installation of LED bulbs (Appalachian Power, 2014; Loge & Graeber, 2018; The Dayton Power and Light Company, 2017; VanderLaan, 2018; Vermont Energy Investment Corporation, 2015). Among the five programs, four were initiated through utilities and one through a coalition of universities. Two programs (in Ohio and Washington D.C.) targeted low-income households by distributing energy efficient light bulbs at local food banks; others did not require specific participation characteristics. Only one program conducted post-program data reporting, and only one of the five programs utilized a light bulb “swap” format (VanderLaan, 2018). A summarized comparison of program elements can be found in Table SI.1.

1.2.4. Local “exchange” models

Utility-sponsored energy efficiency programs are a common model to encourage residents to adopt more energy efficient technologies. However, this model typically relies on residents proactively seeking, purchasing, and then installing or hiring someone to install the more energy efficient device. For residents who face a high energy burden or have limited disposable income, the utility-sponsored energy efficiency programs are not a perfect fit. There are additional programs offered through other entities to support local emissions reduction efforts.

The Energy and Sustainability Office at Utah’s Weber State University worked in a partnership with other organizations to host a “Cut Pollution–Mow Electric” lawnmower exchange program in 2018. This program subsidized the cost of over 700 electric lawnmowers for residents living in non-attainment areas. Participants, selected by a lottery system, were required to exchange a functioning gasoline lawnmower, and received a significant discount on the cost of the electric mower (participants pay \$100 while the mower retails for \$329). Waivers for the \$100 fee were available for those in need. This program exchanged over 800 electric lawnmowers and cut over 91,000 pounds of carbon dioxide emissions annually (Christiansen, 2018).

Salt Lake County’s Health Department manages a vehicle repair assistance program that assists with the cost of improving the emissions of existing vehicles that fail emissions tests. This program subsidizes 100% of the cost of vehicle repairs up to \$1,000 for income qualifying residents living in Salt Lake County.

2. Methods

2.1 Program description

2.1.1 Structure, Scope & Funding of the Utah Clean Energy Pilot Program

In a similar manner as exchange program models by non-utility entities, we present a case study on a pilot program administered by local SLC environmental non-profit, Utah Clean Energy (UCE). From January to August 2018, UCE staff attended various community events in targeted areas of the city to hold “Light Swaps”. This provided the free opportunity for community members to exchange up to 15 older, functional light bulbs with up to 15 energy-saving 9-watt LEDs. The exchange element to this program was imperative for reporting purposes, as this assumed that participants would install the new bulbs immediately, therefore leading to immediate energy, financial, and emissions savings that could be quantified. Comparable to 60-watt light bulbs, these LEDs were 2700 kelvin (emitting warmer light) as opposed to those that emit bluer white light that measure upwards of 6500 Kelvin. Warmer light emitted from the lower-kelvin bulbs has been found to minimize the impact of artificial light on human health (Falchi, Cinzano, Elvidge, Keith, & Haim, 2011). In addition to free LED light bulbs, participants also received educational materials about the connection energy efficiency has to health, air quality, and climate change, as well as information about other available energy efficiency programs in the area.

Funding for the program was provided by various local and national foundations. The expenditures from the 8-month duration of the pilot came to \$25,045. This included expenditures on salary and fringe benefits/payroll taxes, contract costs relating to Utah Conservation Corps, program and meeting supplies, advertising fees, mileage reimbursement, and parking fees. It did not include UCE overhead costs. All bulbs were provided by a local electric utility, Rocky Mountain Power, at a value of \$2,148 in avoided expenses. The UCE pilot compensated a full-time equivalent (FTE) rate of 0.96.

2.1.2 Program Motivation

Two main factors determined the UCE pilot target ZIP Codes of 84104 & 84116. First, the income discrepancy between the eastern and western sides of the city, of which the West Side ZIP Codes of 84104 & 84116 house more low-income residents. Second, the increased pollution and PM_{2.5} concentrations experienced in these two ZIP Codes and on the West Side of the SLV, are higher than its eastern counterpart. Energy-saving light bulbs do not directly improve local air but do provide a tangible first step in educating community members about energy efficiency energy use, pollution, and local air quality. Energy efficient light bulbs also save residents energy and money.

Given the adverse public health and energy burden implications of poor air quality in SLC's West Side and the significant role buildings play in emissions generation (approximately 39% of emissions are attributable to the building sector) (United States Environmental Protection Agency, 2013), there is a considerable opportunity to improve local air quality and community resilience by implementing energy efficiency projects in this area. According to Dominion Energy, the natural gas utility, there is a notable overlap of low-income residents and residents with a higher-than-average consumption of natural gas in these neighborhoods (Camp, 2018). While the bulk of energy efficiency actions capable of improving local air quality are tied directly to reducing natural gas emissions, these actions and technologies are often more expensive and harder for low-income homeowners or renters to implement, especially without existent ideological buy-in to the importance of energy efficiency.

The UCE pilot was created with the aim of starting a larger dialogue surrounding an awareness of energy efficiency and air quality issues in the West Side. The program also addressed energy insecurity problems in the area by delivering immediate and measurable energy savings. In order to accomplish these aims, the UCE pilot contained several novel and notable features.

2.1.3 Provision of LEDs

Although LEDs do not directly contribute to SLC's local air quality problems, they do offer multiple advantages related to the UCE pilot's motivation. LEDs deliver significant energy savings, are easy to install, and both renters and home owners can swap them for conventional bulbs. By providing the LEDs at no cost, the UCE pilot enabled participants to receive immediate payoff and see energy and monetary reductions in their bills. The required exchange of conventional or incandescent bulbs traded for LEDs theoretically ensured that these bulbs would be installed as a replacement for the swapped bulb, thereby validating the energy savings achieved by this program.

2.1.4 Partnership with Utility Contractors

UCE sought out a partnership with Energy Experts, a local contractor a part of SLC's natural gas utility, Dominion Energy, in order to increase participants' energy and monetary savings as well as tackle some of the air quality challenges affecting the area by delivering natural gas savings. Their services are free of charge to residents of ZIP Codes 84104 and 84116, overcoming cost obstacles. Energy Experts' work was part of a Dominion Energy multi-year pilot program aimed at increasing energy efficiency program participation in the West Side by providing a blower door test, air seal, duct seal, and attic insulation at no cost. Through the UCE

pilot's collaboration with Energy Experts, participants were able to take advantage of both electric and natural gas savings. This led to further energy savings realized by program participants and also contributed to local air quality improvements through reduced natural gas emissions.

2.1.5 Air Quality and Energy Use Education

Another equally important facet of the program was its educational component, which focused on energy conservation and its implications on health, air quality, and climate change. The pilot was not solely intended to be transaction-based through the exchange of light bulbs, but also aimed to help participants realize the importance of energy efficiency through educational outreach on the benefits of and opportunities to implement energy efficiency in their own lives. At UCE pilot exchange events, participants received information about additional low- or no-cost energy saving strategies that could be easily implemented in order to further increase energy and monetary savings in addition to their LED bulbs. The UCE pilot also presented information about how certain energy efficiency actions could improve local air quality at community council meetings, radio shows, and television news, and created a standing educational display about the intersection of these topics at a local community center in the West Side. Through this program model, UCE began to build relationships with West Side community members and community organizations.

2.1.6 Collaborative Program Design

In order to appropriately and more effectively deploy this pilot, UCE partnered with local community leaders and organizations with a presence in the target neighborhoods. The program design process was purposely collaborative in order to increase program efficacy. By leveraging these partnerships, UCE was able to develop relationships and build trust with community organizations and community leaders, better tailor direct promotional efforts of the program, and interface with existing energy and health-related programs to maximize offerings. Through various partnerships, the UCE pilot was able to reach a greater number of households with energy upgrades, surpassing our goal of 150 households by 31.

2.1.7 Events & Promotional Tactics

UCE pilot staff attended a total of 23 community events. Many of these events were hosted by partner organizations, which was a deliberate decision on the part of the UCE pilot. We prioritized participating in events sponsored or hosted by partner organization with strong ties to the community, anticipating that events would be more enticing to community members who were previously unfamiliar with Utah Clean Energy and its work. These events occurred at a variety of locations located within Salt Lake City target ZIP Codes 84104 and 84116, and included events held at: senior centers, libraries, schools, community centers, and parks. When possible, we sought to hold these light bulb exchanges at events that were focused on cultural heritage, health, large-scale community festivals, or community council meetings. The UCE pilot also sponsored one longer-term bulb exchange in a community center. The strategic goal was to make participation more convenient to potential participants who were otherwise unable to participate due to time constraints.

In order to promote individual light bulb exchange, UCE utilized Facebook’s targeted ad feature to reach residents of the two ZIP Codes, as well as posted flyers around the target communities. We also worked with community event organizers to brainstorm additional methods of promoting specific Neighborhood Light Swap events. For certain events, UCE also employed additional tactics in order to better tailor promotional efforts to that target audience. For example, one Light Swap event was held at a health fair hosted by a county government senior citizen center. Operating under the assumption that many attendees of that senior center did not have Facebook, UCE staff instead gave a brief presentation about the program one week prior to the event taking place and distributed flyers to remind them to bring light bulbs to the health fair later in the week. As a result, participation rates were one of the highest of the 23 total Light Swaps. In addition to these tactics, the UCE pilot was also featured on local news stations, radio, print newspapers, and a local podcast.

2.2 Metrics recorded

2.2.1 Data Collection

As a component of the light bulb exchange, program participants were required to complete a two-page survey that solicited demographic and geographic information including: participant’s address, ethnicity, preferred language, household income bracket, and number of people in the household. This data was used to both determine program success in reaching a population representative of the area’s demographic diversity, and in helping to iteratively adjust program outreach and messaging strategies.

Utilizing the data collected from participant surveys and exchanged light bulbs, we were able to determine:

- The spatial distribution of program participants throughout participating ZIP Codes, and the relative distance between participating households and swap locations.
- The energy savings and emission reductions resulting from this program, which was based on actual wattage of exchanged bulbs compared to LEDs and was calculated in terms of annual kWh savings and carbon dioxide emissions reductions.
- The percentage of program participants that either fell below the Federal Poverty Line or met the criteria to be classified as “low-income,” “very low-income,” or “extremely-low income” according to the Federal Income Guidelines for Salt Lake City (Department of Housing and Urban Development, 2018).

2.2.2 Challenges with Collecting Demographic Data

There were difficulties present throughout the Neighborhood Light Swap pilot. Complications occurred when soliciting personal information from a small number of participating residents. Most commonly, this was experienced due to: linguistic barriers, cultural differences, and at times, weariness to the survey with regards to how the program sponsor would use the information collected. All participants were informed that their responses were for grant reporting purposes only, but some felt uncomfortable answering certain questions despite the opportunity to opt out of answering more sensitive questions regarding topics like ethnicity and income. Other community members expressed distrust at providing their personal contact

information such as email, phone number, and address out of concerns about their privacy. Additionally, some program participants spoke only Spanish, which complicated verbal communication, as not all staff were proficient in the language.

2.2.3 Follow-up Method

The UCE pilot was not only concerned with energy reduction and financial savings, but also with increasing participants' knowledge on energy efficiency and its implications on health, air quality, and climate change. To gauge this component of the program, UCE emailed a follow-up survey to participants. We measured the success of the program's educational outreach component on the responses from those that completed the survey. Twenty-two percent of those who received the email survey completed it. In order to incentivize participants to complete the follow-up survey, UCE promoted that those who completed the survey would be entered to win one of three \$50 gift cards. Upon reviewing the surveys, UCE found that 75 percent of respondents reported that after participating in the UCE pilot, their understanding and awareness of the connection between saving energy and reducing pollution had *increased some or increased significantly*.

2.2.4 Calculation of Energy and Financial Savings

In order to calculate energy reduction and financial savings associated with the light bulb exchanges, we recorded the wattage of each exchanged light bulb to calculate an average light bulb wattage. Most light bulbs exchanged included the original manufacturer's wattage rating; however, the manufacturer's wattage rating was not visible on 27 of the total 1,432 bulbs exchanged. To account for these 27 bulbs, UCE assumed a wattage of 60 for each. Based on the 1,405 exchanged light bulbs with a visible wattage stamp, UCE calculated that the average exchanged light bulb was 48.6 watts.

2.2.5 Calculation of Avoided Emissions

Calculations of emissions saved relied on data provided by the Emissions & Generation Resource Integrated Database (eGRID) (U.S. Environmental Protection Agency, 2016), which utilizes information provided by the United States Energy Information Administration (EIA) and United States Environmental Protection Agency (EPA) Clean Air Markets Program Data. We utilized eGRID's calculated emission factors for each kilowatt-hour (kWh) of electricity saved in the state of Utah to calculate the equivalent amount of carbon dioxide emissions that are avoided as a result of the electricity saved through the UCE pilot. Specifically, this analysis relies on the categorized output emissions rate based on the specific integrated resource pool used to power the state of Utah (U.S. Environmental Protection Agency, 2016). This rate reflects an aggregate average of the emissions for the Northwest Power Pool to which Utah belongs, and does not take account of the point source emissions from local power plants in specific cities or regions of the state.

Utilizing the eGRID conversion rates of the total kilowatt-hours of electricity saved to pounds of carbon dioxide (CO₂), nitrogen oxide (NO_x), nitrogen dioxide (NO₂), and carbon dioxide equivalent (CO_{2e}) for the state of Utah, the program was able to quantify reductions of each type of emissions annually. The wattage of every light bulb exchanged for a 9-watt LED was recorded to calculate a light bulb average for the entire program which was used in these

quantifications. In order to have a temporal figure, calculations were also based off of an assumption that participant lights, on average, were turned on for 8 hours each day.

2.3 Taking Energy Savings to Scale

UCE utilized pilot data to extrapolate the potential for emissions savings and net benefits if the program were scaled. This coarse estimate of net costs and benefits of expanded programming relies on several key data points collected from the pilot program including: participating households, self-identified ethnicity, program costs, calculated avoided emissions, and calculated cost savings. Other assumptions utilized in calculating program expansion were the average watts for exchanged bulbs, project duration, and events per month. These data sets were used to estimate the scaling up of a wide-reaching “Light Swap” for the ZIP Codes of 84104 and 84116.

There are several key assumptions that UCE changed to estimate expanded programming of a future UCE pilot, but otherwise rely on data reflecting actual participation in the pilot program. In the UCE pilot, approximately 1% of households in 84104 (0.90% actual) and 84116 (0.99% actual) participated in the program. The majority of participants (57% and 73% in 84104 and 84116, respectively) in both ZIP Codes were self-identified white individuals. To estimate expanded participation, we assumed increased participation at the rate of 2%, 5% and 7.5% of households in 84104 and 84116. UCE assumed that participant ethnicity would mirror the actual pilot data in the calculations for expanded household participation (at 57% and 73% of participants self-identifying as white in 84104 and 84116, respectively). The comparison between actual data and modified assumptions for extrapolation in the program expansion are shown in Table SI.6.

To determine the outcome of these expanded assumptions on the number of bulbs exchanged and resulting emissions and cost savings, UCE identified a linear relationship between various event factors in the pilot program. Equation 1 describes the mean response in exchanged light bulbs as a function of the number of participating households and order/number of previous events:

$$\mu_H^E = \beta_0 + \beta_1 H + \beta_2 E \tag{1}$$

Where μ is the number of lightbulbs exchanged during event number E with H participating households. The coefficients β_0 , β_1 , and β_2 were calculated to be -24.0485, 7.6481, and 2.1214, respectively.

We also calculated a cost-benefit comparison of program expansion utilizing the UCE pilot costs, valued energy savings from exchanged bulbs, and avoided emissions valued at the social cost of carbon. Pilot costs include materials for events, such as tabling materials and printing costs, as well as labor hours for outreach, program organization, and events, plus reimbursement of miles traveled for events and meetings. It is important to note that the LED bulbs for the pilot were donated in entirety by Rocky Mountain Power, Salt Lake City’s utility company. For the program extrapolation, it was assumed that a discount of 40% be applied to per unit cost to account for potential discounts due to large bulk acquisition or incentives from partnered retailers. Energy savings from exchanged bulbs were calculated in the same manner as the UCE pilot, utilizing differences in wattage for exchanged bulbs and a rate of \$0.11/kWh.

Lastly, the avoided emissions due to swapped bulbs were valued at the social cost of carbon rate of \$39.19, reflecting a value of \$36 as defined by the EPA (U.S. Environmental Protection Agency, 2013), adjusted for annual growth at an interest rate of 3.5% suggested by Nordhaus (2017). The present value of net benefits was found by subjecting the calculated net value (value of benefits minus cost of implementation) to an interest rate of 5.5% for each implementation year. This was then summed to reveal the total present value of net benefits over the lifetime of an LED. The full present value of net benefits could be considered as the discounted rate of avoided emissions at the social cost of carbon over the lifetime of the LED 9-watt bulb, on average 40,000 use hours (approximately 14 years of daily, 8-hour use).

Finally, we utilized the same key model with adjusted assumptions to examine the outcomes of an expanded Light Swap at one hundred percent participation in the targeted ZIP Codes and all Salt Lake City ZIP Codes. In this scenario, we extended the project lifetime to 5 years of implementation and 8 events per month to reach these ambitious goals.

There are several key items to note about the extrapolation calculations utilizing the linear equation representing the response in bulbs given the number of participating households and number of events. First, as the relationship of bulbs as a mean response of participating households and number of events is a linear relationship, it does not represent the marginal decline in participation after reaching a saturation point of participating households. Second, due to the manner that the linear equation was used in these calculations, there is no way to implement a limit or bound on the number of bulbs exchanged by a household. This does not reflect the 15-bulb limit per household as dictated in the pilot program. Last, as this is an extrapolation beyond observable data, it should be viewed as a coarse estimate that may not reflect actual participation in the program. In this case, it provides a general idea of what large-scale implementation of LED exchange programing may look like.

3. Results

3.1 Program Reach

Throughout 23 events over the eight-month period of the program duration, the UCE pilot reached a total of 181 households and exchanged a total of 1,432 light bulbs with 9-watt LEDs (Figure 3). Twenty-two events were held on a specific day and time as part of a larger community event, while one event was held continuously from March to June 2018 during open hours at a community center to provide greater convenience for residents interested in participating but unable to attend specific events.

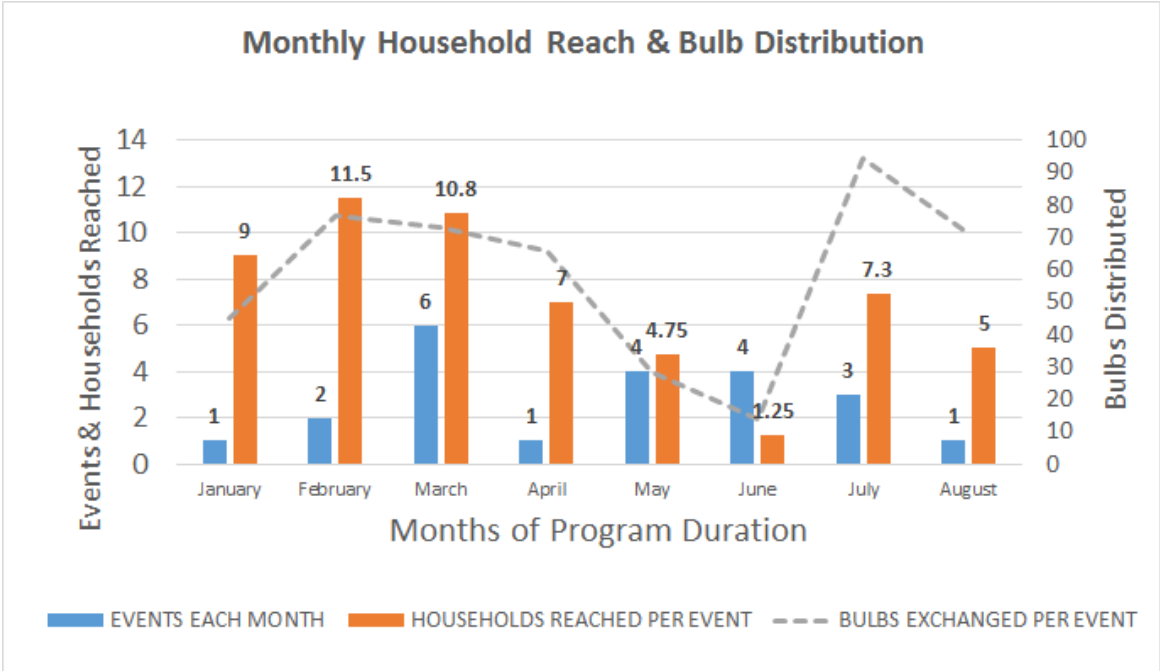


Figure 3. Monthly Neighborhood Light Swap events, average number of participating households, and average number of LED light bulbs distributed per event. This figure does not include the Light Swap that was held continuously from March 2018 to June 2018, where a total of 26 households were reached with a total of 207 LEDs.

In order to gauge the success of outreach, we included a required question on the survey asking how participants heard of the program. 92 percent of households responded to that question, revealing that the most common way participants found out about the Light Swap program was through Facebook (25%), followed by “at the event”, and “at the senior center” (both 13%).

3.2 Metrics recorded

3.2.1 UCE pilot Participant Demographics

Through surveying event participants, we were able to extract demographic information that would be valuable for guiding future community outreach efforts. Based on participant survey responses, demographic data representing the 181 participating households is presented in Table 1. More information collected on demographics can be found in SI.4 and SI.5.

Table 1. UCE pilot participant demographic characteristics based on participant survey responses.

Demographic	Composition of Pilot Participant Pool	Survey Question Response Rate
Average Annual Income	<ul style="list-style-type: none">• \$32,720.85 (low estimate)• \$43,709.04 (high estimate)• (57% - 73% of households is estimated to fall in the “low-income”, “very low-income”, and “extremely low-income” categories outlined for SLCo)	86%
Average Household Size	Three people.	94%
Ethnicity Identities	<ul style="list-style-type: none">• 72% Caucasian• 21% Hispanic or Latinx• 3% Asian• 2% Native American• 1% Pacific Islander	90%
Preferred Language	<ul style="list-style-type: none">• 87% English• 12% Spanish• 1% Other	100%
Home Ownership Rate	<ul style="list-style-type: none">• 81% Owner• 19% Renter	97%

As previously discussed, understanding these demographics (especially those that correlate with a greater likelihood to experience energy insecurity such as income, ethnicity, and renting), is imperative to future community program work. An examination of these figures suggests that future iterations of this program should pursue stronger collaboration with organizations, leaders, and government services agencies associated with vulnerable communities in order to encourage greater participation by community members who would benefit the most from energy efficiency.

3.2.2 Spatial Analysis of Program Reach

The spatial analysis of the participating households was made possible through the collection of self-reported addresses from respondents, which were kept confidential aside from their use for analytical purposes. Of the 181 participating households, 177 addresses were utilized in spatial analysis as there were 4 participating households that did not disclose an address or disclosed an address that was unable to be read or geolocated. Figure 4 shows a heatmap resolved at 0.5-mile resolution for each participant and includes swap event locations.

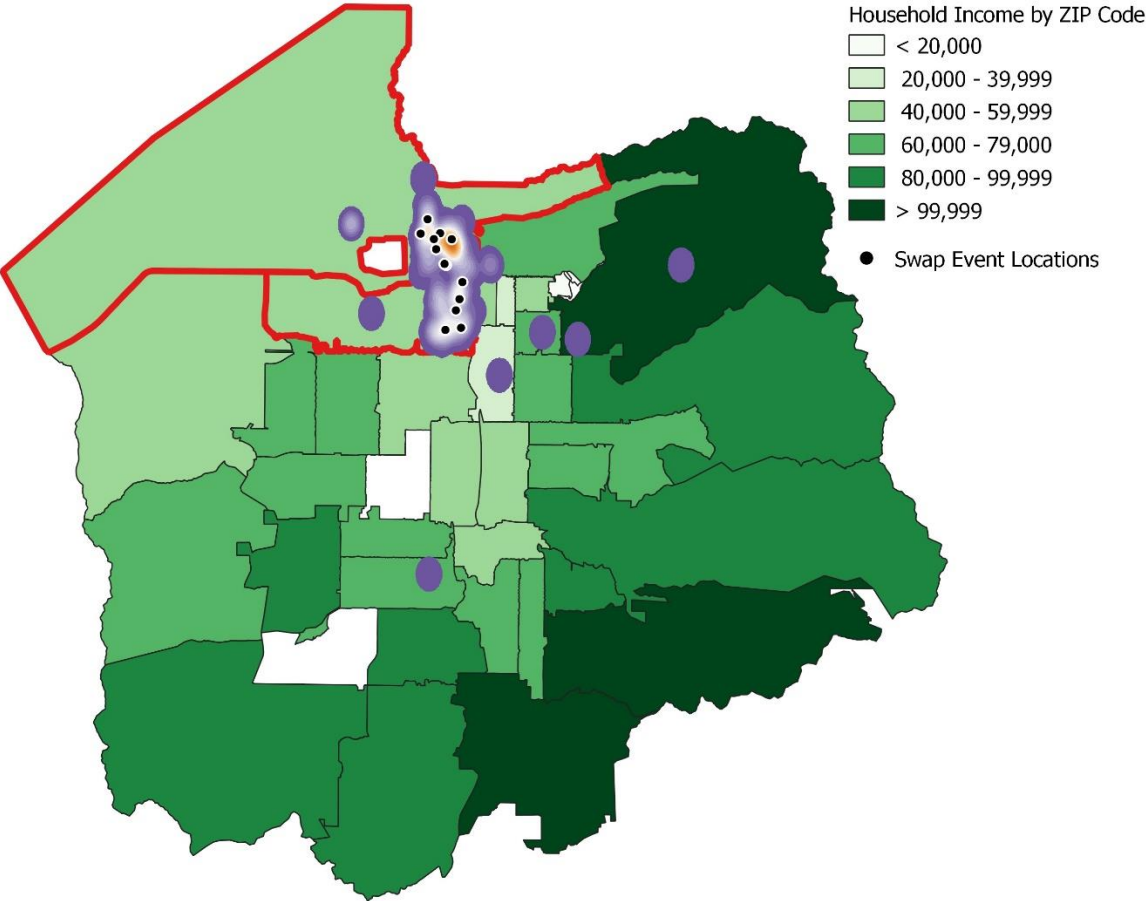


Figure 4. Heatmap resolved at 0.5-mile resolution for all participants. Swap event locations are shown as black dots, target ZIP codes are outlined in red and household income by ZIP code is also displayed.

The event location type with the highest number of participants was the library, which saw 40 participating households across 4 events. This was closely followed by a community center, which was the location of the ongoing Light Swap and two other events seeing 35 participating households.

Some findings of the spatial analysis of the program were:

- 97.80% of participating households were able to be geolocated.
- 92.65% of geolocated homes (164 homes) were found to be within a one-mile radius of an event location.
- Of the geolocated households, 3.95% (7 homes) fell outside the target ZIP Codes due to accidental participation.

3.3 Emissions and energy reduction

3.3.1 Electricity and Emissions Savings Resulting from the Pilot Project

The UCE pilot exchanged a total of 1,432 inefficient light bulbs (with an average wattage of 48.6 watts) for 9-watt LED light bulbs. Given an assumption that each light bulb would be on for 8 hours per day, these exchanged bulbs accounted for 165,623 kWh of electricity savings, which is equivalent to the annual electricity consumption of 19.1 average Utah homes (Clay Monroe, 2019). These values are derived from monthly consumption for 724 Utah homes resulting in an average annual consumption of 8,688 kWh for 2018. The potential annual emissions reductions that the UCE pilot could achieve are listed in Table 2.

Table 2. Annual emissions reductions attributable to UCE pilot.

Pollutant	Amount Reduced Annually (SI Units)	Amount Reduced Annually (US Units)
CO ₂	122.23 tonnes	134.73 tons
NO	251.82 kg	277.58 lbs
NO ₂	3.61 kg	3.97 lbs
CO _{2e}	123.06 tonnes	135.65 tons

Additionally, the UCE pilot delivered an estimated **\$18,219** in financial savings across the total 181 participating households, saving each household an average of **\$100.66**. Rocky Mountain Power charges Utah customers using a tiered rate design, which ranges from \$0.08 - \$0.14 in the summer (May through September) and \$0.08 - \$0.11 in the winter (October through April). Because of this range, UCE assumed an average of \$0.11 to utilize in this calculation (Rocky Mountain Power, 2014).

3.4 Taking Energy Savings to Scale: Estimated Impact

Table 3 reflects the outcome of extrapolated increased participation in the ZIP codes of 84104 and 84116, reflecting the assumptions in SI.7. Calculations are based on a 2%, 5%, and 7.5% participation rate in the targeted ZIP codes.

599 **Table 3.** Estimated impact of increased participation in 84104 and 84116 ZIP codes.

Actual Neighborhood Light Swap Pilot							
		Bulbs	Metric Tons CO ₂	Value of Savings at Social Cost of Carbon	Value of Electricity Savings ¹	Value of Year's Total Benefits	Implementation Cost
8 Month Pilot		1,432	122.23	\$ 4,878.17	\$ 18,218.56	\$ 23,096.73	\$ 25,045.00
Extrapolating 2% Participation in Targeted ZIP Codes							
		Bulbs	Metric Tons CO ₂	Value of Savings at Social Cost of Carbon	Value of Electricity Savings	Value of Year's Total Benefits	Implementation Cost
Year 1:		2,739	242.00	\$ 9,658.15	\$ 36,070.44	\$ 45,728.59	\$ 31,874.58
Year 2:		7,626	673.78	\$ 26,890.49	\$ 100,428.32	\$ 127,318.81	\$ 35,275.93
	Total:	10,365	915.78				\$ 67,150.51
Extrapolating 5% Participation in Targeted ZIP Codes							
		Bulbs	Metric Tons CO ₂	Value of Savings at Social Cost of Carbon	Value of Electricity Savings	Value of Year's Total Benefits	Implementation Cost
Year 1:		4,836	427.26	\$ 17,051.84	\$ 63,683.77	\$ 80,735.60	\$ 33,333.96
Year 2:		9,724	859.10	\$ 34,286.66	\$ 128,050.94	\$ 162,337.60	\$ 36,735.80
	Total:	14,559	1286.36				\$ 70,069.76
Extrapolating 7.5% Participation in Targeted ZIP Codes							
		Bulbs	Metric Tons CO ₂	Value of Savings at Social Cost of Carbon	Value of Electricity Savings	Value of Year's Total Benefits	Implementation Cost
Year 1:		6,584	581.67	\$ 23,214.46	\$ 86,699.40	\$ 109,913.86	\$ 34,550.35
Year 2:		11,471	1013.51	\$ 40,449.28	\$ 151,066.57	\$ 191,515.85	\$ 37,952.19
	Total:	18,055	1595.18				\$ 72,502.54

600 The outcome of the present value of summed net benefits due to valued avoided carbon and
601 electricity savings is shown in Table 4.
602

¹ The value of electricity savings listed for each year corresponds to only the savings associated with the bulbs exchanged in that year.

Table 4. Net present value of benefits over the course LED lifespan in different participation scenarios.

Participation Scenarios	Summed Net Present Value of Benefits During LED Lifetime (14 years)
Actual Neighborhood Light Swap Pilot	\$ 186,835.33
Extrapolating 2% Participation in Targeted ZIP Codes	\$ 1,395,098.72
Extrapolating 5% Participation in Targeted ZIP Codes	\$ 1,997,641.47
Extrapolating 7.5% Participation in Targeted ZIP Codes	\$ 2,499,779.35

Expanding programming to the entirety of Salt Lake City could also provide increased benefits. Utilizing the same key assumptions of the extrapolation within 84104 and 84116 at 2% of total households in all Salt Lake City ZIP Codes (84101-84106, 84109, 84116) added an additional 1,375 participating households for an exchange of an additional 10,513 light bulbs. Expanding the program reach to 2% of the entirety of Salt Lake City equates to an additional 928.84 metric tons of CO₂ in avoided emissions each year after the project implementation is completed. This is a financial benefit of approximately \$2.9 million dollars in electricity savings and valued carbon emissions at the social cost of carbon.

In the final scenario where one hundred percent of participation occurs, we assume that all 18,281 households in 84104 and 84116 and 87,010 households located in all Salt Lake City ZIP codes would participate in the program. The estimated impact from the two ZIP codes would lead to an exchange of 147,383 LED bulbs, amounting to 13,021.74 metric tons of carbon (14,354.01 US short tons) each year after the implementation of the project is completed. Benefits from this exchange would be valued at over \$21 million in net benefits due to electricity savings and avoided carbon emissions over the 14-year bulb lifetime. By assuming all participation of Salt Lake City ZIP codes, these 87,010 households would exchange 673,030 LED bulbs (roughly 8 per household). This equates to a potential savings of 59,464 metric tons of carbon annually after full project implementation and over \$96 million dollars in net benefits over 14 years due to avoided carbon and electricity savings. We estimate the cost of such an ambitious goal to be \$528,365 over a 2-year implementation.

4. Conclusions

4.1 Implications

4.1.1 Overall evaluation of program performance

The UCE pilot successfully achieved measurable energy, emissions, and financial savings in residential households in targeted locations to combat the issue of energy insecurity. This was accomplished by providing free lighting upgrades, resources, and education to residents. The UCE pilot engaged 181 households, exceeding its goal of 150 households, and saved each

household an estimated \$90 annually, on average. The impacts from this pilot have reduced demand for electricity resulting in a reduction of 124 tons of CO₂ emissions per year.

4.1.2 Failure to attract demographically representative participants

Despite the UCE pilot's success in terms of emissions reductions and participation, analysis of participants' demographic data indicates that participants in the UCE pilot were not representative of the ethnic and income demographics of the target ZIP Codes. Several factors may have contributed to this result, including: the distance of UCE pilot event locations from public transit, the lack of culturally relevant messaging, the lack of Spanish-speaking staff at events, and the lack of trusted messengers participating in events. To address the lack of demographic representation among participants, subsequent expansion efforts should include more direct engagement with trusted members of the targeted communities and stronger attempts to engage participants in energy efficiency education.

4.2 UCE pilot Limitations & Obstacles

Funding for staff time and funding to purchase materials were the greatest limitations for this program. Because the UCE pilot was provided completely free of charge to participants, it could not generate funds to directly support the program offerings and increased staff time. In addition to this limitation, we have also found there to be obstacles of cultural and linguistic differences in reaching more households. Although materials were translated into another common language, Spanish, the UCE pilot would have benefited from engaging a "messenger" with a direct relationship to targeted communities so that participation might increase. This could also aid in the communication of this program as staff have not always been able to accommodate those speaking languages other than English, nor address certain concepts in a way culturally relevant or understandable to some. We envision avenues circumventing this obstacle such as strengthening and creating more partnerships with organizations and groups serving these various communities in the area in our expansion efforts.

4.3 Future Work

This program will continue following the initial mini-pilot. UCE was selected by Salt Lake City as a grant recipient to continue this work administering a Community Energy Engagement program beginning late 2018. Rebranded as "Empower SLC", UCE is moving beyond hosting light bulb exchanges at community events. To provide greater convenience to residents, UCE has established six permanent light bulb exchange locations administered through three partnering organizations in the two ZIP Codes: a community center, a food pantry, and four locations that provide utility bill payment assistance. Participants can exchange up to 15 light bulbs during facility hours of operation at the community center, upon receiving food pantry service, or at their utility bill payment assistance appointment.

In addition to these permanent light bulb exchanges, the Empower SLC program has introduced a partnership project titled Energy Ambassadors. This provides an opportunity to selected organizations or groups working with various communities along the West Side. An Energy Ambassador is a representative (or a small team of representatives) that will 1) teach residents in the target ZIP Codes about the importance of energy efficiency and 2) help residents cut energy waste in their homes through organizing and hosting creative and impactful events at

convenient locations in the community. The Energy Ambassadors initiative seeks both to achieve energy and pollution reductions while furthering the mission of each participating organization through the awarding of a grant to support their core mission. Through this program branch, Empower SLC seeks to reach more diverse households than the UCE pilot, as it has the potential to overcome community distrust, language, or cultural barriers.

In the future, UCE envisions the Empower SLC program moving beyond LEDs in order to encapsulate greater energy-saving opportunities and financial, energy, and emissions impacts. Three upgrades, smart thermostats, furnace filters, and window film, are devices Empower SLC is considering offering as part of this free residential program.

As discussed, the UCE pilot was intended to be a well-rounded, collaborative community program. Through continued improvement in developing this program, there is real potential for this work to influence local air quality and regional greenhouse gas emissions. By providing an easy entryway into greater energy savings, along with resources and education, residents can help their city achieve its climate goals.

On January 30th, 2019, Governor Gary Herbert addressed the Utah House of Representatives and discussed his request for \$100 million to be allocated towards quantifiable efforts to improve air quality across the state. While the ambitious amount was not met, approximately \$29 million in air quality related appropriations passed during the 63rd Legislature 2019 General Session which marked the state's largest investment in air quality improvement. Appropriations included funding for retrofitting state-owned buildings for teleworking, exchange programs for wood fire furnaces, as well as free transit fares during poor air quality days, as well as more stringent measures against modified diesel vehicles (also known as "rolling coal"). The LED exchange program fits within the proposed measures as an affordable and easily actionable measure to decrease energy consumption and help reduce the economic burden of electricity bills, particularly in less affluent community members.

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Author Contributions:

Conceptualization: DM, ER, KE, SS, SW; Methodology: ER, KE; Software: DM, ER, SS; Validation: ER, SS, SW; Formal Analysis: ER, SS, SW; Investigation: DM, ER, SS, SW; Resources: DM, KE; Data Curation: ER, KE, SS, SW; Writing – Original Draft Preparation: SW; Writing – Review & Editing: DM, ER, KE, SS, SW; Visualization: DM, SS; Supervision: DM, KE; Project Administration: KE; Funding Acquisition: KE.

Conflicts of Interest: The authors declare no conflicts of interest.

Supplemental Information

Table SI.1 Community residential energy efficiency programs conducted in the United States that contained a light bulb exchange, direct install, or distribution element in their model.

Program Location	Requirements of Program	Exchange or Distribution Component	Secondary Information Collected
Southern West Virginia	*Undetermined.	Distributed at local food banks.	None.
Washington D.C.	Yes, income.	Direct install program.	Yes.
Dayton, Ohio	*Undetermined.	Distributed at local food banks.	None.
Avon, Colorado	None.	Exchange component.	None.
University of California, UC Davis, coalition of local community colleges	Yes, must be an alumni, faculty or staff member, or student.	Discount program on various LED light bulbs.	None.

* We were unable to determine if these food banks had income requirements to receive their service.

Table SI.2 Household income brackets participants could select from as well as an option to “opt out” on their survey. While these income ranges are based on federal and Salt Lake City poverty guidelines, they slightly differ from these values for several reasons, including: improved ease of completing the survey from the participant perspective; increased ability to determine income classifications outside of the poverty range (including low-income and extremely low-income categorizations) as determined by Salt Lake County's Housing and Human Development Income Guidelines (Department of Housing and Urban Development, 2018); and increased ability to determine participants' eligibility for weatherization services (200% of poverty threshold) (Department of Health and Human Services, 2017), in order to send targeted referrals to qualified participants.

Income Bracket #1	\$0 - \$12,060
Income Bracket #2	\$12,061 – \$24,360
Income Bracket #3	\$24,361 – \$36,180
Income Bracket #4	\$36,181 - \$48,721
Income Bracket #5	\$48,722 - \$64,960
Income Bracket #6	\$64,960 +

*Bracket ranges:

Income bracket #1: lower and upper boundaries based on 2017 federal poverty guidelines for a single person household.

Income bracket #2: lower boundary based on the upper bound of **Income bracket #1**; upper bound based on 2017 federal poverty guidelines, 150% poverty line for a 2-person household

Income bracket #3: lower boundary based on the upper bound of **Income bracket #2**; upper bound based on a value between the Salt Lake City Housing and Community Development Dept's income guideline: very low income value for 3 person household (\$36,050) and to the 150% of the federal poverty line for a 4 person household (\$36,900).

Income bracket #4: lower boundary based on the upper bound of **Income bracket #3**; upper bound based on 300% of the federal poverty line for a 2 person household (\$48,720), which is close to 200% of the federal poverty line for a 4 person household (\$49,200) and 150% of the federal poverty line for a 6 person household (\$49,440).

Income bracket #5: lower boundary based on the upper bound of **Income bracket #4**; upper bound based on 400% of the federal poverty line for 2 person household (\$64,960), which is between the 150% of the federal poverty line for an 8 person household (\$61,980) and 200% of the federal poverty line for a 6 person household (\$65,920).

Table SI.3 lists the conversion rates used in our emissions calculations, including eGRID’s original units (lbs per kWh) along with the converted rates to SI units (kg per kWh).

Emission Type	Kilograms (kg) emissions per kWh of electricity generated	Pounds (lbs) of emissions per kWh of electricity generated
CO ₂	0.738 kg	1.627 lbs
NO _x	0.00076 kg	0.001676 lbs
NO ₂	0.000010 kg	0.000024 lbs
CO _{2e}	0.743 kg	1.638 lbs

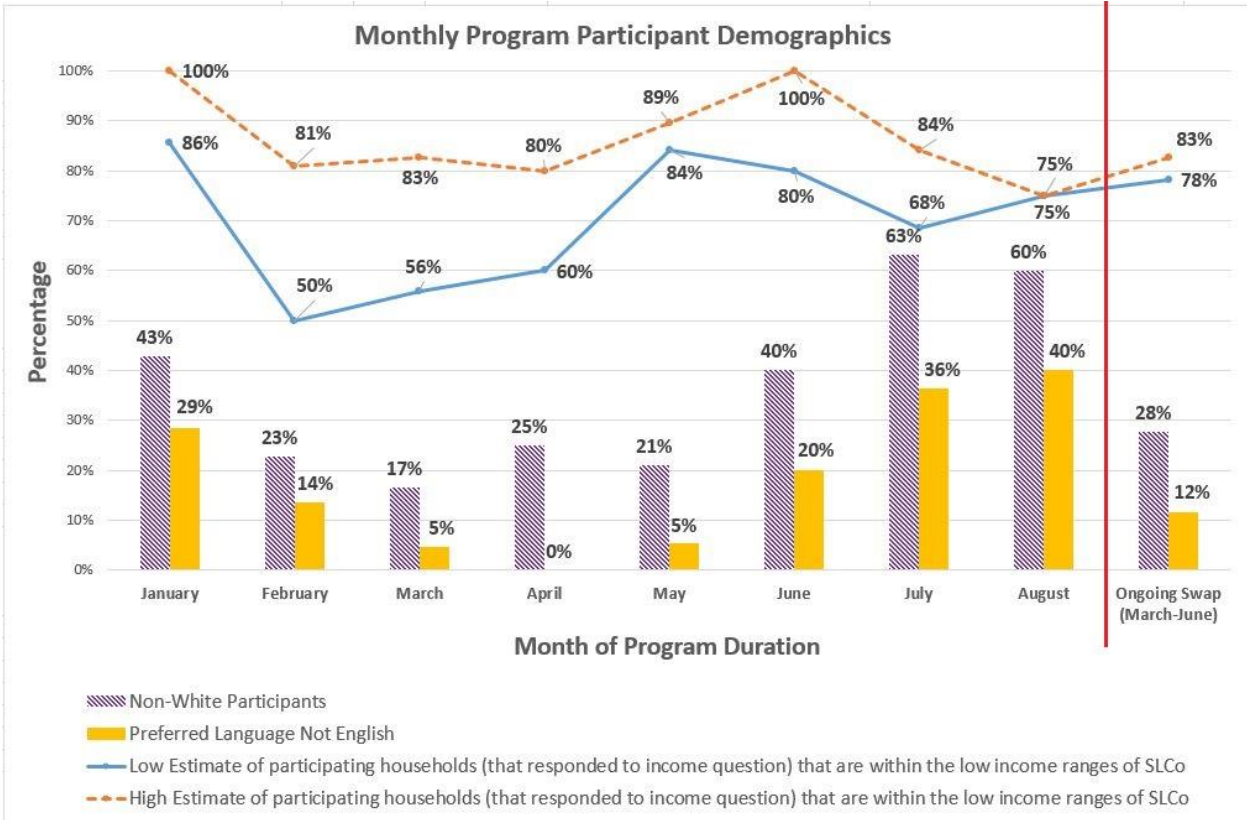


Figure SI.1 Monthly participant demographics using survey responses on income, ethnicity, and preferred language. An additional category- “Ongoing Swap” – represents the permanent light bulb exchange hosted by a local community center from March to June 2018. Percentages are based on completed survey question responses (income: 86%, ethnicity: 90%, language: 98%).

Table SI.4 Low and high estimated percentages of participating households that would be considered at least “low-income” by SLCo but may also fall into “very low-income” or “extremely-low income” categories as well. Also included is the estimated percentages of participants that would qualify for state weatherization services.

	<i>Low Estimate-</i> Households qualifying as “low-income” ^a (SLCo standard)	<i>High Estimate-</i> Households qualifying as “low-income” ^a (SLCo standard)	<i>Low Estimate-</i> Households qualifying for weatherization assistance services (at/below 200% of federal poverty line)	<i>High Estimate-</i> Households qualifying for weatherization assistance services (at/below 200% of federal poverty line)
Number of households ^b	103	132	65	90
Percentage of total households	57%	73%	36%	50%

a: This includes participants qualifying as also “very low-income” or “extremely-low income”.

b: Number of households in this table are representative of the 86% of participants that responded to the income survey question.

Table SI.5 Transit accessibility of event locations using the addresses of participating households.

Number of participating households that live greater than a 10-minute walk from a bus stop	Number of those households identified that were within a 10-minute walk of an event location	Event locations within a 10-minute walk of at least 3 bus stops	Average number of bus stops within a 10-minute walk of all 23 event locations
3 of 181	2 of 3	23 of 23	18.64

Event locations were not selected for their proximity to transit, but it is important to consider the existence of accessible transportation options to event locations for participants without vehicles. To assess the difficulty or ease of attending event locations, we have examined the number of participants that are located within a 10-minute walk of Utah Transit Authority bus.

It is important to note that in this analysis, the schedule of bus routes was not examined in context of event times. In future iterations of LED exchanges, it may be worthwhile to collect information on how participants arrived to exchange their light bulbs to evaluate if participants utilized public transportation to arrive at event locations.

772 **Table SI.6** Key assumptions of program expansion extrapolation.

	Neighborhood Light Swap Pilot		Extrapolated Program Expansion
Proportion of participating households	ZIP 84104 0.90%	ZIP 84116 0.99%	2.0%, 5.0%, 7.5% (for both ZIP Codes)
Project duration	8 months		24 months
Average events per month	2.75 events		4 events
Exchanged bulb watt average	48.61		50

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