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Solar Energy for the Soul: Solving America's Fuel Poverty Problem with Solar Panels for the Poor

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by

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Abstract

ST. MARIE, SAMANTHA Solar Energy for the Soul:
Solving America's Fuel Poverty Problem with Solar Panels for the Poor

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In the United States today, at least 14 million Americans live in fuel poverty. These Americans spend at least ten percent of household income on energy costs ranging from fuel to electricity. The purpose of this thesis is to identify an innovative solution to mitigate the effects of the energy affordability crisis in the United States. After examining national trends and researching localized efforts, I determined that solar panels may be able to support the modern energy needs of the fuel poor. The study uses a least squares regression model with fixed effects to determine factors influencing solar adoption at the zip code level across the United States between 2010 and 2015. Following an analysis of the results, the regression residuals and the connection between income and solar installations are examined. The research finds the income, incentive programs, and the cost of electricity positively influences solar installations at the zip code level.

The idea for this thesis and the solution to lessen the impact of fuel poverty came from examining the efforts taking place in Rutland, Vermont. In the city, the local utility Green Mountain Power is initiating programs to weatherize and supply solar panels for the poor to create long-term energy independence and a more comfortable living environment.

The project recommends tax policies, grants, education, and initiatives taken by electric utilities as programs that can encourage lower income Americans to install solar panels and make their homes more energy efficient.

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Do you know what my favorite renewable fuel is?

An ecosystem for innovation.

- Thomas Friedman

1. Introduction

Throughout the developed world, access to energy services is almost universal. With the widespread ability to utilize energy in the forms of fuel and electricity, the only hurdle left between consumers and obtaining such services is cost. The inability to afford such energy expenses creates a segment of the population in the developed world know as the fuel poor. In the United States, today, more than 14 million Americans live in fuel poverty. These fuel poor individuals and families are classified as spending more than 10 percent of household income on energy-related expenses ranging from electricity to propane to natural gas. The low-income households unable to adequately heat their homes to comfortable levels are left living in cold, damp housing. These conditions can also negatively impact the health of the fuel poor. Young children and the elderly are especially susceptible to cardiovascular diseases, respiratory ailments, malnutrition, and even death when residing in cold living spaces.

The U.S. government provides some assistance to fuel poor Americans through social assistance programs. Programs such as the Fuel Assistance Program and the Low Income Home Energy Assistance Program subsidize energy services for low-income households. While the funding helps the poor in the moment, multiple studies have found that fuel poor households continue to suffer from long term energy inefficiencies. Fuel poverty continues to be a contentious issue in the United States, unlike much of the Western World. The competing political parties in the U.S. debate the very definition of fuel poverty, the feasibility of program to end the crisis, and the costs of maintaining the programs in operation.

A potential solution to solve the fuel poverty crisis is the adoption of solar photovoltaic systems among low income households, multi-family living residences, and poor communities. The prospect of supplying low income Americans with solar PV systems to power their homes forms the basic research question of this thesis. If fuel poor households install solar energy systems on their homes then these households can become energy independent and realize energy savings. Positive outcomes exist for other groups when a program that introduces solar panels to low income families is introduced. The government benefits from a reduction, overtime, in required funding for fuel assistance programs, communities benefit from economic development in the renewable energy sector, and the environment improves from a reduction in pollution when many households adopt renewable energy.

The purpose of this thesis is two-fold. The prevalence of fuel poverty across the United States will be considered, while an in-depth study of the adoption trends in solar PV systems will play a prominent role. Furthermore, the thesis will focus particularly on Rutland, Vermont where widespread poverty and lack of economic development existed for decades until movements geared towards renewable energy began to grow the economy again in the early 2000s. Since then, the city's trends in solar adoption have made Rutland a model for New England and even the country. Following a review of the existing literature, a national regression model will track the trends in solar adoption, the results of the regression will be discussed, and a case study of Rutland will be presented. Finally, a discussion of how a solar program for the fuel poor would look, be funded, and turned into policy will be considered.

2. Review of Existing Literature

In order to understand both fuel poverty and the factors influencing solar adoption in the United States, the prevailing research in both fields requires examination. The literature on fuel poverty extends beyond the United States, especially among European countries where government policies specifically tackle the issue. Fuel poverty research also covers fields outside of economics including energy policy, health studies, and social justice.

Researchers in the field of solar energy typically investigate adoption trends of solar photovoltaic systems by different sectors of the population including farming, rural communities in the developing world, commercial businesses, and residential households. The prevailing research is also particularly concerned with determining what specific factors influence the growth in the solar industry overtime.

Few academic authors make a connection between fuel poverty and solar energy. When researchers do make a connection, they typically suggest that solar photovoltaic panels be used to deliver electricity to people living in the developing world. Across the United States, though, localized efforts to fund solar for low income people are growing. Despite the lack of extensive research that combines the two fields of fuel poverty and solar energy, the literature in each area, separately, aid the current research by providing important definitions, raising fundamental policy questions, describing sources of data, and creating points for disagreement.

2.1 Fuel Poverty

The study of fuel poverty originated in the United Kingdom in the late twentieth century. Liddell et al. (2012) traces the earliest constructions of the term fuel poverty.

The concept became widely accepted following the 2001 release of the UK's Fuel Poverty Strategy, a policy meant to reduce the prevalence of fuel poverty by 2010 through programs to insulate homes, reduce fuel costs, and improve energy efficiency in residential homes (Wicks and Morley 2005). Prior to 2001, researchers like Isherwood and Hancock (1979) first defined fuel poor individuals as households that spent more than twice the median expenditure on fuel and electricity based on information collected by the Family Expenditure Survey (Liddell et al. 2012). According to Isherwood and Hancock (1979) fuel poor households spent more than 12 percent of household income on energy services at the time.

In *Fuel Poverty*, Boardman (1991) redefined fuel poverty as households unable to adequately heat their homes for less than 10 percent of household income (Liddell et al. 2012). Boardman (1991) furthermore introduced the measure of what a household "needs to spend" on energy services to sufficiently heat and cool the home. According to Boardman (1991), the amount of spending needed to heat a low income home often exceeds actual spending. Instead of spending a greater percentage of income on fuel or electricity, poor households will devote that money to food or other necessities. By 2001, the UK's Fuel Poverty Strategy adopted the 10 percent fuel poverty point identified by Boardman and classified adequate temperatures in a home as between 18 degrees Celsius and 21 degrees Celsius based on the World Health Organization's adequate room temperature measures (WHO 2007).

Liddell et al. (2012) present the historical context of the fuel poverty measure in order to dispute the parameters of its construction. The authors specifically target the viability of the 10 percent cut off for the measure of fuel poverty. Liddell et al. (2012)

argue that at the time the UK released the Fuel Poverty Strategy in 2001, the 10 percent threshold exceeded the actual twice mean expenditure on energy services, which was recorded at 7 percent. Therefore, the threshold at 10 percent significantly underestimated the number of UK residents in fuel poverty by at least one million (Liddell et al. 2012). The 10 percent measure continues to be a problem for countries in the United Kingdom, especially since the measure does not resemble the high energy costs realized in Northern Ireland, where a fuel poverty threshold would need to be much higher (Liddell et al. 2012).

In the U.S., fuel expenses are less than those in the United Kingdom. For example, prices for a gallon of gas average around five dollars in the U.K., whereas in the U.S. a gallon of gas is typically two to three dollars less. European countries also typically spend more on electricity, which ranges between $0.20 to as much as $0.41, while in the U.S. the highest cost of electricity per kilowatt hour is $0.33 in Hawaii. Given the differences in costs of energy services, the fuel poverty measure in the U.S. may capture more Americans actually in fuel poverty if the measure was lowered below a 10 percent threshold.

While prices for energy are more in Europe as compared to the United States, energy consumption among European countries is a fraction of U.S. consumption. According to the CIA World Factbook, in 2015 the United States consumed an estimate 3.119 trillion kilowatts per hour for the year in electricity. In comparison, the European Union as a whole, consumed an estimated 2.771 trillion kilowatt hours of electricity for 2013 (CIA). The population of the EU is nearly 514 million, which is 200 million more than the United States, where the population is only 324 million (CIA).

Liddell et al. (2012) ultimately recommend a frequent and critical review of the fuel poverty threshold, and to change the threshold based on changes in energy costs. Despite the recommendation, some researchers continue to utilize the 10 percent measure. Teller-Elsberg et al. (2016) examine the extent of fuel poverty in Vermont between 2000 and 2012 using data collected from the American Community Survey. According to Teller-Elsberg et al. (2016) fuel poverty in the state grew by 76 percent over thirteen years. The researchers claim the growth in fuel poverty occurred as a result of the increase in energy expenditures while income levels remained unchanged.

Teller-Elsberg et al. (2016) make twelve policy recommendations with the belief that the policies will lessen the prevalence of fuel poverty in the state. The researchers divide the recommendations into four sections based on the actors instituting the policies, including the Vermont Legislature, community groups, other state agencies, and Vermont utilities and fuel providers. Teller-Elsberg et al. (2016) suggest that rental property improvements in energy efficiency could play a significant role in lessening the energy burden experienced by low income households who often rent, rather than own, their living spaces.

The authors argue that financial incentives provided by the state government or the potential threat of regulation would encourage landlords to make their apartment buildings more energy efficient. Teller-Elsberg et al. (2016) provide no evidence for the rate of success from a program like this one, since, thus far, no widespread adoption of energy efficiency initiatives have taken place among rental property owners. If part of the energy efficiency program adopted by landlords involved the installation of solar panels, then more than just improved efficiencies could be realized. In a program like this, the

landlord may serve as both the energy provider and the collector of electricity expenditures, while the apartment residents could benefit from lower electricity costs. In this scenario, both parties are better off.

Other recommendations to address fuel poverty put forth by Teller-Elsberg et al. (2016) depend on additional funds and corporate social responsibility. Based on interviews conducted with Hal Cohen of Capstone Community Action, an organization to aid low income Vermonters, the hurdle that exists between providing assistance programs and ending fuel poverty is the lack of funding to programs like Weatherization Assistance Program (WAP) and the Federal Low Income Home Energy Assistance Program (LIHEAP) (Teller-Elsberg et al. 2016). According to the researchers, the WAP program's shortfall of funds could be countered by increasing the Fuel Gross Receipts Tax (Teller-Elsberg et al. 2016). The tax is imposed on the retail sale of heating oil, propane, and other diesel fuels at $0.02 per gallon, the sale of natural gas and coal at 0.75 percent, and the sale of electricity at 0.5 percent (2503 Fuel Tax). Teller-Elsberg et al. (2016) do no indicate if the tax should increase for a specific energy source, nor by how much the Fuel Gross Receipts Tax should increase in order to raise sufficient funds.

Teller-Elsberg et al. (2016) further encourage utilities and providers to deliver more assistant to those customers about to be disconnected from power and to diversify the energy services those providers offer. Green Mountain Power (GMP), an electric utility in Vermont, is leading programs to assist fuel poor households by improving insulation, replacing old windows with new ones, and installing solar panels on roofs, especially in Rutland County. Unfortunately, Teller-Elsberg et al. (2016) neither acknowledge the renewable energy work done by GMP nor do the researchers explicitly

name other companies in the state that should diversify the energy services those firms provide. While the researchers outline some specific policy recommendations, most of the recommendations lack details about the extent to which funding to programs should increase or how the different actors creating the policies could cooperatively institute them.

Overall, the somewhat scattered approach to fuel poverty policy from Teller-Elsberg et al. (2016) represents the scattered approach that U.S. policy tends to take towards fuel poverty at the state and federal levels. In the United Kingdom, a specific Social Action Plan outlines the extent of assistance to fuel poor households, and a specific timeframe to complete a reduction in fuel poverty. Fuel poverty policy is complicated in the U.S. on account of governmental decentralization, whereby many policies are determined by states. Fifty-one different regulatory bodies set residential energy rates by state, while the political divides across the country creates disagreement over a finite measure of fuel poverty and ways to pursue its end.

Hughes (2014) researches the complicated and scattered nature of fuel poverty policy in the United States. Hughes (2014) focuses on the Colonias communities in Texas along the Mexican border, a region with high rates of poverty. The residents of the Colonias experience high rates of fuel poverty and a lack of extensive resources in terms of fuel assistance programs due to the remoteness of the region. To make matters worse, the communities suffer from low approval rates to obtain bank accounts preventing the residents from saving their money or applying for regular consumer loans. High energy costs and poor housing quality in the region resemble that of the developing world.

Based on the resemblance, between the developing world and the Colonias communities in Texas, Hughes (2014) argues that in order to combat fuel poverty, the Colonias should adopt microfinance in the same way remote lands in developing world have in recent years to fund loans for home improvements, electricity, and other infrastructure projects. Hughes (2014) indicates that the Energy Impact Fund in Texas is trying to reduce the impact of energy bills on the fuel poor through microloans. Hughes (2014) argues that the microfinance route is the most innovative solution to handle the fuel poverty in the Colonias.

The unique research from Hughes (2014) provides a much different solution for the fuel poverty problem in remote locations in the U.S. when compared to this paper's recommendation for programs to aid the adoption of solar systems by poor Americans. The microfinance feature of Hughes (2014) research may serve as a potential solution to enable the poor to fund their own installations of solar PV systems instead of going through assistance programs. Microfinance for solar installations among lower income people becomes more feasible as the cost of panels continues to fall.

2.2 Excess Winter Deaths

One of the primary concerns among state and national governments in addressing the fuel poverty crisis is to reduce the number of excess winter deaths. Again, the definition for excess winter deaths, like the definition for fuel poverty, has its origins in the United Kingdom. The U.K. Office of National Statistics defines the winter period as December to March. The Office then compares the number of deaths that occur during the period to the average number of deaths that occur during the preceding months from August to November and the subsequent four months from April to July (Amery 2015).

As expected, wintertime deaths exceed the number of deaths during the non-winter period, a phenomenon referred to as ‘excess winter deaths.’

Healy (2002) supplements the research on excess winter mortality focused on England and Wales with an analysis of winter mortality rates in all 14 European countries from 1988 to 1997. Healy (2002) unexpectedly finds that the countries in Southern Europe, especially Portugal and Greece exhibited the highest variation in winter time mortality compared to non-winter deaths despite having the mildest winter climates. In order to explain the phenomenon, Healy (2002) identifies socioeconomic indicators that provide information about the wellbeing of the population including fuel poverty, income inequality, poor housing quality, and poverty in general.

Few studies concerning excess winter mortality that are as well-defined as Healy (2002) for Europe exist for the United States. Teller-Elsberg et al. (2015) identify excess winter deaths in Vermont between 2000 and 2012. Based on the data that the researchers collected, the results indicated that the number of excess winter deaths during the time frame actually exceeded the number of deaths resulting from automobile crashes (Teller-Elsberg et al. 2015). The conclusion is alarming. Nevertheless, one of the pitfalls with excess winter death measures, which Teller-Elsberg et al. (2105) articulate in the article, is that the definitive causes of wintertime deaths may never be known. Thus, the assumption that wintertime deaths occur, at least partially, as a result of fuel poverty and the inability to keep the home warm is not altogether accurate.

Researchers consider the other health issues linked to fuel poverty in the prevailing literature. Braga et al. (2002) and Gonseth et al. (2015) identify a rise in wintertime deaths as a result of cardiovascular diseases and respiratory diseases in the

United States. The researchers argue that the underlying health issues are exacerbated by socioeconomic inequalities such as the inability to afford warm clothing and energy services (Gonseth et al. 2015). Liddell and Morris (2010) review the literature on the health impacts of fuel poverty on children in the early 2000s. The researchers identify that children who live in cold, damp homes are more likely to have respiratory problems, miss more days of school compared to their peers, and suffer from malnutrition as their bodies use more calories to stay warm (Liddell and Morris 2010). Warriner (1981) and Wright (2004) find that the elderly, who spend a great deal of time in their homes, suffer from poor health and malnutrition as a result of fuel poverty.

The research on excess winter deaths and the health issues associated with cold, damp homes supports the cause for concern among low income households that suffer in fuel poverty. Preventable deaths caused by inadequately heated homes and the healthcare costs of exacerbated and continuous cardiovascular and respiratory ailments prompts this thesis project to suggest policy recommendations that will reduce the impact of fuel poverty on individuals' wellbeing.

2.3 Energy Social Justice

Oftentimes, in the prevailing literature related to fuel poverty and excess winter deaths authors include a discussion about energy social justice. Given the high costs of electricity and energy in the United States, social and economic inequalities boil to the surface. Hernández (2015) identifies four basic human rights to energy including a healthy and sustainable energy production, the right to the best available energy infrastructure, the right to affordable energy, and the right to uninterrupted energy

services. Despite the rights that Hernández (2015) argues should exist for every person, the reality of energy injustice is ever present.

Reames (2016) models distributive energy injustice and the implications of racial segregation in administering fuel poverty assistance programs. Reames (2016) researches the differences in rates of energy consumption and energy efficiency among households in the Kansas City, Missouri tri-county metropolitan area. The tri-county area is of interest given the high concentration of Community Action Agencies (CAAs), which are nonprofit social service organizations (Reames 2016). CAAs are responsible for administering low-income energy assistance programs such as the Low Income Home Energy Assistance Program from the Department of Health and Human Services and the Department of Energy's Weatherization Assistance Program (Reames 2016). Another important reason Reames (2016) makes for his specific examination of the Kansas City area is that based on data from the Energy Information Agency indicates that the average Missouri household consumes more than 12 percent the average American household consumes.

Reames (2016) uses data from the Energy Information Administration's Residential Energy Consumption Survey (RECS) to determine the household-level energy consumption from actual household utility statements. Reames (2016) also utilizes the American Community Survey from the Census for the period 2006 to 2010 in order to capture household data such as decade constructed, primary heating fuel, home size, and household income. Reames (2016) also uses ordinary least squares to analyze how housing features influence, what Reames calls, the annual heating energy use intensity (EUI), which in basic terms merely refers to the energy efficiency of a home.

Reames' (2016) regressions indicate significant variables and results important for policy. The author finds that homes with higher EUIs, or those homes that were less energy efficient, were predicted to be in Census block groups with lower median incomes, a greater percentage of racial and ethnic minorities, a greater percentage of individuals in poverty, and more people with less than a high school education. The results reveal that the energy assistance programs in existence currently are not doing enough to improve the energy efficiency homes that house low income families. Reames (2016) also indicates that the energy disparities occur along racial, socioeconomic, and educational lines.

2.4 Adoption of Solar Energy

In recent years, both academic and non-academic researchers have written extensively about solar power across the globe, and the adoption of the energy source by different sectors of the population. Academic writers are especially concerned with the factors that determine whether or not consumers install solar panels on their homes as well as the patterns associated with the types of consumers adopting solar energy.

Trends in solar adoption are complicated. Many authors of the prevailing literature try to simplify the trends by identifying one variable that serves as the most significant determinant, but those analyses tend to be oversimplified. Kwan (2012), on the other hand, outlines a comprehensive model for the number residential solar PV systems in the United States based on economic, political, and social variables. Kwan (2012) analyzes zip code level data made available by the 2000 Census. Of the 33,000 zip codes identified in the 2000 Census, only 5,442 contained any residential PV units (Kwan 2012).

While the paper explicitly describes the utilization of zip codes pulled from 2000 Census data, Kwan (2012) documents solar PV installations beyond 2000. Kwan (2012) filters the data between January 2005 and November 2010. Kwan (2012) selected the years between 2005 and 2010 for the solar panel data collection based on the presence of federal policy. The federal government introduced the Energy Policy Act, which provided tax credits for homeowners installing solar panels in 2005 until February 2009 when the credit was extended in the American Recovery and Reinvestment Act. Kwan (2012) thus captures data through 2010 to capture the effect of the Act's extension in 2009.

The different datasets utilized by Kwan (2012) aid the collection of data for this thesis model. The Open PV Project from the National Renewable Energy Laboratory (NREL) dataset captures the cost of installation, cost of energy per watt, and time and place of installation of the residential solar systems. Demographic data concerning race, income, age, household density, and political affiliations can all be garnered from the 2010 Census, and 2011, 2012, 2013, 2014, and 2015 American Community Surveys. Information and data on the incentives offered by state comes from the Database of State Incentives for Renewables and Efficiency (DSIRE). Finally, the average cost of electricity can be located at the state level through U.S. Energy Information Administration.

Whereas Kwan (2012) studies the influence of environmental, social, political, and economic variables on solar PV systems in the U.S., other researchers study the impacts of individual and specific factors that influence solar adoption. Graziano and Gillingham (2014) find that neighbors at the street level have a stronger effect on solar

adoption than trends at the zip code level. Graziano and Gillingham (2014) specifically recognize the significance of neighbors who install solar panels influencing other neighbors to also install solar panels within 0.5 miles; the variable loses significance between 1 and 4 miles.

The researchers perform the analysis for the town of Durham in Connecticut. Based on the analysis, Graziano and Gillingham (2014) make the claim that small and mid-sized centers are important for diffusing solar adoption. The case study of the mid-size town of Durham aids this project's case study of Rutland, Vermont. While the significance of neighbors identified by the researchers will be considered for the case study, the influence of neighbors will not necessarily be considered in the national regression given that the significance level identified by Graziano and Gillingham (2014) occurs at a much smaller level than the zip code.

2.5 Solar Incentives

Also of interest to researchers examining solar adoption is the importance of state and federal incentives. Borenstein (2015) examines the extent to which the services offered by electric utilities, tax incentives, and rebates are impacting the adoption trends in solar rooftop systems in California. Borenstein (2015) employs residential data from Pacific Gas and Electric, the utility with the largest number of residential solar customers in the U.S., for the years 2007 to 2014. California features prominently in the prevailing literature, in general, given that the state contains about half of all the country's residential solar systems.

The purpose of Borenstein (2015) was to determine the effectiveness of the California Solar Initiative (CSI) a state subsidy as compared to the federal tax incentive

and the cost of electricity in the state in promoting the adoption of solar. Of special interest to Borenstein (2015) is tracking the income of the residences that adopt solar. Borenstein (2015) ultimately concludes that while solar is continuing to be adopted at a higher rate by the more affluent residents, the differences between the rates of adoption between the wealthy and the poor has been closing in the past five years. This conclusion suggests that lower income residents in California are finding ways to adopt solar systems. Unfortunately, Borenstein (2015) does not go into great detail about how low income residents are going about adopting solar, other than to avoid the high electricity costs in California. The articles also does not identify if the low income residents adopting solar are concentrated in one area or spread out across the state.

Borenstein (2015) explains third-party ownership (TPO) as a possible incentive for consumers to adopt solar by having a third party company pay the costs of installing the panels on a customer's rooftop. The company effectively owns the panels. The homeowner can thus either lease the panels or buy the electricity generated by the panels from the company for a lower price than the cost of electricity. Despite the clear benefits of a program like this for those who cannot afford the upfront costs of panel installation, Borenstein (2015) finds that the program is slightly more utilized by wealthier customers than the lower income brackets. The conclusion is perplexing, but Borenstein (2015) does not dig further to find the source of the slight under-utilization among lower income people.

Borenstein (2015) also finds that while lower income customers tend to adopt small solar systems. However, these customers actually produce more electricity relative to annual home consumption. The potential to harvest the extra electricity generated by

the lower income brackets potentially through additional energy savings or income may be of interest for utilities or policymakers.

Crago and Chernyakhovskiy (2016) examine the impact of incentives on solar adoption, with a focus on Northeastern states. Like Borenstein (2015), the researchers find that the financial savings realized by installing solar panels over electricity costs is a determining factor in solar adoption trends. Unlike Borenstein (2015) and Kwan (2012), though, Crago and Chernyakhovskiy (2016) find that the value of a rebate for solar panels is the most significant financial incentive for consumers in the Northeast.

Crago and Chernyakhovskiy (2016) utilize data from the National Renewable Energy Laboratory (NREL), the U.S. Energy Information Administration, and the Database of State Incentives for Renewables and Efficiency. The authors argue for the robustness of the research by using the individual representations of policies as opposed to a single incentive or the lump sum of all of the incentives available by state. Crago and Chernyakhovskiy (2016) find that in Northeastern states offering rebates, the cost of solar installation is reduced on average by 31 percent. Furthermore, for every $1 per watt increase in the size of the rebate, the solar capacity in the state can increase by as much as 47 percent (Crago and Chernyakhovskiy, 2016). Capacity refers to the amount of solar energy a system can generate and does not refer to the number of solar panels or installations.

Crago and Chernyakhovskiy (2016) identify important policy implications based on increasing the size of rebates for consumers. Crago and Chernyakhovskiy’s (2016) make the policy recommendation to suggest that increasing rebates may encourage adoption of solar in places without extensive adoption already. Rebates may also help

low income areas adopt solar. If low income households can realize savings upfront, with other programs to support the costs of solar, then they can become more open to solar as an energy source.

2.6 Contributions

While the prevailing literature on solar adoption and, separately, on fuel poverty is extensive, few studies combine the two fields or recommend solar energy as a potential solution to end fuel poverty. My research, therefore, will add to the literature with the argument for policy measures that utilize solar energy to end fuel poverty and encourage energy independence among lower class Americans. Another unique feature of my research will take shape as a case study of Rutland, Vermont, which in 2015 was dubbed the solar capital of New England. Rutland is pursuing a number of exciting solar programs led by the local electric utility, Green Mountain Power. As a result of the growth of the renewable energy sector in the city, Rutland's economy is improving and serving as a model for other low-income communities.

An in-depth look at Rutland, Vermont will prove informative of what is unique about the conditions in the city and how cities across the nation can replicate those conditions. More importantly, the regression results from the national study will reveal where Rutland falls relative to the model's predictions. By looking at the residual for Rutland and the data values that are contributing to the high level of solar adoption, then the conditions that influence Rutland can be identified and compared to conditions nationally.

3. Econometric Model

The following section will include a discussion of the model and the model's variables. After the overall model and a comprehensive list of the variables are presented, each of the variables is examined in closer detail. The units of the variables, the years of the data, the sources of each variable, and the variable level, either state or zip code is included in the discussion.

3.1 Statement of Model

The regression model will use least ordinary squares to study determination of adoption of solar power by zip code in the United States for the years between and including 2010 and 2015. Prior research, especially Kwan (2012), identified independent variables and available data sources. Differences exist between previous studies and this model. Firstly, Kwan (2012) pulled zip code level demographic and economic data only from the 2000 Census. Kwan (2012) then used solar data from 2005 to 2010. This model will differ from Kwan (2012) by use more recent zip code and demographic data from the 2010 Census and the 2011, 2012, 2013, 2014, and 2015 American Community Surveys. This model will also match the demographic data year to the year of solar panel installation.

Secondly, this model will include fixed effects for years and zip codes. Fixed effects work in panel data by creating a dummy variable for each unique observation of the fixed variables. Accounting for every possible variable that may influence how solar adoption plays out in each zip code is impossible. Fixed effects, though, control for all of the effects that like the dummy variable is unique to each particular zip code (Schmidt 2004).

3.2 Description of Model Variables

The dependent variable for the model is the total number of observed solar arrays by residential unit as provided by the National Renewable Energy Laboratory (NREL). Solar installations are captured at the zip code. The independent variables with the data source are listed below. The independent variables are measured for the years 2010 to 2015 for U.S. zip codes, with a few exceptions. The price of electricity and the number of incentive programs are measured for each year 2010, 2011, 2012, 2013, 2014, and 2015, but the measurements are captured for each state, not for each zip code. The Census Bureau data comes from the 2010 Census and the 2011, 2012, 2013, 2014, and 2015 American Community Surveys all at the zip code level.

- Average cost of solar panel installation provided by NREL
- Average price of electricity by state by year from Energy Information Administration (EIA)
- Renewable energy incentive programs by state by year provided by Database of State Incentives for Renewables and Efficiency (DSIRE)
- Median income by zip code from the 2010 Census, and the 2011, 2012, 2013, 2014, 2015 American Community Surveys
- Total population provided by the 2010 Census, and the 2011, 2012, 2013, 2014, 2015 American Community Surveys
- Total number of houses provided by the 2010 Census, and the 2011, 2012, 2013, 2014, 2015 American Community Surveys
- Median value of houses provided by the 2010 Census, and the 2011, 2012, 2013, 2014, 2015 American Community Surveys
- Years 2011, 2012, 2013, 2014, and 2015 fixed effects
- Zip code fixed effects

3.3 Solar Adoption Variable

The dependent variable in the study is the adoption of solar photovoltaic energy systems. Available data concerning the adoption of solar power by residential homes is documented by the federal government's National Renewable Energy Laboratory's Open PV Program (NREL). According to NREL's online database, the project serves as a forum to accept data from large contributors like the Lawrence Berkeley National Laboratory (LBL), which produces an annual *Tracking the Sun* report. NREL also accepts solar installation data from smaller contributors including utility companies, solar installers, incentives programs, and the public.

The NREL dataset comprises relevant information about the installation. The data include the location and date of installation, the cost of the installation, and the price of energy per kilowatt hour. Data values are currently available for solar installations installed between 1998 and 2015. Other online data sources such as EnergySage provide similar information with regard to solar installations. EnergySage also provides more up to the date data on solar installations, but the information is not comprehensively comprised into one dataset.

3.4 Cost of Panel Installation Variable

A database containing the price of solar panel installation is available from the National Renewable Energy Laboratory's (NREL) Open PV Program. The comprehensive database contains information for the years between 1998 and 2015. In order to reflect the dropping price of solar panels in the United States, the price of solar panel installations reported by NREL between the years 2010 and 2015 will be included. The values captured by the installation cost variable only reflect the watt size of the solar panels multiplied by the cost of energy per watt of the panels. The cost of labor required

to install the panels is therefore not reflected in the cost. The expected impact of the variable indicates that if solar panels are expensive in a zip code, then the expected impact would be fewer solar panel installations in that area.

3.5 Cost of Electricity Variable

The U.S. Energy Information Administration provides a dataset with the cost of electricity for residential homes by state by year. The price of electricity and the number of solar PV systems installed on homes are inversely related. If the cost of electricity is high, then the number of PV systems installed is expected to also be high since consumers would turn to an alternative and cheaper source of energy. The electricity prices included will be input by state and by each year, 2010, 2011, 2012, 2013, 2014, and 2015.

3.6 Incentive Programs Variable

Data on the number of state and national incentives for the installations of solar PV systems on residential homes and commercial buildings can be found from the Database of State Incentives for Renewable Energy (DSIRE). The database breaks down the total number of these incentives by state and categorizes programs based on the name, type (rebate, financial incentive, regulatory policy, grant, loan, etc.), date instituted, ending date, and date updated.

Some academic research indicates that not all incentives are created equal, but rather, that certain incentives have a greater impact on households' decisions to adopt solar or not to adopt solar. Crago and Chernyakhovskiy (2016) find that among financial incentives, rebates have the greatest impact on increasing annual solar PV capacity in the Northeast by residential installations. When only rebates were captured in this thesis

model, the variable became insignificant. The lack of rebate significance in the national model may indicate that research from Crago and Chernyakhovskiy (2016) only reflects the conditions in the Northeast.

After the rebate model failed to be significant, a different approach to include incentives was tested. For this model, the programs variable measures the incentive programs listed by state and by year. The data filtered out programs that ended prior to January 1, 2010. Thereafter, each year captures the number of programs that existed in that year for each state. For example, if in 2011 two new programs were created, then the total number of programs for 2011 was equal to the number of programs that carried over from 2010 plus the programs added in 2011. Overall, the number of programs available increased each year. The only assumption that was made for the incentives was that each program was available for every zip code in the entire state.

3.7 Median Household Income Variable

Another independent variable is median household income by zip code. The data are available from the Census Bureau. The data for 2010 come from the Census, while the data from 2011, 2012, 2013, 2014, and 2015 come from the American Community Survey. The inclusion of this variable is to account for the ability of wealthier areas to more readily afford the installation costs of solar panels. A higher median income in a zip code therefore is predicted to be related to a greater number of solar panels.

3.8 Total Population Variable

Since the dependent variable, the number of solar installations by zip code is not in per capita terms, the variable total population needs to be included to reflect the size of

zip codes. The total populations for 2010 come from the Census. The populations for 2011, 2012, 2013, 2014, and 2015 come from the American Community Survey.

3.9 Total Number of Houses Variable

The total number of housing units reflects a house, an apartment, a group of rooms, or a simple room occupied as a living quarter. Studies show different results for urban and rural areas in the adoption rates of solar photovoltaic systems. For example, Kwan (2012) finds that urban areas and a greater number of houses discourage solar adoption. While the larger the number of housing units overall, the fewer the solar panel installations that may be expected, the results may be more complicated. Residential solar arrays are typically installed on the roofs of homes. If more homes exist in an area, there too exists more opportunity to install more solar panels. The total number of homes variable does not reflect urban and rural areas as a different Census variable separately captures those conditions.

3.10 Median House Value Variable

While the total number of housing units is of interest, how the values of these units affect the number of solar installations by zip code is also of interest. Solar panels are expensive and may require individuals to take out loans to install them. As the value of a home increases, then the homeowner has more leverage to obtain a larger loan for something expensive like solar panels. Thus, higher median home values are expected to positively impact the number of solar installations.

3.11 Fixed Effects

Two types of fixed effects will be included in the model, year and zip code. The year fixed effects variable is straightforward, and must be included since the number of

changes that occur in each year that may possibly impact the adoption trends of solar is too great to know or even capture in the model.

The other fixed effects variable, zip code is a little different. The variable accounts for the variations by zip code that either cannot be measured or are far too numerous for the model. To include the full five digit zip codes as the variable would have been too computationally challenging for the model to make predictions. The fixed effects zip code variable will be limited to capture the first three digits of the zip code and create dummy variables based on those first three digits. A zip code's first three digits represent the postal facility that services the designated area. The office is known as a Sectional Center Facility with the purpose to process and distribute mail through the United States Postal Service. While a three digit zip code is not as specific as the five digit zip code, the three digits still capture an area of relatively small size.

3.12 Regressions

Two regressions will be produced with the variables listed above. The first regression will contain all of the variables with the number of solar installations as the dependent variable. The second regression will include all of the independent variables, with the addition of year fixed effects. Further description of the data sources, the way in which the data was collected, edited, and merged, the descriptive statistics, and the regressions will follow in the next sections.

4. Data Description

The Data Description section contains a discussion about the data sources used for the model. The collection of the data by those sources is discussed along with the units and potential limitations or biases that exist in the collection methods. An account of the ways in which the data were filtered and merged will follow. The descriptive statistics for the national dataset will be compared to statistics for the observations from the solar data subset that was used for the regression model.

4.1 Data Sources

Four different data sources contained the data necessary for the regression model. The Census Bureau provided median income, total population, total number of houses, and the median value of the houses. The 2010 Census and the American Community Surveys for 2011, 2012, 2013, 2014, and 2015 provided data at the zip code level. The Census is a survey. Every ten years, the census counts every resident in the United States. The 2010 Census, therefore, reaches the most people and collects data on age, education, employment, etc. in greater detail. The American Community Surveys, on the other hand, occur every year, but these surveys select a smaller portion of the population.

The National Renewable Energy Laboratory created the Open PV Project, which presents information on solar panels installations made nationwide. The data are collected from solar incentive programs, utilities, installers, the public, and mainly from the Lawrence Berkeley National Laboratory (LBL). The installation data spread from 1998 until the end of 2015. Only the installations made in 2010, 2011, 2012, 2013, 2014, and 2015 were of interest for this regression model. The data were also filtered only to include solar installations that were classified as residential. The relevant information for

each installation included cost of installation, which reflects the size and cost of the panels, and the date of installation.

The Open PV Project database contains a substantial amount of data and contributors of the data typically contribute data voluntarily; therefore weaknesses in the data exist. For example, upon closer examination of the data, I found that residential solar installations appeared to be missing for the data the Rutland zip codes relevant to the case study. While residential solar installations were captured for 2010, 2011, and 2012, no residential installations appeared for 2013, 2014, and 2015. Other types of installations classified as ‘education’ showed observations for the later years, but unless an installation was classified as residential, it was kept out of the model. While the data supplied by the Open PV Project has provided a lot of information and data about solar installations made across the United States, a more localized approach to data collection might be necessary, though, that collection process would require time and energy.

Other researchers have used the data from the Open PV Project. In general, the researchers do not seem to indicate downfalls of the data for the purposes of their research. Klein and Coffey (2016) are interested in community projects that bring renewable energy from the top down, from the government or community groups, to community members. Klein and Coffey (2016) identify the NREL’s Open PV Project as a comprehensive database for solar installation data across the U.S., but the database lacked a community based identifier in the types of installation category. Whereas the database identified installations as residential or commercial or agricultural, no specific category for a community solar array exists.

Burns and Kang (2012) use the Open PV Project database to capture the installation costs of solar arrays ranging in size from 1 to 10 kilowatts. The database proved helpful for the researchers who examined only six states (MA, DE, MD, NC, NH, NJ, OH, PA) and Washington D.C. for the purpose of running a comparative analysis on solar renewable energy credits, which enable homeowners to sell certificates, representing energy produced by their solar array, on the open market (Burns and Kang 2012). Burns and Kang (2012) only use a small subset of data from the Open PV Project, but express no concern for missing data.

Pasqualetti and Haag (2011) examine the solar economy of the American southwest to suggest the next steps the area should take to encourage the growth in the solar industry. Pasqualetti and Haag (2011) use the Open PV Project database to rank states based on solar capacity. Arizona ranked eighth in solar capacity, a rank lower than Connecticut and Massachusetts (Pasqualetti and Haag 2011). Pasqualetti and Haag (2011) do not blame mistakes in the dataset for the low solar capacity that exists in Arizona. Instead, the researchers argue that Arizona lacked solar capacity because the state failed to develop a coordinated plan to promote solar energy. Furthermore, state officials had only just begun to systematically educate the public about solar opportunities. Pasqualetti and Hagg (2011) use the dataset to confirm that Arizona's policies were not enough to increase solar capacity in the state prior to 2011.

Based on the lack of concerns for the data in other research that uses the Open PV Project dataset, I chose to move forward with using the database to run the regressions. The data for the database is provided voluntarily by utilities, installers, the public, and other reputable sources including the Lawrence Berkeley National Laboratory. The

number of solar installations for the time period, 2010 to 2015, in the United States is relatively small. While some observations are likely missing from the database, the researchers who have used the database in research suggest that it is safe to assume that enough data, at least 75 percent of the solar installation observations across the country, are captured.

The dataset from the U.S. Energy Information Administration includes the cost of electricity for residential homes by state by year. The average cost of electricity is measured in cents per kilowatthour. The costs were filtered to pertain to each state for each year 2010, 2011, 2012, 2013, 2014, and 2015 and only for residential homes. The data were collected from state utilities and then comprised into the dataset by the federal government. The average by state comes from average the rates charged by the utilities in that state.

The final dataset for the regression model is the Database of State Incentives for Renewables and Efficiency (DSIRE). This dataset provides a comprehensive list of incentives provided by state. The data were filtered so that incentives ending prior to 2010 were eliminated. Then a cumulative sum that added the programs created in each year added to the programs that existed in the previous year was created. For ease, the assumption that each program was available for every zip code in the entire state was made. The monetary values of the program were disregarded as well. The data on the programs was collected by the University of North Carolina and can be verified by looking at the programs on state government websites.

4.2 Merging Datasets

The data were tidied, merged, and manipulated using R Studio. The section will briefly explain the methodology for creating the final dataset used for the regression model. For the Census and American Community Survey data sets, each variable for each year (2010, 2011, 2012, 2013, 2014, and 2015) was combined into individual datasets. Then, each dataset containing the variables median income, total population, median home value, and total number of homes for the zip codes was comprised. Finally, the datasets were stacked and merged into a final Census dataset with the 33,120 zip codes for each year six times.

The other datasets concerning electricity costs, incentive programs, and solar installations required less manipulation. Only the relevant variables with the sets were selected. The solar installation data acted as the main source of data to which the other sources were merged into. The Census dataset was merged by year and by zip code. The programs data was merged into the solar installations by state and year. The electricity data was merged by state and year as well.

The merged dataset represented every zip code for all six years. To examine closer the differences between the zip codes with solar installations, I filtered out the observations with 0 solar installations.

4.3 Observations

The full dataset contains 198,720 zip code level observations. The number of observations reflects the approximate 33,120 zip codes in the United States occurring each year for the six years (2010, 2011, 2012, 2013, 2014, and 2015) of interest. Of those observations a subset of the data was created to find the number of observations that

actually had solar installations. The total number of observations with solar installations is 33,907. The subset of 33,907 was used to run the regression models. National trends are of interest, thus to understand what is influencing places to adopt residential solar, the variations between places that have solar need to be captured and understood.

Tables 4.1a and 4.1b show descriptive statistics of the variables for the full national dataset and the subset used in the regression model respectively. The tables show the mean, median, maximum, and the standard deviation. When compared, the descriptive statistics in Table 4.1a and Table 4.1b shows that in general the zip codes with solar installations have higher median incomes, higher populations, a greater number of homes, and a higher median home value.

Table 4.1a Descriptive Statistics for all Zip Codes

Variable	Mean	Median	Maximum	St. Dev.	N
Total_Population	9,492	2,799	115,500	13,893	197,860
Median_Income	51,880	47,550	247,800	22,215	191,611
Homes_Total	4,035	1,325	47,940	5,613	197,860
Median_Value	168,900	125,100	1,000,000	133,477	188,456
Solar_Install	4	0	1,063	25	198,720
Avg_install_cost	34,610	31,590	1,300,000	25,445	28,840
Avg_electricity_cost	15.04	15.34	37.34	2.87	33,907
Programs	81	62	170	48	33,907

Sources: Tot_Pop, Median_Income, Homes_Total, and Median_Value collected from 2010 Census, and 2011, 2012, 2013, 2014, 2015 American Community Surveys. Avg_install_cost collected from the Open PV Project. Avg_electricity_cost captured from the U.S. Energy Information Administration and measured in cents per kilowatthour. DSIRE presented the Programs variable. The variable Solar_Install was calculated by grouping the number of solar installations made per zip code per year. Total observations are 198,720.

Table 4.1b Descriptive Statistics for Zip Codes with Solar Installations

Variable	Mean	Median	Maximum	St. Dev.	N
Total_Population	19,177	13,960	115,538	17,864	33,118
Median_Income	67,590	62,204	247,768	27,441	32,964
Homes_Total	7,695	5,798	39,665	6,731	33,118
Median_Value	297,988	254,100	1,000,000	179,447	32,353
Solar_Install	23	4	1,063	57	33,907
Avg_install_cost	34,609	31,591	1,300,000	25,445	28,840
Avg_electricity_cost	15.05	15.34	37.34	2.87	33,907
Programs	81	62	170	47.8	33,907

Sources: Tot_Pop, Median_Income, Homes_Total, and Median_Value collected from 2010 Census, and 2011, 2012, 2013, 2014, 2015 American Community Surveys. Avg_install_cost collected from the Open PV Project. Avg_electricity_cost captured from the U.S. Energy Information Administration and measured in cents per kilowatthour. DSIRE presented the Programs variable. The variable Solar_Install was calculated by grouping the number of solar installations made per zip code per year. Total observations are 33,907.

Table 4.2 ranks all 50 states and Washington D.C. based on the number of solar panel installations in each state made from 2010 to the end of 2015.

A lot of variability exists in the differences among states in terms of solar installations. Whereas California lists approximately 484,960 installations made between 2010 and 2015, states like North Dakota and Oklahoma list only one installation each for the same time period. As previously discussed, the national database may not be capturing all of the residential solar installations made in each zip code in each state, or solar installations are actually very low for these states.

While the observations in the Open PV Project database may differ from actual values, the scale of the numbers still reflect the conditions that exist to create environments conducive for residential solar installations in zip codes and states. The

regression model presented in the following section will shed more light on the factors influencing solar adoption rates across the country.

Table 4.2 States ranked by number of solar installations between 2010 and 2015

Rank	State	Total Number of Solar Installations made between 2010 and 2015	Rank	State	Total Number of Solar Installations made between 2010 and 2015
1	CA	484960	27	TN	180
2	AZ	77448	28	MN	164
3	MA	61581	29	MI	104
4	NY	39488	30	WA	102
5	NJ	39143	31	AR	100
6	CT	14453	32	WV	66
7	NV	13637	33	IL	60
8	TX	10119	34	IA	55
9	PA	8855	35	ME	51
10	MD	8598	36	MS	44
11	NM	5952	37	VA	22
12	DE	3423	38	KY	12
13	MO	3293	39	AK	11
14	NH	2687	40	NC	9
15	OR	2241	41	KS	8
16	DC	1947	42	WY	8
17	CO	1276	43	GA	7
18	WI	1266	44	ID	5
19	FL	1199	45	SD	5
20	OH	1104	46	NE	4
21	VT	993	47	AL	3
22	IN	444	48	SC	3
23	UT	338	49	MT	2
24	RI	299	50	ND	1
25	HI	284	51	OK	1
26	LA	215			

Source: The sum of solar installations by state was calculated using the data from the Open PV Project.

5. Results

The results section examines the results from the regression model. A brief description of the model will appear in Section 5.1 and will contain explanations as to why certain variables were not included in the model, followed by a reiteration of the role of fixed effects. Also included will be an analysis of the coefficients and signs on the variables. Finally, some conclusions about the model will be reached, and some suggestions for future models made.

5.1 Regression Description

Two regressions were produced using the data subset of 33,907 observations. Figure 5.1shows the regression results with the coefficients and significance of the variables. The dependent variable is solar_install, which captures the number of solar installations made in the zip code during the time from 2010 to 2015.

A few clarifications must be made about the model before discussing the results. Since the model includes fixed effects in terms of zip codes, only variables that change over time were of interest to include. For example, Kwan (2012) includes solar radiation in his model since weather variables impact solar installations. Overall, weather and climatic conditions do not change considerably overtime, especially over a timeframe of just six years. Weather variables such as temperature, solar radiation, or snowfall precipitation, therefore, were not individually included. Whereas Kwan (2012) included solar radiation, in this model, weather conditions are treated as variations among zip codes captured by the fixed effects.

Like weather, the age structure of the population, the percentage of the population with higher education degrees, and race variables did not change considerably within the

time span from 2010 to 2015. These variables were tried in previous models without fixed effects and in Kwan's (2012) model. When included without fixed effects, the signs on the variables were the opposite of what was expected and many of the variables were not significant.

Fixed effects account for the fixed characteristics of zip codes that cannot necessarily be captured by including additional variables. Examples of fixed effects include education spending or the culture of the area.

5.2 Regression Results Analysis

Figure 5.1 display the regression results. The results from the second regression model with the year effects variables will be discussed. As noted the zip code fixed effects are included in the model and captured by the first three digits of the five digit zip code. The results for the variable zip3 are suppressed from Figure 5.1. Each variable will be discussed in terms of the dependent variable, solar installations.

The coefficient on the average installation cost is negative and significant. The negative value supports the expected outcome, as the cost of installation increases, the number of solar arrays declines. For every $1,000 the installation cost increases, the number of solar installations within the zip code decreases by year, by 0.05. The small change in solar installations is to be expected since the number of solar installations by zip code is small already.

The coefficient on the average cost of electricity is positive and significant. The positive value supports the expected sign, as the cost of electricity increase, the number of solar installations decreases. The unit on the cost of electricity is cents per kilowatt

hour. For an increase in electricity costs of one cent per hour, the total number of installations is expected to increase by 0.07 per year.

The coefficient on the incentive programs is also positive and significant. The positive value supports the expected outcome. The more and more programs offered within a state, the higher the number of solar arrays that are expected in a zip code. When the number of programs increases by one, the number of solar installations by zip code also increases by one each year.

The coefficient on median income is positive and significant. With more available income, households are more likely to spend money on luxury or alternative goods like solar panel arrays. Also with more income, people may be able to qualify for loans that have income qualifications for renewable energy updates. According to the model, when median income increases by $1,000, the number of solar installations each year increases by one in the zip code.

The total homes coefficient is positive and significant as well. More homes with available roofs in an area create more places to install solar panels. The model indicates that when the total number of homes in an area increases by 1,000, the number of residential solar arrays by zip code increases by one each year.

The coefficient on total population is positive and significant. The positive value supports the expected outcome. The greater the population in the area, the greater the number of solar installations is expected. When the total population increases by 1,000 residents, solar panel installations increase by one each year.

Figure 5.1 Regression Results

	Dependent variable: solar_install (1)	(2)
avg_install_cost	-0.0001***	-0.00005***
	(0.00001)	(0.00001)
avg_electricity_cost	9.716***	7.419***
	(0.379)	(0.470)
Programs	1.060***	0.996***
	(0.045)	(0.071)
Median_Income	0.001***	0.001***
	(0.00002)	(0.00002)
Total_Population	0.001***	0.001***
	(0.0001)	(0.0001)
Homes_Total	0.001***	0.001***
	(0.0002)	(0.0002)
Median_Home_Value	-0.00001	-0.00001*
	(0.00000)	(0.00000)
YearF2011		-5.901***
		(1.144)
YearF2012		-3.097**
		(1.356)
YearF2013		-7.025***
		(1.418)
YearF2014		-2.502
		(1.623)
YearF2015		8.740***
		(1.842)
Constant	-253.928***	-210.935***
	(6.383)	(8.409)
Observations	27,528	27,528
R2	0.425	0.430
Adjusted R2	0.413	0.418
Residual Std. Error	47.536 (df = 26956)	47.317 (df=26951)
F Statistic	34.884*** (df = 571; 26956)	35.346*** (df=576; 26951)

Source: Created using R Studio. Significance indicators *p<0.1; **p<0.05; ***p<0.01
Note: zip3 fixed effects included but suppressed from output

The year fixed effects of the regression paint a more complicated picture. The number of solar installations did not increase every year nor was every year significant in terms of installations. The years 2011, 2012, and 2013 show negative but significant values. The negative values indicate that during those years, solar installations did not grow. The coefficient on year 2014 is not significant. Only the year 2015 shows a positive and significant coefficient of 8.74, indicating that the year 2015, contributed an additional 8.74 solar installations by zip code.

5.3 Regression Conclusions

The regressions overall, align with what was expected. Electricity rates positively and heavily influence the number of solar installations by zip code. Programs, too, play a role in increasing solar installations. Median income also notably and positively contributes to encouraging more solar arrays each year. Total population and the total number of homes also help the number of solar installations.

The R squared value indicates that roughly 43 percent of the variation in the data can be explained by the regression. Given the pretty high variation in the data based on the standard deviations, the model performs well and is able to predict almost 50 percent of the observed solar installations based on the independent variables selected and the use of fixed effects.

6. Rutland, Vermont Case Study

Rutland, Vermont is situated at the intersection of U.S. Route 4 and 7 near the state's boarder with New York. The region's rich history shaped the city's modern day political, manufacturing, and social atmospheres. New Hampshire Governor Benning Wentworth chartered the city in 1776. By the early 1800s, Rutland became a bustling commercial center where merchants and artisans manufactured furniture and clothing. During the antebellum period, marble quarrying in the region took shape on a larger industrial scale. Rutland also became the railroad center for Vermont. Following the end of the Civil War, and the continued growth of railway connections, the country's largest marble business called Rutland home (Rutland Historical Society).

At the turn of the twentieth century, the landscape of Rutland changed. The city developed local appreciations for art through the construction of opera houses and a theater. While the Great Depression did not impact Rutland or Vermont particularly hard, the presence of the Civilian Conservation Corps (CCC) helped to reconstruct the city after widespread flooding wrought havoc downtown. After World War II, the Chamber of Commerce and local service groups energized the city with parades, a new hospital, and an annual Winter Carnival (Rutland Historical Society). Slowly but surely, the automobile overtook the train as the mode of transportation among most people. The marble industry in Rutland also became less about the large, elaborate pieces of marble, and more about suppling companies like OMYA with calcium carbonate for goods like toothpastes and paper used around the world.

Today, government officials and economic development groups are revitalizing Rutland. The AMTRAK train re-established daily passenger connections to New York

City and the marble industry still operates. Rutland is a destination community for skiers and snowboarders across the country with premier ski areas like Killington Mountain. The Paramount Theater, downtown retail shopping, and local restaurants offer rich nightlife options for visitors and locals alike. On the other hand, an aging population and a relatively poor community afflicted by the opioid epidemic represent the struggling side of an otherwise transitioning city.

Despite some of the demographic challenges, Rutland remains committed to innovation, especially renewable energy innovation. In 2015, Rutland became the solar capital of New England based on solar output per capita. Since then, more and more people have adopted residential solar panels or have bought in to community solar projects. The electric company that services the state, Green Mountain Power became the country's first energy utility to become a certified B corporation based on the company's commitment to renewable and clean energy.

A certified B corporation is a for-profit company certified by a nonprofit group called the B Lab. The business certification is similar to what a Fair Trade certification is to coffee or what the USDA is to milk. The company must meet high standards of social and environment performance, accountability for the company's actions, and transparency between the company and the public (Certified B Corportation).

A case study of Rutland, Vermont provides a human and localized touch to the national research and regression model presented in this project. The section will be broken down into four parts. First the results of the regression model and where Rutland falls in national solar adoption trends will be discussed. The political agenda and policies behind establishing renewable energy sources in Vermont will be considered at state

level. This section will also describe the impact that policies are having on the way utilities are adapting to solar generation. The second section will detail the economic and business side of solar energy. Questions such as why would an electricity company actively encourage consumers to switch to solar, and how is the solar industry changing will be answered. Finally, the social and personal aspects of why Vermonters are devoted to renewable energy and why Rutlanders are installing solar on their homes will be examined. Each of these sections will contain interviews with Vermonters who in some way, shape, or form influenced or are influenced by the solar industry in the state.

6.1 Rutland Data, Residuals, and Maps

For a few reasons, I selected Rutland, Vermont to examine more closely as a case study. As mentioned above, in 2015 the city became the solar capital of New England based on solar output per capita. Since Rutland is my hometown, I have physically witnessed this expansion in the solar industry, and the increasing dedication among community members to solar energy.

From the subset of data of the national regression, the Rutland county observations were pulled. Observations beginning with the first three digits “057” were selected into the subset for Rutland observations. A snapshot of the data from Rutland can be seen in table 6.1a. The descriptive statistics for Rutland observations are shown in Table 6.1b.

Table 6.1b can be compared with Table 4.1, which shows the descriptive statistics for the national observations, to understand where Rutland stands in relation to national averages. Mean and median values for total population, median income, total homes, median value of homes, average installation costs, and the number of incentive programs

available for Rutland, Vermont all fall below the mean and median values for the national observations. As for the average rates of electricity, Vermont has an average rate of 16.47 cents per kilowatthour, which is higher than the average national rate of 15.05 cents per kilowatthour. Finally, in terms of solar installations, the average number of installations for Rutland is below the national average. But, the median number of solar installations for Rutland is 5.58, which is greater than the national median value of 4 solar installations.

Table 6.1a Snapshot of Rutland Data

zip code	Tot Pop	Median Income	Homes Total	Median Value	Year	State	Solar Install	avg install cost	avg electricty cost	Programs
05732	708	44375	584	239900	2010	VT	1	21469	15.57	30
05733	5895	45784	3145	166600	2010	VT	2	34787.14	15.57	30
05734	1306	61172	702	231300	2010	VT	2	32300	15.57	30
05739	1407	57353	757	219900	2010	VT	1	0	15.57	30
05753	10491	54245	3921	240100	2010	VT	3	30150.69	15.57	30
05767	1143	45385	836	181300	2010	VT	1	25062.39	15.57	30
05777	3420	48917	1546	164700	2010	VT	1	24516	15.57	30
05701	20484	41859	10009	170000	2011	VT	3	20004.21	16.26	30
05730	206	47188	226	218100	2011	VT	2	*NA*	16.26	30
05733	6045	45784	3346	166600	2011	VT	1	20145	16.26	30
05737	769	66250	458	242600	2011	VT	1	25440.9	16.26	30
05738	1031	64050	494	207200	2011	VT	1	29301.05	16.26	30

Sources: Tot_Pop, Median_Income, Homes_Total, and Median_Value collected from 2010 Census, and 2011, 2012, 2013, 2014, 2015 American Community Surveys. Avg_install_cost collected from the Open PV Project. Avg_electricity_cost captured from the U.S. Energy Information Administration and measured in cents per kilowatthour. DSIRE presented the Programs variable. The variable Solar_Install was calculated by grouping the number of solar installations made per zip code per year.

Based only on the descriptive statistics, the rate of electricity for Rutland, Vermont could be a key factor in creating the environment for solar adoption in the city.

Since the rates for electricity are high, residents may be finding that solar panels are a viable alternative.

Table 6.1b Descriptive Statistics of Rutland, Vermont Observations

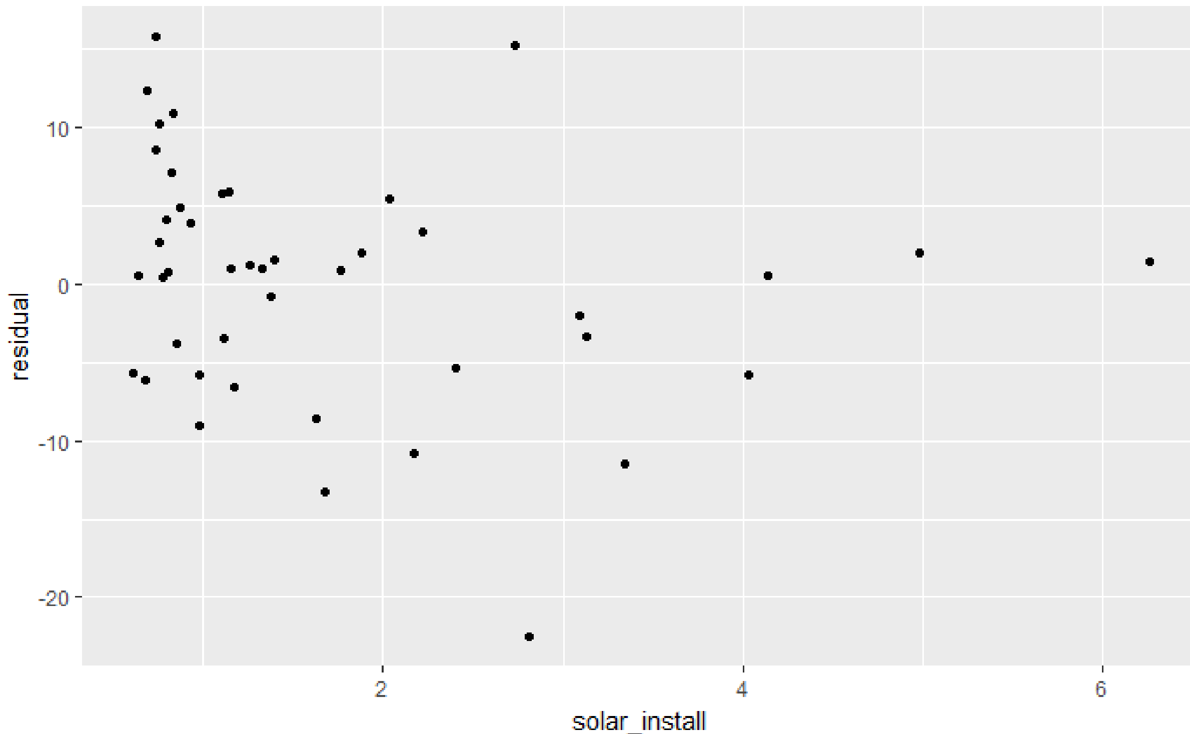
Variable	Mean	Median	Maximum	St. Dev.	N
Tot_Pop	1,206	3,279	20,480	4,642	44
Median_Income	53,600	53,280	68,860	7,963	44
Homes_Total	1,689	776.5	10,150	2,159	44
Median_Value	207,900	207,400	294,500	34,539	44
Solar_Install	6	5.58	12.7	1.2	44
Avg_install_cost	26,020	25,400	55,080	12,221	41
Avg_electricity_cost	16.47	16.26	17.01	0.53	44
Programs	31	30	32	1	44

Sources: Tot_Pop, Median_Income, Homes_Total, and Median_Value collected from 2010 Census, and 2011, 2012, 2013, 2014, 2015 American Community Surveys. Avg_install_cost collected from the Open PV Project. Avg_electricity_cost captured from the U.S. Energy Information Administration and measured in cents per kilowatthour. DSIRE presented the Programs variable. The variable Solar_Install was calculated by grouping the number of solar installations made per zip code per year.

Figure 6.1c shows the observed number of solar installations in the Rutland area against the residuals for the Rutland solar installations. The residual values were calculated by subtracted the model’s predicted installation values from the actual number of solar installations.

The residuals graph shows that each point is an observation of a solar installation within the “057” zip code of the Rutland area. The residuals are on the y-axis. The distance from 0 on the y-axis indicates the difference from the actual solar installation value observed by the model. The random nature of the model suggests lack of bias or heteroscedasticity.

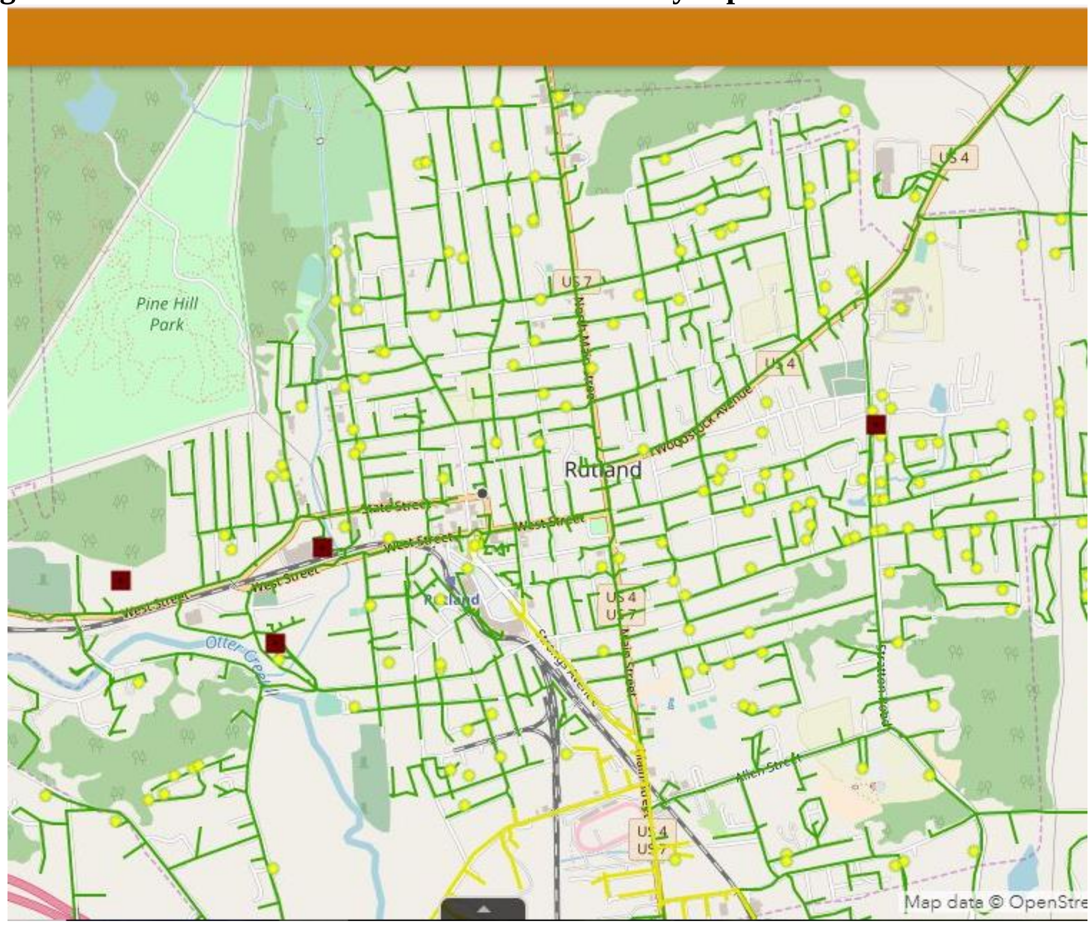
Figure 6.1 c Rutland Solar Installations vs Residuals of Solar Installations



Source: Created using R Studio. Solar_install calculated using data on solar installations by zip code from the Open PV Project.

While the Open PV Project dataset only captured 44 observations of solar installations for Rutland between 2010 and 2015, more solar installations in the city of Rutland, especially, exist. Figure 6.1d shows the residential solar arrays installed across the city. The map, which comes from Green Mountain Power, only pinpoints the locations of the installations, and does not reveal the cost of installation, date of installation, size of the array, and other characteristics. The data from the map, therefore, cannot really be examined further in the model, due to the lack of information, but the map does show that Rutland has grown in the number of solar installations.

Figure 6.1d Residential Solar Panels in Rutland City Zip Code "05701"



Source: Green Mountain Power (greenmountainpower.com) the yellow stars represent residential solar installations. See Appendix for larger map

6.2 Solar Politics

Beginning three decades ago, Vermont's legislators grew interested in tracking the relationship between the state's economy and energy sources. In 1989, Vermont Governor Madeleine Kunin called for a comprehensive review of the forms of energy being used in the state with a plan to improve the environmental quality, affordability, and renewability of those energy sources (VT Dept. of Public Services 1998). From Governor Kunin's mandate came the 1991 *Vermont Comprehensive Energy Plan*. At the time, the main concern for the condition of energy in the state was the level of CO_2 emissions (VT Dept. of Public Services 1998). The report recognized that the expiration

of Vermont Yankee's nuclear contract set to end in 2012 represented an opportunity to increase the state's use of renewable energy and reduce the amount of greenhouse gases released by the state (VT Dept. of Public Services 1998). The report did not outline specific forms of renewable energy that should be pursued but solar has played an increasing role in Vermont's energy sector since then.

Following the release of the 1998 plan, the legislature called for the periodic update of the plan to continually evaluate Vermont's energy position. In 2011, the state released another Comprehensive Energy Plan (CEP). More so than the plan released in 1998, the 2011 plan was distributed in pamphlet form to comprehensively inform the public about Vermont's energy position and future.

Renewable energy featured prominently in the 2011 plan. Former Governor Peter Shumlin wrote in the report "I believe there is no greater challenge and opportunity for Vermont and our world than the challenge to change the way we use and produce energy" (VT Dept. of Public Services 2011, 1). Shumlin's sentiment translated into the state's goal to have 90 percent of Vermont's energy needs to come from renewable energy sources by 2050 (VT Dept. of Public Services 2011, 3). At the time of the report, 50 percent of Vermont's energy came from renewable sources, which includes heating with local wood and hydropower from Hydro Quebec (VT Dept. of Public Services 2011, 4). The rest of the CEP discussed how the renewable energy goal could be achieved. According to the authors, the components necessary for success included the innovation and expertise, finance and funding, outreach and education, and regulations and policies.

The state legislature released the most recent CEP in 2016. The plan not only increased in length but also specificity. Coupled with the state's goal to meet 90 percent

of Vermont's energy needs through renewable sources, the legislature also called for the reduction of total energy consumption per capita by 15 percent by 2025. End-use renewable energy goals also existed for different sectors of the economy. By 2025, the transportation sector is expected to use 10 percent renewable energy. All new buildings constructed are expected to be "net zero" by 2030, while 30 percent of energy usage by commercial buildings is expected to be 30 percent. Finally, the legislature required that 67 percent of electric power must be renewable by 2025 (VT Dept. of Public Service 2016, 2-8).

With the most recently updated CEP plan in place, Vermont companies are expected to plan for Vermont's energy future. Based on the goal of supplying 90 percent of Vermont's energy needs through renewable sources by 2050, the planning will take considerable effort. Understanding how companies in the electric sector are reacting and transforming their approach to renewable energy is of special interest for this project given the connection between solar power and electricity.

6.2 Solar Energy's Impact on Electric Transmission

The changes made to renewable energy policy have impacted the ways in which transmission centers operate. Electricity is delivered to consumers through a complex network of generation power plants, substations, transmission centers, and countless power lines. Eventually, through the interconnected networks that make up the electrical grid, power in the form of electricity reaches the homes of consumers (EIA 2017). Following World War II, many utility companies combined their transmission centers in order to improve economies of scale and offer customers lower electricity rates (EIA 2017).

In 1956, Vermont's local utilities followed national trends by joining together to form Vermont Electric Power Company, Inc., otherwise known as VELCO (VELCO 2018). VELCO, headquartered in Rutland, Vermont was the United States' first transmission-only company established to create and maintain an interconnected transmission grid for an entire state (VELCO 2018). Today, VELCO manages over 800 miles of transmission lines and 55 substations, supports fiber optic communication networks, and maintains the transmission infrastructure.

While transmission centers only make up part of the entire electrical grid, their role is significant. VELCO's Communications and Policy Advocate, Shana Louiselle described the grid like a highway system. Exit ramps represent substations. Highway roads represent the wires that deliver power over the lines. Side streets represent the wires that bring power directly to consumer homes. Transmission stations are the backbone of the entire grid and therefore support the entire highway system (Louiselle 2018).

As a transmissions-only utility, VELCO's responsibilities include abiding by federal policies, securing the systems, and maintaining the infrastructure of transmission lines (Louiselle 2018). Since the company's formation, VELCO has spent millions of dollars to maintain the system's infrastructure. The systems has to be constructed and reinforced by engineers so as to sustain the system when the maximum amount of energy is being processed over the lines, also known as peak times. The greater the peak times, the more infrastructure to support consumer energy needs is required (Louiselle 2018).

Prior to 2010, VELCO managed peak time load growth of peak times that increased by at least one percent every year. After 2010 and especially after 2012, load

growth flat lined, in large part due to the increasing growth of the solar market in Vermont. The widespread adoption of solar is hugely significant for VELCO and not necessarily a bad thing for the company either. Louiselle explained that when more and more consumers transition to solar, they begin to generate their own electricity. With less electric demand, VELCO can devote resources once necessary to sustain infrastructure, elsewhere (Louiselle 2018).

One of the places VELCO is devoting resources instead is to better weather monitoring tools that tie directly to solar energy's expansion in the state. As more consumers install solar panels or buy into community solar arrays, the peak energy time, when the demand for electricity is the greatest, is being pushed later in the day. For example, ten years ago, peak energy time started between 3 and 5 o'clock in the afternoon as people came home from school or work and turned up the heat, turned on the lights, or started making dinner. In recent years the peak time in the summer especially has been pushed back to 7 o'clock, 8 o'clock, or even 9 o'clock in the evening after the sun sets and people are no longer pulling from solar generation.

Peak times have to be closely monitored so that the people on the front lines of managing the flow of electricity can make sure the system can withhold the burden. These peak times can also be influenced by the weather, which is why VELCO has devoted more resources into weather monitoring tools connected to the Vermont Weather Analytics Center. The detailed weather predicting programs can predict weather 72 hours in advance and can specify the weather conditions in specific one kilometer areas across the state. With these tools, VELCO can predict storms and send teams where necessary to save time in getting consumers back on the grid, and predict solar output so as to reduce

and manage peak times. In the long run, weather tools like this can reduce overall rates for consumers since the maximum amount of energy demanded can be better managed (Louiselle 2018).

Clearly, solar energy has impacted the way transmission centers, the very backbone of the electric grid, operate. The changes made at VELCO due to state and federal renewable energy plans and solar adoption trends have not been detrimental. Rather, greater solar energy usage among households has led VELCO to devote money to other projects like weather monitoring, which has overall enabled lower rates for consumers.

6.4 Green Mountain Power

Vermont is serviced by a relatively small number of electric utilities. A map from the Vermont Public Service Department shows just ten different companies responsible for delivering power to the entire state. Of the utilities, Green Mountain Power (GMP) is by far the largest electric utility and serves the majority, about 70 percent, of the state's customers, especially in Southern Vermont. Despite the monopoly power exercised by GMP, the company remains committed to competing based on electric rates and especially through the services the company provides.

About ten years ago now, GMP began to transform, both in terms of the utility's mission and in the company's approach to delivering electricity. The reconfiguration occurred when GMP hired current President and CEO Mary Powell in 2008. Powell has been credited as the "backbone" of GMP's cultural transformation, service quality improvement, and innovation strategy (GMP).

According to the VP of Customer Care and Ambassador of Rutland, Steve Costello, as Green Mountain Power began to restructure, three main customer concerns came to the forefront. The concerns included the cost of electricity, the reliability of the system, and the attention to and introduction of renewable energy (Costello 2017).

Costello described GMP's position to either adopt or ignore the growing presence of renewable energy as a pivotal point for GMP's future. Both Costello and GMP's Chief Financial Officer Dawn Bugbee referred to the continued downfall of phone companies over the past twenty years as an example of what could happen to electric utilities that avoid preparing for the changes to the grid created by different sources of renewable energy (Bugbee 2017). Fifteen years ago, almost 90 percent of homes had a landline phone, today as few as 20 percent of homes have one. According to Costello, phone companies failed to see the changes coming to the marketplace and to technology. As a result, many companies fell behind, consolidated, or shutdown.

For GMP, the answer to surviving the changing energy marketplace rests not in fighting against renewable energy, but by embracing and innovating with the presence of energy sources such as hydro, solar, and wind. GMP innovated through programs devoted to weatherization, efficient energy sources like air source heat pumps and solar panels. Some of the services are especially geared towards lower income people.

In 2014, Green Mountain Power pioneered the eHome and eBiz programs. GMP started the program by partnering with homeowners and businesses across Vermont to install the latest energy technology, reduce energy costs, and improve energy efficiency (GMP 2014). The program began with the Borkowski family two years prior to eHome's official start. The family of four lives on Baxter Street in Rutland. Their 94-year-old

1,540 square-foot home is situated on one of the poorest and most crime-ridden streets in the city. The age and size of the house contributed to large monthly energy bills and less than ideal living conditions. Old wiring, drafty windows, and poor insulation led to waste both in terms of fuel and electricity usage.

After former Rutland city mayor Christopher Louras recommended the Borkowski's as an ideal and deserving family for GMP's trial run of the eHome program, renovations were underway. Today, the Borkowski's home includes a heat pump hot water heater, two air source heat pumps for heating and cooling each floor, complete weatherization, LED lighting, and rooftop solar panels on their garage (GMP 2014). The Borkowski's worked with GMP to finance the expenses through their electric bill. Similarly, other families who participate in the eHome program can buy their systems like solar panels or heat pumps through a payback program in which the energy savings realized by the family are returned to GMP until the system is paid off.

The Borkowski's home made national headlines when the renovations were completed in 2014. Since then the family has welcomed countless visitors interested in seeing the changes made to their home. Visitors have included former Energy Secretary Ernest Moniz and the Vermont congressional delegation as well as news reporters. In an article by Bill McKibben for The New Yorker, McKibben commented, "I've travelled the world writing about and organizing against climate change, but, standing in the Borkowski's kitchen and looking at their electric bill, I felt a fairly rare emotion: hope. The numbers reveal a sudden new truth – that innovative, energy-saving and energy-producing technology is now cheap enough for everyday use" (McKibben 2014).

In a matter of days following the changes to the Borkowski's home, the family reaped the rewards. According to McKibben and Green Mountain Power, between October 2013 and January 2014, the Borkowskis used 3,411 kilowatt hours of electricity and 325 gallons of fuel oil (McKibben 2014). Following the improvements, between October 2014 and January 2015, the Borkowskis cut their electricity usage down to 2,856 kilowatt hours and used 0 gallons of oil (McKibben 2014). Within the short time frame, GMP and the Borkowskis reduced the carbon footprint of the home by 88 percent (McKibben 2014).

Since the Borkowski's eHome renovation, Green Mountain Power completed an additional 150 to 200 eHome projects (Costello 2017). Not all of the projects have been as extensive as the Borkowski's, and many have been as simple as increasing insulation or installing air source heat pumps (Costello 2017).

GMP is in the process of pursuing other projects to help improve energy efficiency among Vermont residences. Within the past six to seven months, GMP began an incentive program to install Nest thermostats in homes for free with the condition being that GMP has the power to reduce the temperatures of the homes by a few degrees when necessary to reduce peak loads (Costello 2017). The slight temperature changes help the homeowner to experience energy savings, and helps GMP deliver electricity, ideally at lower rates, since peak loads can be reduced.

A final program created by Green Mountain Power worth noting is the GMP Rutland Innovation Home Contest, which started in February 2018. GMP bought a foreclosed home on Cleveland Avenue, another crime-ridden street in a relatively poor area, from the city of Rutland for just one dollar (Company Innovation 2018). GMP then

completely refurbished the home, and installed solar panels, air source heat pumps, a Tesla Powerwall, and state of the art insulation (Company Innovation 2018). Green Mountain Power is even calling the project one of the most energy efficient homes in Vermont. The kicker is that the utility is giving the home away for free, without any mortgage payments required (Company Innovation 2018). To win the home, participants must write a 500 word essay about why energy efficiency homes are important and what they can do for the Rutland community by living in the home (Company Innovation 2018). According to GMP, the company is pursuing a project like this to show GMP's commitment to the city and supporting renewable energy even in the lower income regions of the city and the state.

6.5 Selling Solar

A growing number of companies selling solar panels are setting up operations in Rutland. The largest provider of residential and community solar is SunCommon. More than 3,500 people in Vermont have been serviced by SunCommon through residential solar panels, commercial arrays, or community solar opportunities. SunCommon Solar Community Organizer Nora Woolf spoke with me about SunCommon's role in boosting sales of solar panels in the state since 2011 when the company was founded by Duane Peterson and James Moore (Woolf 2017).

According to Woolf, a large part of SunCommon's success has been reliant on an education based approach to informing the public about the benefits of solar power. One of the largest barriers other than cost to increasing solar adoption is education about the newest technology. SunCommon pursues education in different ways. Woolf referenced occasional presentations given by SunCommon to third, fourth, fifth, and sixth graders at

schools in the state, as well as workshops about solar panels and financing programs held at the SunCommon Gallery in Rutland.

Another large part of SunCommon's success comes from partnering with Green Mountain Power. The partnership even produced a community solar array in Middlebury Vermont that opened to the public at the end of 2017 (Edwards 2017). The purpose of the project was especially geared towards lower income Vermonters in Addison County. Without having to make a personal investment or taking out a loan to install solar panels, customers could buy into the community array installed on top of GMP's Middlebury service center (Edwards 2017). Membership in the community array required that household income fell within 150 percent of the federal poverty line, for a family of four that meant household income of less than $36,900 (Edwards 2017). Memberships started as low as twenty dollars a month.

Same Sun is another Vermont based company that sells solar panels and solar energy services in Rutland. The growing company has helped residential customers as well as non-profits including St. Peter Church, the Paramount Theater, the Rutland County Parent-Child Center, and BROC-Community Action in Southwestern Vermont install solar arrays (McArdle 2018). Other solar arrays have been installed at places like Castleton University, Green Mountain College, and even the Burlington home of Vermont senator Bernie Sanders (McArdle 2018).

During an interview with the Rutland Herald, co-owner and president of Same Sun Phillip Allen commented that some Vermont customers thinking about transitioning to solar have become concerned about the recently federally instituted tariffs on Chinese modules of solar panels (McArdle 2018). Fortunately, for both Same Sun and

SunCommon neither company use foreign made panels, but panels made in California, which are not affected by the federal tariff.

6.6 Consuming Solar

Families in Rutland city, Rutland County, and the state of Vermont install solar panels on their homes for different reasons. Arguably a large portion of Vermonters with solar arrays on their homes, install panels based on their concerns for the environment and due to their interest in reducing their household's carbon footprint. Others turn to solar for the energy savings. Solar installations also appeal to Vermonters who live in remote areas of the state; solar gives these households the ability to become more energy independent and less reliant on the electric company that may struggle to reach these homes when the power goes out due to weather events.

Taborri Bruhl built his family home in New Haven, Vermont with the plan of living off the grid. In the past two years, the Bruhls connected back to the grid to reap the financial rewards and benefits of net metering through Green Mountain Power; every year the Bruhl family can earn a credit worth 1,000 dollars from GMP for the extra solar energy generated by the solar panels (Bruhl 2017). Had the family remained off the grid, they would lose out on selling unused energy back to the utility. Bruhl is also unique in that he installed his solar panels himself and purchased the panels wholesale for less than market price.

Bruhl built his home with the purpose to get the greatest benefit out of the environment. The home is net zero, which means that the amount of energy used by the home on an annual basis is approximately equal to the amount of renewable energy created at the home. Solar energy generates the home's electricity, the family heats with

wood from the surrounding area, while they only use a bit of propane for cooking (Bruhl 2017). Another important consideration for making the home net zero, energy efficient and environmentally friendly was to construct the home facing south. According to Bruhl, by having the home's windows and living spaces open to the south, the main rooms get more sunlight throughout the day and can stay warmer in the winter (Bruhl 2017). The Bruhls can live comfortably in their home and be net zero in large part just by harnessing the natural location of the sun and by utilizing solar panels.

Another family I spoke with, the Carpenter family of Rutland had not necessarily thought of installing solar panels until the national company Solar City visited the area looking for homes with the best sun exposure (Carpenter 2017). Solar City, which became a subsidiary of Tesla in 2016, installed a total of 36 solar panels on the roof during the summer of 2016 (Carpenter 2017).

Solar City incentivized the Carpenters to go solar through a third party ownership agreement (TPO) that Solar City refers to as a Power Purchase Agreement. In a TPO agreement, the Carpenters do not own the solar panels outright; rather Solar City owns the system and determines the electricity costs owed by the Carpenters based on the amount of solar produced minus the amount of electricity used each month. The conditions of the contract included that Solar City incurred the costs of reinforcing the home's roof (and would have installed a new roof had been necessary), the costs of the solar panels and system, and the labor required during planning and installation (Carpenter 2017). Furthermore, by signing the agreement, the Carpenters agreed to twenty years of keeping the Solar City solar panels on their roof.

The final family I spoke with was Toni and Ben Boltz who purchased their solar panel array from SunCommon. Engineers installed the 26 panels on their roof in July 2017. Around the same time, the Boltz also installed air source heat pumps and a Tesla Powerwall both through Green Mountain Power (Boltz 2017).

Through SunCommon, the Boltzs paid for their installation with a monthly payment which will be paid off over the next seven years. They also received the Federal Tax Credit which reduced the cost of the panels by 30 percent. According to Boltz, much of the monthly payment can be paid with the energy savings realized since the panels and heat pumps were installed (Boltz 2017). During the summer prior to the installations, a typically monthly electricity bill for the Boltz was $200 due to air conditioning running all the time (Boltz 2017). The summer electricity bills that came in after the panels and pumps were up and running were as low as if not less than $20 (Boltz 2017).

For the Boltz, they ultimately decided to go solar after hearing good reviews about SunCommon, after they grew tired of pricey money electricity costs, and as they became more aware of environmental issues. During the interview, the Boltz, both of whom grew up and attended school in Pennsylvania spoke about the environmental destruction wrought in the state due to the coal mining industry (Boltz 2017). The couple described the loss of complete mountains as the coal was continuously chipped away. The Boltz see solar energy and use solar as a way to not only realize energy savings but to help the environment.

6.7 Paying for Solar

Different financing options, grants, and organizations exist in Rutland to help people looking to install solar panels at any income level. Many of these programs are especially geared towards supporting lower income Vermonters. A specific organization called NeighborWorks of Western Vermont stands as a leader in assisting the reconstruction of homes with attention to the energy sources and weatherization of homes in low income areas. The organization services Rutland, Addison, and Bennington counties (NeighborWorks 2018). In 2017 alone, NeighborWorks loaned $3,402,118 to current or new homeowners in the region (NeighborWorks 2018). A portion of that amount was made to people who qualified for energy loans and who received energy audits through the organization.

Green Mountain Power is another source of energy loans. GMP partners with local credit unions on a regular basis to get customers low rates for energy projects, especially through the eHome program (Costello 2017). Costello estimated that most eHome projects are financed for a loan worth between $7,000 and $10,000 (Costello 2017).

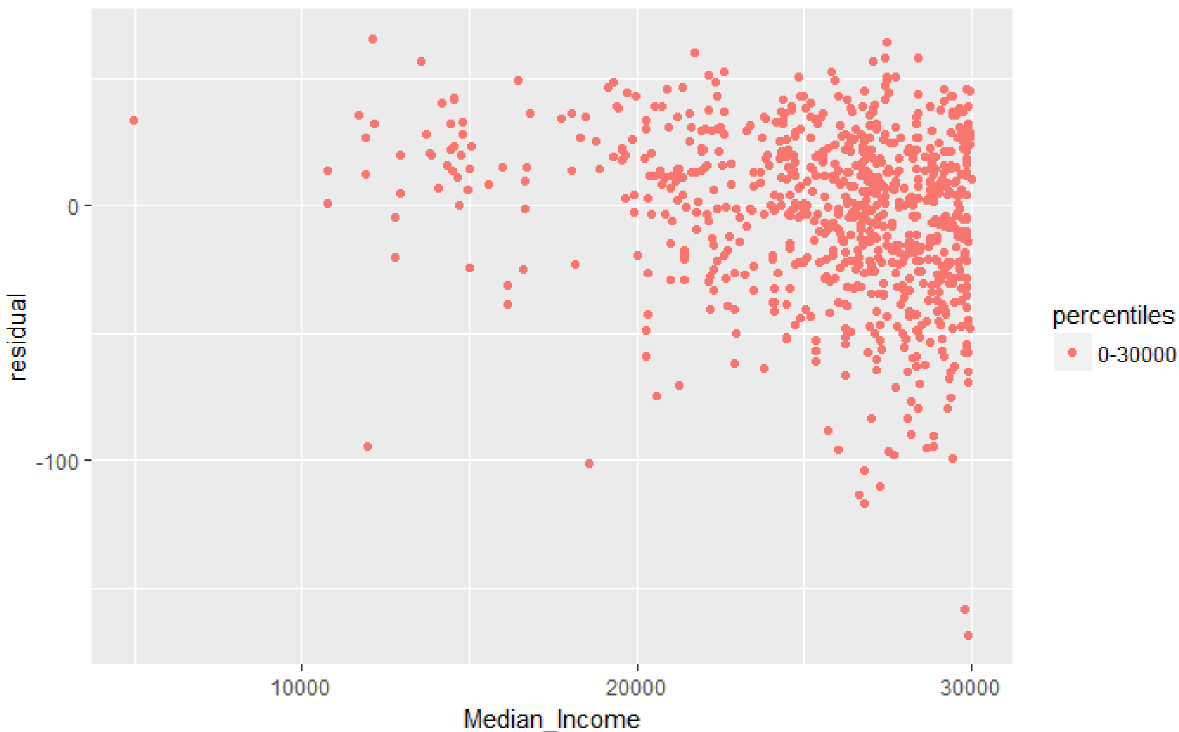
According to Costello, despite the number of different loan options and grants available, many people remain hesitant about installing solar panels, leasing air source heat pumps, or weatherizing their homes in large part due to their dislike of change (Costello 2017). For some people, they have always lived in cold rooms with drafty windows or doorways. They end up spending large sums of money on heating fuel that goes right out the window quite literally.

Overcoming the barrier really takes overcoming a generational mindset that believes things are just the way they are and cannot be changed by making even small changes like more insulation in the home (Costello 2017). An important factor in changing that mindset for Costello is not only explaining the number of financial plans offered for lower income Vermonters or the amount of money the changes with save the household overtime, but also how much more comfortable their lives could be made when they live a warm, energy efficient home (Costello 2017).

7. Solar and Fuel Poverty Inquiry

The following section will spend some time linking what has been covered about solar energy, between the national regression model and the case study of solar in Rutland, back to fuel poverty and lower income Americans. After the regression was performed, the differences between solar installations based on the income brackets were examined. Figure 7.1 graphically shows the residual plot of the observations for the income bracket ranging from 0 to 30,000 dollars.

Figure 7.1 Residuals of Solar Installations for Income Bracket $0-$30,000



Note: Total number of observations equal to 785.

The positive residuals in Figure 7.1 are of interest in linking solar installations with fuel poverty. Positive residuals indicate that the solar installations in the zip codes with median income less than $30,000 are exceeding the model's predictions. Table 7.2 captures the top 20 residuals from Figure 7.1.

Table 7.2 Top 20 Residual Observations for Income $0-$30,000

zip code	Total Population	Median Income	state	solar install	avg install cost	avg electricity cost	Programs	predicted installs	residual
18913	185	12109	PA	2	77840	12.7	41	-63.43	65.43
78873	1709	27442	TX	2	33024	11.08	98	-62.38	64.38
32616	872	21741	FL	1	304500	11.44	53	-58.83	59.83
79902	20440	27402	TX	12	33936	11.08	98	-46.22	58.22
78204	11125	28403	TX	2	18185	11.6	82	-55.98	57.98
93650	4137	27072	CA	71	23182	14.78	152	14.29	56.71
18101	3897	13544	PA	1	25000	12.7	41	-55.36	56.36
78538	11941	25806	TX	6	14213	11.35	106	-46.34	52.34
78202	12490	22584	TX	1	15650	11.08	98	-51.25	52.25
94102	24754	22159	CA	40	21893	14.78	152	-10.87	50.87
79903	18107	27729	TX	2	14800	11.08	98	-48.79	50.79
11224	42535	27481	NY	1	27216	18.79	76	-49.75	50.75
78203	5807	24846	TX	1	8637.9	11.35	106	-49.43	50.43
20006	2884	16450	DC	3	27509	13.4	9	-46.19	49.19
90015	18986	25911	CA	2	16184	14.75	135	-47.12	49.12
75212	24997	27460	TX	26	7820	10.98	105	-23.09	49.09
10454	37850	19271	NY	2	44666	17.62	75	-46.63	48.63
89501	3533	22345	NV	3	41098	11.89	28	-45.25	48.25
95573	1744	27411	CA	2	20819	14.75	135	-44.78	46.78

Sources: Total Population and Median Income collected from 2010 Census, and 2011, 2012, 2013, 2014, 2015 American Community Surveys. Average install cost collected from the Open PV Project. Average electricity cost captured from the U.S. Energy Information Administration and measured in cents per kilowatt hour. DSIRE presented the Programs variable. The variable Solar_Install was calculated by grouping the number of solar installations made per zip code per year. Total observations are785.

Some of the predicted values in Table 7.2 made by the model are quite negative because the actual values of the solar installations at the zip code level are relatively small. The specific factor or factors influencing the solar installations in these areas, despite low median incomes, are unknown. Researchers may find that leaning more about the conditions in these zip codes that favor solar could be of interest to future research.

8. Policy Recommendations

This section will present particular policy recommendations thought to be best for supporting solar energy among people with lower incomes across the nation. These policies include refundable tax credits, loans for solar, grants, utility services, and education programs. These recommendations should ultimately create more income for lower income Americans and incentivize them to invest in solar energy and or weatherizing their living spaces.

8.1 Refundable Tax Credit

A large refundable energy credit that is available many times over the taxpayer's lifetime could encourage lower income people to considering renovating their living spaces to become more energy efficient. Since many lower income people also live in apartments, having a special tax incentive for landlords may be a way of helping multiple families at once. Energy credits vary by state. At the federal level, the government did away with an energy credit worth $500 over the taxpayer's lifetime for installing new windows or doors, a new furnace, insulation, etc. late in 2017. The credit will no longer exist for the 2018 tax year.

If a new energy credit is to be created, the credit would best serve lower income people when structured as a refundable credit. Since lower income taxpayers have very little tax liability, they often do not have the ability to qualify for nonrefundable credits. A refundable credit, though, can reduce a taxpayer's tax liability beyond zero and increase the refund due to the taxpayer or lessen what they own in taxes. The energy credit as a refundable credit could work similarly as the earned income credit has

encouraged low income people to work and earn at least a little income to reap the rewards of the federal return.

8.2 Loans for Solar

Special loans could be created specifically for solar installations for the fuel poor. These types of loans could be shaped at the corporate level or by local credit unions or by big banks. The loans should lessen the restrictions on income requirements or credit score ratings for a few reasons. Lower income people likely do not have the money upfront to pay for solar panel installations, but they could pay back the loan through energy savings on their monthly energy bills. The household does not necessarily have to see money coming in to pay off the loan, but either pay with the difference between their higher previous electricity bills or earn the solar credits by selling additional solar energy back to the utility.

Similar loans for solar energy have already worked for higher income people who meet the income requirements. Even among higher income people, though, they still tend to pay off the loan not with the income they are earning but merely through their realized energy savings or through their utility net metering.

8.3 Grants

Additional grants to community organizations can help encourage home renovations and solar panels installations at a local level. For example, when NeighborWorks of Western Vermont receives grants from the federal government or other organizations, NeighborWorks then does all of work on the frontlines from the energy audits to research to education and financial planning with the households.

8.4 Utility Services

Utility services will definitely need to change the types of services they provide in order to keep pace with the changing energy climate and the transition to renewable energy sources like solar, wind, and hydro. Green Mountain Power serves as a great example for what types of services electric utilities could offer especially to lower income people. Projects like eHome and eBiz could take shape nationally. Also net metering should be encouraged. If people have the opportunity to sell to the utility solar energy they generated but did not need, then households will not only feel more environmentally responsible but as if they are making money on the investment they made by installing solar panels.

8.5 Education Programs

Alongside these programs to financially support lower income people in becoming more energy independent, must be education to help this segment of the population understand the benefits of going solar and having a home that is more energy efficient. These education programs may take the form of being tied to a loan, in which the person or family looking to obtain a solar loan must also attend a class or take an online course with regards to solar energy. Perhaps the class simply requires a tour of a home that has already gone through the renovation, weatherization, and installation processes. The more lower income people are educated about the opportunities that exist for them to lead more comfortable lives in warm homes, the more they begin to become more energy independent.

As Nora Woolf from SunCommon mentioned, education must also start young at the grade school level. The earlier people start to hear about the benefits of solar and the

feasibility of obtaining solar panels for homes, the more willing they become to accept a changing energy environment.

8.6 Policy Conclusion

At the end of the day, policy recommendations to support solar energy among the fuel poor will be important for the greater community. As more and more consumers in the upper middle class and above invest in solar energy, they become less reliant on the electric utilities. When energy independence grows, electricity rates become higher because fewer people demand the good. The higher rates rest on the shoulders of the people without solar panels on their homes, which include the lower middle class and the poor. Higher rates throw the people already struggling to make ends meet into a deeper cycle of fuel poverty.

9. Conclusion

This project came to a few important conclusions that can be used to formulate current policy measures, and shape future research in the fields of solar energy and fuel poverty. The purpose of this thesis was two-fold. Alongside the review of the literature regarding fuel poverty, an in-depth study of the adoption trends in solar PV systems developed into a national regression model. From the model, important factors influencing solar installations across the United States were identified.

Furthermore, the thesis included a case study on Rutland, Vermont where widespread poverty and lack of economic development existed for decades until movements geared towards renewable energy began to grow the economy again in the early 2000s. Since that time, the city's trends in solar adoption, and the role of Green Mountain Power in encouraging solar among the lower income population have made Rutland a model for New England and even the country.

The regression model revealed that during the time frame from 2010 to 2015, solar installations increased. The significant factors that are influencing solar adoption includes total population, median income, the total number of homes, electricity rates, installation costs, and the number of incentive programs available. The model also included fixed effects for zip codes and years so as to capture the differences among zip codes that cannot necessarily be identified by including additional independent variables.

As identified in the paper, some weaknesses may exist in the solar installations data as captured by the Open PV Project from the National Renewable Energy Laboratory (NREL). An opportunity for future research may lie in creating a better and more representative database that captures the number of residential solar installations at

the zip code level. The NREL database has definitely built a foundation for a project like this to go further. Researchers will likely have to take it upon themselves to research individual zip codes or states to identify solar arrays instead of asking for the numbers and characteristics to be supplied voluntarily.

From a comprehensive solar database, different studies can be produced. An example of a future study could come from this regression model and link to fuel poverty. The graph and residuals from Section 7 show how zip codes with low income but higher than predicted solar installations can be used to identify zip codes that can have fuel poverty while simultaneously turning to solar energy. Similar researcher can use the path lain out by this regression to identify what zip codes are outperforming fuel poverty, which are falling behind, and where to target policy measures to combat the fuel poverty in those areas.

Future research may also try to develop different models if the factors that influence solar adoption change as solar panels become less expensive overtime. More zip codes may also add new solar arrays since this paper was written. Altering the model variables into logarithms may also benefit the results since so many of the observed zip codes in the United States do not have any installations identified by the NREL dataset.

The case study of Rutland, Vermont specifically reveals how a city can harness the power of the sun to transform a drug-afflicted and poor city through renewable energy projects geared towards lower income residents. Initiatives for these types of project rest on the shoulders of the state government, companies, and utilities. The work done by the engineers, developers, and the leadership team at Green Mountain Power shows the

evolving role that electric utilities can have in the changing energy environment. The utility is fostering energy independence among the poor at a very local level.

The initiatives to fund programs to help the poor have access to energy efficient living conditions and solar panels in Vermont can play out at a national level. While the lucrative Federal Tax Credit that cut 30 percent of solar installations costs is phasing out and the current administration approved tariffs on Chinese solar modules are both cutting solar energy's bottom line, different policies exist. Refundable tax credits or tax incentives for landlords, special loans without income requirements, grants, services provided by the utility, and education programs could all be molded to benefit lower income people install solar panels and become more energy independent.

Solar energy is only becoming less expensive overtime and more and more are turning to solar panels as their household's source of energy. Electricity rates will be higher as this trend continues and will burden the poor who cannot afford to install solar panels, live in apartment buildings, and who have little money to spare on higher energy expenses. By pursuing projects like Green Mountain Power has in Rutland, Vermont and considering the energy needs of lower income Americans, harnessing the power of the sun to warm the living conditions of the fuel poor should be at the forefront of the minds of the policy makers across the country.

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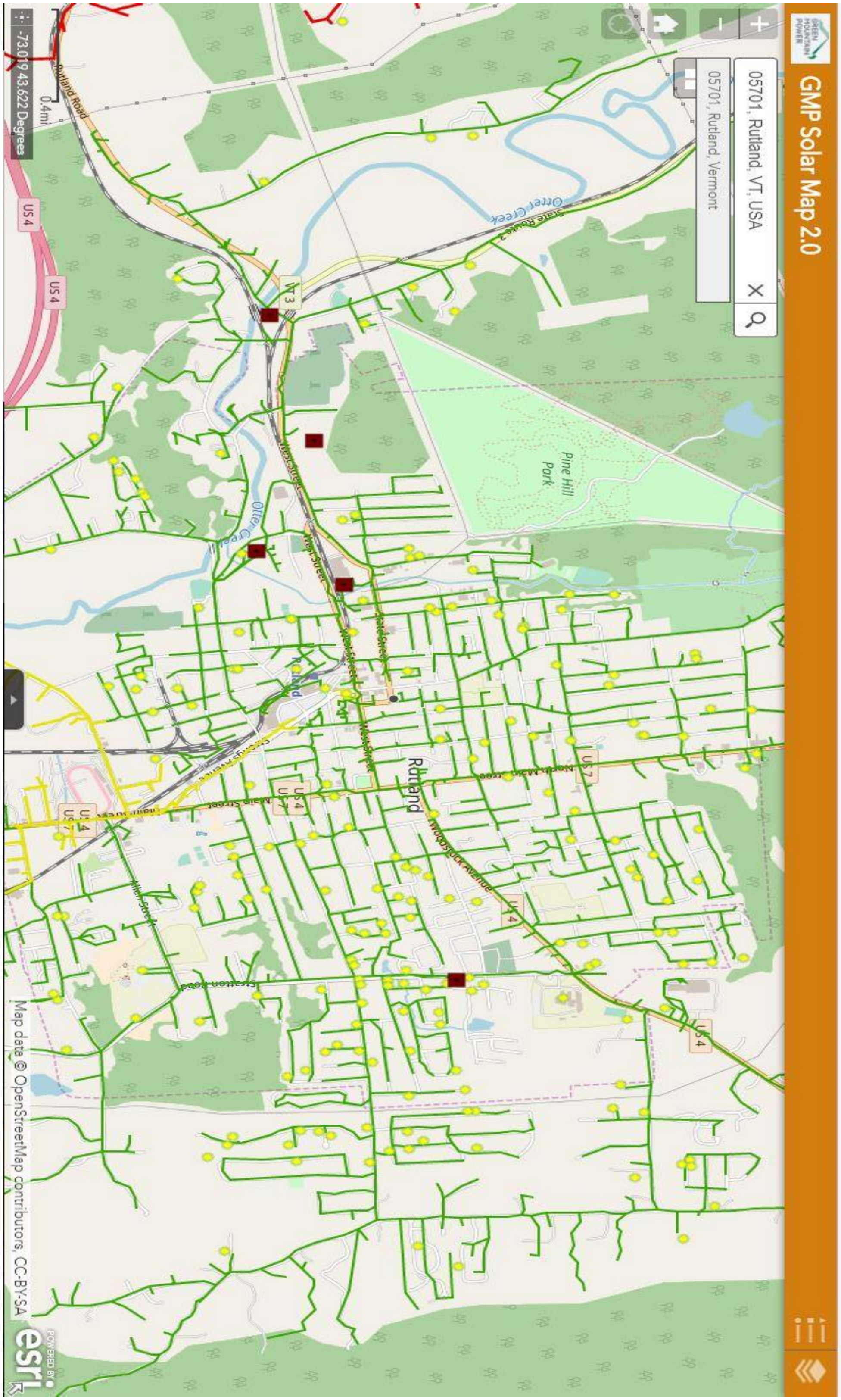
Appendix


GMP Solar Map 2.0
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