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California's Single Family Affordable Solar Homes Program: Investigating the Potential for a Rebound Effect

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:
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In California, a series of solar incentives were launched in 2006 to increase domestic energy generation while tackling rising carbon emissions. One of those incentives is the Single-family Affordable Solar Homes (SASH) program which offers low to no-cost solar PV systems to qualified low-income families. This program combines the use of solar energy and energy efficiency improvements to reduce the burden of high energy bills on low-income families and promote energy savings. However, a growing number of studies have found that the energy savings resulting from improvements in efficiency have been offset due to adverse energy consumption behavior. In energy economics, this is termed the rebound effect. The purpose of this study was to conduct an evaluation of the SASH program to determine if the potential for a rebound effect exists. The results of the program evaluation found that participants may be likely to engage in adverse energy use behavior as a result of switching to solar energy, enacting energy efficiency measures, and gaining awareness about their relative energy consumption. The implications of this finding are that solar incentives, may not be as effective in promoting energy savings as they are perceived to be. Due to the limited scope of this study and unavailability of gross consumption data, further research is needed to determine whether the rebound effect does indeed pose a threat to energy savings.

Keywords: Rebound effect, California, energy justice, solar incentives, fuel poverty, energy poverty, energy efficiency, program evaluation.

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List of Abbreviations

AB 217	Assembly Bill 217
ACNEEP	Alliance Commission of National Energy Efficiency Policy
CPUC	California Public Utilities Commission
CSI	California Solar Initiative
DECC	Department of Energy & Climate Change
IPCC	Intergovernmental Panel on Climate Change
NEM	Net Energy Metering
MASH	Multi-family Affordably Solar Housing
PII	Policy-Induced Improvement
PV	Photo-voltaic
RPS	Renewables Portfolio Standard
SASH	Single-Family Affordable Solar Homes
SB 350	Senate Bill 350
SDG	Sustainable Development Goals
ZCB	Zero-Cost Breakthrough
MW	Megawatt

1. Introduction

1.1 Problem Definition

One of the most common definitions for energy is the capacity to do work. Understood in this manner, it is easy to see why countries with vast energy resources are pressured to rapidly exploit those resources in pursuit of development. The more energy they exploit, the more growth they can achieve. This practice, however, has led to disastrous consequences for the climate. Climate change and rising energy demand are at the forefront of today's energy challenges. Due to the complexity and interactions between climate change and rising energy demand, seemingly logical solutions to one may contribute or exacerbate the problems of the other. Take climate change for example, the scientific community has reached consensus that the rise in global annual temperatures is unequivocal and major actions must be taken to reduce greenhouse gas emissions to mitigate future impacts (IPCC 2014). Since the energy sector accounts to the largest share of emissions, major reductions in emissions will have serious implications for energy systems. Many government leaders and environmental organizations are openly advocating for decarbonization of energy production which would require a shift away from fossil fuels and towards renewables. Although this energy transition would help mitigate climate change, it would impose serious constrains on the energy sector's ability to cope with rising energy demand. Improvements in energy efficiency can help reduce the overall demand for energy, but data shows that emissions continue to rise despite reductions in carbon intensity (York 2010). Furthermore, some researchers argue that improvements in efficiency may lead to increases in energy consumption. In energy economics, this is termed a rebound effect. This goes to show that technological solutions, such as renewable energy and higher efficiency, can lead people to behave in unexpected ways that can undermine the purpose of the energy solutions. Thus, proposed energy strategies to deal with climate change and rising energy demand must take a holistic approach by a recognizing and addressing the impacts the strategies will have on carbon emissions and energy consumption.

The Sustainable Development Goals for 2030 serve as a prime example of a holistic attempt to address energy challenges. Goal number seven of the SDGs aims to ensure access to affordable, reliable, sustainable, and modern energy for all (SDG 2015). It makes specific reference to those in the developing world who still lack access to electricity and modern energy sources; relying mainly on wood or animal dung for their cooking and heating needs. By promoting energy solutions for all, the SDGs highlight the energy injustices that often go overlooked in the developed world. Similarly, goal number 14 aims to take urgent action on climate change and its impacts. Many climate scientists have pointed out that these consequences will not be equally distributed among the populace. Vulnerable populations will not be able to buffer themselves from the effects of climate change. As such, a discourse has developed around the subject of energy justice, which aims to bring attention to the inequalities evident in the way energy crises affect disadvantaged communities- such as the poor- and also aims to advance solutions that correct those inequalities.

Energy policy responses to the oil crisis in 1973 embodied earlier attempts to address the disproportionate energy burden placed on poor households. Many were unable to afford basic energy services and had to use a higher percentage of their income to meet their energy needs. Governments opted for technical solutions to the energy crisis by establishing energy efficiency measures but the application of those measures followed a social approach and showed a deeper understanding of the energy problem. Governments in the U.S. and the UK established energy efficiency programs directly aimed at low income communities in recognition that the crisis affected this community the most; forcing many of them into fuel poverty. Researchers have continued to study how energy problems specifically affect poor and vulnerable populations, leading to an expansion of the literature on energy justice and sustainable development. Of growing concern in the energy justice discourse is the lack of inclusion of low income households in application of energy solutions. While government sponsored energy efficiency programs have been lauded for their successful implementation in low income communities, programs promoting residential rooftop solar systems have been far less successful in that respect. Rooftop solar photovoltaic (PV) systems are among the few renewable energy technologies that are available at a residential scale, yet this technology has been exclusionary towards low income households due to economic barriers. Few policies and programs have addressed the inequality in access to residential solar energy or attempted to promote a more equitable distribution of solar systems.

One of the few programs in existence that aims to increase solar energy ownership among low income communities is California's Single-Family Affordable Solar Homes (SASH) program. This program states that their goal is not only to increase access to solar energy for low income communities, but also to increase the positive benefits associated with clean renewable energy including: energy bill savings, raised awareness about renewable energy, increased solar jobs in the area, and reduced air pollution from fossil fuel plants. However, some unintended outcomes may arise along with the benefits in the form of a rebound effect. The rebound effect is generally used to describe adverse energy consumption behavior that follows the implementation of measures intended to promote energy savings. The most commonly understood example of the rebound effect is when a driver switches to a more fuel-efficient car but offsets the expected savings by driving more miles.

In the literature, the rebound effect is largely confined to studies on energy efficiency and is defined as the loss of potential energy savings from improvements in energy efficiency due to an increase in consumption. However, the adoption of renewable energy may also produce unexpected changes in consumption behavior, which in effect reduce the total expected energy savings. Many empirical studies have measured the rebound effect and found that it is significant. Significant estimates of the rebound effect pose serious implications for energy efficiency policies. Of the few studies that have investigated the rebound effect across income grouping, their findings have shown that there are some variations in rebound effect that are associated with income level. No studies exist that have attempted to determine rebound effect on solar homes.

1.2 Aims and Objectives of Study

This thesis will investigate the intended and unintended outcomes of the SASH program. The aim is to understand how the program may influence participant's energy consumption behavior and determine whether the rebound effect may arise as an unintended consequence of the program. If a rebound effect exists, then the expected benefits from solar technology would be minimized by the increase in energy consuming behavior. The results of this work have the potential to bring attention to some deficits in program design which program administrators may find useful. To investigate the potential for a rebound effect, a program evaluation was conducted. The evaluation consisted of an assessment of need for the program and an assessment of the program theory.

Objectives:

- Understand how the Single Family Affordable Solar Homes (SASH) program functions by conducting a program evaluation.
- Identify the goals of the program.
- Investigate the intended and unintended outcomes of program participation.
- Determine if potential for a rebound effect exists.

1.3 Scope of Study

This thesis focuses on the U.S. because Americans have one of the highest per capita energy consumption and CO2 emissions. The scope of the thesis is further limited to California because it has proven to be a leader in solar energy and many of its energy efficiency and environmental policies are gradually being adopted at a national level. The SASH program was chosen as the focus of the study because it is one of the few solar energy programs that provides services to low income communities. Recent literature on energy justice has shown the importance of integrating low income communities in energy solutions. Low income families have the highest motivation to reduce utility costs due to their minimal income, often sacrificing their level of comfort to reduce monthly expenses. Due to the relatively recent adoption of PV systems among low income families, research on this population is lacking and the significance of impacts of PV adoption by low-income households has mostly been overlooked.

1.4 Structure

Having provided the objectives and aims of this study, this paper now describes the methodology used in conducting the program evaluation. The second chapter presents the literature review. The review begins with a focus on energy burden on the poor and describes the different policy approaches to energy challenges focusing on energy efficiency, conservation and renewable energy. It then offers a review of debate on the rebound effect and the implications that it poses to energy policies attempting to mitigate climate change and rising energy demand. The fourth chapter provides background information on the SASH program. The following chapter presents the results of the program evaluation and describes the potential pathways for a rebound effect. The last chapter provides a summary of the research and findings and offers recommendations for future research.

2. Methodology

The previously stated objectives of this research were to understand how the SASH program operates and investigate the potential for increases in electricity usage as an outcome of the program. The research was focused not only on defining the intended and potential outcomes, but also on understanding how the design of the program and its actions were expected to produce those outcomes. By investigating the how, the researcher could gain more meaningful information about the source of failure or success which would be critical to making appropriate recommendations. The method chosen for this study consisted of a systematic program evaluation which included assessments of the program at multiple levels.

2.1 Overall research design

The program was evaluated using a systematic approached developed by Rossi *et al.* (2004). Program evaluation as defined by Rossi *et al.* consists of "the use of social research methods to systematically investigate the effectiveness of social intervention programs in ways that are adapted to their political and organizational environments and are designed to inform social action in ways that improve social conditions" (2004). The building blocks for program evaluation studies can be understood as a hierarchy of assessments focused on the particulars of a specific program (See Figure 1). To conduct and yield meaningful results from program evaluation, the lower assessment levels must be conducted and produce acceptable results in order to conduct assessment of issues above it in the hierarchy. For the purpose of this thesis, the evaluation research was focused on need of program and program theory.

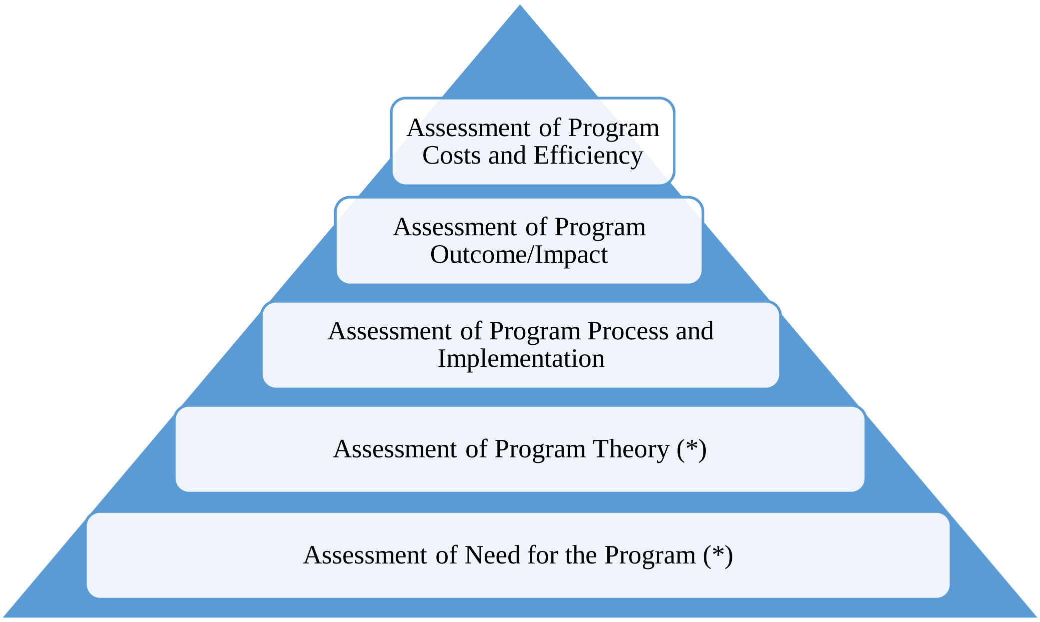

Figure 1: Evaluation Hierarchy Pyramid. Source: Rossi *et al.* 2004.

2.2 Data collection

2.2.1 Secondary Data

The majority of the data used to conduct the program evaluation was obtained from secondary sources, mostly program documents. The California Public Utilities Commission (CPUC), which oversees the SASH program, hired Navigant Consulting Inc. to prepare a series of assessment reports on the SASH program as mandated by law. These reports were publically accessible through the CPUC's website. Other sources that provided information about the program included the SASH program handbook issued by the CSI, quarterly reports from GRID Alternatives, and program webpages from GRID Alternatives, CSI, and CPUC websites. The following reports were utilized in this study:

- California Solar Initiative- Biennial Evaluation Studies for the SASH and MASH Low-Income Programs, Impact and Cost-Benefit Analysis, Program Years 2011-2013, Issued by Navigant Consulting, Inc. on December 2015.

- California Solar Initiative- Biennial Evaluation Studies for the SASH and MASH Low-Income Programs, Market and Program Administrator Assessment, Programs Years 2011-2013. Issued by Navigant Consulting, Inc. on October 2015.
- California Solar Initiative- Low-Income Solar Program Evaluation, Final SASH Program Biennial Report. Issued by Navigant Consulting, Inc. on June 2011.
- SASH Semi-Annual Program Status Report issued on July 2015.
- SASH 2.0 Program Handbook. Issued by CPUC August 2014.

The reports provided the following information:

- Program goals and objectives
- Organizational structure
- In-depth interviews of SASH program administrators and CPUC staff

The interviews were conducted by Navigant Consulting, Inc. Navigant completed interviews with PA staff, including three with Grid Alternatives staff. These interviews included topics such as the PA goals, the organizational structure, funding/staffing levels, the PA's understanding of the markets, barriers to participation as seen by the PAs, and thoughts on the program changes. Additionally, two interviews were conducted with CPUC staff involved in the SASH programs. The interviews covered the policy objectives of the program the current status of the programs, and the barriers to achieving the program's objectives. This interview data provided insight to program goals and program process not articulated in the program documents that was used to help elucidate the program theory.

2.2.2 Primary Data

The data derived from the program documents was supplemented with information obtained from personal correspondence with GRID Alternatives program administrators and one CPUC staff member involved in designing the SASH program. The names of the individuals have been changed to preserve their anonymity. One interview was conducted via

Skype with a GRID Alternatives Outreach Coordinator who participated in the SASH program prior to being hired. The interview followed a semi-structured approach with open ended questions. The questions used in the interview and email correspondence were focused on the program's design, implementation, and personal experience with program participation.

2.3. Data analysis

The information obtained from the primary and secondary sources served as the basis for conducting the program evaluation. The evaluation consisted of two main stages: assessment of need for the program and assessment of the program theory. The first assessment consisted of analyzing the data obtained from the documents and personal communication to clarify what conditions the program aimed at improving and who their target audience was. The second assessment involved identifying the program theory and assessing it based on the reliability of its assumptions.

2.3.1 Assessment of Need for the Program

In conducting a program evaluation it is important to identify the social conditions which a program is meant to improve. By having a thorough understanding of the social conditions and the needs of the targeted population of the program it is possible to determine whether a new program is needed. The assessment of the need for the program consisted of defining the problem or condition which the SASH program aims to ameliorate, identifying population at risk, devising social indicators capable of measuring the social condition over time, and analysis of indicator data. The stages of the needs assessment are shown in Figure 2. If the findings show that conditions are not improving or even worsening for the population of interest then, it can be assumed that the need for the program is real and justified.

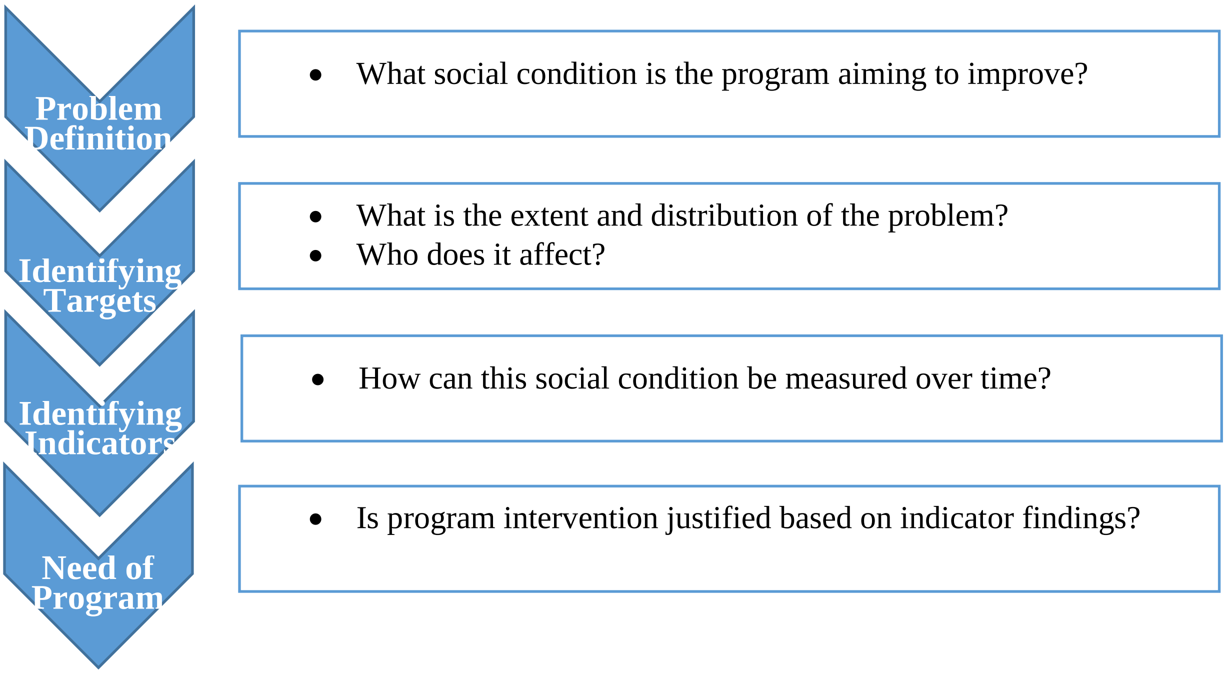

Figure 2: Assessment of Need of Program. Source: Rossi et al. 2004.

2.3.2 Assessment of Program Theory

The program theory describes how the program is intended to function and the assumed cause and effect relationship between program activities and intended social benefits. The program theory can often be visualized through a logical model. Prior to assessing the program theory it is necessary to first define the theory that the SASH program is based on. This was accomplished by linking program goals and objectives to the corresponding program components and activities. This process seeks to clarify the assumptions made by program administrators about how program actions are expected to produce desired outcomes. Determining the program theory is critical for program evaluation because can identify weaknesses in the program's design by uncovering flaws in assumptions that may undermine the program's ability to achieve its goals. The assessment intended to uncover the program theory as it is described on paper, and how the theory is understood from program planners, administrators, and participants' perspective. A logical model representing the program theory was created, similar to the model outline in Figure 3. The program theory was then assessed on the basis of its critical assumptions. Evidence for support of these assumptions was searched for in research and documented practices. The assumptions were used to assess the logic and plausibility of the program theory.

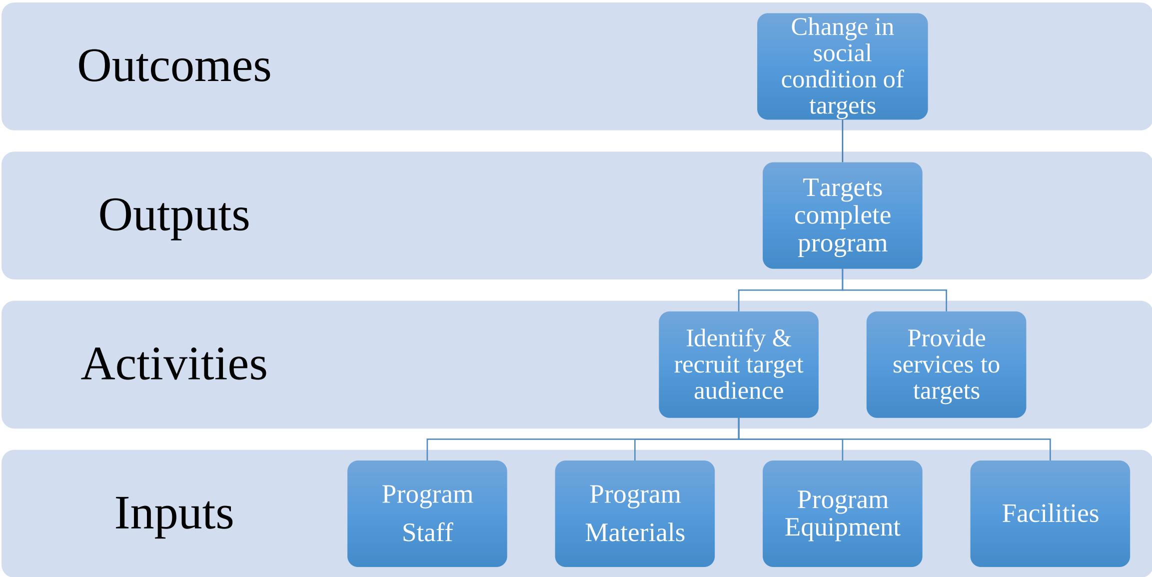

Figure 3: Program Theory Logical Model. Source: Rossi *et al.* 2004.

2.4 Limitations of research

Due to a variety limitation in data collection, it was not possible to conduct an actual impact assessment of the program outcomes (intended and unintended). As such, the aim of the thesis is limited only to investigating the *potential* for a rebound effect, rather than an investigation of whether the rebound effect exists in practice. It was not possible to conduct an actual impact assessment on participant's household energy usage due to a variety of limitations including time constraints, limited resources, and restrictions on sensitive information. Furthermore, data on household electricity usage could not be determined based on homeowner's electric bill data due to measurements based on Net Energy Metering (NEM). Due to NEM, electric utilities measure only the amount of electricity fed in to the grid by the solar system and drawn from the grid to meet the home's energy demand. The homeowners are then provided with a net consumption based on total kilowatts consumed from grid subtracted by total kilowatts generated. However, the "totals" stated on the bill are skewed because the utility does not measure the total amount of electricity generated by the system nor the amount of electricity used on-site. Data on the total system production would be required to derive the on-site consumption. The on-site (or rather, in-home) consumption could be derived by calculating the difference between the amount of kilowatts produced stated on the Envoy Enphase monitoring system and the total amount of kilowatts generated stated on the electric bill. Without these data points, it is impossible to get an accurate measure of the household's total electricity consumption.

Although this research cannot provide definitive evidence of a rebound effect, this work could serve as a starting point for future studies aimed at detecting and quantifying the rebound effect (if found). Future studies could conduct an impact assessment of the program using electricity generation and usage data to determine the changes in household electricity usage after solar installation and compare to usage prior to installation.

The use of secondary data also presents some concerns on the validity of the conclusions drawn, however, the objectives of the consultant company responsible for data collection was the same for this research: to conduct a program evaluation. Thus, the information derived from these sources was directly relevant to the first objective, but did not provide significant data for the second objective: to assess the potential of a rebound effect. The interview questions from the program reports did not probe program administrators about the potential for a rebound effect. This limitation was overcome by using the available data to help elucidate the program theory and identify unintended program outcomes (i.e. rebound effect).

3. Literature Review

I3.1 Energy and the Disadvantages of the Poor

Energy prices became a matter of public contention in the United States due to the OPEC embargo in 1973. As energy prices soared, the people who suffered the most were those who were already at a disadvantage prior to the oil crisis: low-income Americans. The energy crisis spurred interest in energy policy and the impacts of rising energy costs for low-income families. One of the first studies that linked low incomes with high energy costs was conducted in 1975, which found that income was a strong indicator of energy expenditures, and found a negative correlation between the two, showing that as income increased, energy expenditures as proportion of income decreased (Newman and Day 1975). Cooper *et al.* elaborated on this finding in the book "Equity and Energy" which examined the relationship between energy use, household incomes, and living standards (1983). Their research was instrumental in highlighting the disproportionate amount that low income families spent, in relation to higher income households, to meet their energy demands. Their analysis looked at the costs of different energy sources including natural gas, oil, and electricity from 1973-1983; however, the increasing oil costs were most pronounced during this period due to the oil crisis. Their data (presented in Table 1) indicated that in 1973 low income homes were spending twice as much of a percentage of their income to meet their energy needs compared to lower middle-income households, (11% and 5.2% respectively). This percentage of income spent on energy dropped even lower to 2.5% for non-low income households. In 1981, the percentages grew to 23.2% for low income homes and 3.5% for non-low income homes demonstrating a widening of the energy burden gap. This finding was in spite of the fact that low income families consumed overall less energy than their higher income counterparts (Cooper *et al.* 1983; Van Raaij and Verhallen 1983).

Table 1: Home Energy Expenditures as a percentage of income. Source Cooper *et al.* 1983.

	1973	1980	1981
Low-income	11.0%	21.1%	23.2%
Lower middle-income	5.2%	8.9%	9.7%
Non-low income	2.5%	3.5%	3.5%

In the book, Cooper *et al.* argued that society faced a moral obligation to address the energy burden on low income Americans. Their definition of low income Americans was more broadly defined than in previous literature or policy definitions based on the federal poverty line. Their classification of low income households encompassed the bottom 33% of the income scale whose incomes fell below $10,000 in 1979. In the same manner that societies concerned with the wellbeing of their poorest and most vulnerable members had implemented welfare programs to address the problem; the authors argued in favor of programs devoted to address the energy burden issue. Both the severity and pervasiveness of the problem, they argued, were reason enough to conduct investigative research and warrant societal intervention. Their research had found evidence that rising energy costs were not only decreasing the purchasing power of low-income household, but also deteriorating their living standards. They found that due to the high costs of energy, many low-income families were under heating their homes, closing off rooms, and cutting back on other costs. Cooper *et al.*'s survey of household data also revealed that low income Americans lived in more energy inefficient homes than non-low income Americans. Low income homes were more likely to lack energy efficiency infrastructure and appliances that were more common in non-low income homes (Cooper *et al.* 1983). This meant that they weren't getting the full energy benefits from the energy that they purchased. The authors feared the social consequences of inaction on the rising energy burden for low income Americans were threatening individual's wellbeing, health and safety by forcing many to reduce their consumption beyond what is necessary to maintain a decent standard of living.

A later study by Byrne *et al.* in 1986 supported previous findings on the disproportionate impact of energy costs on the poor, choosing to focus solely on the impact of electric prices on the low income. This paper was published after sufficient time had passed for economic recovery from the oil crisis. In light of decreasing oil prices, research on the energy burden on the poor in the U.S. shifted from oil prices to electricity prices, which accounted for the majority of energy costs in the 1990s (Baxter 1998). The study recognized that these households had few, if any, options to reduce their energy burden due to cost barriers of energy-efficiency improvements. Echoing Cooper *et al.* 's work, Byrne *et al.* 's study proved that electricity was a very inelastic demand compared to other energy services; since there were few substitutes for this type of energy and low-income homes were already doing what they could to reduce their electricity demands which often translated to lower standards of living. The authors advocated for policies that priced electricity using a baseline which meets basic electricity needs, the first of which had been introduced in California as “lifeline rates”. While many policies were directed at offering subsidies to offset increasing electricity costs, Byrne *et al.* argued that lifeline electricity rates would offer more benefits that specifically address the increasing energy costs for low-income households. They claimed that the resistance towards adoption of lifeline electric rates was a strategy for utilities to take advantage of the inelastic demand from low income households.

The language around this issue shifted from energy burden to fuel poverty with the publishing of Brenda Boardman’s book “Fuel Poverty: From Cold Homes to Affordable Warmth” in 1991. Although there had been previous research on fuel poverty and earlier attempts to define it (Bradshaw and Hutton 1983), Boardman’s “Fuel Poverty” gained national and international attention and helped raise this issue beyond academia and into public sphere.

It is important to note that Boardman, a British researcher, chose a different term (fuel) in talking about the affordability of energy for the poor than the energy source that American researchers had come to focus on (electricity). It is evident that the language and urgency on the topic of energy affordability largely reflect the context of the times and place in which the discourse arose. Subsequently, “affordable warmth” became a buzzword around the issue of fuel poverty. However, the focus remained beyond sufficient heating for low income households. Boardman’s work echoed the concerns over deteriorating quality of life for low income households who had to make do with rising energy costs. She detailed the sacrifices many families were forced to make in desperate attempts to reduce their energy consumption and the impact that those effects were having on their health and well-being.

Despite differences on energy source focus, there was a strong consensus among those involved in the energy affordability discourse that energy efficiency had great potential in reducing fuel poverty. Recognizing that low-income families lacked the upfront capital required for many energy efficiency upgrades, government sponsored programs were deemed a suitable solution to addressing fuel poverty. This gave rise to many energy efficiency and weatherization programs across the U.S. aimed at reducing energy costs for low-income households; however, they mostly focused on helping households meet their heating needs and failed to address affordability of electricity (Baxter 1998).

Boardman offered a definition of fuel poverty based on energy expenditures as a percentage of income in accordance to the literature and research on energy burden of the poor. Households were classified as being fuel poor if their energy expenditures exceeded 10% of their household income. Boardman’s definition of fuel poverty gained lots of traction and made it easy enough for governments and researchers to identify the population suffering from fuel poverty. However, the simplistic threshold proved to be problematic and insufficient for other researchers. In a review of fuel poverty definitions, Moore pointed out that there was still some debate on the matter (2012). He noted that although there was a no consensus on the definition of energy or fuel poverty with the European Union, there was a general understanding that energy poverty referred solely to electricity and gas costs, while fuel poverty offered to more encompassing definition including home fuels used for cooking, heating, and lighting, as well as fuels used for personal transportation. Moore also described the arguments for eliminating housing costs from household income used in in fuel poverty determinations, stating that households are unable to use the portion of their income set aside for housing payments to meet their energy bill obligations. More importantly, he argued that expenditures on fuel, even if combined with other energy sources, remained a poor indicator of a household's energy poverty status (Moore 2012). Similar, to Byrne *et al.'s* argument for using electricity "lifeline rates", Moore proposed that fuel poverty should be measured using costs required for basic energy services. This proposal was in recognition that poor households tend to under heat their homes and put their health and comfort at risk to reduce fuel costs. Thus, he chose to advocate for the use of required fuel costs to maintain "adequate thermal comfort, safeguard health, and cover other normal fuel usage to measure fuel poverty". However, he did acknowledge the difficulties in determining the required fuel costs- particularly with respect to differences in climate conditions, levels of comfort, and energy prices that can vary widely based on geographic region, season, household size, and other factors.

Research on fuel poverty eventually grew beyond the UK and the U.S. The increase in research on the manifestation of fuel poverty in developing countries resulted in a fragmentation of the literature with some academics focusing on the problems within advanced and developed countries and the others focusing on the problems in the developing world. Certainly, there were also those who opted to take a more global perspective on the issue, but the circumstances of fuel poverty in developing and developed countries made it difficult to examine and address the issue in each context using the same approach; it necessitated a more nuanced look at the problems so as to investigate the appropriate policies to address the issue.

The unique context of fuel poverty in developing countries motivated some researchers to develop new terminology. Guruswamy introduced the term "energy oppressed poor (EOP)" to look at a specific form of fuel poverty in developing countries where poor people don't have access to modern energy sources (2010). Similarly, the term "energy poverty" was used to describe the situation for people who regularly live without electricity and rely upon biomass fuels – primarily wood or animal dung – for heating and cooking purposes (Sovacool 2013; Van de Graaf 2013). Their research revealed an important distinction between energy poverty and fuel poverty. Whereas energy poverty generally referred to the lack of access to modern energy sources, sometime due to lack of necessary infrastructure which impeded distribution of energy resources, fuel poverty dealt more with the affordability of energy resources in places were modern energy and infrastructure is available. However, the lines between the two terms, fuel poverty and energy poverty, were not so neatly defined. There was considerate overlap between the two related terms. Although energy poverty as described above is presented as a phenomena exclusive to developing countries, Sovacool and Bickerstaff *et al.* assert that this isn't the case. He asserts that even in wealthy nations – notably the United States- poor populations living in densely urban areas can also be said to suffer from energy poverty (2013). With this new focus on energy poverty across the globe, researchers began to frame the problem as an issue of injustice, subsequently engaging in a new discourse around "energy justice" (Walker and Day 2012; Sovacool 2013; Sovacool and Dworkin 2015; Bickerstaff *et al.* 2013).

When Cooper *et al.* published "Equity and Energy" in 1983, they stated that energy was a vital necessity for life. Later, with the release of the Millennium Development Goals in 2000 followed by the Sustainable Development Goals in 2015, energy access was cemented into the international humanitarian agenda. Goal number seven of the SDGs is to ensure access to affordable, reliable, sustainable, and modern energy for all (SDG 2015). As a result, energy, much like water or clean air, is increasingly being perceived as a human right. The idea being that every person should have access to basic energy services to maintain a dignified existence. The introduction of the justice framework was also a result of the recognition of the deeply rooted inequalities in the distribution of energy benefits and harms (Guruswamy 2010; Sovacool 2013; Van de Graaf 2013). By examining fuel and energy poverty from a justice perspective, researchers moved beyond focusing on the impacts of disproportionately high energy costs. They began to investigate: how poor people were impacted by the fuels used in the production of energy, the distribution of energy, the siting of heavily polluting power plants in poor and vulnerable communities, the pressure to unsustainably exploit energy resources for economic development, and the impacts of climate change on the poor.

The energy justice discourse took a great deal of interest in the climate change debate. Surmounting evidence of human induced climate change and the subsequent policy initiatives to mitigate it raised many concerns about justice. Academics and the public wanted to know what would happen as a result of climate change and equally important, who was responsible. As evidence came to light that burning of fossil fuels was the single greatest human activity contributing to climate change, the energy industry faced strong and vocal criticism. Numerous reports by the Intergovernmental Panel on Climate Change (IPCC) provided evidence of the link between burning of fossil fuels and a rise in global mean temperatures (IPCC 2014). Much of the early efforts to address climate change were solely focused on the reduction of greenhouse gas emissions- the largest of which emanated from the energy sector (Guruswamy 2010). Proposed policies to reduce emissions on an international scale faced heavy opposition from many developing countries who felt that restrictions on greenhouse gas emissions would impede their economic and social development. There was even more resistance from developing countries to reduce emission in recognition that wealthy developed nations bore the highest responsibility for historic greenhouse gas emissions. Studies on the impacts of climate change consistently showed that poor developing countries would be disproportionately burdened by rising sea levels, increasing water stress, shortage of food crops, and associated health impacts (Guruswamy 2010).

Within academic and the public spheres, it was difficult to have a discourse about climate change without referencing the energy and justice dimensions of the issue. Although it was clear that action needed to be taken at an international level to reduce emissions, there was heavy debate over which countries should take action. In general, Northern developed countries argued for rapidly developing countries – namely China and India – to curb their emissions, whereas developing countries urged developed countries – namely the U.S. – to take responsibility and reduce their emissions. The developing countries' argument for rich and advanced nations to take action was that they were the ones chiefly responsible for climate change and that they possess the wealth and technology necessary to achieve those reductions; while a push for the developing world to limit emissions would diminish their ability to alleviate poverty and increase standard of living for their people. To reconcile the demand from developing countries to address the justice dimensions of climate change and developed countries in the North's resolve to take action on greenhouse gas emissions, sustainable development arose a platform and objective that both sides could agree upon (Najam 2005). As such, the conversation on climate change mitigation shifted towards sustainable development, in an effort to be more representative of developing nation's primary objectives- although it can be said that the two often have competing goals (Guruswamy 2010). Sustainable development brought more developing countries, collectively referred to as the global South, to the table at climate change negotiations (Najam 2005).

Even as climate change negotiations progressed with greater consideration of sustainable development objectives, there was concern that energy poor individuals continue to be neglected by decision-makers who were directing their efforts towards high energy consumers in the developed world and their transition to a low-carbon economy (Guruswamy 2010). In *Energy Justice in a Changing Climate*, Bickestaff *et al.* details the plight of "the global North" in their transition to low-carbon energy systems, mainly through the replacement of inefficient power plants and growth in renewable energy (2013). The authors remark that even within the wealthy developed countries that are actively promoting a low-carbon energy system, energy poverty persists and energy injustices are often perpetuated with the introduction of residential solar systems. A similar concern over wealthy countries' disregard for energy poor individuals is expressed by Walker and Day who fear that future policies will focus more on improving energy efficiency in housing rather than eliminating distributional inequalities of incomes and energy pricing (2012). In response to the injustices that arise from policies and processes related to energy systems, Sovacool and Dworkin developed a framework of energy justice to aid energy planners and consumers in the diagnosis of energy problems and devise appropriate solutions (2015). This framework for decision-makers is presented in Table 2.

Table 2: Sovacool and Dworkin's (2015) Energy Justice Decision-making tool.

Principle	Explanation
Availability	People deserve sufficient energy resources of high quality
Affordability	All people, including the poor, should pay no more than 10% of their income for energy services
Due process	Countries should respect due process and human rights in their production and use of energy
Good governance	All people should have access to high quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making
Sustainability	Energy resources should not be depleted too quickly
Intragenerational equity	All people have a right to fairly access energy services

Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict in the world today
Responsibility	All nations have a responsibility to protect the natural environment and minimize energy related environmental threats

3.2 Addressing energy challenges in the U.S.: energy efficiency, conservation, and solar

In recent years, energy related legislation in the United States has focused on the environmental and social challenges presented by climate change, rising demand for energy services, pollution from energy production, and continued dependence on foreign oil. To address those challenges, energy conservation, energy efficiency, and renewable energy have been proposed as potential solutions. From the start of the oil energy crisis in 1973, policies were directed at conservation and efficiency with later efforts shifting more towards renewable energy. The first national energy policy introduced during the energy crisis in the U.S. was the Energy Policy and Conservation Act of 1975. The policy was designed to promote energy conservation to help meet the country's rising energy demands by introducing conservation programs and setting vehicle fuel standards (ACNEEP 2013). This policy was followed by the Energy Conservation and Production Act of 1976 which introduced the first federal weatherization programs for low income families. This Act also provided funding for renewables and set up a program tasked with devising building conservation standards. In response to the oil crisis, Congress passed a series of acts collectively known as the National Energy Act of 1978. The package included the National Energy Conservation Policy Act, Public Utility Regulatory Policies Act, Energy Tax Act, Power Plant and the Industrial Fuel Use Act, and the Natural Gas Policy Act. When the Act was first signed into law by President Carter, he remarked that the policies were forged out of three main principles: to learn how to use energy efficiently, to provide incentives to support domestic energy supplies, and to shift towards renewables – primarily solar(Gerhard and Woolley 2015). Renewable energy and energy efficiency policies have proliferated since the passing of the National Energy Act of 1978.

Environmentalists and policy makers have used energy conservation and efficiency measures as a way to reduce energy consumption and tackle climate change. The push for higher energy efficiency operates on the idea that reducing the amount of energy required to achieve optimal operation will result in overall decreased energy consumption and decreased greenhouse gas emissions. The International Energy Agency's website defines energy efficiency as "a way of managing and restraining growth of energy consumption" (IEA 2015). Similarly, renewables have increased in popularity due to their ability to generate energy domestically and offset greenhouse gas emissions from carbon emitting and polluting methods of energy production.

In the U.S., there have been energy efficiency policies introduced at every level of government: federal, state, and local. At the state level, California has been at the forefront of energy efficiency policy with many of its policies being adopted at the federal level. In 1977, the state introduced the first building and appliance efficiency standards which served as a model for standards set at the national level. Initially, the aim of these efficiency policies was to reduce overall energy demand. Overtime, policies began to embrace other potential benefits of improved energy efficiency including: reductions in water use, improved air quality, and reduced greenhouse gas emissions.

Despite political efforts to curtail emissions and constrain rising energy demand by enacting conservation and efficiency measures, research has shown that they've been met with limited success (York 2010). Even though policies have led to improvements in energy efficiency and reductions in CO_2 intensity, a study of CO_2 emission trends within the U.S. from 1960-2003 has shown that emissions continue to rise (York 2010). A graph showing the findings of this study is shown in Figure 5. Studies on CO_2 emissions have generally put great importance on trends in the U.S. and China due to their large contributions to global carbon emissions. Data on historic carbon emissions have shown that the U.S. is responsible for the largest share of cumulative emissions of any other country by a fairly wide margin (Monasterkly 2009). The U.S. had continually ranked as the largest annual emitter of CO_2, up until 2007 when China took its place (Cyranoski 2007). China's rapid growth in emission has mostly been due to its large population and growing economic activity, yet it maintains a low emissions per capita rate (Cyranoski 2007). In contrast, the U.S. has the highest per capita CO_2 emissions rate among the top five largest emitters plus the EU, as seen in Figure 4 (Olivier *et al.* 2015). York's study confirms that while per capita emissions and per capita energy use has slightly decreased since the oil crisis, the numbers still far exceed the global average. He notes that by taking action to reduce per capita energy consumption, the U.S. could effectively reduce its total CO_2 emissions. However, he does recognize that due to inequalities, energy use and emissions can vary considerably based on income, with the wealthiest populations exerting a dominant impact.

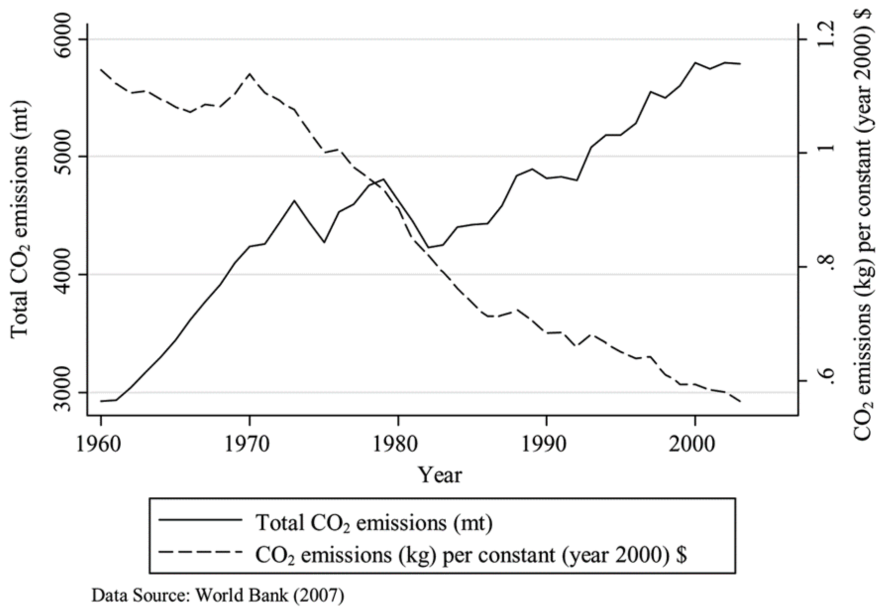

Figure 4: Total CO2 emissions and CO2 intensity for United States 1960-2003. Source: York 2010.

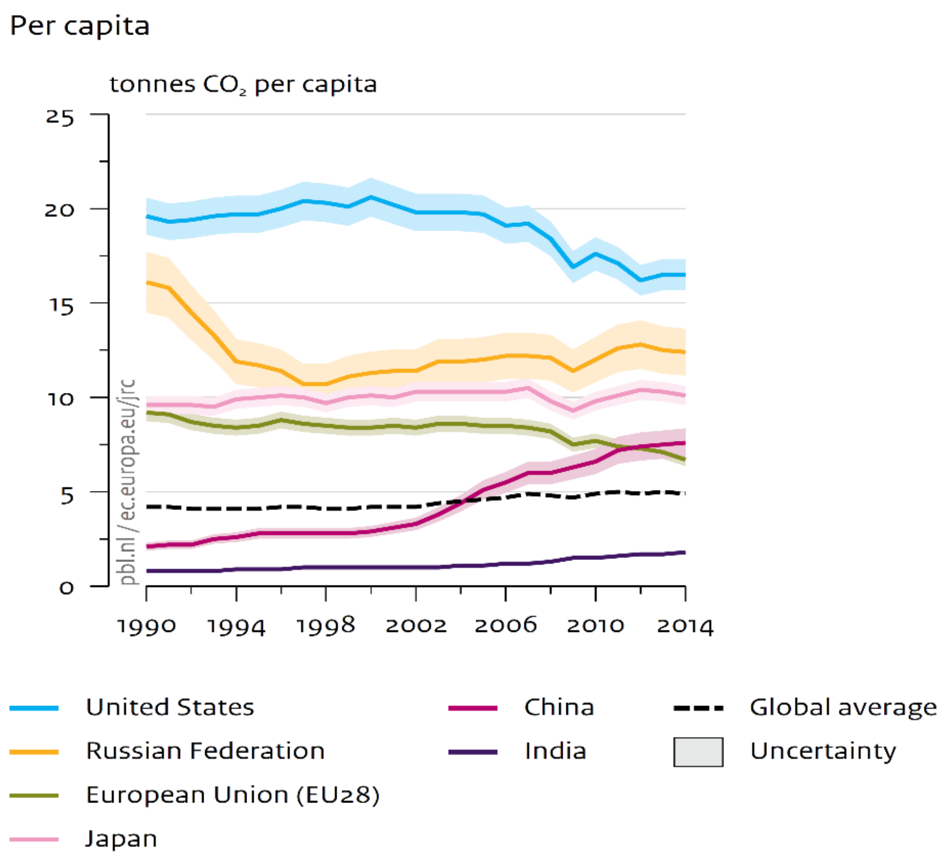

Figure 5: CO2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and the EU. Source: Olivier *et al.* 2015.

The limited success of energy conservation and efficiency policies motivated legislators and regulatory agencies to examine the non-economic factors that influenced energy consumption and production. In 1980, early research on the social dimension of energy consumption was carried out by the Committee on the Behavioral and Social Aspects of Energy Consumption and Production, which had been established by the National Research Council at the behest of the U.S. Department of Energy. Their goal was to conduct a comprehensive review of literature within behavioral and social sciences that could improve policy makers' understanding of energy consumption and production and ultimately help create better energy efficiency policies. The result of their work was a report titled, *Energy use: the human dimension*, which presented three central characteristic of the country's energy system: diversity, uncertainty, and mistrust (Stern 1984). The report claimed that policies based on analysis of statistical averages overlooked the differences in the many ways people use energy. Additionally, the report stated that these policies were less effective than those that accounted for the diversity exhibited in people's attitudes and use of energy. They felt that this was particularly true during energy emergencies because differences tend to be exaggerated as with the oil crisis when low income Americans were impacted the most by rising energy costs. They also argue that uncertainty is characteristic of the energy system due to changes in energy markets, political environments, and other factors which can lead to widespread confusion and uncoordinated responses. Likewise, the report finds that mistrust is prevalent amongst energy consumers. Their work revealed that many energy consumers showed skepticism toward energy efficiency information provided by utilities and ignored energy savings recommendations based on their perception of utilities being untrustworthy. The more recent work by Sovacool shows that distrust towards utilities continues to serve as a barrier to the effective implementation of energy efficiency measures (2009).

One key finding from Stern *et al.* report on energy use was the importance of values, particularly those concerning control and freedom. The authors claimed that for many energy consumers in the U.S., energy represented either control or lack of freedom in their lives depending on their access and ability to afford energy services. This led them to the conclusion that energy conservation and efficiency programs have a better chance of being accepted by the public and reaching their objectives if they are able to increase individuals' control over their energy situation. Similarly, they argue that the success of energy programs can be maximized if they are compatible with the values of the target population; thus, the program planners must gain a good understanding of the target population's need and values.

The importance people place on control over their energy situation was highlighted in an experiment which investigated the effectiveness of automatic energy saving thermostats. This experiment was part of a larger study of residents' energy-related attitudes and it revealed that initial resistance to automatic energy saving thermostats dissipated when the design of the thermostat was altered to give residents more control over the system by adding an option to temporarily override the system settings (Becker *et al.* 1979). This study also showed that attitudes towards thermal comfort offered the best and most reliable correlations with energy use, even when compared against attitudes about the energy crisis and about energy cost. The study included many experiments related to energy conservation and efficiency programs, including the one mentioned above on thermostats and another on the utility of feedback for achieving energy conservation.

Monitoring of residential energy consumption has been identified as a viable method for achieving energy conservation for quite some time. The 1979 study by Becker *et al.* stated that the role of consumption feedback in energy conservation programs was equivalent to the role of bathroom scales in dieting. They were quick to point out that feedback does not automatically generate reductions in energy consumption, but that it can enhance the likelihood of success in energy conservation so long as the resident makes a prior commitment to conserve, the feedback allows for useful assessment of their progress, and information provided is perceived as credible. Fragidis and Olshewski take a similar position on the role of feedback on consumption but add that information on consumption usually only motivates above-average consumers to reduce their consumption, while below-average consumers may be encouraged to consumer more (2015).

Many studies show a positive correlation between conservation behavior and increased awareness about consumption, however, they mostly focus on conservation in "typical" households (Westergren *et al.* 1998; Abrahamse *et al.* 2005; Ueno *et al.* 2006; Chetty *et al.* 2008). Fewer studies have focused on "non-typical" households such as environmental conscious households –which tend to be more affluent – (Woodruff *et al.* 2007) or low income households (Dillahunt *et al.* 2009). A study on the feedback effect on conservation efforts in low-income communities found that energy use behaviors were closer to those of more affluent environmentally friendly households than typical households (Dillahunt *et al.* 2009). The findings reported by the study were in line with past research about cost and comfort also having a big influence consumption behavior (Becker *et al.* 1979; Cooper *et al.* 1983; Van Raaij and Verhallen 1983). As with previous research on energy use in low-income households, the study found that many of the participants were unable to afford energy efficient appliances and lived in low quality housing lacking energy efficiency infrastructure (Cooper *et al.* 1983; Byrne *et al.* 1986; Boardman 1991). In spite of this, the study reported more diverse and creative energy saving strategies within the low-income households than in "typical" or "green households. Many of study participants lived in apartment buildings where they did not receive regular utility bills, some only received a bill if their energy usage exceeded a predetermined threshold, which left many households unaware of their energy consumption (Dillahunt *et al.* 2009). The study also identified barriers to reductions in energy consumption specific to low-income households which included: lack of feedback on energy use, lack of control over other people in their residence, and lack of necessary capital for energy saving investments. Surprisingly, the study showed that many participants engaged in energy saving behavior even when they weren't paying for their utility costs, which the participants attributed to ingrained habits and concern for future generations. This attitude towards conservation among low income residents appears to deviate from the findings of other surveys of the American public at-large.

Repeated surveys by Ansolabehere and Konisky on the American public's attitude towards energy have shown that despite growing concern over climate change, the majority of Americans demonstrate an unwillingness to reduce consumption patterns or support policies that move energy production away from fossil fuels (2007, 2012, and 2014). Their surveys found that attitudes towards energy are largely shaped by cost and environmental harms, resulting in Americans' demand for clean and cheap energy. They add that many who initially supported clean renewables changed their mind once they became aware of the price tag for those clean energy sources. In an analysis of the social and cultural barriers to energy efficiency and renewables, data reveals that many Americans feel entitled to energy intensive lifestyles and demonstrate an aversion to energy conservation approaches (Sovacool 2009). The article puts a heavy focus on values, which can be seen as continuation of the Stern *et al.* report's assessment of the role values play in energy decisions. Sovacool claims there has been a shift in American values from the nineteenth century when great importance was placed on labor intensive work and frugality, to today's values which are now centered on consumerism and leisure (2009). The article concludes that the principal barriers to energy efficiency and deployment of renewable energy technologies are: public apathy and misunderstanding, conceptions of consumption and abundance, and psychological resistance. The conclusions are based on interviews with a variety of stakeholders including electric utilities, regulatory agencies, interest groups, and non-profits from 2005-2008. Their findings suggest that Americans exhibit a general lack of understanding about electricity production and distribution processes, ignorance about renewable energy, and distrust towards utilities. An even more disturbing discovery concerning barriers to energy efficiency was reported by an energy efficiency consultant who observed that energy efficient technologies were stigmatized by affluent residents who perceived them as being low-class and trashy due to these technologies being distributed by energy programs serving low income areas in the vicinity (Strand 2005).

Given the apparent unpopularity of conservation and efficiency measures among Americans, energy policies have increasingly embraced renewable energy as a sustainable solution to satisfy the nation's rising energy demand while also helping to decarbonizing energy production. Policies have encouraged the growth of renewables by helping reduce its cost and make it more competitive with conventional energy sources by providing loans, grants, research and development, subsidies, and also through the adoption of Renewables Portfolio Standard (RPS) (Barry and Jaccard 2000). These standards require utilities to obtain a certain percentage of annual electricity sales from renewable sources within a set timeframe. The state of California has adopted one of the most ambitious RPS goals within the country by requiring its utilities and electricity providers to obtain 33% of their electricity from renewables by 2020 (CPUC 2016). The recent passing of SB 350 has further raised those targets by requiring 50% of electricity from renewables by 2030 (De Leon 2015). California's RPS has been the main driver for growth in renewable energy from the supply side, but programs like the California Solar Initiative and Self-Generation Incentive have taken the lead in encouraging renewable energy production from the customer's side.

3.3 Rebound Effect

While energy efficiency and renewable energy have been celebrated as effective strategies for managing and constraining growth in energy consumption and carbon emissions, many researchers have expressed doubts. In response to reliance on efficiency strategies to curb emissions and reduce energy consumption, many scholars have openly questioned the assumption that efficiency gains will necessarily lead to reductions in consumption (Brookes 1979; Khazzoom 1980; Greenhalgh 1990; Sanne 2000, 2002). What has ensued in light of these investigations is a resurgence of the debate on the Jevons paradox (Alcott 2005; Foster 2010; Sorrel 2009). The Jevons paradox arose from William Stanley Jevons' research on the impact that the exhaustion of coal reserves would have on Britain's economy (1865). Jevons' research took place in 19th century Britain, during the time that abundant and cheap coal fueled the national economy. He feared that the existing rates of consumption would inevitably lead to an exhaustion of the coal mines and result in a devastating economic downturn. His book, *The Coal Question*, argued against the claims of Hull and other coal researchers who proposed that improvements in efficiency of extraction of energy from coal would reduce overall coal consumption and prolong the operation of the coal mines (Jevons 1865; Hull 1861). Contrary to public opinion at the time, Jevons believed that efficiency improvements would have the exact opposite effect on the consumption of coal. He claimed that the increased efficiency of coal would decrease its cost and subsequently result in an overall increase in demand. This idea became known as the Jevons paradox.

Jevons' predictions on the exhaustion of Britain's coal mines were abandoned and forgotten, but his theorized effect of efficiency on consumption survived. The debate over the so-called Jevons paradox continued to resurface, particularly during times of energy shortages. Over time, the paradox was expanded and labeled the "rebound effect". Debate over the rebound effect has evolved in the last two decades with greater attempts to define it and measure its magnitude (Berkhout *et al.* 2000; Brookes 1990; ECA 2014; Gillingham *et al.* 2015; Saunders 2000; Greenhalgh 1990; Greene 1992; Sanne 2000, 2002). Consequently, there are many different definitions for the rebound effect. One of the best and most coherent attempts to define the rebound effect describe it as the difference between actual reductions in energy use resulting from efficiency improvements and the expected reductions in energy use that overlook consumer and market responses (Gillingham *et al.* 2015). The rebound effect is often described as the product of income and substitution effects and is reported as a percentage of savings that are offset by consumer responses. The substitution effect is understood as the change in consumption that occurs when a consumer substitutes towards the more efficient product, which is now relatively less expensive (Gillingham *et al.* 2015). The income effect is the change in consumption that occurs from the increase in purchasing power that the consumer experiences as a result from substituting towards the more inexpensive and efficient product or service. Research on the rebound effect is generally divided into three categories depending of the scope of the study: direct, indirect, and economy-wide. Studies that attempt to estimate the direct rebound effect focus on the changes in consumption of the more efficient product or service. On the other hand, studies on indirect effects focus on the changes in consumption of other energy intensive products or services resulting from the increased efficiency of one energy product or service (ECA 2014). Research on economy-wide effects focuses on the effect that increased efficiency has on the economy as a whole. Investigating the economy-wide rebound effects is considered a macroeconomic approach and requires consideration of both direct and indirect effects. The methodologies for estimating rebound rates are diverse, but the most reliable estimates are based on the price elasticities of demand for the more energy-efficient product or service. The price elasticity of demand is a measure of how demand for a product changes as a result of changes in the product's price. Estimates based on price elasticities are appropriate for calculating the direct rebound effect, as they only look at changes in demand on the energy-efficient product. The majority of the literature is focused on estimates of the direct and economy-wide rebound effect, with fewer studies investigating the indirect rebound due to difficulties in making reliable estimates.

One of the first empirical studies that attempted to quantify the magnitude of the rebound effect was conducted by Khazzoom in 1980. His work focused on estimating direct rebound effects of improvements on household energy efficiency appliances and revived the debate on Jevons paradox (Khazzoom 1980, 1987, 1989). During the time that Khazzoom was conducting research on microeconomic rebound effects, Brookes was also engaged in research on the Jevons paradox but focused his work on the macroeconomic rebound effect (Brookes 1979). Brookes' work made strong arguments for economy-wide rebound effect, arguing that increases in energy efficiency would not only increase productivity of the more energy efficient good, but also increase productivity across multiple sectors leading to an overall increase in consumption (Brookes 1979, 1990, 2000). Brookes' work also offered heavy critiques of government energy efficiency policy. In 1992, Saunders formulated the "Khazzoom-Brookes Postulate" by bridging the works of the two researchers and advancing his own claim that efficiency gains could ultimately lead to a higher rate of consumption than if no efficiency improvement had been introduced. He arrived at this claim for "backfire" by incorporating neoclassical growth theory (Saunders 1992, 2002). The argument for backfire sits on the extreme end of the debate over the rebound effect and is a rather unpopular claim.

The majority of empirical studies on rebound demonstrate evidence for a significant rebound effect, but few even indulge the claim for backfire (Greene 1992; Greene *et al.* 1999; Greenhalgh 1990; Sanne 2000, 2002). A study by Berkhout expanded on Khazoom's work by investigating the rebound effect in multiple commodity cases and found a small rebound rate 0-15% (2000). Foster *et al.* found that most estimates of the direct rebound were relatively small and fell within a range of 10-30%, but the effect could prove to be extremely significant once indirect effect were accounted for (2010). Gillingham *et al.* claim that microeconomic rebound ranges from 20-40% in most cases and that far less is known about the macroeconomic rebound due to difficulties inherent in estimating indirect rebound and shortage of reliable studies (2015). While supporting claims for significant rebound rates, they refute the idea of backfire entirely, stating that there is no evidence for the claim and that the macroeconomic rebound effect would likely be smaller than the sum of its parts.

A more neutral stance is taken by some researchers who argue that current evidence for the rebound effect is insufficient. There have been many critiques on the methodologies currently employed since the majority of arguments for the rebound effect rely on a combination of experimental observations and theory. Some argue that reliable methods for estimating indirect and economy-wide rebound effect do not exist, which they partly attribute to the lack of consensus on the definition of these terms (Alcott 2005; Madlener and Alcott 2009). Sorrel takes a similar stance by identifying the empirical and theoretical weaknesses in arguments presented by Brookes and Saunders, concluding that there is no strong evidence in support of the rebound effect but that further research is necessary (2009).

Evidently, claims against the existence of a rebound effect emerged from the time that the Jevons paradox was first proposed. Earlier work by Hull had asserted that coal would continue to fuel the nation's economy despite rapid growth in consumption through parallel increases in the efficiency of coal (1861). The consensus agreed that efficiency strategies would suffice to meet rising demand of coal and were shocked by Jevons' claims. Mundella was among those who quickly refuted the idea that efficiency gains would lead to increases in consumption (1878). Using the same example of pig iron production that Jevons had presented in *The Coal Question*, Mundella argued that even though the efficiency and production of pig iron had increased- due to increases in efficiency of coal- the consumption of coal used in pig iron manufacture had decreased. He had accepted Jevons' link between increases in efficiency and reductions in price, but failed to understand how that would raise demand because he only looked at the consumption of coal used in the manufacture of pig iron, rather than observing the total amount of coal used in manufacture of all goods. Mundella's treatment of Jevons' claims had been too narrow in scope by focusing on coal consumption in the iron production sector, while Jevons' arguments had been focused on multi-sector, economy wide effects on coal consumption.

Regrettably, the overwhelming majority of energy efficiency strategists do not engage with the rebound effect debate. Along the same sentiment of energy efficiency policies, many researchers disregard the rebound effect and proclaim that pursuit of greater efficiency is a sustainable approach to environmental and energy challenges (Goodland 1992; Mikesell 1992; Schmidheiny 1992; Stern *et al.* 1985; Vincent and Panayotou 1997; Von Weizsacker *et al.* 1997). Those that do investigate the rebound effect, conclude that estimates are low and even upper bound estimates are not significant enough to undermine the role of energy efficiency in reducing carbon emissions (Greening, *et al.* 2000; Lovins 1988). Only one study from the efficiency strategist camp has admitted that backfire can occur, as is evident in the coal and pig-iron case, but add that those cases are not the norm but the exception (Schipper and Grubb 2000).

While earlier studies on estimating rebound effects were mostly focused on estimating rebound effect on more energy-efficient products and services, more recent studies have come to light that examine the rebound effect resulting from an energy efficiency policies. Due to the differences in the conditions that can produce an energy efficiency improvement and the implications it can have on the rebound effect, Gillingham *et al.* established a distinction between rebound effects resulting from "Zero-Cost Breakthrough" (ZBC) and "Policy-Induced Improvement" (PII) (2015). The first type, ZBC refers to efficiency improvements achieved at no cost and constitutes the majority of research conducted on rebound effect. The second, PII is the rebound effect resulting from improvement in efficiency achieved through energy efficiency policies. Although studies devoted to investigating rebound effects from energy efficiency policies are few, there does appear to be an increase in recent years.

Interest in examining the effects on energy efficiency policies appears to be growing in parallel to interest in research on the effect on income on the rebound effect. A study of Canadian households' energy use before and after installation of energy efficiency improvement found that low income households tended to conserve significantly more energy after the efficiency improvements compared to the higher income group which tended to consume more (Parker 2005). This finding was supported by another study on UK households which aimed at examining whether the rebound effect reduced carbon savings for people who received energy efficiency measures under fuel poverty programs (Pett 2009). The authors of this study observed similar behavior among low income households with efficiency improvements; they found that they did not raise their consumption, but instead decreased it significantly. They concluded that reducing carbon emissions for households in fuel poverty through energy efficiency schemes is unlikely to lead to indirect rebound effects. However, the findings of this study are unreliable due to the small sample size and self-selection bias. In contrast to this these studies, more recent work has found that low income household have greater rebound effects. A study conducted by Chitnis *et al.* on the rebound effects from energy efficiency improvements and behavioral changes found that the low income households in the UK exhibited the largest rebound effect (2014). The study goes on to conclude that, “measures that are subsidized or affect highly taxed energy commodities may be less effective in reducing aggregate emissions” (Chitnis *et al.* 2014). Another study aimed at investigating rebound effects from both efficiency and sufficiency measures for different income groups in the U.S. reported an indirect rebound rate that ranged from 5-15% and found that rebound effects are inversely related to household income (Thomas and Azevedo 2013).

Admittedly, the rebound effect is almost exclusively discussed in the context of energy efficiency. However, its application is useful with regards to measures, which seek to displace energy consumption through substitution of an alternative energy form (ECA 2014). While there have been no studies to investigate the potential for a rebound effect in solar homes, there have been studies that investigate changes in energy consumption behavior in solar homes (Motlagh *et al.* 2015; DECC 2015). These studies have pointed out a gap in knowledge on the amount of energy used in solar homes due to difficulties in determining the amount of generated energy that is consumed on-site. They have also encouraged new research to further the understanding of consumption behavior in solar homes.

4. California Solar Initiative

In the United States, California is one of the leading states in solar energy. The state is on track to meet its goal of having 33% of its retail electricity sales come from renewable energy by 2020. Advances in technology combined with policy incentives have made rooftop photovoltaic (PV) systems accessible to many homeowners. A little over a decade ago, residential rooftop PV systems were not an economically viable option for most homeowners due to their large upfront costs and long payback period. In recent years the tide has changed allowing for greater adoption of residential PV systems in California even among low-income households. In 2006, the state launched the California Solar Initiative (CSI) which consisted of a series of solar rebate programs. Through the CSI rebates, economic benefits are playing an increasingly larger role in homeowner's decisions to adopt PV systems.

4.1 Overview

The aim of the CSI programs, and the larger Go Solar California campaign is to increase domestic electricity generating capacity through solar energy systems and make "renewable energy an everyday reality". The push towards renewable energy comes from the recognition that dependence on fossil fuels is not only bad for the economy but also for the environment due to CO_2 emissions and the role they play in climate change. The CSI programs are overseen by the CPUC, which has authority over California's investor-owned utilities (IOUs). The CSI consists of four solar rebate programs and a solar grant program for research, development, demonstration and deployment. The solar rebate programs are offered to eligible residents who are customers of the state's four largest IOUs: Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). The programs that are part of the CSI are described below.

- CSI General Market program: an incentive for PV and thermal (hot water) solar systems on existing homes and buildings.
- CSI Thermal program: an incentive for solar thermal systems for homes and businesses.
- Single-family Affordable Solar Homes (SASH) program: an incentive for low-income single family homes.
- Multifamily Affordable Solar Housing (MASH) program: an incentive for low-income affordable multi-family housing units.
- CSI Research, Development, Demonstration, and Deployment (RD&D) program: a grant program to fund research, development, demonstration and deployment of solar technologies.

The programs were launched in 2006 and were given a total budget of $2.16 billion to fund the programs for 10 years. Their goal is to collectively reach 1,940 MW of installed capacity by the end of 2016. The programs are funded by electricity rate payers who receive service from PG&E, SCE, and SDG&E through a surcharge added to their monthly bills.

4.2 SASH Program

The concept for the SASH program arose out of concern that low-income ratepayers who contribute to the CSI program budgets, would not be able to benefit from the program due to economic barriers. The SASH program was announced in 2007 as one of the two CSI programs that would provide incentives for qualified low income families. During the time the CSI was created, it was mandated that 10% of the program would go directly towards incentives for low-income families. The 10% was split between the SASH and MASH programs, with each program receiving $108 million to fund projects throughout 2016. The two programs were given a combined capacity goal of 190 MWs. In 2008, GRID Alternatives, a non-profit solar installation organization, was chosen to be the sole administrator of the SASH program. The first SASH solar installation was completed by GRID Alternatives in 2009. Since then, GRID

Alternatives has managed a total of 5,246 PV system installations to date (Go Solar California 2016).

4.2.1 Program Goals

The following are the goals the SASH program had set out to accomplish:

- Decrease electricity usage by solar installation and reduce energy bills without increasing monthly expenses
- Provide full and partial incentives for solar systems for low-income participants
- Offer the power of solar and energy efficiency to homeowners
- Decrease the expense of solar ownership with a higher incentive than the General CSI Program
- Develop energy solutions that are environmentally and economically sustainable
- Provide job training and employment opportunities in the solar energy and energy efficiency sectors of the economy

4.2.2 Eligibility Requirements

There are some preconditions a household must meet before qualifying for the SASH program. The following are the minimum eligibility requirements for applicants:

- Own and live in their home
- Have a household income of 80% or below the area median income (AMI)
- Receive electrical service from PG&E, SCE, or SDG&E
- Live in a home deemed as "affordable housing" by California Public Utilities Code 2852

4.2.3 Assembly Bill 217

The SASH program was originally scheduled to sunset in 2016 like the rest of the CSI programs. In 2013, the California state legislature passed Assembly Bill 217 (AB 217) which extended the SASH and MASH programs (Bradford). The bill authorized an additional $108 million for the low income programs and set a new goal of 50 MW of installed capacity across both programs. The adopted capacity target was divided between the programs with 35 MW as the target for MASH and the remaining 15 MW as the target for the SASH program. The program has been extended to 2021 or whenever funds are exhausted. In addition, the bill reduced the incentive to $3 per watt. Prior to this bill, the incentives ranged from $4.74-$7 per watt (Navigant 2011). AB 217 also sets the following new program goals:

- Maximize the overall benefit to ratepayers;
- Require participants who receive monetary incentives to enroll in the Energy Savings Assistance (ESA) program, if eligible; and
- Provide job training and employment opportunities in the solar energy and energy efficiency sectors of the economy.

5. Discussion

The results from the needs assessment and assessment of program theory are presented in the following sections. The needs assessment confirms that there is a necessity for a solar incentive program that directly targets to low income families who would not be able to afford the cost of the system otherwise. The program theory is presented in a logical model that breaks down how the program components and activities are designed to achieve its goals. The crucial assumptions inherent in the program design were evaluated based on evidence found in the literature. Research on the rebound effect highlighted some weaknesses in the program's assumptions, and indicated potential pathways for a rebound effect in the program design.

5.1 Assessment of Need for Program Results

The assessment of the need for the program consisted of: problem definition, target identification, determination of indicators, and evaluation of need of program. The first step in conducting the program evaluation was to identify the problem(s) the program is intended to ameliorate thorough the provision of its services and determine whether those services correspond to the needs of its target population. Since the program documents failed to explicitly state the problem(s) the program is aimed at resolving, some interpretation of the text was needed. Information obtained from interviews and personal correspondence with GRID Alternatives staff and CPUC staff was also utilized in the assessment.

In order to identify the problem(s) the program aims at tackling, it was necessary to review the program documents. The SASH program handbook, quarterly program status reports, evaluation reports, and program website provided information about the program's directive and its goals. This information was useful for identifying what the program aims to accomplish and by what methods. The program's goals serve as an indicator of the social conditions they aim to improve and give an impression of what they perceive as the problem(s) affecting their target audience. As described in the previous chapter, the SASH program has undergone many changes since its inception and has modified its goals and targets. Table 3 lists the most current program goals along with the inferred problem they are directed at solving and indicators which can be used to measure changes in the social condition. The indicators monitor an improvement or worsening of the problem and were used in the assessment to determine if preliminary indicator data suggests the population in need stands to benefit from the program.

Table 3: SASH Program Goals, Targets, and Indicators

SASH Program Goals	Problem targeted	Indicator(s)
1. Decrease electricity usage by solar installation and reduce energy bills without increasing monthly expenses	High energy bills for low income households	% of income spent on energy services, household electricity usage
2. Provide full and partial incentives for solar-systems for low-income participants	Underutilization of state incentives by low income households	Number of systems for low income homes installed using incentives, % of statewide incentives used by low income homes
3. Offer the power of solar and energy efficiency to homeowners	Barriers to owning solar energy and making energy efficiency improvements	% households with solar and energy efficiency improvements
4. Decrease the expense of solar ownership with a higher incentive than the General CSI Program	Incentives not high enough to make solar affordable for low income households	Incentive level, cost of solar energy system
5. Develop energy solutions that are environmentally and economically sustainable	Environmental degradation, climate change from fossil fuel energy generation, high cost of renewables	Household energy consumption, carbon emissions, environmental quality, cost-effectiveness of program
6. Provide job training and employment opportunities in the solar energy and energy efficiency sectors of the economy	Unemployment in low income communities	Number of solar jobs created, hours of job training offered
7. Designed to maximize the overall benefit to ratepayers	Incentives unequally distribute benefits among ratepayers	Cost-effectiveness

8. Require participants who receive monetary incentives to enroll in the Energy Savings Assistance (ESA) program, if eligible	Total potential energy savings not fully realized	% of homes enrolled in ESA program

The first stated goal of SASH is to decrease electricity usage and bills by solar installation without increasing monthly household expenses. From this statement it can be inferred that program planners were concerned with the burden of electricity cost on homeowners. It also suggests a recognition that the high cost of solar could put a further strain on a household income. Although it is clear that the SASH program is aimed at reducing the energy burden of low income households, the language of the program documents make no specific mention of energy burden, fuel poverty, energy poverty, or energy justice. However, throughout interviews and correspondence with GRID Alternatives and CPUC staff, the program administrators have acknowledged the relevance of energy justice and energy burden in the program's design (pers. comm. Burke, Roberts). The program administrators frequently point out that low income households are negatively impacted the most by fossil fuel generation and stand the most to gain from solar energy. They explain that fossil fuel plants are disproportionately located in low income communities, imposing on them a higher burden of pollution and environmental degradation. They also repeatedly described the burden of rising electricity costs on low-income households and the potential for solar energy to help offset those rising costs. They highlight that savings on electricity bills have the greatest positive impact on low income families and reduce their overall dependence on low income energy bill subsidies, thereby providing a more sustainable and permanent solution to high energy costs.

The problem of high energy costs can stem from high household energy usage and/or low household incomes. Potential indicators of the problem include the total household energy consumption and percentage of household income spent on energy costs. The energy burden indicator appears to be the most appropriate measurement of high energy costs in this context, since it puts cost of energy in perspective to income instead of looking at gross household energy consumption. Unfortunately, there is little available data on the energy burden of California households. One recent study however did find that nearly 650,000 households in California spent 10% or more of their income on electricity (Lesser 2012). This means that about 650,000 households could be classified as "electricity poor". The study also claims that energy poverty in the state will likely continue to rise. They find that while electric rates in the state rose by 35% from 2004-2014, the rates were still above the national average. Data from the U.S. Energy Information Administration shows that electricity rates in California were 31% higher than the national average in 2014. Given this information it is evident that energy costs do present a high energy burden for many households in California, and it is likely that the majority of those experiencing "electricity poverty" are low income households.

The second goal of the program is to promote access to solar energy for low income families. This goals seems closely aligned with the fourth and seventh goal which aim to decrease the cost of solar by providing a higher incentive than the general CSI program and maximize benefits to all ratepayers, respectively. The fact that the program is directly aimed at assisting low income families implies that there are specific barriers to solar energy access for this population which have not been eliminated by other state or federal incentives. Therefore, the problem the program attempts to rectify is the unequal access to solar energy. There has been a notable lack of low-income households taking advantage of state and federal incentives for renewable energy which cannot be solely attributed to a lack of interest or awareness of these incentives. Despite the reductions in the cost of solar provided by program rebates, the cost of owning a solar system is still quite high. Prior to the introduction of the SASH program, there were no incentives that fully covered the cost of the system. As such, homeowners interested in owning a system had to pay for a significant portion of the costs either out of pocket or with a loan. Low income households not only have less disposable income, but they generally also have lower credit scores which impedes their ability to take out a loan to finance a solar system. Furthermore, some of the renewable energy incentives come in the form of tax credits. Low income households generally do not have a tax liability high enough to make these incentives appealing to them. Consequently, medium and high income households have benefitted the most from renewable energy incentives. Thus, the problem can be better explained as the disproportionate exploitation of incentives by middle to high income households which promotes unequal access to solar energy.

The unfair distribution of renewable energy incentives may likely be a result of the high cost of owning a solar energy even after incentives are factored in. The extent of the problem can be measured by determining the proportion of incentives going towards low income households. Other indicators of the problem include the cost of a solar system and the size of the incentive. However, the distribution of incentives according to income provides a better context for examining the problem because it takes income into consideration. A newly released study of the income distribution of rooftop solar customers from 2008-2015 found that while the adoption rates of solar among low income households has increased, the majority of solar installations came from middle to high income (>$55,000) households (Kevala 2015). Since the analysis does not identify the share of incentives that went to each income group, it is not possible to determine the distribution of incentives according to income. Regardless, it is clear that low income households require higher incentives to afford solar systems, which is exactly what the SASH program provides.

The next two goals to be discussed relate to energy efficiency among low income households. Goal three of the program simply aims to offer solar and energy efficiency to program participants simultaneously, while goal eight takes a firmer stance by requiring program participants to enroll the Energy Savings Assistance (ESA) program. ESA is an energy efficiency program offered at no cost to low income energy customers for weatherization improvements to their home. As previously discussed in chapter 3, low income families tend to reside in homes that are not energy efficiency and miss out on substantial energy savings because they cannot afford to make energy efficiency updates to their home. It appears that the program aims to kill two birds with one stone by promoting solar energy and efficiency improvements through the SASH program in an attempt to deliver program participants maximum energy savings. This move is also in recognition that there is an overlap in eligible households for the SASH program and EAS program. This last goal requiring eligible participants was introduced in 2013 with the passing of AB 217. The percentage of program participants who have implemented energy efficiency improvements or enrolled in efficiency programs serve as an indicator of the problem and has been continually monitored by program administrators. The SASH biennial report released in 2011 found that the energy efficiency component of total energy savings is substantial for participants who qualify for energy efficiency programs, yet there are some that chose not to enroll. Program reports and communication with GRID Alternatives staff revealed the ESA enrollment requirement was introduced in response to many homeowners not taking advantage of the energy savings opportunities available to them.

The following program goal aims to develop energy solutions that are environmentally and economically sustainable. This goal seems to allude to the environmental challenges posed by fossil fuels and the economic challenges associated with the high cost of renewables. Environmental quality, energy consumption, and carbon emissions can serve as indicators of the impact that energy production has on the environment. Heavy reliance on fossil fuels and high consumption of energy have been the main drivers of environmental problems including climate change, degradation of air quality, and acid rain. Renewable energy generation would likely result in an improvement of environmental indicators, however, the environmental benefits of renewables come at a high cost. The introduction of CSI program incentives has without a doubt played a role in the expansion of renewable energy and subsequent reduction in its cost. As such, using carbon emissions and cost of renewables as indicators, it's clear that the SASH and other CSI programs are moving the indicators towards a better social condition.

The sixth goal is related to job training and employment opportunities in solar and energy efficiency sectors. This had always been an implicit goal of GRID Alternatives, but it was not until the passing of AB 217 that it was officially recognized as a SASH program goal. The problem that this program goal aims to alleviate is unemployment and lack of occupational training opportunities in many low income communities. Program administrators stressed once more that the program aims to bring employment benefits to those that need it the most, speaking of low income communities (pers. comm. Blake, Hernandez, Burke). The number of solar jobs offered and training hours provided can be used as an indicator of job growth in the communities served by the SASH program. The program utilizes volunteer labor for the majority of its installations with experienced and paid supervisors at each site. All volunteers gain hands-on experience installing solar systems with the guidance of trained installation staff. In addition, GRID partners with local job training organizations and job trainees can use the experience they gain towards obtaining solar installation certification. For more complicated installations, which would be difficult to complete using volunteer labor, GRID Alternatives uses external installation contractors through a subcontractor partnerships program (SPP) and requires them to hire at least one job trainee for each install. A 2013 SASH program report states that more than 17,000 volunteers and 3,500 job trainees have participated in installations, with 143 trainees participating in paid SPP installations (Navigant 2015a). On the basis of this indicator the program does appear to be strengthening the solar workforce in low income communities by increasing employment and job training opportunities.

Having identified the problems the program appears to address and the indicators which can be used to monitor the social condition, the next step was to identify the population affected by the problems. Analysis of the targeted problems and the social indicators suggests that there is a real necessity for such a program. What is left to determine is whether the population in need corresponds to the program eligible population. Put in other words, are the services provided by the program reaching the population that is affected most by the problems identified?

Of all the problems identified it is evident that low income households are negatively impacted the most. Research on fuel poverty has proven that low income families suffer the most from high energy bills but lack the resources to make energy efficiency improvements to their homes, let alone purchase a solar system. Although the high cost of solar energy and some energy efficiency improvements prevent many households across different income scale from adopting these energy solution, low income families face even higher economic barriers to implementing these measures. The other identified problems: environmental degradation, climate change, and unemployment also impact low income communities the most. Fossil fuel generation plants are often cited in low income areas releasing large amounts of pollutants that not only damage the environment but also negatively impact people's health. Climate change researchers have also noted that the effects of rising temperatures and increased frequency of natural disasters will disproportionately affect low income communities who lack financial and social resources to buffer themselves from the impacts of climate change.

Accordingly, the SASH program clearly targets low income households, however there are eligibility requirements that narrow down the scope of the program. Eligibility for the SASH program is dependent on home ownership, family size, income, utility service territory, and deed restrictions. A rough estimation of the program eligible population is presented in Figure 6. The estimate was derived using census data from the 2009 American Community Survey. According to the survey data, at the time of data collection the total number of households in California was 13.5 million from which 5.6 million were single family owner-occupied homes (U.S. Census Bureau 2009). To account for SASH income requirements, households with incomes above $55,000 were eliminated from the pool. The actual income requirements for SASH use Area-Median Income (AMI) which varies by county. The $55,000 cutoff was derived by calculating 80% of AMI averaged from the whole state. The target population was further narrowed based on utility service areas. Only the households served by the three IOUs: PG&E, SCE, and SDG&E qualify for the program. The three IOUs provide electricity to 75% of Californians, that's 10 million households out of the 13.5 million (CPUC 2016). Given that ratio, 1.28 million of the 1.7 million low income owner-occupied households receive service from the IOUs. Lastly, the requirement for deed restrictions was applied by using census designated empowerment or enterprise zones as a proxy. Homes located within empowerment or enterprise zones are presumed to have resale restrictions which makes them eligible for the program. Approximately 10% of the IOU's service area falls within enterprise/empowerment zones; therefore, it can be estimated that 128,000 of the 1.28 million low income owner, occupied households serviced by the three IOUs are eligible for the SASH program (Navigant 2011).

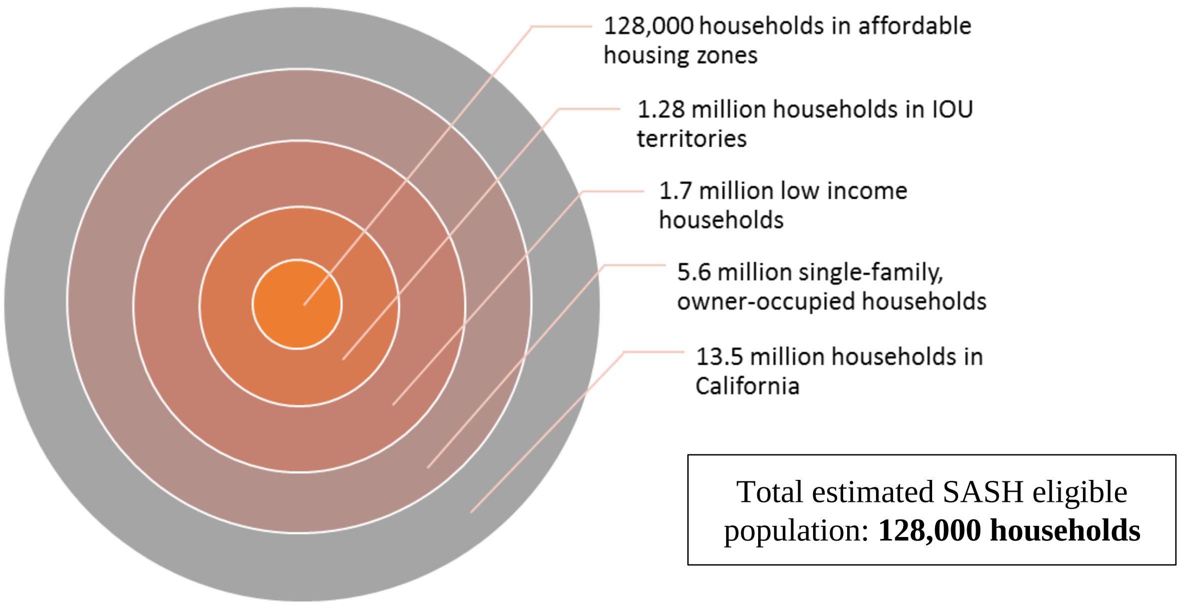

Figure 6: Estimated SASH Eligible Households

The total eligible population is clearly a rough estimate and overestimates the true eligible population because it assumes all households are solar-ready. A solar-ready home requires a roof in good condition with adequate space, optimal orientation, no shading, and abundant solar resource (Navigant 2011). The solar resource and roof orientation are completely dependent on the house structure and location. Shading and roof condition can be modified by the homeowner, but doing so often incurs large expenses. The program does not provide any funds for repairing a damaged roof or removing trees, the costs of which can pose a significant barrier to participation.

In review, the SASH program aims to improve the lives of low income households by providing solar energy as a solution to the problems posed by high energy bills, high cost of renewables and efficiency improvements, environmental degradation and unemployment. The households impacted most by those problems does in fact correspond with the program eligible population. However, the eligibility requirements serve as a limitation preventing the program from providing assistance to low income households who could benefit from program but fail to meet all the requirements.

5.2 Assessment of Program Theory Results

Having recognized that a need for the SASH program exists, what followed was determining whether the program's plan to satisfy the need is reasonable. In order to do that, the plan had to be identified first. In program evaluation, the "plan" is referred to as the program theory. It describes how the program functions, why it is designed that way and reveals what assumptions are made. The program's plan of action could easily be determined from program documents, but the reasoning behind its actions (the why) was less explicit. Information derived from interviews with program administrators and planners helped fill in those gaps and identify the implicit assumptions. A logical model of the program theory is presented in Table 4 which summarizes how the program is intended to function. Table 5 further elucidates the link between the program actions, theory, and goals. The relationship between the program actions and goals revealed some of the assumptions inherent in the program theory. The major assumptions built into the program's design were evaluated for their plausibility.

Table 4 Logical Model of SASH Program Theory

Inputs	Activities	Outputs	Initial Outcomes	Intermediate Outcomes	Long-term Outcomes
Program staff: regional directors, outreach coordinators, solar installation supervisors, construction staff, volunteer training associates, volunteers Regional Offices Program handbook, website, & education tools PV system equipment Program Budget for incentives	Identify & recruit eligible homeowners Provide solar education & post-installation training Provide incentives to defray costs of solar Design & install solar systems Provide home energy audit Refer to energy efficiency programs Provide training & jobs in solar installation	Eligible applicants successfully complete program and obtain low to no-cost solar PV system Program participants attend post-installation orientation Program participants obtain home energy audit Volunteers & solar job trainees assist in solar installation	Decrease in electricity consumption and reduced energy bills Increased awareness of solar & energy efficiency benefits Increased awareness on home's energy usage motivates energy saving behavior Eligible homes enroll in energy efficiency programs & make efficiency improvements Volunteers & trainees gain work experience in solar	Increase in energy saving behavior Reduced dependence on fossil-fuel generated electricity Reduction in cost of owning solar PV system Volunteers & trainees obtain jobs in solar	Reduction in pollution & CO_2 emissions from fossil fuels Increase in energy efficient & self-sufficient homes Increase in affordability of solar for low income homes even without incentives Growth in solar industry Increased generation of domestic clean solar energy

Table 5 Relationship between Program Actions, Theory and Goals

Program Actions	Program Theory	Program Goals
Identify & recruit eligible homeowners	Eligible applicants successfully complete program and obtain low to no-cost solar PV system	Offer the power of solar and energy efficiency to homeowners
Provide incentives to defray costs of solar	Program participants use system generated electricity & save on energy bills	Provide full and partial incentives for solar systems for low-income participants Decrease the expense of solar ownership with a higher incentive than the General CSI Program
Provide solar education & post-installation training	Program participants are aware of benefits of solar & energy efficiency	Designed to maximize the overall benefit to ratepayers
Provide home energy audit	Increased awareness on home's energy usage motivates energy saving behavior	Develop energy solutions that are environmentally and economically sustainable
Refer to energy efficiency programs	Eligible program participants enroll in energy efficiency programs & make efficiency improvements	Require participants who receive monetary incentives to enroll in the Energy Savings Assistance (ESA) program, if eligible
Design & install solar systems	Program participants decrease electricity use & save on energy bills	Decrease electricity usage by solar installation and reduce energy bills without increasing monthly expenses
Provide training & jobs in solar installation	Volunteers & trainees gain work experience in solar	Provide job training and employment opportunities in the solar energy and energy efficiency sectors of the economy.

The first major assumption the program is built around is that the main barrier preventing low income families from owning a solar energy system is cost. It follows that the program tries to remove that barrier by providing high incentives that either completely eliminate the cost or significantly reduce it. The decrease in cost of residential solar systems resulting from reduction in manufacturing costs and increased federal and state incentives has undoubtedly played a large role in the rise of solar adoption rates. In addition, a recent study on the barriers in adoption of solar for households in northern California found that expected financial gains and concerns about system maintenance and operating costs were the most decisive factors for the surveyed households' choice to buy a residential PV system (Rai *et al.* 2015). Another study of solar adoption rates in California shows that income is positively correlated with solar adoption (Stridh *et al.* 2015). These findings lend further credibility to the assumption that cost has been the largest barrier for adoption of solar, particularly for those with the least amount of disposable income.

The following assumption is that low income households who own rooftop PV systems will decrease their electricity usage and witness substantial energy savings. The implication that solar energy will result in "decreases in electricity usage" is flawed. Installing a rooftop PV system cannot guarantee that a household will decrease its electricity consumption. A household's consumption is dependent on the household members' electricity consuming behaviors, not on the source of electricity generation. When a family switches from fossil fuel to solar generated electricity, it may very well consume the same amount of electricity, all else being equal. A decreases in a home's electricity bills after installing a rooftop PV system does not necessarily mean that the home has reduced its consumption; rather it may represent a decrease in amount of electricity exported from the grid to the home. The majority of residential PV systems are installed in a way that allows the home access to the on-site generated electricity from the system, but it depends on how the system is connected and the type of meter installed. All SASH installations provide homeowners direct access to the electricity generated by the rooftop PV system. Demand for electricity transferred from the grid can be offset by the system generated electricity, thereby decreasing the household electricity charges. A better way to have phrased that assumption would have been to say that solar energy results in a decrease of electricity demand from the grid.

Furthermore, the assumption that electricity usage will decrease after solar installation neglects to take the rebound effect into consideration. Although energy efficiency is identified as the primary driver for the rebound effect, strategies aimed at offsetting consumption and producing energy savings can also bring about rebound effects. The mechanism for a rebound effect in solar energy is visualized in Figure 7. The downward pointing arrow represents the substitution effect that occurs when homeowners substitute their solar generated electricity for electricity transferred from the grid. The upward arrow represents the income effect. Similar to the efficiency-driven rebound scenario, the substitution for solar electricity occurs in response to a relative decrease in the price of the product being substituted towards. The difference lies in the source of the price drop. The reduction in price can emanate from a zero-cost breakthrough or a policy induced improvement in the efficiency-driven rebound effect, as noted by Gillingham *et al.* (2015). Whereas, in the solar-driven rebound effect, the relative price decrease is solely the result of policy incentives. The current cost of solar energy is too high in comparison to fossil fuel derived energy to make it cost competitive and produce an economically motivated substitution. The income effect functions the same way for both solar and efficiency-driven rebound effect. The switch towards the less expensive product or service, results in an increase in disposable income which can be used to consume more of the substituted product/service (direct rebound) or other energy intensive goods (indirect rebound). Recent literature on the rebound effect also seems to indicate that the magnitude of the effect is higher for low-income families (Chitnis *et al.* 2014; Thomas and Azevedo 2013). This implies that the solar-driven rebound effect could be higher among SASH participants compared to other solar homes with higher incomes.

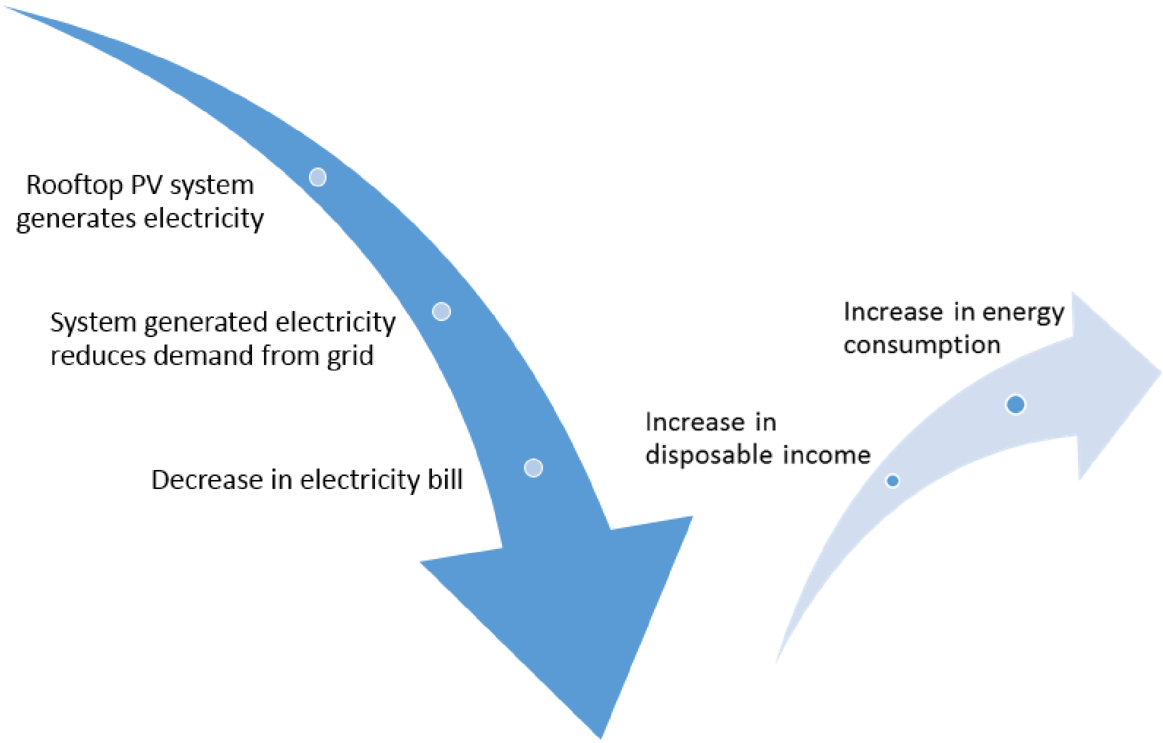

Figure 7 Rebound Effect Scenario for Solar Customers

Another major assumption inherent in the program theory is that educating homeowners about ways to improve the energy efficiency will lead them to engage in energy saving behaviors. This assumption can actually be split into two parts: 1) increasing awareness about how to obtain free or low cost energy efficiency will result in low income homes implementing those efficiency improvements in their home and 2) efficiency improvements will result in energy saving behavior. The first part of the assumption implies that a barrier to energy efficiency in low income homes is lack of awareness. Aside from promoting solar energy, the SASH program also promotes energy efficiency by providing education and referring participants to energy efficiency programs for low-income families. This shows that they identify cost as an additional barrier in implementing energy efficiency improvements. The large number of studies reviewed in Chapter 2 that have investigated energy efficiency in response to fuel poverty have agreed that government energy efficiency programs have been very successful in low income communities. Although, engaging in energy saving behavior entails much more than just making the decision to adopt cost-free energy efficiency improvements. Energy saving behavior is more consistent with lifestyle conservation practices. To that end, studies have shown that people's energy consumption behavior is in part controlled by habits and that American's attitudes show a preference for high consumption rather than conservation. Clearly, cost and awareness are not the only factors that influence energy consumption/conservation behavior.

The second part of the assumption, that efficiency improvements stimulate energy saving behaviors, touches upon the growing debate on the rebound effect. As described in Chapter 2, researchers are increasingly questioning the assumed link between efficiency and savings. The majority of findings are overall supportive of the assumption but warn that not all the expected savings will be achieved and that energy savings in one area may be offset by spending in another. For example, as a result of a homeowner switching from incandescent to LED lightbulbs, the homeowner may feel that they can "afford" to keep the lights on longer. As a result, some of the savings from switching to the more efficient product will be cancelled out because the lights will remain on for longer periods. In the literature, this type of rebound effect would be described as "direct" because the improvement in efficiency of the product results in an increased demand for it. In the context of the SASH program, an indirect rebound effect would be when a homeowner uses the money saved from energy efficiency improvements to purchase other high energy consuming products or services. The literature also indicates that the size of the rebound effect grows when estimating indirect or economy-wide effects, but the uncertainty of the measure also increases at larger scales. What is important to take away from this is that the relationship between efficiency and energy savings is more complicated than previously thought. Since the link between efficiency and savings is not as straightforward as the assumption implies, it is likely that some unintended outcomes may arise.

The next assumption to be assessed also concerns energy saving behavior. The assumption is that raising a homeowner's awareness of their household energy consumption will encourage them to engage in energy conserving behavior. Studies that have investigated the impact of energy-use feedback on consumption have found that in many cases the feedback does help motivate people to consume less, but usually only under certain conditions like when they consume more than their neighbors or when they have made a prior commitment to conserve (Fragidis and Olschewski 2015, Becker *et al.* 1979). These findings point to some weaknesses in the assumption, particularly since studies have shown that low-income households consume less energy than the average. If the program participant becomes aware that they are using less energy than the average household, they might feel that they are entitled to consume more especially since they are already undertaking measures (installing the rooftop PV system) that will reduce their energy charges. Another possible outcome may be that since program participants tend to live in areas where their neighbors are also low income, they might find that their energy usage is about the same or maybe higher and thus be motivated to reduce consumption.

Upon reviewing the critical assumptions that the program theory hinges on, it appears that some of the assumptions are open to doubt. While it would be premature to accept that the rebound effect poses serious implications to the program theory, it should at least be acknowledged that there is some uncertainty over the program's effect on overall consumption. It is clear that the imagined pathways between the program's actions and the intended outcomes are not as well established as previously thought. Having said that, the research on rebound effect has failed to provide convincing evidence of a backfire, when the increase in consumption is higher than the produced savings from efficiency. Given this deficit, it is very unlikely that a large rebound effect (>100%) exists. No evidence to date points to any program participants experiencing negative energy savings. Some insights from GRID staff hint at the possibility of a rebound effect (pers. comm. Hernandez) but there is no reliable program data to support that claim. Even if a rebound effect occurs, it is unlikely that it would completely undermine the positive attributes of the program. A more plausible conclusion would be that actual energy savings would be lower than the total expected energy savings, but that the program would still be able to achieve its goals.

5.3 Addressing Rebound Effect

After assessing the need for the program and the program theory, the findings indicated an oversight regarding the impact the program might have on participant's energy consumption behavior. Three pathways for adverse energy consumption behavior were identified. The first consists of a solar energy-driven rebound effect, the second an efficiency-driven rebound effect and the third a consumption awareness-driven rebound effect. The discovery of these potential rebound pathways suggests that the energy savings brought on by the program are lower than expected. This implication of the existence of a rebound effect should be of interest to program administrators and it is surprising that it has not been directly addressed in previous program evaluations.

While the solar-driven rebound effect also applies to solar customers who have not participated in the SASH program, the implications for the rebound effect are much stronger for low-income households. Recent and fairly reliable studies have provided evidence of a negative correlation between household income and rebound (Chitnis *et al.* 2014; Thomas and Azevedo 2014). If low-income households rebound the most, as the literature suggests, then it is likely that the solar-driven rebound effect would be most common among SASH installed solar homes, who as a condition of program participation are low-income.

Further implications of a significant rebound effect among SASH participants arise from suggestions that some SASH eligible homes may lower energy services below their normal use due to their inability to afford the cost of the energy services. If these household successfully complete the program, it is possible their consumption will rise as the prices become more affordable. Recent estimates put electricity poverty in California at over 650,000 households (Lesser *et al.* 2015), while the SASH eligible population is estimated to be well under 128,000 households. Given this information, it is reasonable to assume that some overlap between the two populations exists as visualized in Figure 8. It is possible that not all of the estimated 650,000 households in electricity poverty can be considered low-income, although the study reports that energy bills were substantially higher among residents in the poorest counties when compared those of much wealthier counties. This finding indicates that a significant percentage of households with high electricity burden are in fact low-income. Moreover, studies on fuel poverty have found that households overburdened by energy bills are likely to take measures to decrease their energy consumption below comfort levels (Cooper *et al.* 1989). The SASH program theory seems to overlook the possibility of program participants underutilizing energy services prior to obtaining their PV system. As a result, their overall energy consumption may increase to reach their comfort levels after obtaining the solar PV system.

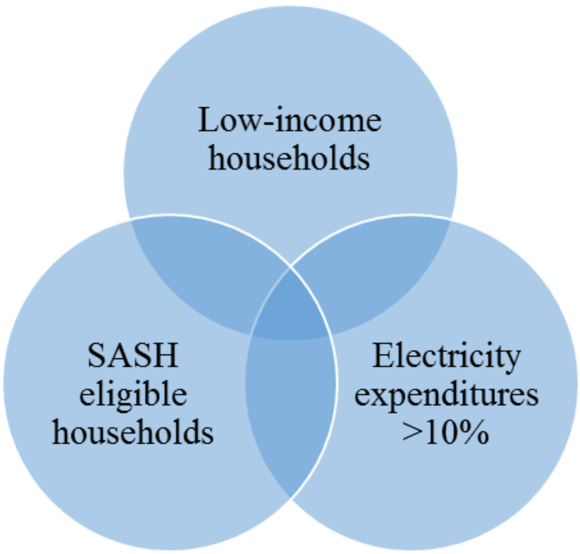

Figure 8: Overlap in Low-income, "Electricity Poor", SASH Eligible Homes

The discovery of the potential for rebound effect resulting from a switch to solar energy is not intended to be used as an argument against solar. Instead, these findings hope to stimulate further studies on the subject to determine the extent of the effect (if any) and devise appropriate responses to deal with it. It is in society's best interest to maximize the benefits of solar and determine whether the rebound effect poses a threat to energy savings. The SASH program would be a good place for researchers to investigate the rebound effect for solar. The program administrators keep track of energy savings for their installations meaning that they have access to the necessary data to conduct a proper study on the rebound effect. In addition, the program is limited to low-income participants which empirical studies have found have higher rebound rates. As such if a rebound effect exists, it would be most observable among this population.

Of the three identified pathways for the rebound effect, the energy-efficiency pathway is the most investigated and subsequently the most understood. The SASH program promotes energy efficiency by referring homeowners to energy efficiency programs provided by the utilities which eliminate the costs barriers to implementing energy efficiency improvements. The energy efficiency dimension of the SASH program aims to maximize energy savings for program participants while the rebound effect works to offset some of those savings. It is in the clear interest of not only SASH program administrators, but also for energy efficiency programs to investigate whether the rebound effect poses a significant threat to their ability to generate energy savings.

Aside from referring program applicants to energy efficiency programs, the SASH program also provides home energy audits to increase program participants' knowledge of their energy consumption. The energy audit is intended to help homeowners understand where their home is least energy efficient and modify their behavior to encourage conservation. However, some studies have shown that energy awareness does not necessarily lead to conservation (Fragidis and Olshewski 2015). If the household is using less energy relative to their prior consumption or less relative to their neighbor's consumption they may feel as if they are entitled to consume more. As such, the SASH program's attempt to increase participants' energy saving behavior by increasing their knowledge about their consumption could have a rebound effect.

Through an evaluation of the program, this work has presented three different ways in which the rebound effect could arise as a potential outcome of the SASH program. As of yet, the program evaluation reports do not make any mention of a rebound effect or give any indication that this is something on their radar. Furthermore, GRID Alternatives staff have revealed that there have been cases where households have experienced significantly lower energy savings than expected and have been surprised by high energy bills. One of the outreach coordinators attributed this loss of expected savings to homeowners' lack of awareness on energy saving behavior and the 12 month billing cycle which can cause some confusion about their monthly electricity consumption (pers. comm. Hernandez). The results of the program evaluation combined with the anecdotal evidence provided by GRID staff hints to the possibility of a rebound effect, but stronger evidence is needed.

Perhaps one of the main reasons the rebound effect has not garnered attention is because of the emphasis on energy bill reductions rather than reductions in consumption. Determining the program's effect on energy consumption rather than on bill savings would be helpful towards future attempts at identifying or estimating a rebound effect for the program. It is clear that neither homeowners nor program administrators are getting a full picture of the actual changes in energy consumption post-solar installation due to a disaggregation of consumption data. A homeowner's gross consumption is split between the system generated electricity usage and the electricity usage from the grid. The latter is reported in monthly bill statements as a net value of usage minus generation. The former is not reported by the utility because the grid never makes contact with the system generated electricity used in the home. Thus, it is evident that to determine the program's effect on energy consumption (and be able to detect a rebound effect), the program must first overcome the challenges in obtaining comprehensive consumption data.

5.4 Monitoring Household Electricity Usage

The lack of comprehensive data on gross household energy usage for families with PV systems makes it difficult to identify the actual changes in consumption resulting from SASH program participation. This lack of clarity on actual impacts of solar incentive programs has not been addressed in the past nor does it appear to be an issue of concern for program administrators. Given the stated goals of the SASH program to reduce electricity usage and the portrayal of CSI rebate programs as solutions to climate change, the investigation of its actual impacts on consumption should be prioritized.

5.4.1 Net Energy Metering

Measuring total household consumption for families with PV systems is challenging due to the multiple energy sources. Prior to PV installation, families and utilities could easily discern their total household energy consumption by simply reading their electricity meter or looking at their electricity bill. All SASH projects utilize Net Energy Metering (NEM), which requires the installation of a bidirectional meter that allows excess electricity generated from the PV system to be exported back to the grid. This means that when the home is using less electricity than it is producing, the meter will run backwards and their overall electricity charges will be lower because they are offset by the “free” solar energy. The NEM scheme operates under a 12 month billing cycle which allows for excess electricity generated during summer months to offset electricity usage during winter months when the system is less productive. Although this billing scheme maximizes the solar energy savings for the household, it makes it difficult to monitor actual energy consumption. To determine a household’s gross consumption, the consumption from the grid must be added to the consumption from the system produced electricity as presented in Figure 9. The amount of on-site consumption from the PV system can be hard to determine because it is not reported in monthly utility bills, but it is possible to derive its value using the equation in Figure 10. Homeowners who obtain their PV system from the SASH program can determine the total electricity generated from the system through the use of an Envoy Enphase system included in the installation. The energy production data can be read directly from the system just as one would read consumption from a meter. The information provided from this system combined with information of grid consumed electricity can reveal the households on-site energy consumption and the total energy consumption from the system and from the grid. Yet, the inconvenience in compiling the data and difficulty in evaluating the data may prevent many homeowners from taking these steps to learn about their energy consumption.

Figure 9: Calculating Gross Consumption in Solar Homes

Figure 10: Calculating On-site Electricity Consumption in Solar Homes

Of the few studies that have investigated the impact of residential solar energy generation on household energy consumption behavior, one limited its scope to households in Australia with Gross Metering because it provided the consumption data that was necessary for their analysis (Motlagh *et al.* 2015). Gross Metering allows for easier interpretation of household energy consumption. Under this metering scheme, the homes do not have direct access to the electricity produced by the system. All system generated electricity is exported directly to the grid, therefore household gross consumption is accurately reflected in monthly utility bills. A different study on electricity consumption in solar homes under a Feed-In Tariff (FIT) scheme in the UK also attempted to investigate changes in consumption behavior post-solar installation, however the analysis was limited to metered electricity consumption (DECC 2015). Under the UK's FIT scheme, the amount of electricity consumed from the grid is monitored, but the amount of electricity exported to the grid is not typically measured unless a second meter is installed specifically to monitor exports. The installation of the second meter is not required and under the FIT scheme those without the second meter are assumed to export 50% of generated electricity and are compensated accordingly. The study did not provide any justification for the assumption that 50% of generated electricity is exported to the grid.

A potential advantage of the FIT scheme over NEM, is the avoided costs of monitoring exported electricity. On the other hand, not measuring the actual exported energy could end up being more costly if the FIT is compensating solar homes for more electricity than it is actually receiving. That is to say, if solar homes are consuming greater than 50% of the PV generated electricity. Partly in light of this uncertainty, the CPUC requested as study to be conducted to evaluate the cost-effectiveness of NEM which revealed that on average only 20-50% of generated energy is exported to the grid (E3 2010). The study highlights the necessity of monitoring solar home's electricity consumption, relative to their electricity generation, to make better informed policy decisions. However, this data can also be beneficial to homeowners and may even encourage energy saving behavior provided the homeowner makes a commitment to conserve and the data is presented in a way that can be useful towards evaluating how or how poorly they are doing with respect to reducing consumption.

6. Conclusions and Recommendations

The purpose of this study was to conduct an evaluation of the SASH program to determine if the potential for a rebound effect exists. After conducting an assessment of the need for the program and an assessment of the program theory, three potential pathways for a rebound effect were identified. The evaluation found participants may be likely to engage in adverse energy use behavior as a result of switching to solar energy, enacting energy efficiency measures, and gaining awareness about their relative energy consumption. The potential increases in energy consumption behavior may in effect reduce the overall energy savings generated by the program. The implications of this finding are that solar incentives, such as the one provided by the SASH program, may not be as effective in promoting energy saving behavior as they are perceived to be. The findings presented here are not intended to undermine the positive attributes of the program, but rather point to weaknesses in the program design that should be addressed.

The assessment of the need of the program along with the assessment of the program theory helped provide a deeper understanding of the SASH program. The information provided by program documents and information obtained from personal communication with program administrators were utilized in this stage of the assessment to identify what the program intends to achieve and why. The needs assessment revealed that the program aims to tackle a variety of problems including the high energy burden on low-income households, the economic barrier to residential solar energy, unequal distribution of solar incentives, environmental and climate impacts of fossil fuels, and lack of employment opportunities in low income communities. The assessment also found that the services provided by the program were appropriately directed towards the population that has been burdened the most by these problems.

The second assessment was conducted on the program theory to determine if the program's method for achieving its intended outcomes was reasonable. The program documents and information obtained from conversation with program administrators was also utilized in this assessment to help elucidate the program theory. This processed identified the critical assumptions made by program planners and administrators regarding how the program actions would produce the intended outcomes. The assessment of the program theory and the assumption inherent in that theory exposed some unintended outcomes that may arise. The findings of some studies on the rebound effect provided contradictions to the some of the assumptions made in the program theory.

In regards to the intended outcome of the program to decrease electricity use and encourage energy saving behavior, this study showed a pathway through which the decreases in electricity charges as a result of PV installation could increase a household's disposable income which could then be used to consume more electricity. This pathway is described in this work as the solar-driven rebound effect. The same logic follows when consumers make energy efficiency improvements; the savings from switching to a more energy efficiency product or service are offset by some degree due to increases in income which in turn motivates people to consume more. There is a significant amount of published studies devoted to identifying and estimating the magnitude of the offset savings stemming from efficiency improvements. In fact, the literature on the rebound effect has thus far only focused on the ways in which the rebound effect can arise out of efficiency improvements and largely overlook how it could arise out of other measures intended to promote energy savings.

The assessment of the program theory also revealed that the program services aimed at increasing participant's awareness of their energy consumption are intended to encourage participants to engage in energy saving behavior. In reviewing the research on the effect of energy consumption feedback on energy consumption behavior, this study concluded that under some conditions the feedback may promote energy saving behavior but under other conditions it may have the opposite effect and encourage households to consume more. The research has shown that feedback is only effective in promoting conservation behavior when there is a prior commitment to conserve and when the household's consumption is higher relative to their peers or their own prior consumption (Becker *et al.* 1979; Fragidis and Olschewski 2015). This study has shown that for SASH program participants who on average tend to use less electricity than their neighbors, there is a potential for a rebound effect to occur.

The potential pathways for rebound identified in this work have not been addressed in previous evaluations of the SASH program or any other solar incentive programs. If the rebound effect does in deed exist, it would mean that the projected energy savings produced by solar incentives overestimate the actual savings that are achieved. There is much debate and lack of consensus over the degree to which savings could be offset by the rebound effect. Due to the limited scope of this study and unavailability of data, this work does not find definitive evidence of a rebound effect. Since results of this study are unable to provide definitive proof of the rebound effect for the SASH program or give an indication as to how significant the loss of savings are, it would be premature to offer recommendations on how to manage the rebound effect. Instead, this study recommends that future studies and program evaluations investigate the program's effect on participant's electricity consumption. The study also recommends that data on SASH participant's gross electricity consumption is monitored and made easily accessible to homeowners and program administrators. By monitoring the gross household gross consumption, rather than the net, homeowners and program administrators can easily discern changes in consumption and determine the program's effect on participant's electricity consumption. This information can in turn be useful in determining whether the rebound effect exists, whether it poses a significant threat, and if it warrants any changes to the way solar incentive programs are designed.

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