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Clean, Cheap, and Just: Sustainability Values Expressed in Austin's Residential Solar Rebate Policies and by Austin Residents

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Clean, Cheap, and Just: Sustainability Values Expressed in Austin's Residential Solar Rebate Policies and by Austin Residents

by

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Thesis

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Dedication

To Andy, for his patience and support.

To my parents, for encouraging my curiosity.

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Abstract

Clean, Cheap, and Just: Sustainability Values Expressed in Austin's Residential Solar Rebate Policies and by Austin Residents

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Residential solar panels have great promise to reduce dependence on energy from carbon-emitting sources. However, the high cost of solar panels puts the technology out of reach for many residents and compels utilities to provide subsidies for their purchase. This master's thesis investigates the manifestation of economic, environmental, and social equity interests in Austin Energy's residential solar rebate program through the perspective of the utility and of the residents of Austin, Texas. I situate the thesis in the context of climate change, local inequality, and the externalities of conventional energy choices. I then evaluate the expression of sustainability values embedded within solar technology policy and implementation through three areas of inquiry: an examination of residential solar incentives, including interviews with utility personnel at Austin Energy and CPS Energy in San Antonio; an analysis of survey data indicating resident perceptions of solar technology; and a comparison of the energy used by solar panel owners and non-owners. I found that, as hypothesized, economic interests dominate a more moderate showing of environmental values and a smattering of social issues in terms of policy design and residential perceptions. However, energy use data showed that solar panels do significantly reduce household energy consumption drawn from the grid, including during times of peak demand. Research findings indicate a need for a better connection of social interests with economic and environmental values when it comes to residential solar technology policy and adoption.

Table of Contents

List of Tables xi

List of Figures xiv

Chapter 1: Introduction 1

Global Climate Change and Local Connection 4

Local Context and Equity 6

Climate Change and the City of Austin 8

Local Residential Solar 9

Research Questions 11

Research Design and Methodological Approach 12

Chapter 2: Literature Review 15

The Balance of Sustainability and Ecological Accounting 15

Economics of Solar Energy 17

Techno-Economic Assessments 18

Economic Risk to Residents and Utilities 21

Levelized Cost of Electricity 22

Consumer-Oriented Economic Solar Incentives 24

Solar Energy: Perceptions and Behavior 26

Consumer Values and Technology Adoption 26

Influence of Technology on Energy Use 28

Literature Related to the Pecan Street Project. 30

Literature Review Discussion 31

Chapter 3: Cities, Electric Utilities, and Solar 34

Electric Cities 34

Fuel Sources, Trade-Offs, and Externalities 38

Residential Solar Energy Incentives and Regulations 46

Notable Incentive Programs 51

Chapter 4: Central Texas Utility Case Studies 54

Austin Energy 54

Austin Energy Interview 58

Design 58

Interview 59

CPS Energy Interview 66

Design 68

Interview 68

Discussion 72

Chapter 5: Presence of Economic, Environmental, and Social Interests Concerning Solar Panels among Austin Residents 76

Data Source 76

Methods 77

Limitations 79

Results 80

Chapter 6: Solar Panels and Energy Use in Austin – Who Has Technology and Does It Decrease Energy Use 87

Data Source 89

Binary Variables 89

Continuous Variables 89

Categorical Variables 90

Methods 93

Limitations 95

Results 96
Annual Energy Use 96
Energy Use Characteristics Discussion 101
Peak Energy Use 102

Chapter 7: Conclusions 104

Recommendations 105
Increasing Equity in Utility Rebate Structure 105
Increasing Trust 106
Further Research 106

APPENDICES 108

Appendix A: Austin Energy Data 108

Appendix B: Austin Energy and CPS Energy Interview Protocol 113

Appendix C: Pecan Street Project 2014 Survey Protocol and Results 116
PV System Questions 116
Survey Responses 118

Appendix D: Pecan Street Project Energy Usage Results 127

REFERENCES 131

List of Tables

Table 1: Literature Concerning Influences on Sustainability Behaviors and Adoption of Renewable Energy 27

Table 2: Literature Concerning Influence of Technology on Environmental Focused Behaviors 29

Table 3: 2015 Electricity Generation Sources in the United States........39

Table 4: 2016 US Annual Carbon Dioxide Emissions from Energy Consumption by Source, Including Transportation Fuels........41

Table 5: Carbon Intensity of Fossil Fuels, Including Transportation Fuels 41

Table 6: Austin Energy Residential Solar Rebate Structure........57

Table 7: Federal Solar Tax Credit Schedule........58

Table 8: Austin Energy Value of Solar Price Components, 2017 62

Table 9: Austin Energy Value-of-Solar Tariff Changes, 2012 - 2017........62

Table 10: FY 2017 Available Solar Incentive Rebates for CPS Energy 67

Table 13: Reasons for Not Pursuing Home Solar (Question 10)........83

Table 14: Total Negative Responses per Participant (Question 10)........83

Table 15: Appealing Attributes of Solar Panels by Ownership (Question 11)......84

Table 16: Total Number of Positive PV Factors Selected by PV Owners and Non-Owners (Question 11)........85

Table 17: Austin Energy System Peak Demand, 2007 - 2016........91

Table 18: Day Ahead ERCOT Peak Demand, 2013 - 2014 92

Table 19: Descriptive Statistics of All Participants........96

Table 20: Descriptive Statistics of PV Owners........97

Table 21: Annual Portion of Electricity Provided by Grid vs. On-site Generation for PV Owners 97
Table 22: Descriptive Statistics of Non-Owners 98
Table 23: Hourly Peak Energy Use Descriptive Statistics....102
Table 24: Austin Energy Residential Customer Data, 2006 - 2014....108
Table 25: Percent Change in Austin Energy Residential Customers, Revenue, and Prices, 2006 - 2014 108
Table 26: Austin Energy Carbon Intensity per KWh, 2005 - 2014 109
Table 27: Austin Energy Generation Mix, 2006 - 2015 110
Table 28: Change in Austin Energy Generation Mixes, 2006 - 2015....110
Table 29: Austin Energy Renewable Power Purchase Agreements 111
Table 30: Austin Energy Residential Customer Satisfaction, 2006 - 2015 112
Table 31: Austin Energy Time-of-Use Pricing....112
Table 32: Question 2 Economic, Social, and Environmental Interest Results 118
Table 33: Question 3 Satisfaction Results 118
Table 34: Question 4 Economic, Social, and Environmental Interest Results 119
Table 35: Question 4 Answer Categories 119
Table 36: Question 5 Economic, Social, and Environmental Interest Results 119
Table 37: Question 5 Answer Categories 120
Table 38: Question 6 Economic, Social, and Environmental Interest Results 120
Table 39: Question 6 Answer Categories 120
Table 40: Question 7 Economic, Social, and Environmental Interest Results 120
Table 41: Question 7 Answer Categories 121

Table 42: Question 8 Economic, Social, and Environmental Interest Results 121
Table 43: Question 8 Answer Categories 121
Table 44: Question 8 Economic, Social, and Environmental Interests Results by Category 122
Table 45: Question 9 Economic, Social, and Environmental Interest Results by Category 122
Table 46: Question 10 Answer Categories 122
Table 47: Question 10 Number of Negatives Selected.......................................123
Table 48: Question 11 Answer Categories 124
Table 49: Question 11 Number of Positives Selected 124
Table 50: Question 11 Results by PV Owner versus Non-Owner.......................125
Table 51: Question 12 Economic, Social, and Environmental Interest Results by Category 126
Table 52: Question 12 Answers by Category 126
Table 53: Peak Energy Use (kWh) for All Households......................................127
Table 54: Peak Energy Use (kwh) Per Person for All Households 127
Table 55: Peak Energy Use (kwh) for Households with PVs.............................128
Table 56: Peak Energy Use (kwh) Per Person for Households with PVs...........128
Table 57: Peak Energy (kwh) Use for Households without PVs........................129
Table 58: Peak Energy Use (kwh) per Person for Households without PVs.......129

List of Figures

Figure 1: Heffron, McCauley, and Sovacool's Energy Law and Policy Triangle .17

Figure 2: State Financial Incentive Structures 47

Figure 3: State Solar Photovoltaic Regulatory Policy Categories 49

Figure 4: 2015 Austin Energy Generation Mix 55

Figure 6: CPS Energy Interview Word Cloud 66

Figure 7: The Position of Austin Energy's Solar Rebate Policies on Campbell's Triangle 74

Figure 8: Scatterplot of Income Categories and Annual Household Energy Use..99

Figure 9: Scatterplot of Income Categories and Household Annual Energy Generation 99

Figure 10: Scatterplot of Education Achievement Categories and Household Annual Energy Generation 100

Figure 12: Austin Energy Carbon Intensity per KWh, 2004 - 2014...................109

Figure 13: Relationship between PV Array Size per Person and Annual Energy Use per Person in Each Household 130

Chapter 1: Introduction

This master's thesis investigates the value of residential solar energy to residents of Austin, Texas and to the publicly-owned utility. For these purposes, value refers to not just the financial or monetary value of solar electricity generated on residential rooftops, but also the social and environmental value of that energy. I investigate this three-pronged concept of value through two areas of investigation. The first part of this research explores how utilities value solar through qualitative archival and interview-based analysis. The second realm of research investigates the perceptions of Austin residents regarding residential solar electricity and their actual energy usage of Austin residents to see how behavior mirrors policy and perception. By exploring value through the realm of the economic, the social and equitable, and the environmental, I aim to provide a holistic analysis of solar energy. Analyzing solar energy during a period of human-influenced climactic warming provides impetus for this project and makes the research pertinent to both the utility and residents.

The remainder of this introductory chapter will contextualize the research through a problem statement, present research questions, and will consider the research design and the methodological approach used to address the key research questions. The problem statement introduces a theory of sustainability and filters the research through that theory by discussing global climate change, and then addressing equity issue and climate change on the local scale. I then present the key research questions and sub-questions considered through this research. I conclude by outlining the methods I employ over the course of this research.

Residential solar energy frequently turns up as an example of a climate mitigating energy source. Yet despite a rapid decline in the cost per kilowatt (kW) of solar arrays, the installation price of solar photovoltaic panels remains high and impedes the more rapid deployment of the technology. These dual threads—solar as savior, cost as failure—permeate discussions of the technology and its viability as a sustainable mitigating option. The tensions between the cost of the technology and the effects of technology on the environment recall the well-worn tensions in the pursuit of sustainability exemplified by the planner's triangle and the triple bottom line (Campbell, 1996; Elkington, 1998). Campbell's triangle of sustainability provides a model for understanding how tensions between equity, the environment, and the economy create conflicts that impede sustainable economic development. Resource conflicts emerge between economic growth and environmental protection; development or environmental justice conflicts emerge between environmental protection and equity/social justice; property conflicts emerge between equity/social justice and economic growth. Elkington's triple bottom line takes a similar stance, but with a business focus, arguing for businesses to include environmental quality and social justice with profitability when measuring one's profits or earnings.

This research is concerned with how the local value of residential energy may challenge or conform to the dominance of the economy in the current balance between economy, equity, and environment. For instance, multiple levels of government provide subsidies and incentives to address the market access failure of residential solar technologies and to encourage their adoption, representing a valuation that goes beyond pure upfront costs; by passing an economic incentive to customers the utility is trading economic value for the environmental.

The willingness of governmental entities to provide incentives and rebates for solar energy relates to inefficiencies of pricing of conventional energy. Conventional energy, particularly coal and natural gas, produce an array of negative externalities, especially concerning the environment (see Chapter 3). The price of both the natural resources and the energy generated through their combustion do not include the full costs of treating their many deleterious effects like asthma from particulate matter or climate change from greenhouse gas emissions (Greenstone, 2001). The failure to adequately price these negative externalities results in market inefficiencies, whereby conventional sources appear to be the clear economic choice despite multiple downstream costs absorbed by the public sector and individuals over time (Borenstein, 2012; Borenstein & Bushnell, 2015). Since solar energy produces very few negative externalities, the government subsidies of the technology have a strong economic rationale. The trade-off between economic value and environmental benefit (as evidenced by government subsidies for solar energy) resolves economically given the avoided negative external costs.

The most efficient market solution would entail accurate pricing of conventional energy sources. The cost and prices of energy generated from these sources would likely increase. However, accurately priced energy would facilitate true informed decision-making in terms of energy choices. The price differential between conventional and renewable energy resources like solar would close and the avoided remediation costs of energy sources become more apparent (Rhodes et al., 2016).

Equity and social justice appear to occupy less space in terms of the value and interests of solar energy, which may occur as a function of the outsize influence of the economic sphere over others (Oden, 2016). Yet the social equity and environmental implications of the energy sector remain tremendous, both locally and globally. Utilities that use fossil fuels for electricity production are institutional actors in terms of global climate change. Climate change threatens the environment to such a significant degree that it causes social inequities through environmental and climactic injustices. Meanwhile, global economic growth and performance are dependent on climate aggravating fossil fuels. The high capital plus operating costs of renewables delays deployment of climate mitigating technologies such as solar panels. Yet those most vulnerable to climate change effects may not be able to access these technologies due to their cost.

Global Climate Change and Local Connection

Global climate change poses a significant challenge to any attempt to balance economic, environmental, and equity interests. The transformation of our air is a truly global phenomenon, shared and experienced by all of those who live on earth. Every person on the planet lives under a blanket of atmosphere that protects us from the vacuum of the cosmos, and due to the consumption of natural resources and carbon dioxide emissions stemming from conventional fuel sources, that blanket is changing. The urgency and universality of climate change provide us with an “opportunity to transform energy governance and ensure a radical reduction in carbon emissions” (Frances & Stevenson, 2017, p. 1).

Yet climate change does not affect us all equally, which brings us to the question of trade-offs and balance between economic, environmental, and equity interests as every scale. How individuals, communities, and even nation states will fare and are faring under a changing climate depends on the local capacity to adapt. How deeply the changing climate penetrates, how strongly it disrupts, depends very much on the natural world (geography, biology) as well as human resources like capital and knowledge. Given the current level of income inequality across the world, it is not surprising that climate change threatens poor communities more than it does the rich. Even within affluent communities and countries, those with fewer resources tend to suffer more consequences (Francis, 2015; Olsson et al., 2014). Because the experience of climate change depends so much on local context, it is appropriate to analyze mitigation activities locally.

I chose Austin, Texas as the local area of study for this research because I have access to institutions and data sources that facilitate local analysis as well as an understanding of the local economic, environmental, and social landscape. Additionally, the City of Austin has demonstrated a commitment to responding to climate change locally. In 2007, City Council adopted a goal of carbon neutrality for the city's operations by 2020. In 2013, City Council enacted a resolution to study climate change effects in Austin. In 2015, City Council adopted a Community Climate Plan that provides a path forward for the city reach net-zero greenhouse gas emissions by 2050. Furthermore, the Imagine Austin Comprehensive Plan addresses climate change, as does the Hazard Mitigation Plan, the Urban Forest Plan, and the Austin/Travis County Community Wildfire Plan (City of Austin, 2017).

Most relevant to this research is the climate action taken by Austin Energy, the city's municipally-owned utility. Due to its public ownership, the utility responds to the directives of City Council and therefore can pursue the city's climate goals. The utility operates an Austin Generation Resource Planning Task Force that provides strategic planning and sets emission standards and energy portfolio mixes for the city and includes citizen input (Austin Energy, 2014). Since the utility engages in democratic planning initiatives, it may be better suited than others to address a full suite of concerns when planning for climate change mitigation and adaptation.

Local Context and Equity

The inequities caused or exacerbated by climate change can be seen legibly at the local scale. Austin, Texas faces several social inequities, particularly racial and economic segregation. With a history of explicit racial segregation along I-35, Austin continues to struggle to integrate its neighborhoods and prevent displacement (E. M. Tretter, 2013). Decades of discriminatory policies included the segregation of schools and public facilities, redlining, environmental injustices, and system of city government that minimized the representation of people of color (Long, 2014; E. M. Tretter, 2013; E. M. Tretter, Cowen, Heynen, & Wright, 2016).

Despite the city's impressive population growth from 2000 to 2010, Austin is the only city in the United States that "suffered a net loss in its African-American population" (Soloman, 2015; Tang & Ren, 2014, p. 1). Combined with quickly escalating home values, the development pressure felt in the central city has created a difficult environment for lower-income home owners to maintain their properties and for prospective low and middle income in-migrants to live in more central city areas (Diaz, 2014; Toohey, 2012; Zehr, 2015). Meanwhile, peripheral suburbs have absorbed a significant amount of growth within the region, while also offering a more affordable alternative to minority residents feeling the squeeze (Long, 2014; MacLaggan, 2014; Soloman, 2015). Despite this displacement, the major patterns of income and racial segregation continue across Austin.

Inequities in Austin also surface as environmental injustices. Though the city is not a historically important industrial city, tech firms that located in the city in the 1980's disproportionately located manufacturing facilities that required toxic release permitting in poor, black, and Hispanic neighborhoods, according to activist groups. This activity mobilized environmental justice groups, particularly PODER (People Organized in

Defense of Earth and her Resources) to lobby for remedies to the environmental consequences that disproportionately affect people of color in Austin (E. Tretter, 2016). Austin Energy has also perpetuated environmental injustices by locating and operating power plants in low-income neighborhoods. The Holly Power Plant, for instance, was approved for construction in the 1950's and was sited directly in a Hispanic Latino neighborhood—a legacy of Austin's 1928 Master Plan which allowed industrial uses in non-white neighborhoods (Renteria, 1994). The power plant continued operating in this neighborhood until 2007.

While the Holly Power Plant exposed a lower income Latino neighborhood to near-term air pollutants, it also emitted greenhouse gas emissions. Until 1996, Austin Energy's energy portfolio solely contained natural gas, coal, and nuclear power plants (Austin Energy, 2017). As discussed in Chapter 3, combustion of natural gas and coal emits greenhouse gases and leads to climate change. One of the ways in which the Austin area experiences climate change is the greater frequency of precipitation events. The areas in Austin that are most vulnerable to flooding from these events are in east and southeast Austin, where the clay soils quickly become water logged and unable to absorb precipitation (City of Austin, 2014). East Austin also is home to many of the city's lower-income neighborhoods—many of which are built in low-lying areas.

The Dove Springs neighborhood in southeast Austin exemplifies the climactic vulnerability and inequities faced by Austin residents. On October 31, 2013, a flash flood in Onion Creek submerged the neighborhood, killing five people and destroying or seriously damaging nearly 600 homes. The City of Austin spent $36.5 million on recovery efforts, including home buyouts, and received an additional $11.8 million from the federal government to continue relocations and repairs (McGee, 2014). The public sector and individuals paid the costs of the damages. While the floods cannot be entirely attributed to greenhouse gases, they are related, and those costs are not included in the price of conventional greenhouse gas emitting energy.

Austin's patterns of racial, economic, and environmental injustices extend to the conversation about residential solar energy policies as they directly involve: 1) how a public entity collects fees and distributes incentives in a city with a history of disenfranchisement and 2) the mitigation of climatic changes that disproportionately affect Austin's poor. Despite the permeation of Campbell's sustainability triangle throughout the discipline, planners continue to have difficulties integrating equity into the core of research and practice (Moore, 2016; Oden, 2010). A study by Saha and Paterson that investigated sustainability-related policies from 215 cities confirms this somewhat. In practice, sustainability policies adopted by cities tended to focus on the environment first, then the economy, and finally equity, with little overlap between the three. When cities have policies and programs that address equity, they are seldom incorporated into those that address sustainability (Saha & Paterson, 2008).

Climate Change and the City of Austin

The residents of Austin, Texas are experiencing changes in climate that include hotter temperatures and, as discussed in the Dove Springs example, greater frequencies of severe precipitation events. For instance, we know that, within a range, the frequency of very hot summer days are likely to increase. Precipitation will probably not change greatly, but that it will be concentrated into fewer rain events. Depending on the rate of continued greenhouse gas emissions, the weather and climate we experience in Austin could be on the higher or lower end of that range (Hayhoe, 2014). The City of Austin's Office of

Sustainability interpreted local climate change projection data and crystallized them into four areas of risk: extreme heat, drought, wild fires, and flooding (City of Austin, 2014). In addition to these four areas of concern, the EPA notes that the state will likely face major challenges in terms of sustaining adequate water resources, maintaining air quality standards, and preserving inland infrastructure integrity as coastal communities move away from shorelines (EPA, 2016).

The City of Austin is perhaps more well-equipped to consider climate change on a local level than some other municipalities given that it owns the electric utility, Austin Energy. Therefore, there is a level of democratic process in managing the electricity supply that is unavailable to cities where electricity has been deregulated or privatized. Yet Austin is experiencing a demographic shift at the same time it is experiencing a change in climate. As the population grows, the frequency of extremely hot days grows along with it, setting the potential for greater energy demand (NOAA, 2017; U.S. Census Bureau, 2017). This growth presents a challenging situation for the electric utility; demand for electricity grows through natural population growth and through increased demand for air conditioning on hot summer days.

Local Residential Solar

If the scale of climate change is global, why consider small-scale solutions as a focus of study? First, the scale of the city provides a useful context for mitigation measures. Cities are where people experience climate change through public health effects, through the urban heat island effect, and during weather events. Cities have the social and political frameworks through which adaptation measures must pass. Taken together, the climatic variation and the cultural and political variation mean that alternative paths must be understood and evaluated within each local community.

Furthermore, when solar is implemented on a local scale, it provides opportunities for distributed generation and to increase energy efficiency and conservation through smart grids. Distributed generation provides some opportunities for greater urban resilience as it may continue to generate electricity in the event of emergencies, rolling black-outs, or interruptions in electricity service. It reduces transmission costs, land-use effects, and right-of-way costs as the electricity does not need to be transported from the source of generation to consumption. It can also improve electric system reliability and quality (US DOE, 2007). In addition, distributed solar generation compliments and supports smart grid efforts by deploying meters and inverters that can communicate with grid operators. This provides information to utilities that promotes the informed generation. It also supports home energy storage, whether through stand-alone batteries or through electric vehicles (Austin Energy, 2013; Behr, 2011).

Second, solar electricity provides an attractive mitigation solution. While the upfront capital costs of solar panels remain high, they produce electricity directly from the sun's radiant energy. The fuel (radiant solar energy) is free, and the generation has zero emissions on-site, and therefore does not contribute to climate change. Furthermore, the photovoltaic panels produce electricity at times that align reasonable well, although not perfectly, with periods of peak demand. Peak demand, or the period at which a utility's customer base consumes the most energy, tends to drive power plant expansion. In Texas, peak demand is often met by coal and natural gas, both fossil fuels that contribute to climate change (Webber, 2015). The distributed nature of residential solar also allows for the productive use of urban space. They are also less ecologically burdensome than large scale solar farms (Turney & Fthenakis, 2011). Furthermore, there is some evidence that solar panels can produce a cooling effect in urban environments through their absorption of radiant energy and shading (Hu et al., 2015).

Third, solar technologies are experiencing accelerating adoption and the industry is growing quickly. Solar electricity provides a growing proportion of energy in the United States, Texas, and at Austin Energy (US EIA, 2015, 2017b; Wisner, 2016). In 2015, the residences in the state of Texas generated 1.8 trillion BTU of energy, which was about 28% of its total solar energy production (US EIA, 2015). At the national level some recent studies suggest that jobs in the solar industry have eclipsed those in conventional sources as well (Popovich, 2017). Investing in distributed residential solar locally may provide local economic development effects.

RESEARCH QUESTIONS

The research question this work seeks to address is:

What are the environmental, economic, and equity values held by Austin residents and the Austin Energy electric utility concerning solar technology policy, deployment, and use?

This larger inquiry is broken down into several secondary questions:

1. Do Central Texas utilities capture the environmental benefits of solar energy and control costs for their customers in a way that encourages rapid technology deployment?
2. What do the perceptions of Austin residents indicate about how they value residential solar energy?

3. Which residents of Austin have solar panels and what are their basic income and educational characteristics?
4. Does the actual usage and deployment of solar panels reflect the environmental, economic, and equitable values espoused by the utility and Austin residents?

I generally hypothesize that economic interests dominate environmental interests and that environmental interests dominate social justice and equity interests at the scale of both the utility and the household when it comes to solar residential energy. However, I do not predict that economic interests dominate the deployment of solar energy technology to the detriment of the environment or to social equity; it is certainly possible that energy policy can promote generation and use that is clean, cheap, and fair. Instead, I hypothesize that a dominating economic interest may not fully capture the environmental and social benefits of solar energy, thereby limiting access and delaying the deployment of critical energy technologies.

RESEARCH DESIGN AND METHODOLOGICAL APPROACH

This study utilizes a pragmatic framework to evaluate the environmental, economic, and equity values held by Austin residents and the Austin Energy electric utility concerning solar technology policy, deployment, and use. I assume that solar energy should be deployed given the negative externalities of other sources of energy and their effect on residents, particularly the most vulnerable residents. As discussed in this introduction, the impetus for this research lies in unearthing embedded inequities within the political and economic spheres of the local energy industry in the context of climate change and decades of economic and racial segregation in Austin, Texas. However, the energy industry is guided by measurable, quantitative data and a focus on profitable, capitalistic production of energy resources. A pragmatic approach acknowledges the language of the energy industry and frames the discussion within it.

This thesis is divided a literature review (Chapter 2), four areas of inquiry (Chapters 3, 4, 5 and 6), and conclusions (Chapter 7). The literature review situates this research within the context of previous scholarship. Domains included in this literature review include research concerning sustainability accounting, the economics of solar energy, the perceptions of solar energy, and research completed using the Pecan Street dataset. These themes will inform the areas of further inquiry.

Chapter 3 delves into the role of cities and city-owned utilities deploying electricity and solar technologies. Chapter 3 first provides a history of the electricity in cities, introducing the electricity utility as a one of American cities first foray into the provision of municipal utility services. The second part of Chapter 3 analyzes the current availability of fuels sources used by both public and private utilities, including a discussion of their externalities and the trade-offs between them. The chapter concludes with a discussion of solar energy incentive programs and policy regulations.

Chapter 4 analyzes the current state of energy utilities and solar programs and policies and their role in encouraging distributed residential solar. Here, I discuss the strategies employed by utilities and government entities to increase residential access to solar technologies. This chapter concludes with a brief comparative case study of Austin Energy and San Antonio's CPS Energy, which is also publicly-owned. This research portion draws on current utility documentation and interviews with staff at each utility to understand the solar policies and programs offered by each.

Chapters 5 and 6 use data collected by the Pecan Street Project, an Austin non-profit focused on the research and development in the energy and water utilities sector.

Chapter 5 focuses on the Pecan Street Project's annual survey of participants that includes questions concerning the attitudes and perceptions concerning residential solar energy. Chapter 6 entails a quantitative analysis of Pecan Street Project participant hourly energy usage and behavior. I explore the relationships between income, education, and race, presence of solar panels, energy usage, and peak demand energy usage.

Chapters 4, 5, and 6 employ multiple tactics, both quantitative and qualitative, to triangulate the value of solar residential energy as perceived by the utility and residents and how these values translate to behavior and energy use. Taken together, these methods of research form a bricolage wherein separate, yet related pieces of information are stitched together in order to answer the research question (Denzin & Lincoln, 2008). The findings of each chapter are synthesized in Chapter 7, which provides this report's conclusions.

Chapter 2: Literature Review

THE BALANCE OF SUSTAINABILITY AND ECOLOGICAL ACCOUNTING

In the introduction of this work I discuss frameworks of sustainability including Campbell's triangle and Elkington's concept of the "triple bottom line." Several researchers and scholars have explored other methods of balancing competing interests and some have developed methods of integrating the environmental and justice considerations into more conventional economic frameworks.

Costanza's work on ecological economics predates much of the sustainability literature. The theory of ecological economics amends input-output analysis to include embodied energy, thus revealing and remedying a perceived flaw in traditional economic analysis that views indirect energy as independent and outside system boundaries. Costanza also provides a discussion of an "embodied energy theory of value" which is "really a cost-of-production" theory with all costs carried back to the solar energy necessary directly to produce them (Costanza, 1980, p. 1224). It is important to note that by solar energy, Costanza means the source energy for all but gravitational energy, as solar energy is necessary to produce biomass and all fossil fuels. This line of thinking inspired many other academics to consider ways of evaluating economics in terms of the environmental interactions that must occur through human activity.

Costanza's later work with other authors builds upon his earlier work to illustrate a series of factors that have led to societal decline due to lack of resiliency or "locked-in" world views. The new regime envisioned by the authors includes a focus on "well-being metrics" and calls for recognition of "natural and social capital" (Beddoe et al., 2009, p. 2487). This theory frames externalities in terms of their value in preventing societal decline—a dramatic proposition that could support renewable energy distribution. Bithas answers this call to recognize natural and social capital by exploring the validity of a sustainability definition that relies on a full accounting of externalities into pricing and valuation (Bithas, 2011).

The literature on energy justice represents an approach to considering the value of energy and energy sources more holistically. Sovacool and Dworkin posit that energy infrastructure cannot simply be considered in terms of security, resources, or infrastructure, but it must be considered from a justice standpoint. They ask us to consider "what values and moral frameworks ought to guide us, and who benefits" when making investments in energy (Sovacool & Dworkin, 2015, p. 441). Energy justice considers three facets of justice: spatial, recognition, and procedural. Spatial energy justice entails the fair distribution of energy resources and evaluates where energy resources are located. Recognition-based energy justice concerns which parts of society are recognized, misrepresented, or ignored in energy decision-making. Finally, procedural energy justice focuses on the processes that decision-makers use to "engage with communities" (Jenkins, McCauley, Heffron, Stephan, & Rehner, 2016, p. 175).

Heffron, McCauley, and Sovacool refine the concept of energy justice through a triangle not unlike Campbell's, with economics, environment, and politics occupying each corner. Within this framework, each corner exerts influence on energy law and policy. The authors note that the economic interests wield the most influence in energy-related decision-making. For energy policy and law to be just, it must strike a balance between the three interests. They create an energy justice metric that maps a scorecard of economic, political, and environmental parameters and maps them onto their energy justice triangle.

Their map, which curiously omits solar, is reproduced from their work in Figure 1 (Heffron, McCauley, & Sovacool, 2015).

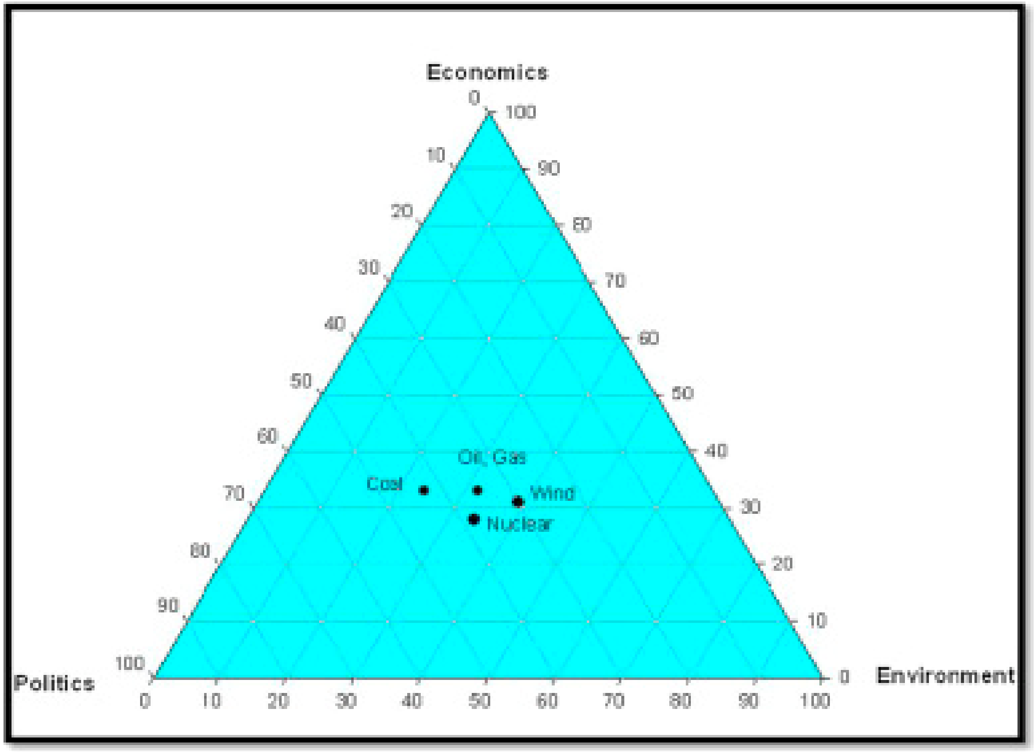


Figure 1: Heffron, McCauley, and Sovacool's Energy Law and Policy Triangle

Source: Heffron, McCauley, & Sovacool, 2015.

ECONOMICS OF SOLAR ENERGY

This section of the literature review will explore the current state-of-affairs and literature in the economic realm of solar energy distribution in four areas: techno-economic assessments, economic risks to residents and utilities, the levelized cost of electricity, and consumer-oriented economic incentives. The literature can be divided into three broad categories: assessments of emerging technology itself, those that consider the utility perspective of technology integration, and those addressing the consumer perspective of economic access to solar energy and technologies. Content-wise, the literature focuses on the cost per kWh afforded by technological improvements to photovoltaic design, the reconfiguration of the utility industry to support and accept distributed generation, the cost effectiveness of solar energy generation compared to conventional generation, and the incentives or pricing structures needed to make the technologies economically attainable to homeowners.

Techno-Economic Assessments

Techno-economic assessments consider the whole economy of solar power, from technology, to utility design, to customer access from a technological perspective. Techno-economic evaluations provide valuable insight as they do not separate the technical and/or environmental performance of photovoltaics from their economic performance (Barbiroli, 2013). Techno-economic assessments for solar photovoltaics may look at overall system efficiency or focus on the residential or utility perspective. These assessments take into account the decreasing capital costs in the context of changing technology and increasing technological efficiency.

First, I will address the technology itself. Solar photovoltaic performance relies on solar irradiation, which varies with weather and climate. As such, their economic performance in terms of price per kWh is uncertain (Liu, 2014; Yang, Wei, & Chengzhi, 2009). A study of eight Australian cities found that the performance of photovoltaic systems will increase across their lifetimes given projected climate change scenarios. This could lead to further decreases in cost per kWh, thus incentivizing deployment at the utility and residential scale (Ma, Rasul, Liu, Li, & Tan, 2016). These results are encouraging since solar photovoltaic panels are generally less efficient under hotter conditions because the voltage decreases as temperatures increase (Bartos et al., 2016; Eisenmenger, 2011; Nelson, 2003). Newer technologies increase the efficiency of solar photovoltaic cells through mechanisms that decrease reflectiveness and increase absorption of solar irradiation (Green et al., 2017). Past assessments indicated that silicon crystalline cells provided the best performance in terms of cost-effectiveness, despite efficiency losses of the material. Newer technologies may show promise combining higher cost, but more efficient gallium arsenide phosphide cells with the silicon crystalline cells (Abdul Hadi, Fitzgerald, & Nayfeh, 2016; Hadi et al., 2015).

Techno-economic assessments at the utility-scale analyze how the solar technology deployment and efficiencies affect the utility's economic interests. The literature reveals a few areas of concern for utilities transitioning to support distributed energy generation, as home solar generation reduces electricity sales. For instance, the vast majority of homes with solar panels still require the full suite of energy grid services: connections, metering, and distribution infrastructure. The cost of these services remains the same whether or not a home has solar panels, yet utility rate structures may not recover them (Sioshansi, 2017). For example, a techno-economic assessment of solar PVs in the UK found that the installation of the technology reduced the costs of electricity as a commodity for participating households, but it did not reduce the costs associated with the utility. A similar assessment in Seattle, Chicago, and Phoenix found that if 20% of each city's residents installed solar panels, the utilities subsequent revenue loss varied drastically from city to city. In Phoenix, where solar insolation is highest, the utility would need to increase peak electricity rates by 24% to account for electricity sales losses, whereas Seattle would require an 8% increase (Janko, Arnold, & Johnson, 2016). Finally, a techno-economic assessment in Spain found that low levels of PV penetration increased grid stability, but these benefits eroded under models with greater distributed generation and without policy change (Calpa, Castillo-Cagigal, Matallanas, Caamaño-Martín, & Gutiérrez, 2016).

Techno-economic assessments concerned with the residential perspective look at technology prospects and return on investment available to producer-consumers. While the capital costs of residential solar photovoltaics has decreased markedly in recent years, they remain out of reach for many consumers (Fares, 2016; US EIA, 2012). A recent techno-economic assessment indicates that the internal rate of return for solar photovoltaics produce economic benefits for most households, even as subsidies for the technology expire or dissolve (Lang, Ammann, & Girod, 2016). Part of these benefits stem from the increasing efficiency of new home builds—as home efficiency increases smaller solar panels can contribute towards more of the overall electricity costs, which decreases the total cost per kWh of electricity across the systems' life. Studies by the US Energy Information Agency (US EIA) note that homes built between 2000 and 2009 use the same amount of energy homes built before 2000, but do so at a 30% larger size (US EIA, 2013). These increases in energy efficiency stem from improvements in appliance efficiency (US EIA, 2017a) and from improved building codes (Walker & Sherman, 2008). Buildings following the ASHRAE 90.1-2010 standard as opposed to the 90.1-2004 standards reduce site energy by 32.7% and energy costs by 29.5% before plug loads (Thorton et al., 2011). Studies on highly efficient homes indicate that solar photovoltaic panels can generate as much energy as they consume (Charron & Athienitis, 2006; Coley & Schukat, 2002). However, studies on net zero building occupant behavior indicate that, without feedback loops, residential energy demand is likely to trend upwards (Faruqui, Sergici, & Sharif, 2010; Sparn, Earle, Christensen, & Norton, 2016).

Economic Risk to Residents and Utilities

The economic risk of solar technology deployment takes two opposing sides. Consumer economic risk considers how the higher prices of solar electricity compared to grid energy may influence willingness to adopt the technology. The focus of consumer-oriented risk literature tends to assume that increased market penetration of distributed solar energy generation is preferable. The focus on utility risk, on the other hand, takes the opposite position. It tends to problematize increased residential solar energy production, viewing it as a risk to utility rate structures.

Consumer aversion to risk may reduce overall market efficiencies when it comes to the predictable deployment of solar technologies. Individuals weigh losses twice as much as gains when evaluating risk, which may explain why consumers are less likely to adopt new technologies, even if they are demonstrably cost-effective in the long-run (Greene, 2011). There is little literature concerning the gap between energy efficiency values and willingness to pay or adopt solar photovoltaic technology. However, a number of studies investigate this concept in terms of energy efficient transportation options (Brandt & Ameli, 2014; Verboven, 2002). In the case of transportation, a perceived economic loss (Greene, Evans, & Hiestand, 2013), a lack of information (Turrentine & Kurani, 2007) or an undervaluation of future costs and benefits (Allcott & Wozny, 2013) prevents technology deployment even in cases where a techno-economic assessment validates a choice. Internalizing the price of negative externalities into fuel costs provides consumers with better pricing signals that can influence willingness to pay for clean energy technologies (National Research Council, 2010).

From a utility management perspective, delays in the adoption of solar technology could be advantageous. Some policy analysts fear that as solar technologies become more appealing to consumers, their rapid adoption will disrupt the utility business and trigger a utility "death spiral" as customers without solar panels are forced to absorb rising costs of service (Borenstein & Bushnell, 2015, p. 458; Kind, 2013). Models of this death spiral predicted that brittle utilities incapable of quick adaptation would be affected, whereas more nimble utilities could survive (Graffy & Kihm, 2014). Others demonstrated that the death spiral concern is valid only when utility costs are high and PV adoption is widespread (Laws, Epps, Peterson, Laser, & Wanjiru, 2017) or when the utility fails to develop policies that tie photovoltaics to the grid (Kantamneni, Winkler, Gauchia, & Pearce, 2016). Further analyses indicate that simple amendments to utility rate structure can prevent disruption entirely. Some policy analyses indicate that residents with solar panels rely on the grid more than residents without, as they draw power and send excess solar power. Therefore, utilities should consider rate transmission and distribution charges for customers with solar panels (Felder & Athawale, 2014). Other analyses posit that the "death spiral" is largely hyperbolic and the discussion of utility failure is premature; no utilities have failed due to the expansion of the residential solar electricity industry (Costello & Hemphill, 2014). The discussion of this "death spiral" is relevant to the discussion of the utility perspective of Austin Energy and CPS Energy in Chapter 4.

Levelized Cost of Electricity

Studies that evaluate the cost of solar electricity provide important justification to this research, given the economic assumptions underpinning the goal of increasing access to the technology. The literature on the levelized cost of electricity (LCOE) include discussions of its shortcomings and attempts to resolve them. This literature illustrates how economists and energy engineers approach market energy costs. Methods for calculating the LCOE attempt to normalize the costs of energy across sources and rank them according to cost-effectiveness. This measure includes "capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed realization rate for each plant type" (US EIA, 2016, p. 1). The LCOE is used to determine "grid parity" for renewable energy resources. Grid parity refers to the point at which renewable energy sources cost no more than conventional electricity sources (Frank, 2014).

Joskow initiated a critical discussion in the literature about the LCOE when he argued that it cannot provide the basis for accurate comparisons or rankings between constant sources of electricity, like coal, gas, and nuclear, and intermittent sources of electricity, like solar and wind because it does not take into account the costs associated with peak demand (Joskow, 2011). Since Joskow, many researchers and economists have conveyed doubt about the validity, accuracy, and utility of using the LCOE to rank or compare conventional sources of energy with solar. Researchers evaluating the LCOE warn about using the measure to make comparisons between centralized energy production and distributed energy production (Bazilian et al., 2013). Others note that the public and private sectors bear the costs of energy choices differently. The LCOE does not account for externalities and may distort the role of subsidies (Borenstein, 2008, 2012). The LCOE does not account for the full cost of carbon (Frank, 2014) nor the differences in energy supply and demand according to geography (Branker, Pathak, & Pearce, 2011). Finally, Wible and King (2016) note that communities do not always choose energy according to the lowest cost, and instead sometimes opt for more expensive, but cleaner sources based on values that are not incorporated into the price of electricity (Wible & King, 2016).

This critical literature of the LCOE demonstrates that the full cost of energy varies with the geography—both generation site and consumption site—and according to the time of day and the level of demand. Furthermore, it does not take into account the externalities of energy production or transparently represent the costs absorbed by the public sector. These findings have inspired some researchers and analysts to devise new methods to calculate the cost of energy. Rhodes et al. (2016) incorporated costs of environmental externalities and determined the relative price of electricity per unit on a county-by-county basis. This analysis demonstrated that many counties have achieved grid parity with renewables—particularly solar in the southwest United States and wind in parts of the west (Rhodes et al., 2016). A report by the Brookings Institute incorporated the cost of avoided emissions according to various carbon prices, fuel costs by time-of-day, and avoided or net capacity costs to the price of electricity. They found that carbon prices in the United States and in the UK are currently too low to incentivize the use lower carbon energy sources (Frank, 2014). The LCOE literature pertains to this research in its efforts to recalibrate and expand the definition of costs to include a richer suite of environmental, economic, and even social values.

Consumer-Oriented Economic Solar Incentives

Chapter 4 explores how two Central Texas utilities—Austin Energy and CPS Energy in San Antonio—incentivize residential solar energy installation and compensate for market failure due to technology prices. Utilities and industry have developed an abundance of documentation and reports concerning rate setting, net metering, and other incentives, but the number of academic studies concerning these options are relatively light. The literature that does examine the effectiveness of these incentives largely surrounds European and Australian communities, which clearly have different political and institutional contexts than the study area of this thesis. There is a significant opportunity for United States-based research on solar incentives given the variance in geography, culture, and local government structures.

The portfolio of solar incentives offered by government entities and utilities assist residents with technology acquisition through rebates and capital financing loans that discount the installation and capital costs across the technology's lifetime. The feed-in tariffs (FIT) is a popular consumer-facing strategy that allows residents to harness PV panel energy for their own uses and then sell surplus electrons back to the grid at a rate that exceeds the market rate (Alizamir, de Véricourt, & Sun, 2016). Research from Germany, Spain, and Denmark indicates that feed-in tariffs provide an effective incentive for residential solar power and hasten the rate of technology deployment (Mendonça, 2007).

However, other studies question the efficiency and equity of these policies. There is evidence that FITs increase renewable generation capacity and stimulate research and development, but they are not as effective as renewable portfolio standards in terms of reducing carbon emissions (Sun & Nie, 2015). Others posit that FIT rates are too high and thus disincentivize efficient solar technology deployment (Lesser & Su, 2008). Research concerning Italy's popular FIT program found that policy structure led to $9 billion in additional surcharges on ratepayer energy bills (Antonelli & Desideri, 2014). A study on the redistributive effects of FITs in Germany found that they essentially act as a regressive tax by subsidizing the energy bills of high-income households and increasing the energy bills of the lower income (Grösche & Schröder, 2014).

There is slightly more American literature concerning upfront capacity-based rebates or subsidies for solar panels. Researchers analyzing California's rebate incentive structure for solar panel purchases posit that only half of the state's solar installations would have occurred without subsidies (J. E. Hughes & Podolefsky, 2015). California-based research also indicates that upfront rebates are more effective than those based on the energy produced (like a FIT) in terms of encouraging solar adoption (Burr, 2014). A study in Miami-Dade County found that rebate incentives were effective in deploying technology, but not to lower income residents (Varela-Margolles & Onsted, 2014) .

Other authors discuss the potential of distributed energy to add value to social housing. Since solar generation potential corresponds with peak energy use, this benefit is substantial, and can help reframe the conversation surrounding low income households from one of consumption to one of valuable production that benefits all utility users. (Bahaj & James, 2007; Lewis, n.d.; Moore, 2014). The households serve the greater grid by providing their rooftops for energy generation. A more in-depth discussion of solar incentive structures is included in Chapter 3.

SOLAR ENERGY: PERCEPTIONS AND BEHAVIOR

Perceptions towards solar energy and the behavior of those households that have solar energy are important to this research because they reveal how economic, environmental, and social interests manifest psychologically and into practice and behavior. Chapter 5 examines survey data from Austin Energy customers with and without solar panels to understand what those values might be and Chapter 6 examines how they might translate into use.

Consumer Values and Technology Adoption

There are several studies that examine relationships between intrinsic and extrinsic environmental and social drivers or values and a household’s likeliness to pursue energy efficiency technologies and actions. A selection of these studies are provided in Table 1.

Table 1: Literature Concerning Influences on Sustainability Behaviors and Adoption of Renewable Energy

Authors	Year	Geographic Area	Key Findings
Bollinger & Gillingham	2012	California	Social effects such as peer pressure increase adoption of solar technology.
Jacobsen, Kotchen, & Vandenburg	2012	Tennessee	High energy users with concern for the environment more likely to enroll in green energy programs, but the same group was likely to use more energy after enrolling.
Korcaj, Hahnel, & Spada	2015	Germany	Willingness to adopt solar panels in influenced by social status and economic gains.
Caird, Roy, & Herring	2008	UK	Adopters of renewable energy and energy efficiency measures for financial reasons and to ensure environmental integrity.
Mills & Schleich	2012	EU and Norway	Reasons for adopting energy saving and renewable energy technologies varied by age; highly educated households and households with children were more likely to consider environmental benefits, whereas elderly households were more concerned with economic reasons.
Brandt & Ameli	2014	US	Income, knowledge, and social pressure influences investments in renewables.
Gadenne, Sharma, Kerr, & Smith	2011	Australia	Environmental values contribute to energy saving behaviors, but subsidies do not influence energy saving behaviors.
Hansla, Gamble, Juliusson, & Garling	2008	Sweden	An individual's positive attitude and association with green energy correlated with their willingness to pay more for the technology.

The literature concerning the influence of attitudes and values on the likelihood of adopting solar and renewable technologies indicates that there is some causal effect between the two. However, the values, attitudes, and beliefs tested do not discretely test the influence of all three E's (environmental, economic, social equity) in one study. This makes sense considering Campbell's sustainability triangle containing them concerns policy, rather than individual behavior. Within this micro household and individual focus, researchers coded peer influence or pressure as social values, rather than concern for the well-being of others. Environmental and economic values in this series of research do reflect those used in this research. This literature focuses more on the mechanisms by which these values influence one's likelihood to adopt technology.

There is also a sustainability-focused subset of consumer decision-making and environmental psychology literature that studies how attitudes fail to translate into behavior. Much of this literature focuses on consumer economic interests and social value as understood through peer influence (Blake, 1999; Claudy, Peterson, & O'Driscoll, 2013; Newton & Meyer, 2013). Frederiks notes that consumers "fail to align with their knowledge, values, attitudes and intentions" and that policy makers fail to align energy conservation adoption measures with social psychology (Frederiks, Stenner, & Hobman, 2015, p. 1391). Others posit that although reducing costs of environmental choices can increase pro-environmental behaviors, those behaviors may not be sustained in the long-term; however, appealing to normative values may induce sustainable behavior over time (Steg, Bolderdijk, Keizer, & Perlaviciute, 2014).

Influence of Technology on Energy Use

Chapter 6 considers the actual energy usage of homes with and without solar panels to test if behavior changes with the adoption of technology. Several studies have approached this question. A selection of these studies are provided in Table 2.

Table 2: Literature Concerning Influence of Technology on Environmental Focused Behaviors

Authors	**Year**	**Geography**	**Key Findings**
Wittenberg & Matthies	2016	Germany	Total energy consumption in households with solar photovoltaic panels was not lower than households without them
Good, Martínez Ceseña, Zhang, & Mancarella	2016	UK	Households with solar panels do not reduce overall energy consumption.
Keirstead	2007	UK	Households with solar panels engage in further energy-reducing activities and lower overall energy usage.
Abrahamse, Steg, Vlek, & Rothengatter	2005	-	High information households are more likely to adopt solar technologies, but are not likely adopt further energy efficiency behaviors.
Bahaj & James	2007	UK	Adding PV panels results in a temporary reduction in energy use as the connection between electricity use and generation is made apparent through the act of installing solar.

This brief literature review indicates that solar panels may not reduce a household's total energy expenditures, but instead offsets power that would have come from the grid with cleaner solar energy. However, there is little consensus on the mechanisms by which one's beliefs might influence one's likelihood to adopt solar technologies or change one's behavior outside the realm of household electricity consumption. While the theoretical situating of this research entails values, its pragmatic foundation focuses on the behavioral aspects. The values matter if they inform a movement towards substantive justice. Like the other subsections of this literature review, few studies of this nature are located within the United States. Because these international studies involve institutional and climatic contexts that are not readily applicable to the United States, Texas, or Austin, this constitutes a research gap.

LITERATURE RELATED TO THE PECAN STREET PROJECT.

Energy data from the Pecan Street Project has comprised the basis for many scientific studies and journal articles, many from researchers at The University of Texas at Austin. These studies tend to have an engineering focus that employs use of the detailed energy meter readings. Rhodes, Gorman, Upshaw, and Webber used this data to evaluate the accuracy of building energy usage software employed by architects and engineers by comparing models with actual usage (Rhodes, Gorman, Upshaw, & Webber, 2015). This data source contributed to research concerning the integration of the solar panels with a combined natural gas heating and power plant unclear during peak demand (Ondeck, Edgar, & Baldea, 2015). Another study examined models used to optimize the size of household energy storage systems under dynamic pricing scenarios (Y. Yoon & Kim, 2016). Similarly, researchers have used Pecan Street project data to explore demand response controller technologies. Yoon, Bladick, and Noveselac used actual energy consumption data from Austin residents to calibrate energy use models. They found that these technologies can significantly reduce HVAC loads and reduce household costs (J. H. Yoon, Bladick, & Novoselac, 2014).

Additional work based upon the Pecan Street data found that newer builds, higher income, greater knowledge of water, and greater knowledge of energy reduced energy consumption among participant homes, whereas bigger houses, more children, and more adults living in a home increased energy usage (Rhodes et al., 2014). This effort used regression analysis to analyze the relationship between household characteristics and energy use. My research draws upon Pecan Street Project annual survey data, which I analyze in Chapter 5. However, I did not find any research that performed a qualitative analysis of short answer survey responses. The lack of research on the qualitative, human side of this data source reveals a gap in the small locus of the academic community using this consumer utility data.

LITERATURE REVIEW DISCUSSION

This review of academic literature and studies encompassed four broad arenas: sustainability balance, economics of solar, how perceptions and attitudes influence behavior, and studies using Pecan Street data. It finds no studies that have directly approached residential solar analysis through a balanced system of economic accounting that includes the environmental, social, and economic aspects. However, there is a broad literature on economic accounting and the balance of sustainability factors that can inform this research.

In terms of the economics of solar energy, this literature review finds many variables in terms of residential solar access that change across geography, political regimes, and through the changing technological landscape. Generally, the decreasing cost of solar panels and increasing panel and home energy efficiencies bode well for residents wanting to install them, though the choice to install may be marred by lack of information on costs and trade-offs. However, utilities face challenges in integrating these technologies. Most researchers agree that rate structures will need to change to incorporate the distributed energy landscape, though they disagree about the characteristics of rate changes and how feasible these changes might be. Most utilities have incorporated incentives to their customers to address the failure of the market and energy policies to appropriately price solar energy in comparison to conventional energy. However, there is disagreement about if, when, and how these economic incentives should phase out.

Literature concerning consumer perceptions and behavior provide some insights for Chapters 5 and 6, which evaluate the ecological, social, and economic values espoused by a sample of Austin residents as well as their actual energy use. Many studies analyze what factors might influence consumers to adopt solar energy technology or other environmental efficiency measures. Many of these studies concluded that social perceptions, influence, pressure, and/or status influence one's willingness to invest or adopt technologies. Measures of environmental-friendliness also increased likelihood to pursue low or no carbon household energy measures. Studies concerning the behavior of people who adopt these technologies do not note a strong interest in total energy use reduction. However, they do result in net environmental gains by offsetting energy that otherwise would be derived from fossil fuel sources.

Finally, the literature concerning the Pecan Street Project indicates that little research has used their qualitative survey data. One attempt to merge the energy usage data with qualitative statements concerning energy literacy was made. Overall, this is a significant gap given the breadth and availability of data.

This literature reveals three significant gaps that this study will attempt to reconcile. First, this research investigates both the utility policy and the values and behavior of the residents in the service area. No other studies attempted an analysis that merges the provider with the consumer. Second, this research extends Campbell's triangle from the larger, policy level to the more-refined scale of the household unit. Previous studies examined a range of influences more tailored to the psychological, sociological, and marketing perspectives, rather than following the chain of planning theory down to a household level. Third, there is a dearth of literature concerning American households and utilities at the city or regional scale when it comes to solar energy technology adoption and policy. Many of the related studies were based in Germany or the UK. This thesis is an exploration of a source of American data (and, more specifically, Austin, Texas data) that has been exploited in terms of the engineering possibilities, but not the social and policy perspective.

Chapter 3: Cities, Electric Utilities, and Solar

This section includes the role of cities in encouraging electric utilities, the changing sources and transitions between sources of energy, and how residential solar energy challenges the status quo and presents new engineering challenges. This chapter concludes with a brief discussion about how governments and utilities incentivize the adoption of solar arrays. Though much of this research focuses in the Austin area, the history of electrification and cities demonstrates how city officials, engineers, business interests make decisions about energy generation and service delivery. This analysis is designed to provide context for Chapter 4, which will answer the following research question:

- How do Central Texas utilities capture the environmental benefits of solar energy and control costs for their customers?

ELECTRIC CITIES

Electricity, carrier of Light and Power
Devourer of Time and Space;
Bearer of human speech over land and sea,
Greatest servant of man—itself unknown.
Charles W. Eliot's inscription on Washington D.C.'s Union Station, 1908

To understand the current proliferation of residential solar, one must understand the greater context of electricity in cities. In this section, I present a short history of electricity in cities to understand how we have reached the present. In one sense, the rise of distributed residential solar energy emerges as a disruptive force when considered in the context of the centralized, conventional energy sources that power the grid. In another, it harkens back to the days before central utilities, when all energy was distributed and independent.

Before widespread electricity, households incinerated biofuels and biomass for heat, light, and cooking, creating flames from carbon or carbon compounds that “become incandescent” (Bowers, 1998, p. 4). Each household sourced their own fuels—from wood to whale oil. However, these biofuels were not generally healthful or sustainable. Wood burning stoves led to mass deforestation in the American colonies, risk of fire, and respiratory ailments that are still present in areas without electricity today (ERG, 2017). Though trees do renew themselves eventually and lush forests cover large parts of New England today, these are new growth forests as the rate of consumption in the 19th and early 20th centuries outpaced the rate of natural growth. Ironically, it was the discovery of whale oil that helped wean Americans from the environmentally-destructive logging industry. The adoption of kerosene—a fossil fuel—and later, gas, helped to wean Americans from the environmentally-destructive whaling industry (Bowers, 1998; Webber, 2015).

In American cities, the transition from biofuels to fossil fuels occurred largely by 1840, when kerosene became the norm for lighting (Hausman, Hertner, & Wilkins, 2008). Lower income households, however, used coal for cooking into the twentieth century. City governments themselves played a significant role in developing a centralized infrastructure for energy systems through street lighting contracts, and later street cars. The local political economy determined much of “the organization, finance, and competitive strategies of gas and electric operators” (Rose, 1995, p. xiv). The first gas and electric companies evolved from firms and individuals who had experience in competitive industries like banking and the railroads. By the late 1800’s competition between gas and electric companies for street lighting led to a series of price wars. Cities leveraged this competition to make demands of these firms—new suburbs on the urban periphery required the same level of service (Rose, 1995). By the 1890's electricity won the pricing and territorial wars. Cities played a hand in choosing the technological winner by creating policies to encourage electrical development and slashing permitting fees to electricity companies to extend the grid, particularly when they could incentivize the development of electric streetcars and demand service delivery to new and further flung urbanized areas (T. P. Hughes, 1983; Nye, 2001; Rose, 1995).

The development of the electricity grid was decidedly capitalistic and focused on private firms from the onset. City and regional governments had some experience with water and sanitation utility models. Yet the model of services provided by telegraph, railroad, and telephone companies crystalized the private service model to one wherein banks provided access to the required capital for the electricity generation and transmission grids (Nye, 2001). Previously, some large generators served industrial areas in larger cities, co-locating out of technological necessity as electricity could only travel a short distance. As electrification expanded, the mix of currents and voltage systems required centralization and standardization, and private firms chiefly took the reins, building service delivery models that could cross jurisdictional borders (Mega, 2005; Nye, 2001). The first centralized power station was built in 1870, and expansion to service public street lighting and to furnish electrical lighting for wealthy homes began centralizing the energy sector. Households, if they could afford it, no longer needed to source their own fuels for light, and increasingly cooking and heating.

Principally operating as private enterprises, energy utilities needed to make a profit. American consumption of home energy was driven by “educators, home builders, architects, and salespeople” (Rose, 1995, p. xiv). Electric utilities worked with producers of electricity consuming goods to increase electricity sales, promoting the cleanliness and comfort of electric and gas stoves, irons, and other appliances. These sales tactics were gendered—women performed most domestic labor duties, and thus appliances were sold to women, who in turn were in turn dispatched home to make the case to the household's men (Rose, 1995).

The spread of centralized electricity in the late 19th century embodied progress; it made life cleaner, hygienic, comfortable, and convenient. Productivity could be enhanced by prolonging the day, spurring industrial activity. In this era, the "science was modern man's salvation and the scientist engineer was priest—if not savior" (Rydell, 1985, p. 351). The energy utilities capitalized on this sentiment by building out infrastructure with the aid of city and regional governments and secured consumption of their product by partnering with industrial users and producers of electric appliances.

The Progressive Era politics that emerged alongside the advent of electric utilities encouraged two methods of expanding the benefits of electricity: municipal ownership of utilities and state regulation of companies. Regulators wanted to preserve the financial benefits of a "natural monopoly" for electric utilities. The thought was that only large economies of scale could create the necessary capital for infrastructure investments and that the huge capital costs negated the possibility of market competition to drive down prices. Taking the municipally-owned utility route would preserve the economy of scale and prevent the escalation of prices due to stockholder payouts. The state regulation route, on the other hand, was thought to prevent government corruption and remove the temptation of politically-motivated utility mismanagement (Hirsh, 2014).

In 1907, Wisconsin passed the first regulations of the state's electricity firms which created accounting standards and allowed the state to review company accounting records. Within seven years, 43 states passed similar regulatory legislation. As electricity grids crossed state lines, federal regulation followed (Hirsh, 2014). Although municipal utilities persist to this day, state and federal regulation of electric companies remained the status quo for much of the United States.

The basic structure of regulated utility companies persisted through the 1970's, when the oil crises triggered electricity restructuring and reform. In 1978, Congress created the Federal Energy Regulatory Commission, which was intended to keep energy costs down, keep supply up, and to simplify the web of piecemeal federal regulations. Energy reform also allowed for the separation of energy retail from energy generation and energy transmission and distribution. Various structures of electricity markets may allow energy companies to compete in energy wholesale markets, energy distribution markets, and/or retail markets. The Texas model allows for competition in both the retail and wholesale of electricity through the Electric Reliability Council of Texas (ERCOT), which was established in 2002 (Tuttle et al., 2016).

FUEL SOURCES, TRADE-OFFS, AND EXTERNALITIES

Fossil fuels have dominated the American energy industry for over a century. Over 80% of energy consumed in the past 100 years has been generated from fossil fuel combustion (Mobilia, 2017). Solar residential energy represents a departure from conventional electricity formats in terms of delivery system and fuel source. This section provides an overview of popular electric power energy sources, their externalities, and the trade-offs between them. Understanding the conventional sources of electricity provides an important context for understanding the alternatives, particularly solar energy.

Coal, natural gas, and petroleum comprise the most used constituents of what we consider fossil fuels. Fossil fuels are those that derive from organic plant and animal materials buried for millions of years under the heat and pressure of geologic forms (DOE, 2017). In the United States, petroleum products fuel transportation, while natural gas and coal generally fuel electric power plants.

Table 3: 2015 Electricity Generation Sources in the United States

Source	**Thousand Megawatt Hours**	**Percent of Utility Scale Generation**	**Percent Total Generation**
Coal	1,352,398	33.2%	33.1%
Petroleum	28,249	0.7%	0.7%
Natural Gas	1,333,482	32.7%	32.6%
Other Gas	13,117	0.3%	0.3%
Nuclear	797,178	19.6%	19.5%
Hydro Conventional	249,080	6.1%	6.1%
Hydro Pumped Storage	-5,091	-0.1%	-0.1%
Geothermal	15,918	0.4%	0.4%
Wind	190,719	4.7%	4.7%
Solar Photovoltaic	21,666	0.5%	0.5%
Solar Thermal	3,227	0.1%	0.1%
Wood and Wood-derived Fuels	41,929	1.0%	1.0%
Other Biomass	21,703	0.5%	0.5%
Other Energy Sources	14,028	0.3%	0.3%
Total Utility Scale Generation	**4,077,601**		
Estimated Distributed Photovoltaic	14,139	0.0%	0.3%
Total Utility Scale Generation and Distributed Generation	**4,091,740**		

Source: United States Energy Information Agency, Annual Electricity Data, Table 1.2, https://www.eia.gov/electricity/annual/html/epa_01_02.html

The two largest fuel sources for electricity generation in 2015 were coal, at 33.2% and natural gas, at 32.7%. The next largest component of utility scale generation was nuclear, at 19.6%, and no other fuel source accounted for more than 10% of generation (see Table 3). Centralized solar energy contributed to just 0.6% of the total energy mix of the United States for 2015. If you add distributed solar energy, such as rooftop solar arrays, this increases to 0.9% (US EIA, 2017).

Coal and natural gas remain popular choices for fuel generation due to their energy density, reliability, and relative cost effectiveness. The United States used about 850 million tons of coal, mostly bituminous and the lower quality subbituminous for energy in 2015 (EIA). The United States has about 269 billion short tons of coal—the most in the world—which is enough to sustain two centuries of current consumption patterns (National Academy of Sciences). Storing and transporting coal is relatively easy—it is a solid that can be piled and freighted using existing infrastructure. In 2015, coal cost around $2.22 per MMBTU, which is less than natural gas ($3.23) and petroleum ($11.49) (US EIA, 2017, 4.1). This is not the levelized cost of electricity, but simply the resource cost. Coal power plants generate electricity on-demand, so long as they have coal to incinerate. For this reason, coal is a popular fuel choice to satisfy base demand at periods of peak electricity. Paired with natural gas, which can ramp up and down quickly, coal use shoulders peak loads. In Texas, these periods usually occur on hot summer afternoons when air conditioning loads are high.

The drawbacks of coal, however, are significant. Underground mining is dangerous and above ground mining creates major land disturbances. Even the most efficient coal power plants use immense amounts of water for cooling (Webber, 2016). Coal's high carbon content, which marks its energy density, also emits carbon dioxide when burned at a rate of about 205 to 214 pounds per million BTU (see Table 5). Coal's carbon content traps heavy metals and chemicals, acting as a natural filter in the earth's composition. When combusted, these toxins, including sulfur and mercury, are released. Incinerated coal produces soot and particulate matter. Taken together, coal emits pollution that is highly detrimental in the short-term and in the long-term, through climate change. The costs of mitigating the public health and environmental damages caused by coal are not contained in its low price. Ironically, coal is most necessary in hot climates during very hot days, which creates a vicious cycle—burn coal to for climate control, burned coal changes the climate.

Table 4: 2016 US Annual Carbon Dioxide Emissions from Energy Consumption by Source, Including Transportation Fuels

Fuel	Million Metric Tons of Carbon Dioxide	Percent of Total Emissions
Coal	1,353.98	26%
Natural Gas	1,484.99	29%
Petroleum	2,320.05	45%
Total	5,159.03	100%

Source: US EIA 2017 June Monthly Review

Table 5: Carbon Intensity of Fossil Fuels, Including Transportation Fuels

Fuel Source	Pounds of CO2 emitted per million BTUs
Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (Subbituminous)	214.3
Diesel	161.3
Gasoline	157.2
Propane	139.0
Natural Gas	117.0

Source: US EIA 2017, https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

More recently, natural gas has emerged as a strong challenger to coal. Compared to coal and petroleum, natural gas is much cleaner. It emits about 117 pounds of carbon dioxide per million BTUs, nearly 100 pounds less than coal for the similar amount of energy. Like coal, natural gas is abundant in the United States. About 30 trillion feet of natural gas were withdrawn from reserves in the United States in 2014, with nearly equal amounts coming from natural gas wells and shale gas wells. A smaller portion is associated with coalbeds and crude oil. The price of natural gas has dropped dramatically in recent years as engineering advancements have allowed for more extraction from shale beds through hydraulic fracturing, or fracking.

Despite being cleaner than coal, natural gas is associated with many negative externalities on its own. Methane comprises a significant portion of natural gas. Production is associated with leaks at the well site and through pipelines. Methane is a potent greenhouse gas with a much greater global warming potential than carbon dioxide, and these leaks are not accounted for when considering the carbon content of incinerated natural gas. The extraction of natural gas, especially through fracking, requires vast amounts of water which are mixed with particulates and chemical lubricants and blasted underground to free gas from the shale. The wastewater from this process is transported back to the surface and often moved to another site for disposal via injection into the earth. The disposal process introduces many chances for ground level spills and the injection process is associated with heightened seismic activity in unusual places, such as Oklahoma (Keranen, Weingarten, Abers, Bekins, & Ge, 2014; Schultz, 2014)

Natural gas extraction also poses significant land use issues. Wells puncture the surfaces of the shale, creating a network of drill pads that require roads capable of supporting heavy duty diesel equipment. Production is associated with steep increases in trucking and freight in often inconvenient locations in terms of infrastructure availability and incompatible uses. Denton, Texas banned fracking in its city limits to address complaints from residents about the imposition of industry in their neighborhoods, though the Texas legislature later outlawed such bans (Buchele, 2014, 2015; Malewitz, 2014). Like coal, natural gas bears significant health risks. Unlike coal, the long-term health effects of wastewater chemicals that enter watersheds through above ground spills or underground injections are largely untested. This means that the environmental and public health risks are less specifically regulated than coal (Rawlins, 2014). This level of uncertainty makes the proper pricing of external costs of environmental and public health risks associated with natural gas production difficult and perhaps less accurate.

Nuclear energy is the third largest source of electricity in the United States, providing about 20% of our electricity (Webber, 2015). Though nuclear energy is considered a conventional power source, it is not a fossil fuel. Nuclear power plants produce no emissions on site and do not contribute to climate change. Nuclear power is far more energy dense than coal, natural gas, and all other fuel sources, meaning that pound per pound (or equivalent measurement of mass), more energy can be produced from nuclear fuel stocks. The uranium used to generate nuclear electricity is available in the United States, but the largest reserves are in Australia (World Nuclear Association, 2015).

Nuclear energy is less popular than coal and natural gas for many reasons. First, it is significantly more expensive, both in terms of the capital expense of building a nuclear power plant and in terms of the fuel source itself. Second, while natural gas and coal can be ramped on and off to accommodate rapid spikes in demand, nuclear is better suited to producing energy at a slow and steady pace. Third, there are concerns about national security and nuclear proliferation occurring under the guise of legitimate trading of uranium for energy. Fourth, there are safety concerns about nuclear energy, especially after Fukishimi Daiichi, despite a safe record overall. Fifth, nuclear waste requires its own expensive disposal, storage mitigation processes. In one sense, nuclear waste is easier to deal with than the waste of coal and natural gas. Rather than being dispersed through the atmosphere, it is solid. It is easier to pick up, process, and store than small particles that use scrubbers and complicated smokestack equipment. This also allows nuclear power plants to better price their externalities as they must take responsibility for the waste that generates within their own facilities. However, there is not a satisfactory way to deal with this waste that is sustainable and does not put future generations at risk—the half-life of uranium is long and evidence of our use of nuclear power remains for multiple generations. Nuclear energy also requires large amounts of water for cooling.

Hydroelectric power is the largest source of renewable energy. It converts mechanical energy from falling water into electricity with no emissions. Geography limits where hydroelectric power is feasible. Hydroelectric does disrupt ecosystems if it does not contribute to climate change and poor air quality. Dams stop the natural flow of rivers and flood huge swaths of land that are sometimes occupied by people. When dams fail, consequences are immediately catastrophic, especially if there are people living below the dam.

Wind power is a popular renewable resource. The force of wind moves large turbines which create mechanical energy that is then converted to electricity. Geography determines where wind is appropriate. The cost of wind turbines has come down greatly which accounts for its increasing popularity in Texas. The potential for wind energy is often located far from where people consume electricity, and so wind energy requires significant transmission lines which increases its costs. Wind turbines cause little ecological disruption (Webber, 2015). Although they are associated with the death of birds, conventional energy sources from oil spills to transformers kill more birds than wind turbines. Housecats and buildings do even more damage to bird populations in total (Erickson, Wolfe, Bay, Johnson, & Gehring, 2014). People do not like to live near turbines because of the noise and how they can flicker daylight. Most importantly, wind is not constantly available and varies by season and conditions. In Texas, more wind energy is generated at night. This can complement solar energy production.

As described in the introduction, solar photovoltaic panels convert solar radiation from the sun into electricity. Solar electricity creates no emissions or pollution at the point of generation and requires no water or cooling. The variability and size of solar panels mean they can co-locate with people in urban spaces on rooftops, parking garages, or on ground mounts. Co-location reduces transmission costs in terms of transmission infrastructure and prevents transmissions losses. Solar panels can even be used as shading devices.

Pollution from solar energy mainly comes from the process of mining the silicon used in their production and the manufacturing and transportation supply chain (Webber, 2016). In general, the negative externalities are better incorporated in solar panels than in other forms of electricity because they only happen in controlled areas (silicon mines). Large solar farms can create ecological disruptions by blocking sunlight from soil and by disrupting animal habitats. Yet the largest challenges facing widespread adoption to solar energy are economic. First, though the price of panels have dropped rapidly, they are still more expensive per kWh than conventional sources, wind, and hydroelectricity in most American counties (Fares, 2016; Rhodes et al., 2016). Second, the nature of distributed generation means that more utility resources are invested in wires and poles, instead of in the fuel sources and generation materials, which requires a rethinking of the conventional rate structures on behalf of utilities (Sioshansi, 2017).

In 2015, residential electricity consumers used 1,404,096 thousand mWh of electricity. This amounts for 37% of total electricity consumed in the United States. There are 129,811,718 residential energy consumers in American in 2015, which represents 87% of total customers in all sectors. In 2015, the average price for one kWh of electricity was 12.65 cents, which is higher than the average of 10.41 cents for all consumers and nearly double the rate paid by industrial customers (US EIA, 2016). The low cost of natural gas and coal electricity keeps rates low. The infrastructure has largely already been paid for and built, although operation and maintenance costs are significant. The lower cost does not reflect the true costs of negative externalities and is a major obstacle in growing renewable energy.

This history and context is important to understand when considering the challenges of incorporating distributed solar energy systems. Distributed generation runs contrary to the policy and technical structures embedded in a century of utility electrical provision.

RESIDENTIAL SOLAR ENERGY INCENTIVES AND REGULATIONS

The Database of State Incentives for Renewables & Efficiency (DSIRE) catalogs each state's policies and incentives for renewable energy and energy efficiency programs. In 2017, American States offered 3,898 incentives, rebates, or other programs for energy efficiency. California leads the states in terms of number of policies, with 294 programs available to residents. West Virginia, with 15 programs, offers the fewest to its residents. Texas offers 157 policies and incentives. Of all the programs and policies, 973 pertain to solar photovoltaic panels. These include 555 financial incentive programs, 408 regulatory policies, and 10 technical resource programs (DSIRE, 2017).

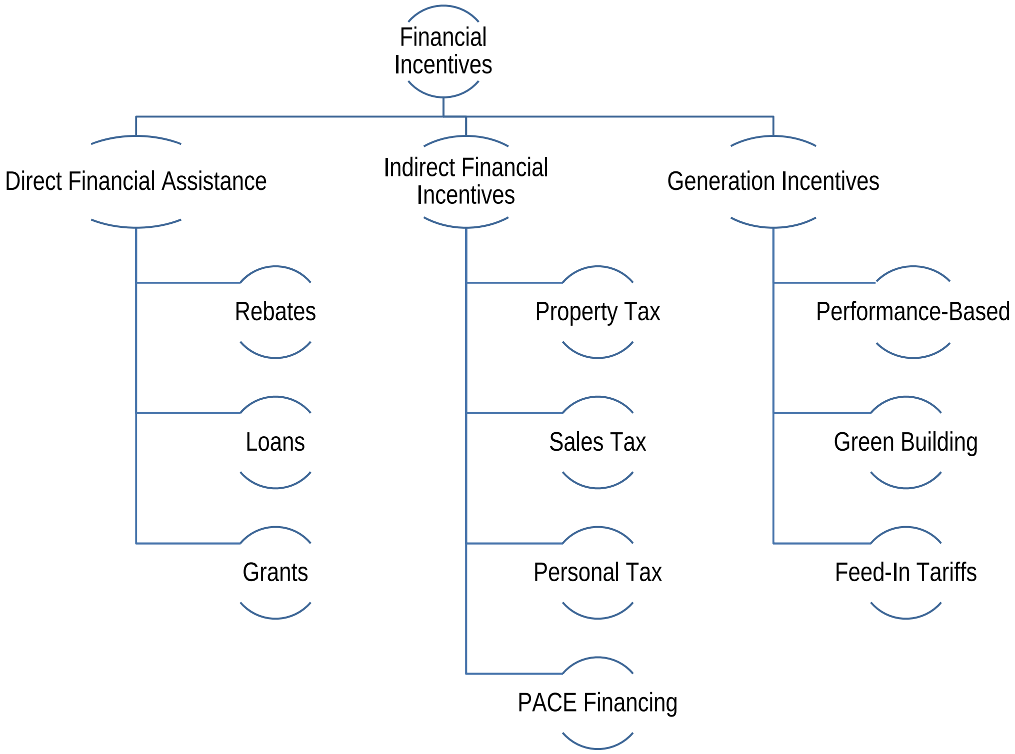


Figure 2: State Financial Incentive Structures

Source: Author's analysis of DSIRE database

Of the financial incentives programs, 118 are rebate programs, 90 are loan programs, 72 property tax exemptions, 46 performance-based incentives, 36 are Property Assessed Clean Energy (PACE) financing programs, 35 sales tax incentives, 34 are grant programs, 23 personal tax credits, 23 corporate tax credits, 16 green building incentives, 15 renewable energy credit programs, and 8 are feed-in tariffs, with the rest comprised of miscellaneous credits, exemptions, or another form of individual polices.

In Figure 2 I sort these various incentives into three categories: direct financial assistance, indirect financial incentives, and generation incentives. Direct financial assistance incentives help with the high costs of solar technology at the point of purchase. Grant programs may entail a competitive bidding process for resources to receive funds, whereas rebates provide assistance for all applicants who meet criteria if funding is available. Indirect financial incentives provide funding for solar technology through tax credits. Under a tax credit model, the customer pays for the panels upfront, but can submit a claim to reduce their property, sales, or income taxes later. Generation incentives do not provide assistance for technology acquisition, but instead provide funds based on the amount of energy generated by a solar array. These incentives are sometimes folded into green building standards as part of a suite of energy efficiency and clean energy incentives.

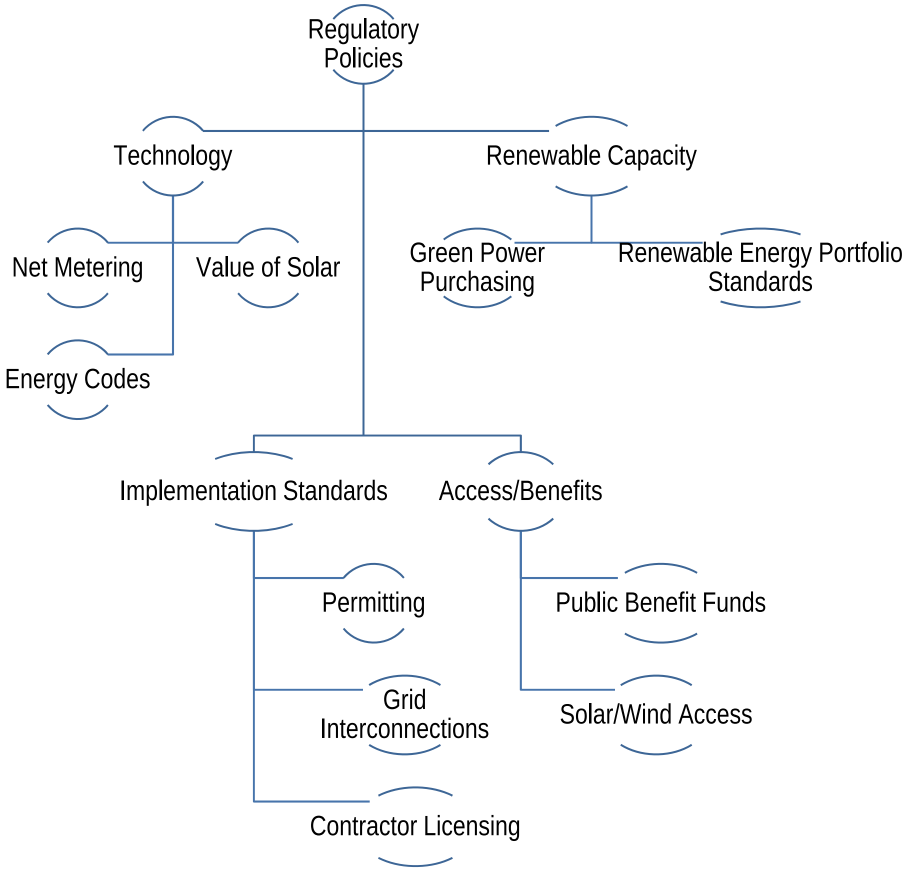


Figure 3: State Solar Photovoltaic Regulatory Policy Categories

Source: Author's analysis of DSIRE database

Of the 408 state regulatory policies, 73 concern net metering, 61 regulate solar and wind electricity access, 49 set renewable energy portfolio standards, 48 designate solar panel to grid interconnection standards, 32 set solar and wind permitting standards, 24 establish or regulate public benefit funds, 17 concern green power purchasing, 17 regulate the licensing of contractors, 16 set building energy codes, and 2 designate a value of solar electricity generated (DSIRE, 2017).

In Figure 3 I sort these various regulatory policies into four categories: technology, renewable capacity, implementation standards, and public access and benefits. Policies that regulate technology set standards for the integration of energy generated and efficiency efforts into the grid. Renewable capacity policies regulate the minimum capacity of renewable energy that a utility or geographic area must provide and offer guidance for purchasing renewable energy from third parties. Implementation standards establish processes for renewable energy generation permitting, regulate the interconnection of solar panels and the grid, and provide licenses for contractors. Public access and benefit policies pertain to the promotion of the social benefits of renewable energy.

Together, this network of regulations and policies provides a rich and undulating map of variation in US solar policies. I will discuss a handful of these incentives that pertain to this research further: direct financial assistance, generation incentives, and technology regulating policies. Solar rebates approach financial assistance through what is generally a one-time rebate that subsidizes the capital equipment and installation price of solar panels. These programs tamp down the sticker shock of a program and reduce the payback period for residents. Usually rebate programs focus on the generation capacity of the solar panel array installed. Loan programs also address the upfront costs of solar technology. State and local utility loan programs can offer residents better interest rates and can scale down payment and repayment requirements based on financial need (DSIRE, 2017).

Generation incentives address the on-going generation capacity of a residential solar array by providing a sale price for electricity generated. This can take the form of a feed-in tariff, as is popular Europe, wherein electricity generated through solar arrays is purchased by a utility for a rate that exceed market prices. These rates may be tiered according to generation capacity, capped at certain dollar amount, or phased out on a schedule. Generation incentives overlap with two important regulatory policies: net metering and value of solar tariffs. Net metering involves the installation of two-way meters on solar panels that measure the electricity generated and the electricity pulled from the grid. Residents are only charged by the utility for grid energy and sell excess energy directly back to the energy utility at a designated cost per kWh (DSIRE, 2017).

Value of solar tariffs differ from net metering in that residential solar producers pay for all their electricity consumed and then receive a credit to their bill for all electricity produced. This incentive structure is more grid-aligned and utility focused as it considers each kWh of solar electricity generated as valuable to the utility while tracking and billing for each kWh used, regardless of its source (Austin Energy, 2015a). This structure may help resolve conflicts between utilities, contractors, and residents with and without solar panels (O'Boyle, 2017).

Notable Incentive Programs

There are several programs in the United States that typify the incentive options available to residents. The California Single-Family Affordable Solar Homes (SASH) program provides a model for income inclusive rebate programs. The Mass Solar Loan program demonstrates a well-utilized, income-inclusive loan program. Hawaii's feed-in tariff program exemplifies the nuance and value of programs given specific geographies. Austin Energy implemented the first value of solar rebate program in the United States, which will be discussed in the next chapter.

California's SASH program provides services for households earning 80% or less of their area's median family income that live in affordable housing and is financed through a portion of the California Solar Initiative, or CSI (Knapp, 2016; Mook, Whitman, Quarter, & Armstrong, 2015). Of the CSI's $3.2 billion in rate-payer sourced funding, SASH receives $108 million to distribute in the form of rebates to qualifying households after other energy efficiency efforts had been undertaken. SASH is administered by GRID Alternatives, a third-party installer. In 2015, the SASH program moved from a tiered system of incentives that declined over time to a flat $3.00 per watt capacity of solar panel installed. (GRID Alternatives, 2017a). The average solar array size for SASH installations is 3 kW (smaller than the norm in California), which results in an average rebate of $9,000 per participating household. Of the budget total, 85% goes directly to rebates, 10% goes towards administration, 4% goes towards marketing and outreach, and 1% goes towards evaluation processes (GRID Alternatives, 2017b).

The Mass Solar Loan program provides an example of how public-backed loans can assist lower-income households finance remaining capital costs. $30 million in funding for the program comes from alternative compliance payments as designated by the state's renewable portfolio standard programs and provides loans at an interest rate of 1.5%. The loans are meant to incentivize household ownership of solar panels. In Massachusetts, many third-party contractors provide solar rentals to homeowners, which may dilute the benefit to the household for that technology. These loans can be used for very small arrays, as the minimum eligible project cost is only $3,000, which could cover the installation of a single kW system. The Mass Solar Loan program also provides two tiers of income based loan support, with 30% of loan costs covered for households earning 80% of median income and 20% of loan costs covered for households earning between 80% and 120% of median household income. Although participants in state rebate programs for solar technologies cannot participate in the program for the same solar, it provides an alternative route to ownership with sliding-scale income considerations (Mass Solar Loan, 2017).

Hawaii's feed-in tariff program established a rate per kWh of electricity generated for renewable energy sources including solar photovoltaics, wind, and hydro power at the residential, community, or commercial level. The program is tiered based on system size, with installations larger than 20 kW receiving a lower rate than those that are smaller. For instance, small scale photovoltaics receive a rate of $0.218 per kWh, while 5 MW arrays receive $0.197 per kWh generated (HECO, 2017). The FIT program "enabled the development of approximately 15 megawatts of clean, solar power in Hawaii" and was so popular that projects filled the program capacity faster than they could be built out (Hawaii Public Utilities Commission, 2014, p. 1). The program was forced to pause in 2014 to allow project build-out to catch-up with demand for program participation. It is no longer accepting new applications and instead moving through the long queue of eligible projects awaiting remaining funds. In this case, the institutional structure throttled the development of solar capacity due to its capacity to process the massive interest in the program.

In summary, local utilities and governments have an immense array of examples and models to choose from when designing solar incentive programs and policies. Setting rates for incentives depends not only on the actual value of electricity rendered through renewable sources, but also according to the rate at which an institution wants to develop capacity or distribute resources to residents along social criteria like need. I believe that the piecemeal approach to solar program design in America could use additional research, particularly in the form of comparative case studies, to identify which programs are using public monies most efficiently in terms of building generation capacity and most equitably in terms of distributing resources.

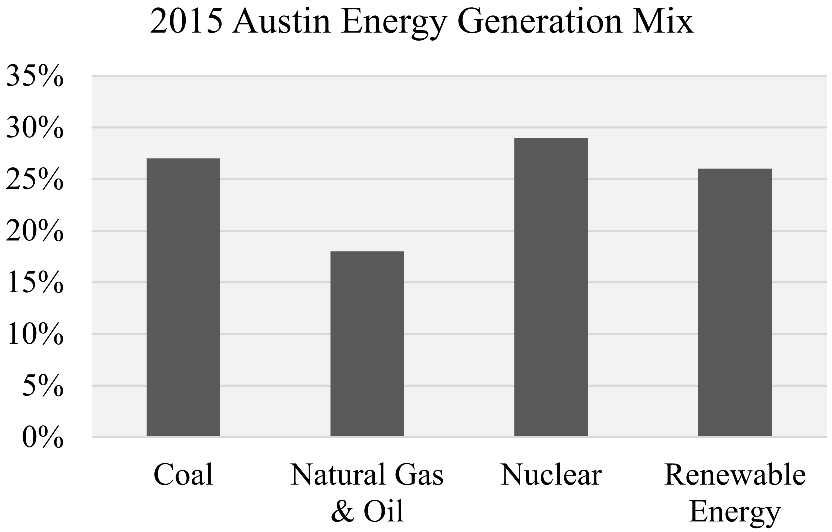
Chapter 4: Central Texas Utility Case Studies

This chapter contains an exploration and analysis of Austin Energy’s residential solar programs in the context of its utility. The analysis below attempts to determine how Central Texas utilities capture the environmental benefits of solar energy and control costs for their customers. This section contains a general overview of the utility, a consideration of its generation mix, and a full explanation of its residential solar programs. I also introduce CPS Energy of San Antonio, Texas for a brief comparative case study. As another publicly-owned utility in a hot, humid climate, CPS provides a suite of approaches to residential solar that can provide a relatively useful comparison and foil for Austin Energy.

Austin Energy

Unlike most utilities in the United States, Austin is served by a public utility, Austin Energy, which was established in 1895. While the City of Austin has considered selling or privatizing the utility in the past, the City has maintained ownership of its utility and even purchased its water utility in 1900. The public ownership of the water utility came in the wake of a tragic and expensive failure of the McDonald dam and hydroelectric power plant in 1900. Buying the water company allowed the city to manage repairs and to acquire the hydroelectric resources, thus laying the foundation for city ownership of electricity production (Robbins, 2013).

Figure 4: 2015 Austin Energy Generation Mix



Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Generation-by-Fuel-Type/ss6t-rumq

As a public utility, Austin Energy reports to Austin's City Council and participates in community energy planning initiatives. In 2014, the Austin City Council passed a resolution directing Austin Energy to reach net zero greenhouse gas emissions by 2050 to enhance and update the previous 2007 Austin Climate Protection Plan. These carbon neutrality efforts include a mandate to address affordability as well (Austin Energy, 2014, 2015b). Current energy mixes at Austin Energy include coal, nuclear, and natural gas fuel sources, as well as renewables (solar farms, residential solar, wind, and biomass) and purchased electricity from ERCOT (Austin Energy, 2012). Of the 4.2 billion kWh provided to Austin homes in 2014, 45% were derived from fossil fuels that produce greenhouse gas emissions during combustion (Austin Energy, 2017b).

In 2014, Austin experienced 15 days of critical energy demand: two in June, four in July, five in August, and four in September. All but one day of critical demand occurred when afternoon temperatures reached 96°F or higher (ERCOT, 2015). In the Austin area, peak demand occurs on hot summer days at times when households, workspaces, and commercial entities all use energy. Austin Energy's pilot program for peak demand energy pricing designates summer afternoons from 2:00 PM and 8:00 PM as times in which higher prices should be deployed to lower demand (Austin Energy, 2017c).

Austin Energy's multiple fuel sources feed the electric grid, which is purchased and consumed by individual households within the service area. Residences with solar panels installed are both consumers of and producers for Austin Energy, generally consuming their own solar generated power for at least a portion of the day and using grid electricity at night. Because the times of peak solar generation happen to coincide with peak energy demand in the hot, sunny, summer afternoons, residential solar installation provides the electricity grid with clean energy when it is needed most; otherwise other sources of power like coal and gas, both of which are carbon intensive, must be used to meet demand. In addition, these households distribute and decentralize energy production, providing reliability and stability in the event of outages related to events like storms and weather occurrences. These households are more integrated and energy secure.

Only 5,600 homes in Austin have deployed rooftop solar out of a pool of 168,574 (ACS, 2015; Austin Energy, 2015). Austin Energy's current solar incentive program is profiled in Table 6. Designed to support early adopters of solar technology, the program provides rebates that are determined by the size of the solar array installed on the home on a per watt basis for solar arrays up to 10 kW AC in size. The program has several tiers of incentives and operates on a first-come, first serve basis. Each tier specifies a dollar amount per watt and a limit on the solar capacity that can be installed. The tiers close when the kW capacity has been reached. The program started with a rebate price of $4.00 per watt, and will end at $0.50 per watt (Austin Energy, 2017).

Table 6: Austin Energy Residential Solar Rebate Structure

Residential Program and Incentive Level	Incentive Bracket Status	Capacity Available kW	Capacity Requested kW	Capacity Reserved/ Installed kW
$1.00/watt	Closed	0	0	1,000
$0.90/watt	Closed	0	0	1,500
$0.80/watt	Closed	0	0	4,000
$0.70/watt	Closed	0	808	1,692
$0.60/watt	Open	2,500	0	0
$0.50/watt	Open	2,500	0	0

Source: City of Austin Open Data Portal

The last 4,000 kW installed will receive $0.50 per watt. Austin Energy customers can apply for rebates on a first-come, first-served basis. This structure incentivizes early adopters who can parse through the application and installation requirements and steps down to accommodate a predicted decrease in solar panel costs moving forward (Austin Energy, 2014; Farmer & Lafond, 2016).

On top of the local rebates, Austin homeowners may also receive a federal tax credit based on the value of their rooftop solar array. These tax credits, like the Austin Energy rebates, step down over time, as indicated in Table 7. Claiming this credit involves finicky paperwork and requires "know how," though installers have learned to use assistance in receiving tax credits as a sales tool. By 2022, these tax credits will only cover 10% of the value of their solar arrays (DOE 2017).

Table 7: Federal Solar Tax Credit Schedule

Year	Percentage of System Eligible for Federal Tax Credits
2016 - 2019	30%
2020	26%
2021	22%
2022 and onward	10%

Source: energy.gov, Residential Renewable Energy Tax Credit

Austin Energy Interview

Design

During this research, I contacted several staff members at Austin Energy and eventually sat down for an hour-long interview with a person working on solar program rate structures. The employee, whose name is redacted, has worked at the utility for over a decade. The interview protocol and questions I asked are available in Appendix B. The questions I asked about the solar programs concerned program design, industry concerns, and customer concerns. I initially hoped to interview several staff members and code their responses to program policy questions in terms of the environmental, economic, and equity that they espoused. Limited time and resources led me to change the research design. Instead, I will condense and narratize the 6,000-word transcript as it best answers the research question: **How do Central Texas utilities capture the environmental benefits of solar energy and control costs for their customers?** Unless otherwise cited with supplementary materials, this information comes directly from the interview transcripts.

Interview

Figure 5: Austin Energy Interview Word Cloud

The interview process yielded significant insight into Austin Energy's solar incentive program design and the reasoning for its unique value of solar tariff. The solar programs of Austin Energy are housed in the Community Energy Services (CES) division where it operates alongside, but independently from the other conservation projects of the utility. Other conservation projects include home performance with Energy Star and Green Building programs. Of about 60 employees at CES, nine work in the solar programs.

Austin Energy's solar programs are comprised of three categories: residential, commercial, and a burgeoning community solar program. The solar programs are paid for by a customer benefit charge that is paid for by all Austin Energy customers apart from some very large commercial customers. These commercial customers "argued successfully that they do not participate in the programs and their contributions are unwarranted."

As an early adopter and implementer of solar programs, Austin Energy has had to adjust policies based on response and feedback, sometimes with great expedience. For instance, in March of 2011, the utility gave an abrupt notice to contractors that the rebate amount would decrease by $0.50 per watt installed the next day after they found residential customers wavering in terms of participation rates. In 24 hours, they received $4.5 million in rebate requests, which consumed an entire year's worth of funding. The utility refers to this day as "Green Day." This triggered the move towards separating commercial incentives to performance-based standards, which left more money to cover residential rebates.

When asked about the challenges of implementing an equitable solar program, the staff member first mentioned the difficulty of customer education and working with an array of contractors who vary in integrity. While City Council has an interest in developing a "green industry" within the city, the utility has an interest in ensuring that solar contractors engage in best practices in terms of technology installation and customer guidance. The utility has had experiences wherein contractors "mislead customers to believe that their investment would have a greater return than it actually would." These unfortunate experiences have led to fine-tuning of both regulations and industry standards as well as customer outreach efforts.

Austin Energy is the only utility that has implemented a value of solar (VOS) tariff, though the State of Minnesota has designed a program and approved its use. The VOS tariff represents a departure from the common utility strategy of net metering. Net metering caused concern for the utility in that it required them to "recuperate fixed costs with volumetric charges." Under net metering, a solar customer offsets their charges with solar production and therefore no longer contributes "their fair share towards fixed costs" like transmission and distribution infrastructure. This put the utility under recovery, and pushed towards options like increasing the base rate of electricity.

The utility thought that increasing base rates of electricity would disproportionately burden low income customers who cannot afford solar panels even with subsidies. Austin Energy's tiered rate structure exacerbates this as it "heavily influences the high-end consumer to go solar" because they are shaving off the top of their upper tier of energy use, which is the most expensive, through their own generation. If a lower energy user installs solar panels under net metering and a tiered rate structure, their panels "might only offset 7% of their charge" where as a high electricity consumer might be offsetting "15% of their charge" for the same amount of electricity production. The VOS tariff decouples the consumption rate of electricity from the solar production credit while preserving the tiered rate structure for non-solar customers. It charges customers based on their total energy consumption and then provides a credit for the production at the same rate as all solar producers. The rate structure also disincentivizes the over-sizing of home solar arrays, as the credit structure does not allow cash payments to residents for excess energy generated.

The VOS rate structure is fully explained in the Value-of-Solar Assessment and is calculated each year as part of the utility's approved electric tariffs. The following tables are adapted from the 2017 City of Austin Electric Tariff.

Table 8: Austin Energy Value of Solar Price Components, 2017

Component	Definition
Energy Value	Estimated avoided cost of energy to meet electric loads as well as transmission and distribution losses, based on the solar production. This is inferred from ERCOT wholesale market price data and future natural gas prices.
Plant O&M Value	Estimated avoided cost associated with natural gas plant operations and maintenance by meeting peak load through customer-sited renewable resources.
Generation Capacity Value	Estimated avoided cost of capital by meeting peak load through customer-sited renewable resources, inferred from ERCOT market price data.
Transmission and Distribution Value	Estimated savings in transmission costs resulting from the reduction in the peak load by locally-sited renewable resources, and savings or costs related capital investments to distribution grid.
Environmental Compliance Value	Estimated avoided cost to comply with environmental regulations and local policy objectives. Set at $0.02 per kWh based on average premium paid in voluntary green power purchasing programs in Texas when the VOS was implemented.

Source: Appendix A, City of Austin Electric Tariff 2017

Table 9: Austin Energy Value-of-Solar Tariff Changes, 2012 - 2017

Effective Date	Value-of-Solar Assessment ($/kWh0	Value-of-Solar Rate ($/kWh)
October 2012	$0.12800	$0.12800
January 2014	$0.10700	$0.10700
January 2015	$0.10000	$0.11300
January 2016	$0.09700	$0.10900
January 2017	$0.09700	$0.10600

Source: Appendix A, City of Austin Electric Tariff 2017

The yearly VOS is comprised of five values. Three of these values concern avoided costs of energy production, power plant operation and maintenance, and peak demand generation, which often prompts Austin Energy to purchase energy on the ERCOT markets. The transmission and distribution value prices the benefit of electricity delivery on-site without the need for wires and poles. These first four charges reside squarely within the realm of utility economic interest. Finally, the environmental benefit cost indicates the value zero emission energy as established by green purchasing programs. The approved rate for each year takes the average of the current VOS with that which was calculated the three previous years (Austin Energy, 2015a, 2016). When creating the VOS tariff, the utility did consider peak demand pricing that might encourage customers to orient their arrays further to the west or to employ battery storage, but studies found that the benefit would be marginal. However, future iterations may be based on time of production.

The environmental compliance value originated through a stakeholder process and direction from City Council. Austin Energy then did a study on "what customers were willing to pay for green energy in Texas." The compliance value derives from that study, and not from a renewable energy credit value. The environmental compliance value has not changed through the years of the program so far. The staff member did mention that the utility is discussing transitioning away from the $0.02 per kWh figure and to a social cost of carbon as determined by the EPA which the utility found "to be a palatable value."

The most recent EPA study on the social cost of carbon pegged it at $40 per metric ton of carbon dioxide, with an expectation they may increase over time as emissions "produce larger incremental damages as physical and economic systems become more stressed in response to greater climactic change" (US EPA, 2017). However, due to political changes at the federal level, there is uncertainty regarding if these measures may be updated over time (Hess, 2017). Peer reviews of the EPA's figure have demonstrated that it is sound (Marten, Kopits, Griffiths, Newbold, & Wolverton, 2015). Austin Energy does not have an alternative plan for amending the environmental compliance value if the social cost of carbon study is not continued.

While the trial-and-error processes of rate setting are primarily economic in nature, the staff member noted that the goals of the programs are chiefly environmental. The utility responds to City Council, who has demonstrated a vested interest in increasing renewable generation capacity. Both City Council and the utility itself have increased solar goals dramatically—by over 900 megawatts between 2006 and 2017, which the staff member did note as a challenge. When asked about the role of customer input into these goals, the staff member responded that "the majority of the input comes from stakeholders and lobbyists" who may represent the customer on "certain points." However, they also noted that "Austin as a whole doesn't disagree with our policies." They also noted that the public ownership of Austin Energy ties these goals to politics, and constituent desires, rather than a bottom line. While these goals are accompanied by increased budgets, the utility has run into some staffing issues as the funding comes before approval to hire a new fulltime city employee.

The staff member saw the role of the program as taking those environmental goals and finding the program structure or design that entices both solar installers/contractors and residents to apply through economic incentives. Austin Energy sees its role as adapting to distributed generation and predicting hurdles and challenges. The staff member mentioned that quick technological deployment could mean the utility gets "caught off guard" which could impact the grid and the utility's financial standing. This could put customers who cannot afford distributed generation or whose properties are not suited for solar energy at a disadvantage. The rates are the mechanism through which the utility can set the pace of deployment.

Austin Energy appears to be on a positive track with a positive view of the future. The employee considered the phase-out of both the utility and federal incentives to be nicely timed with the drop in solar prices, though the staff member did reiterate that industry adjustment to lower subsidies depends on the federal tax credit staying in place through its previously determined schedule. If these federal tax credits hold, the utility does not anticipate a steep drop-off in solar installations as the rebates expire.

New developments may include a commercial value of solar by January 2018. The employee thinks this transition will fix a current undervaluation of the performance-based solar standard for commercial customers. The utility also plans to expand community solar options that allow customers who are not good fits for residential solar due to income or house suitability to invest in offsite arrays. Multifamily solar remains underdeveloped in the Austin Energy service area. The utility is currently developing a strategy for multifamily residences that would enable them to install a solar array with one-interconnection and virtual metering to distribute the generation to separate accounts.

CPS Energy Interview

Figure 6: CPS Energy Interview Word Cloud

CPS Energy provides both natural gas and electric services to over 786,000 customers in San Antonio, Texas. The City of San Antonio acquired the electric utility serving the area in 1942 when the City Public Service (CPS) Energy utility was established (CPS Energy, 2017a). CPS Energy’s solar programs support their Save for Tomorrow Energy Plan (STEP) which sets a goal of saving 771 megawatts of electricity between 2009 and 2020. The goals of the plan are to reduce costs for the utility and for customers while preventing the demand for additional generation capacities and reducing emissions (City of San Antonio, 2017). The utility reports a total of 121,791,848 kWh in energy savings for the 2016 fiscal year across its suite of residential, commercial, demand response, and pilot programs. The residential solar program achieved 10,000,580 kWh of these savings with a budget of $9.9 million dollars (CPS Energy, 2016). These provided rebates for 910 homes whose system size averaged 7.4 kW. Total kW capacity for the 2016 fiscal year reached 6,699 representing an increase of 2,048 kW over the 2015 installations (CPS Energy, 2016).

CPS Energy dedicated $30 million to residential and commercial solar rebate programs for the 2017 fiscal year. These rebates will be distributed on a first-come, first-serve basis according to the schedule in the table below.

Table 10: FY 2017 Available Solar Incentive Rebates for CPS Energy

Tier	Total Rebate Funds Available	Incentive Level
1	$10 million	$1.20 per Watt
2	$10 million	$1.00 per Watt
3	$10 million	$0.80 per Watt

Source: Evaluation, Measurement & Verification of CPS Energy's FY 2016 DSM Programs

These rebates are capped at 50% of the total project cost for both residential and commercial projects. Residential solar rebates are capped at $25,000 total and commercial rebates are capped at $80,000 (CPS Energy, 2016). These amounts are significantly higher than what is available at Austin Energy. New requirements released in June of 2017 offer further refinements to these programs as the STEP program provided an additional $15 million in funding, with $9 million available for residential solar. The rebate total was amended to encourage local manufacturers of solar panels by setting a base per watt installation price of $0.60 that could be increased by $0.08 per watt for projects using local panels and $0.02 per watt for projects using local inverters (CPS Energy, 2017b).

Design

The design of the CPS Energy interview followed the same protocol as the Austin Energy interview that is available in Appendix B. However, in this interview two employees participated, one from the solar rebate program and one representing new pilot projects. I interviewed the two employees together. When necessary to distinguish the participant, I will refer to them by their program names—rebate employee and pilot program employee. As in the Austin Energy interview, their names are kept confidential. Unless otherwise cited with supplementary materials, this information comes directly from the interview transcripts.

Interview

The interview with CPS Energy provided this research with a useful foil to Austin Energy, given the similarities between the two utilities. They are both public and each serves a hot, humid climate in the state of Texas. The utility runs solar programs in two main areas: a solar rebate program and a pilot program. The pilot program includes a community solar program and a solar host program. Each of these programs are housed in the product development division of CPS Energy. The residential solar program provides installation rebates and net metering, the community solar allows customers to invest in an offsite solar array, and the solar hosting program allows residents to lease their rooftops to a third-party provider. Each of these activities are designed to bring access to solar energy to CPS customers with differing needs and to reach renewable generation goals.

CPS Energy's STEP 2020 goals to reduce 771 megawatts of energy consumption do not include the utility's 500 megawatts of utility scale solar. Instead, the goals focus not on the generation of renewable energy, but instead on implementing strategies to reduce energy-consuming behaviors, and only then moving onto increasing generation capacity. The pilot programs employee noted that the rationale behind this was to eventually reduce demand for energy to the point that the utility's remaining coal power plant could be retired. However, the employees both believed that the utility was very close to meeting the goals, which could mean a new period of visioning in the future. The STEP 2020 goals are not a directive from city council, but are internal to CPS Energy. These programs are funded by a fuel adjustment charge levied to each ratepayer.

The CPS solar rebate program has significantly increased in popularity since 2010. The rebate employee noted that seven years ago they received only one application a week whereas today they receive hundreds. This employee believes that customer knowledge and city motivation to "go green" have spurred the recent interest, despite the rebate per watt scaling down from $3.00 to $0.60. In addition to the upfront rebates, CPS Energy implements net metering. Customers are not billed for the use of electricity that they produce. Any electricity production not consumed by the homeowner is purchased by the utility at a rate of $0.0165 per kWh. This rate is based on the avoided costs of transmission. Both employees noted that the reimbursement rate is low enough that it does not incentivize over-sizing of solar arrays. The rebate employee advises residents to average their last 12 months of energy usage and to install a solar array that approaches about 80% of use.

The rebate employee noted that contractors provide a challenge to residents wanting to own solar and that many customers have reported "fly-by-night" sales tactics to sell expensive systems. CPS Energy worked with Austin Energy to develop guidelines released in June 2017 that regulate contractors and enhance consumer protection. The rebate employee also mentioned that credit and income remain problematic for would-be rebate customers, as CPS Energy's customer base includes many low-income households. The rebate program engages in education and outreach efforts meant to equip residents with the information they need to make decisions about solar installation, both in terms of what to expect in terms of payback period and how to select a contractor.

The pilot programs implemented by CPS Energy explore new ways to open access to solar programs to people for whom ownership is not a good fit due to lack of interest, lack of space, or even customers who do not like the look of solar panels. In addition, the programs intend to increase grid resilience and security by distributing solar panels across the grid and balancing the clustering of distributed generation in higher income areas. The roofless solar program is a one-megawatt capacity program that allows customers to purchase energy from off-site solar panels. The Solar Host program is a five-megawatt program built on a power purchase agreement (PPA) with a developer, PowerFin, who installs solar panels on qualifying customer rooftops and passes on "a small portion of that revenue stream to the homeowner to rent roof space." The pilot program employee noted that this program is a good fit for lower-income customers as they pay no upfront costs for solar panels on their home, but receive a \$0.03 production credit for each kWh generated by the system installed.

Despite the opportunities provided by the Solar Host program, the program employee noted that it has created a sensitive spot for the utility. The eligibility requirements for the program tightly regulate which rooftops can qualify in terms of orientation, shading, and structural integrity. Customers with older homes face rejection from the program if their roofs are not strong enough to last 20 years without needed repairs. The employee noted that "it is difficult to explain to homeowners how the house must be perfectly situated." They believe the circumstances were exacerbated by the attractiveness of the \$0.03 credit per kWh generated and the disappointment of residents who thought they might find relief on their energy bills. The program has been able to increase the acceptance rate of from about 3% to about 20% after the contractor re-evaluated eligibility requirements.

Both pilot programs use PPAs derived from a competitive bidding process. The utility releases a request for proposals and third-party providers respond. The utility then picks the best agreement and pursues implementation. Both pilot programs operate entirely on the utility side of the meter—the utility purchases the power, retains any renewable energy credits, and bills or distributes resources to the customers. The programs function like utility-scale solar, although the Solar Host installations are distributed across multiple households. There is no danger of over-sizing arrays in a way that would damage utility financial help because the agreements are fully formed PPAs and not rate structures navigating the interplay of fixed versus volumetric rate structures. The pilot programs also intend to harness the economic benefits of economies of scale—one installer can order five megawatts of solar panels rather than individual contractors installing panels in three to ten kilowatt increments.

Regarding its public ownership, the CPS employees noted that political pressure does influence utility operations and that the utility is sensitive to politics. Both utility customers and solar installers call their City Council members to advocate for their energy needs. When asked if the public ownership was a net positive, the Solar Host employee noted that it does allow the utility to be responsive to customer attitudes which are "migrating into a new mindset." Both employees believe that their programs were established first and foremost for public satisfaction, as they are expensive for the utility to operate. The early charter of CPS Energy was to provide power at the lowest cost possible, but solar programs increase the cost of power in the short run. Public ownership allows for

CPS Energy to analyze the costs and benefits of electricity sources over a longer period. The Solar Host employee noted that "long term costs even out" when "you consider clean air and better public health." The employee also mentioned that value systems going forward are changing as residents demand clean power and that "smoky power plants will be a thing of the past."

The CPS Energy employees are hopeful about future programs. The rebate program employee believes that installations will continue despite decreasing rebate amounts. The pilot program employee is considering new formats for future PPAs and programs that explore new ways to finance solar energy projects.

Discussion

From my analysis of policy documents and from my interviews, it is apparent that both Austin Energy and CPS Energy are invested in capturing the environmental benefits of solar energy while also controlling costs for their customers. Austin Energy's VOS tariff directly pursues an energy policy that is clean, cheap, and fair. CPS Energy approaches the question via diversified programs that provide options for diverse income classes. My impression from the interviews is that both utilities care about providing clean and cheap energy, though Austin Energy is focused more on the clean and CPS Energy is focused more on the cheap.

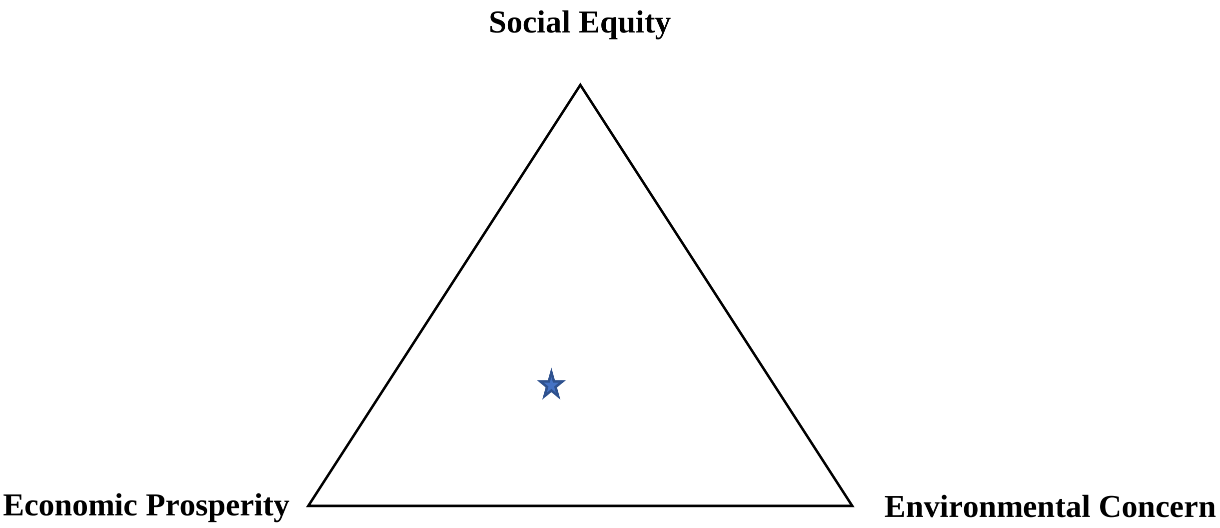
The environmental benefits pursued by each utility are clear, though they are presented in disparate ways. Austin Energy works towards explicit environmental goals set by City Council and by the utility itself. It has assigned a clear value to the environmental benefits offered by solar energy, which it has pegged at $0.02 per kWh generated. However, the validity of this cost may depreciate without updates and without updated federal guidance on the social cost of carbon. CPS Energy pursues similar goals, but cloaks them in a language of energy efficiency and conservation. The utility's 2020 goals are aimed at shuttering a coal power plant, which would result in significant reductions in greenhouse gas emissions and criteria air pollutants. Both utilities pursue environmental goals and emissions reductions to ensure customer satisfaction and respond to political pressure. Both utilities posit that customers value clean energy and that these values are reflected in the policies and goals of their utilities.

Each utility provides evidence of concern for controlling costs as well, although the mechanisms for ensuring affordability diverge. Austin Energy moved to a VOS tariff in part to alleviate pressure for rate hikes that could stem from increased rates of grid defection and minimization by households with solar panels. By decoupling the rates for solar production from energy consumption, they attempt to provide a fair subsidy package while protecting ratepayers who cannot or will not install solar panels. CPS Energy, on the other hand, provides a bigger subsidy per kWh and implements programs that intend to spread access to solar technologies to a larger portion of the population they serve. The employees of CPS wove affordability into the interview when not prompted, as well.

Both utilities expressed concern about solar contractors misleading their customers. This demonstrates a social concern that I did not predict in my formulation of research questions. In addition, each utility representative made direct references to a concern for equity. Austin Energy noted that the previous incentive structure that paired net metering with a tiered rate structure unfairly compensated the highest energy users, most of whom tended to be high income. CPS Energy representatives explicitly stated a concern that the fuel adjustment charge paid by all customers tended to be routed to the higher income households and neighborhoods through the solar program. Each utility then made moves to correct the inequity by changing program design (Austin Energy) or developing new programs to increase access to the technology (CPS Energy).

While Austin Energy may not fully capture the suite of environmental benefits offered by residential solar due to limited financial resources and engineering constraints, it does not appear as though the utility structure hinders the rate of technology deployment significantly given the constant stream of interest in these programs. However, the utility could learn from CPS Energy and implement pilot programs to test innovative ways of delivering solar services. Austin Energy has not exploited the PPA model to deliver services directly to consumers. Given the recent history of collaboration between the two utilities, perhaps there is an opportunity for knowledge sharing between them on this topic.

Figure 7: The Position of Austin Energy's Solar Rebate Policies on Campbell's Triangle



My interpretation of Austin Energy’s policies would indicate that while environmental concerns are embedded throughout the solar program policies, economic concerns remain the most important as hypothesized. However, those economic concerns do consider equity. If I were to map the confluence of Austin Energy’s policy concerns onto Campbell’s sustainability triangle, it would be slightly off the center. A position directly in the center would indicate a perfect balance of equity, economic, and environmental priorities. Austin Energy is close to achieving balance between the economic and equity corners, but is still closer to the economic side. Policies indicate that the utility is even closer to achieving balance between economic prosperity and environmental concern in their solar rebate programs, though economic interests are still given comparatively more weight.

Chapter 5: Presence of Economic, Environmental, and Social Interests Concerning Solar Panels among Austin Residents

As indicated in the literature review, consumer attitudes towards environmental technologies may have some impact on their adoption. This chapter seeks to contextualize this research in the local area. In it, I will answer the following research question: What do the perceptions of Austin residents indicate about how they value residential solar energy?

To address this question, I analyze survey data to understand which components of value and the triple bottom line of economy, environment, and equity emerge through self-reported data from Austin residents.

DATA SOURCE

The Pecan Street Project offers academic licenses to its Dataport, which offers a selection of data to researchers. The organization collects an array of consumer electricity and water data from project participants, who agree to share their meter readings and to participate in surveys. All participants are homeowners in Austin, Texas. The Pecan Street Project's most recent participant survey was in 2014. In it, participants self-reported information regarding household characteristics and behaviors including: time spent at home; educational attainment and income; resident ages; counts of ceiling fans and electronic devices; retrofits, add-ons, and remodels; HVAC system type; thermostat characteristics and temperature settings by day and time; presence of PV/solar panels and size; reasons for installing solar panels and satisfaction with them.

Most relevant to this research is the series of questions asked regarding solar panels (see Appendix C for the complete survey protocol). If survey participants had solar panels on the roofs of their homes, they were asked why they acquired the panels, their satisfaction with them, the features they like the most, the features they would like to change, and what surprised them about their panels. They were also asked what they tell other people about their panels and the reaction of others to their panels. Participants who do not have solar panels were asked what owners of solar technology tell them about the technology. These questions required short-form and open-ended responses. Participants without solar panels were asked why they had not pursued the technology and were asked to select all the answers that applied. All participants were asked what they find appealing about solar panels and to select all answers that applied. All participants were asked what they find unappealing about solar panels and to select all answers that applied.

The Pecan Street Project collected 333 surveys in 2014, of which 326 contained some degree of completeness and are included in the analysis below. Of these 333 participants, 108 reported that they owned solar panels. Of the 108 participants reporting solar panel ownership, 104 provided useful feedback on the size of their panels. Two respondents without PV panels answered questions only meant for owners. These answers were removed from the dataset.

METHODS

The open-ended questions required coding. I followed Bazaley and Jackson's suggested steps by first reading the data to identify relevant information within it, creating a word or phrase that best fits the relevant information in the context of the research question, and by documenting why the node is important (Adu, 2015; Bazeley & Jackson, 2013). For each open-ended question, I coded answers according to the three facets of value central to this study: economic, social, and environmental. I also noted and coded notable repeating themes and if a response was positive or negative, if appropriate.

For each survey answer I assigned codes to the best of my ability based on the goodness of fit with each category. Survey responses that included multiple values received a code for each represented within. Survey responses that did not clearly align with any category received no code assignments. I did not assign a code when an answer was ambiguous. For instance, if someone listed “power generation” as their reason for installing solar panels, I did not note that as necessary concerned with environmental issues or economic issues. However, if someone noted “green power generation” or “clean power generation,” I coded the response “environmental.” If they noted “free power generation,” I recorded the response as “economic.” If someone responded, “free clean power generation,” I would mark the response as both “economic” and “environmental.” I then tallied the number of responses that fit each code. During the coding process, I took notes detailing my coding choices.

One question, presented only to solar panel owners, entailed a multiple-choice format. For this question, I simply tallied the number of each answer selected. Two questions had a “select all” format. One question was presented to each survey participant, and the other was presented to only those owning solar panels. For these questions, I tallied the frequency of each answer across all participants and the total number of answers selected for each participant. I did not include participants who did not select any choices. This may provide a limitation to the analysis of these questions, as each of these questions provided “none” as a distinct answer to select. However, it is possible that survey respondents read the question, did not think any of the provided answers applied, and choose to indicate that by not answering the question rather than selecting only “none.”

After I coded and tallied the twelve survey questions, I created a series of tables and charts for each question indicating the distribution of answers. The results are below and the full set of tables can be found in Appendix C.

Limitations

This research builds on existing data using a survey designed and administered by the Pecan Street Project. As a non-probability sample, this analysis is limited to an exploratory analysis—it indicates what the group of survey respondents thinks, but it cannot be used to extrapolate to all Austin residents. Beyond this significant limitation, the Pecan Street data does not provide information about where these households are located, which makes it difficult to draw comparisons to the Austin Energy customer base.

In addition, I may misinterpret the intentions of participants, particularly regarding the environmental and social interests. First, it is likely that many participants hold environmental attitudes for social reasons and that they could be concerned with equity and climate justice when they mention the emissions-free energy that their solar panels generate. However, with limited information, I could only code those answers as "environmental." Second, the questions themselves were more aligned to the economic and environmental interests than to social issues. The survey itself included energy independence and freedom from utilities in some questions, which are undeniably social concepts. However, they are based on personal self-interest and not social equity in a broader collective sense. As such, they did not fit the purpose of this research and I did not code them as social.

Some questions in the survey design create challenges in interpreting the intent of participants. For instance, two multiple choice questions asked participants to select all answers that concerned what they found appealing about solar panels and what they considered a barrier to adopting solar panels. Each of these questions included an option for "none." However, the response rate was so much lower on these questions compared to the others that I doubt the clarity of instructions. Some participants may have thought by selecting zero answers, they were indicating that they found nothing appealing about solar panels or that they had no barriers to entry in adopting solar panels. However, because I could not interpret those as such, I had to remove them from the data.

RESULTS

Reponses to the short answer section of the survey indicate an overwhelming dominance of economic interests over the environmental and social. Out of the 817 responses to the eight short answer questions, 395 provided a clear economic interest, particularly in terms of the reasons given for implementing solar panels and the questions that owners receive from non-owners. These two questions yielded 91 and 90 answers, respectively. 84% of respondents indicated an economic interest in solar panels as a reason for purchasing them and 84% of respondents indicated that non-owners ask questions concerning economic factors like upfront costs, size of rebates, payback period, and the effect on utility bills.

Table 11: Instances of Economic, Social, and Environmental Interests Present in Short Answer Questions

PV Owners	Question Descript.	Question #	Economic Interest	Social Interest	Environmental Interest	# of Responses
Yes	Reason	2	91	14	63	108
Yes	Features Liked	4	32	4	17	107
Yes	Features Improve	5	19	2	10	107

Yes	Features Surprise	6	16	3	3	107
Yes	Common Questions	7	90	5	5	107
Yes	Common Answers	8	63	0	12	107
Yes	Common Surprises	9	65	0	2	107
No	Common Owner Responses	12	19	2	2	67
		Total	**395**	**30**	**114**	817
		Ratio	**48%**	**4%**	**14%**	66%

As shown in Table 11, environmental interests were present in 114 of the 817 total answers by all participants, representing 14% of all answers compared to the 48% of all answers that referenced an economic interest. Over half of the responses that indicated an environmental interest in residential solar panels occurred in Question 2, which asked owners of solar panels to explain why they purchased them. 58% of respondents indicated a concern for the environment as a reason for purchasing solar panels. However, no other short-answer question inspired a majority, or even a quarter, of respondents to reference an environmental interest. Common environmental references in the remaining questions concerned climate change, emissions, and the negative impact of fossil fuels. Some environmental interests present in the answers were negative. Multiple owners of solar panels noted that their arrays had created wildlife habitats that they found intrusive and burdensome. One of the two environmental answers to question 12—which asked non-owners of solar panels what owners tell them about their systems—included a negative association with pigeons.

As predicted, the social interests had the lowest representation across the 817 answers. Only 4% of total answers referenced a social interest. About half of all the answers that referred to a social interest occurred when participants gave their reasons for installing solar panels on their home. Answers coded as social expressed an interest in supporting the greater good, protecting public health, or supporting the solar industry. Two of the responses indicated a social or peer influence. One survey participant wrote that they appreciate the visibility of their solar panels from the street as they spark conversations and lead to peer influence. One response indicated wherein solar panels produced a conflict with a homeowner's association. A few answers also conveyed exasperation with Austin Energy rate structures, wherein owners felt that having solar panels constituted a contribution of theirs towards the greater good that should exempt them from paying some utility fees.

In addition to the eight short answer questions, participants answered two "select all" questions. **Question 10 asked non-owners: Which reasons have factored into why you or other decision makers in your household have not acquired a rooftop solar panel system?** The responses to this question, as seen in Table 3, indicate an array of negative characteristics or barriers to entry associated with solar panels. The answer choice "too expensive" clearly falls within the realm of economic interest as does "concerned with home value." The other two selections are less clear; "unsure of benefits" is ambiguous, but "ugly" could be social in some circumstances if it related to peer influence. No clear choices pertaining to an environmental interest was provided to the participants. Out of each answer category, economic interests dominated once again.

Table 12: Reasons for Not Pursuing Home Solar (Question 10)

PV Owners	**Too expensive**		**Unsure of benefits**		**Concerned with home value**		**Ugly**		**Other**		**None***	
	#	%	#	%	#	%	#	%	#	%	#	%
No	104	53%	53	27%	9	5%	4	2%	72	37%	15	8%
n = 197, 87% response rate												
**Does not include 28 participants who did not select any answer.*												

Table 13: Total Negative Responses per Participant (Question 10)

"None" selected	**One negative**	**Two negatives**	**Three negatives**	**Four negatives**	**Five negatives**
15	136	36	7	2	1
8%	69%	18%	4%	1%	1%
n = 197, 87% response rate					
**Does not include 28 participants who did not select any answer.*					

Though question 10 did not allow much useful insight on the different types of values that participants held, it did provide an opportunity to analyze the participants' general negativity toward solar panels (see Table 10, above). 69% of participants selected only one negative aspect of the panels, and most of those were economic concerns. **Question 10 asked non-owners: Which reasons have factored into why you or other decision makers in your household have not acquired a rooftop solar panel system?** This question was only posed to participants who do not have panels, so it does not indicate that the panels worsened the economic well-being of participants. Only 5% of participants chose three or more negative factors.

Table 14: Appealing Attributes of Solar Panels by Ownership (Question 11)

PVs	**Independence from Utility**		**Emission-free Electricity**		**Protection Against Utility Rate Increases**		**Other**		**None**	
	#	%	#	%	#	%	#	%	#	%
Yes	24	44%	47	85%	25	45%	15	27%	1	2%
No	133	68%	160	82%	122	62%	28	14%	6	3%
Both	157	63%	207	82%	147	59%	43	17%	7	3%
n = 55 for PV owners, response rate 26%										
n = 196 for non-PV owners, response rate 87%										
n = 251 for all respondents, response rate 75%										

Question 11 asked all participants: Which of the following factors, if any, do you find appealing about solar panel systems? Of the answers available for the participants to select, "emission-free" electricity corresponded with environmental interest and "protection against utility rate increases" corresponded with economic interests. The answer "other" could not be coded. The answer "independence from utility" is much more ambiguous. This could correspond to an environmental interest if the participant is familiar with the energy generation mix of the utility and wishes to reduce their emissions. It could also represent a social interest, though the nature of that interest would depend on the person. Since the utility is publicly-owned, this interest could be anti-government. Because I cannot speculate, I did not code this answer.

For both solar panel owners and non-owners, emission-free electricity was the most popular answer choice, inspiring 85% of owners and 82% of non-owners. This answer also had the smallest amount of discrepancy between participant types. Non-owners were far more like to select "independence from utility" and "protection against utility rate increases." Given that owner frustration with the utility emerged in several short answer questions, this could indicate that expectations regarding the independence and rate decreases were not met by solar panel installation.

Table 15: Total Number of Positive PV Factors Selected by PV Owners and Non-Owners (Question 11)

No Positives Selected	**One Positive Selected**	**Two Positives Selected**	**Three Positives Selected**	**Four Positives Selected**
89	57	75	99	13
35%	23%	30%	39%	5%
				n = 55 for PV owners, response rate 26%
				n = 196 for non-PV owners, response rate 87%
				n = 251 for all respondents, response rate 75%

I totaled the number of positive factors that participants selected for Question 11. About 70% of respondents selected two or three positive factors, and 23% selected one positive factor. Far fewer participants selected four positive factors—about 5%--and only 3% selected none. The distribution of frequencies skewed far more towards the middle choices for the positive factors when compared with the negative factors in question 10.

Overall, economic factors dominated as the major area of concern for residents in Austin, Texas in terms of their perceptions of solar panel which support my hypothesis. Economic factors were considered as both positive and negative—many participants perceived the high cost of solar panels to be a barrier to entry, while owners of solar panels overwhelmingly indicated that the decision to install a solar array was a positive, financially. Several questions in this survey concerned conversations that owners and non-owners have with one another about solar panels. Economic interests dominated here, too.

Owners of solar panels indicated a clear environmental interest in their solar panels, both as a reason for owning them and as a feature they appreciated. However, this interest did not carry over into conversations with non-owners. Several owners indicated that they would like to increase the environmental impact of their solar arrays through installing more panels or by adapting some sort of battery storage to use excess solar energy during dark or cloudy parts of the day.

Social interests had a lower showing in all answers. Part of this likely had to do with the design of the survey. Had I the opportunity to add a socially-oriented question to the survey, it would have asked in short answer form, “How do your solar panels benefit others?” This would have provided participants with an opportunity to make a connection between economic interests and social interests or environmental interests and social interests, or to simply say that they do not.

One of the clearest outcomes from this analysis is that when people talk to each other about solar panels, they talk about the economic aspect of their panels. In general, this economic focus concerned expenses at the household level. Absent from the answers was any mention of distributed solar might mean for all utility ratepayers; not one respondent out of 333 mentioned any connection to the utility at all, save for a few complaints about rate changes, which reflect on a personal level.

Chapter 6: Solar Panels and Energy Use in Austin – Who Has Technology and Does It Decrease Energy Use

Chapters 4 and 5 investigated how energy utilities and residents value residential solar energy. This chapter seeks to analyze:

1. Which residents of Austin have solar panels and what are their basic income and educational characteristics?
2. Does the actual usage and deployment of solar panels reflect the environmental, economic, and equitable values espoused by the utility and Austin residents?

As discussed in Chapter 2, residential solar arrays may be out of economic reach for lower income households. Findings in Chapter 5 indicate that economic considerations have an overwhelming presence in Austin residents' decisions to install or not to install solar panels. These findings lead to the first question posed in this chapter. Given the high upfront capital costs of residential solar arrays, the connection between education and income, and the connection between race and income, I decided to explore the relationship between these factors and the presence of solar panels for households in Austin (Beddoe et al., 2009; Branker et al., 2011; E. M. Tretter, 2013; E. M. Tretter et al., 2016).

Because adopters of solar panels receive rebates from the local energy utility and federal tax credits, they raise questions of fairness and need. All Austin Energy customers, and therefore virtually all Austin residents, pay fees that contribute to the solar rebate incentive funding. Do these fees go to households that need them? While statistical tests cannot unveil if owners of solar panels would have adopted the technology without these rebates, the relationship between income and the presence of solar technology remains important.

The impetus for the second question in this chapter stems from previous research that indicates solar panels may not decrease net energy usage and that environmental values may not inspire ecologically-friendly behavior. In Chapter 5, I found that owners of solar panels valued the environmental benefits of solar panels more than the economic benefits of solar panels when compared to non-owners, who valued economic and environmental benefits more equally. In addition, 58% of solar panel owners surveyed indicated that environmental protection factored into their decision to install the technology. The second question in this chapter seeks to test the effect that solar panels have on actual energy use.

To address these questions, I analyze the energy usage and demographic characteristics of 213 homes in Austin between 2012 and 2016—all of whom completed the 2014 annual survey analyzed in Chapter 5. My original intent was to perform a multivariate regression analysis that would provide a model in which I would use income, education, and race of each as the independent variables and the presence of solar panels as the dependent variable. However, no models I constructed explained more than 30% of the variation between households, indicating missing variables. Instead I analyze the descriptive statistics and basic correlation tests to explore the differences between PV owners and non-owners.

To address the second research question, I also transitioned away from panel regression analysis towards more exploratory techniques given the lack of predictive value produced by trial tests. Instead, I scrutinize household characteristics and energy use information for of PV owners and non-owners and compare the two. I perform this second analysis for annual energy usage and for energy used during peak hours within the month of August.

DATA SOURCE

In addition to the survey data collected by the Pecan Street Project (Chapter 5), participants agree to share energy meter data with researchers. For the purposes of this research I choose data only from homes that completed the 2014 annual survey analyzed in the previous chapter to preserve household characteristic data. Out of the 333 households that participated in the 2014 annual survey, 213 participated in energy monitoring programs. The technical data that I accessed includes hourly electricity meter readings for 213 homes creating a total of 5,924,056 hourly electricity meter readings. In some cases, the number of homes appropriate for analysis dropped to 204 as the observations were incomplete or missing data. The numbers of households are mentioned in each case in the results. The combined technical data and survey data yielded the following variables for each household:

Binary Variables

- PV panel presence: Yes (1) or no (0)
- Caucasian: Yes (1) or no (0)
- Peak month: Yes (1) or no (0)
- Peak hours: Yes (1) or no (0)

Continuous Variables

- Presence at home during weekdays: Monday, Tuesday, Wednesday, Thursday, Friday
- PV panel size
- Hourly total household energy use
- Hourly grid energy use

- Hourly PV generation from solar panels, small generators, or plug-in electric vehicles
- Number of residents in the household
- Number of residents age 18 or younger

Categorical Variables

- Number of residents in the following age categories: Under 5, 6 to 12, 13 to 18, 19 to 24, 25 to 34, 35 to 49, 50 to 64, 65 and Older
- Educational attainment: High school graduate (1), Some college (2), College graduate (3), Postgraduate (4)
- Income categories: Less than $10,000, $10,000 to $19,999, $20,000 to $34,999, $40,000 to $49,999, $50,000 to $74,999, $75,000 to $99,999, $100,000 to $149,999, $150,000 to $299,999, $300,000 to $1,000,000, More than $1,000,000

This data required a significant amount of cleaning and reformatting to make it compatible with Stata—a statistical software that can process the nearly six million data points I extracted from the Pecan Street Dataport. First, I manually cleaned the survey data, for which each household had only one data point, in Excel. Of concern was the size of the PV panels for the households that had them. Many respondents included non-numeric characters such as “kw” which I removed. Some used commas instead of decimals, and some provided the size of their solar arrays in watts instead of kilowatts. Others wrote in phrases such as “I got whatever size they told me to.” These were deleted.

I manually created binary variables for PV panel presence and Caucasian, providing a value of 1 to the “yes” answers and 0 to the “no” answers. I selected variables for peak demand based on Austin Energy’s records as shown in Table 16 and on ERCOT’s critical peak pricing days shown in Table 17. Though annual days of peak demand have occurred in June, July, and September, August afternoons are most frequently represented. Austin Energy's time-of-use pricing (now suspended) implemented peak demand pricing from 2:00 PM to 8:00 PM on Monday through Fridays (City of Austin, 2016).

To simplify the analysis, I created two binary variables used to test peak demand. First, I created a "peak month" variable to mark each meter reading taken during the month of August with a value of 1. Second, I created a "peak hour" variable to further refine and select hours of interest. I selected the 4:00 PM, 5:00 PM, and 6:00 PM hourly readings in the month of August for all households and designated a value of 1 to create the "peak hour" variable. I chose the three-hour window to simplify computing time, starting at the ERCOT peak demand times of 4:00 PM.

Table 16: Austin Energy System Peak Demand, 2007 - 2016

Date	Peak Demand (megawatts)
8/24/2007	2,430
8/13/2008	2,391
8/4/2009	2,514
6/29/2010	2,602
8/23/2011	2,628
8/29/2012	2,714
6/26/2013	2,702
8/7/2014	2,512
8/25/2015	2,578
8/12/2016	2,735

Source: City of Austin Open Data Portal, https://data.austintexas.gov/dataset/Austin-Energy-System-Peak-Demand/a6pm-qynf

Table 17: Day Ahead ERCOT Peak Demand, 2013 - 2014

Date and Time	Peak Demand (MW)	Forecast High (F)
6/20/2013 16:00	57,968	97
6/26/2013 16:00	63,161	99
6/28/2013 16:00	64,659	103
7/24/2013 16:00	63,161	99
7/26/2013 16:00	60,626	101
8/1/2013 16:00	65,566	100
8/7/2013 16:00	67,770	103
8/8/2013 16:00	66,748	103
9/5/2013 16:00	62,757	99
8/30/2013 16:00	64,113	102
8/29/2013 16:00	62,766	100
9/13/2013 16:00	61,568	98
7/2/2014 16:00	59,257	97
7/24/2014 16:00	63,688	100
8/8/2014 17:00	65,761	101
8/21/2014 16:00	62,191	101
8/26/2014 16:00	64,514	100
9/3/2014 16:00	61,356	96
9/9/2014 16:00	61,567	97
9/11/2014 16:00	59,736	97
8/15/2014 16:00	63,264	101

Source: Pecan Street Project Dataport

For each of the categorical variables, I created a number equivalent to each category. For educational attainment, I coded the categories on a scale of 1 to 4, with 1 representing high school graduate and 4 representing postgraduate. I repeated this process for the income categories. I collapsed race into the binary variables, with one value given to people of color and one value given to those who supplied their race as “Caucasian.” I did this in part to simplify the analysis, as my other option was to create a binary variable for each race and to make every statistical test multivariate with all possible self-reported ethnicities. The Caucasian binary variable also allows to test relationships between white people and people of color in one step. I also collapsed the categorical age data into continuous variables. I added the number of people in each category to determine household size. Then I added the number of children into its own category.

METHODS

I initially performed two regression analyses to explore the relationship between: 1) household characteristics and the presence of solar panels, and 2) the presence of solar panels and energy usage. Though I consulted with researchers in the Department of Statistics and Data Sciences to ensure robust model construction, each iteration of each model proved problematic, indicating that the dataset was missing key explanatory variables. Instead I generated a set of descriptive statistics for key variables as well as scatterplot graphs that illustrate relationships.

My first analysis entailed looking at annual energy use and generation data. I summed the six million energy use and grid use observation points in Stata by each unique identification number and by each year. I then joined the demographic data to each data point and exported the 816 observations for each variable to Excel. I then used Excel data analysis functions to derive the descriptive statistics for:

- Educational attainment categories where
    - High school graduate = 1,
    - Some college = 2,
    - College graduate = 3,
    - Postgraduate = 4;
- Income categories where
    - Less than $10,000 = 0,

  - $10,000 to $19,999 = 1,
  - $20,000 to $34,999 = 2,
  - $40,000 to $49,999 = 3,
  - $50,000 to $74,999 = 4,
  - $75,000 to $99,999 = 5,
  - $100,000 to $149,999 = 6,
  - $150,000 to $299,999 = 7,
  - $300,000 to $1,000,000 = 8,
  - More than $1,000,000 = 9;
- A binary ethnicity index where
  - White/Caucasian = 1,
  - People of Color/Not White = 0
- Household annual grid use in kWh, and
- Household total energy use in kWh, including on-site electricity generation.

I then repeated this process, separating households with PVs and those without, thus allowing for comparison of the statistics across the three groups.

For the peak energy usage, I exported only those observations from Stata that were coded as peak variables. This reduced the number of data points to 30,577. Because the annual data includes the demographic characteristics, I only generated statistics for grid energy used at peak hours and total energy used during peak house. I generated these statistics for all participants before separating PV owners and non-PV owners and generating individual statistics for each category.

Limitations

Like the data in Chapter 5, this data derives from a non-probability sample. Therefore, this analysis is at best. The results of this investigation cannot be generalized with any validity beyond the participants included. The individuals who participate in the data gathering are self-selected or approached based on where they live. Furthermore, the participants all own their own single-family homes, meaning that both renters and owners of properties in multi-family buildings are not included. This dataset does not include factors like the physical size of the household or where the household is located that may provide greater insight into the energy characteristics and neighborhood characteristics that may influence energy use. Moreover, it does not provide the age of construction or other physical information such as tree cover or solar screens that would limit solar insolation and thus generation. It also removes a segment of lower-income households without solar panels that may provide a greater depth and richness of energy use characteristics. Finally, the failure of the regression models severely truncates the utility of this analysis; with no predictive ability, the results are a mere exploration of a rich data source.

RESULTS

Annual Energy Use

Table 18: Descriptive Statistics of All Participants

Demographic and Energy Use Characteristics of All Participants					
	Educational Attainment Categories	*Income Categories*	*Caucasian?*	*Household Annual Grid Use*	*Household Total Energy Use, Including On-Site Generation*
Mean	3.63	5.49	0.84	6,960.45	10,088.63
Standard Error	0.02	0.07	0.01	270.90	301.44
Median	4.00	6.00	1.00	4,999.58	8,514.34
Mode	4.00	6.00	1.00	-	-
Standard Deviation	0.57	2.00	0.37	7,738.35	8,610.73
Minimum	1.00	0.00	0.00	-4,803.27	0.00
Maximum	4.00	8.00	1.00	74,596.32	74,596.32
Sum	-	-	-	5,679,725	8,232,321
Count	816	816	816	816	816

As shown in Table 19, the average participant is approaching a postgraduate degree and an income of over $100,000 per year. The average values for education and income are not far from the median and mode, which are the same for each category. The participants are also mostly white. In terms of energy use, the total kWh measured over the course of this dataset reach 8,232,321, including on-site generation. Removing the contributions of solar panels and plugged-in electric cars brings the total grid energy use down by 2,552,596 kWh to 5,679,725 kWh. The carbon content per kWh of energy consumed by Austin Energy customers in 2015 was 0.87 pounds of carbon dioxide equivalent (See Appendix A: Table 25). A conservative estimate of the emissions reductions associated with distributed generation over the study period is 1,110 short US tons of carbon dioxide equivalent. However, many of these observations are from 2012, 2013, and 2014. The carbon dioxide emissions per kWh for these years are greater than they were in 2015.

Table 19: Descriptive Statistics of PV Owners

Demographic and Energy Use Characteristics of PV Owners					
	Educational Attainment Categories	*Income Categories*	*Caucasian?*	*Household Annual Grid Use*	*Household Total Energy Use, Including On-Site Generation*
Mean	3.76	5.56	0.85	5,401.80	11,506.29
Standard Error	0.02	0.10	0.02	356.68	444.97
Median	4.00	6.00	1.00	3,302.03	10,049.95
Mode	4.00	6.00	1.00	-	-
Standard Deviation	0.43	2.05	0.36	7,160.29	8,932.79
Minimum	3.00	0.00	0.00	-4,803.27	0.00
Maximum	4.00	8.00	1.00	46,762.15	61,393.22
Sum	1,516	2,239	343	2,176,924	4,637,034
Count	403	403	403	403	403

Table 20: Annual Portion of Electricity Provided by Grid vs. On-site Generation for PV Owners

Breakdown of Household Energy Consumption by Source for PV Owners		
	Percent of Electricity from Grid	*Percent of Electricity Generated*
Mean	47%	53%
Median	33%	67%

The 403 participants with PV panels are more educated, more highly paid and whiter than the overall group of participants, which was expected given the high capital costs of solar panels. This group also uses more total energy than the average participant, which corresponds to findings in the literature review. However, the offset from grid energy provided by solar panels (and possibly plug-in vehicles) is significant; the average PV-owning participant generated over half of their annual energy load. The median figure is even higher, at 67%.

Table 21: Descriptive Statistics of Non-Owners

Demographic and Energy Use Characteristics of Non-Owners					
	Educational Attainment Categories	*Income Categories*	*Caucasian?*	*Household Annual Grid Use*	*Household Total Energy Use, Including On-Site Generation*
Mean	3.50	5.43	0.83	8,481.36	8,705.30
Standard Error	0.03	0.10	0.02	392.84	396.50
Median	4.00	6.00	1.00	6,516.26	6,775.01
Mode	4.00	6.00	1.00	0.00	0.00
Standard Deviation	0.65	1.94	0.38	7,983.46	8,057.77
Minimum	1.00	0.00	0.00	0.00	0.00
Maximum	4.00	8.00	1.00	74,596.32	74,596.32
Sum	1,445	2,243	343	3,502,801	3,595,287
Count	413	413	413	413	413

Participants without solar panels were slightly less educated, lower income, and less white than participants on average. However, the median and mode for each demographic category remained the same across PV owners and non-owners. Non-owners used less overall electricity, though they used more energy from the grid.

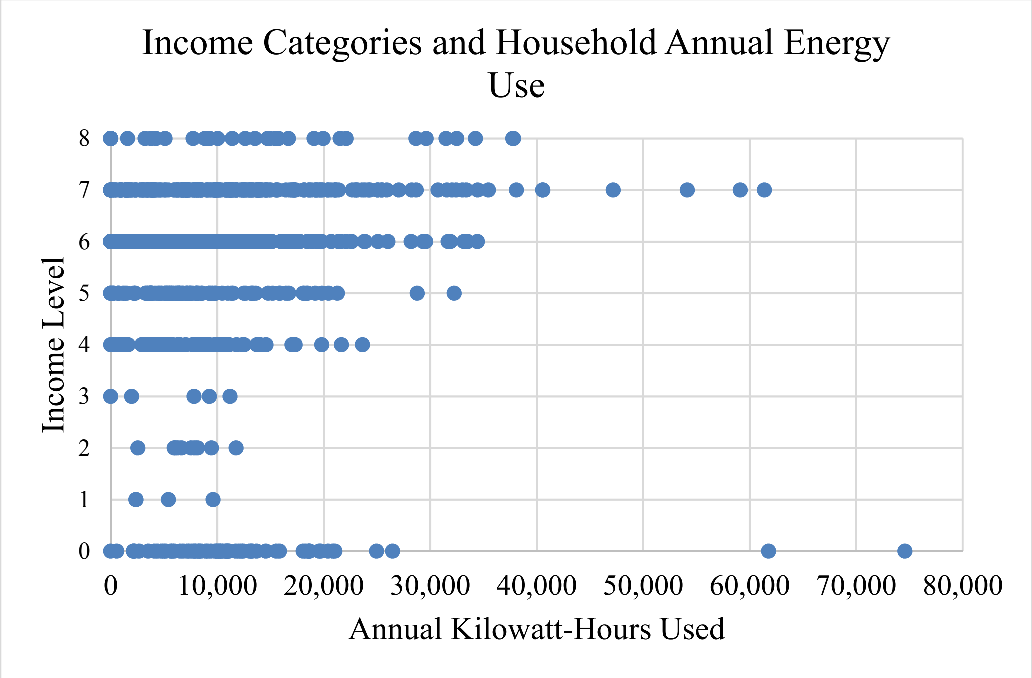


Figure 8: Scatterplot of Income Categories and Annual Household Energy Use

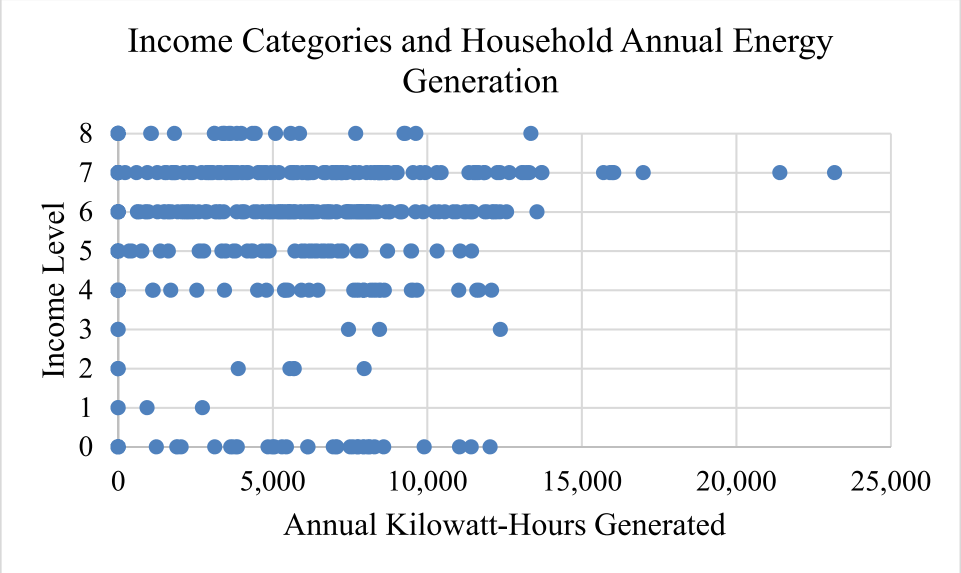


Figure 8: Scatterplot of Income Categories and Household Annual Energy Generation

A higher income level has a loose, positive correlation with both energy use and energy generation, as indicated in Figures 7 and 8. Apart from one or two outliers, it appears as though the highest users of energy have a household income of category 7, which represents an annual income of $150,000 - $299,000 per year.

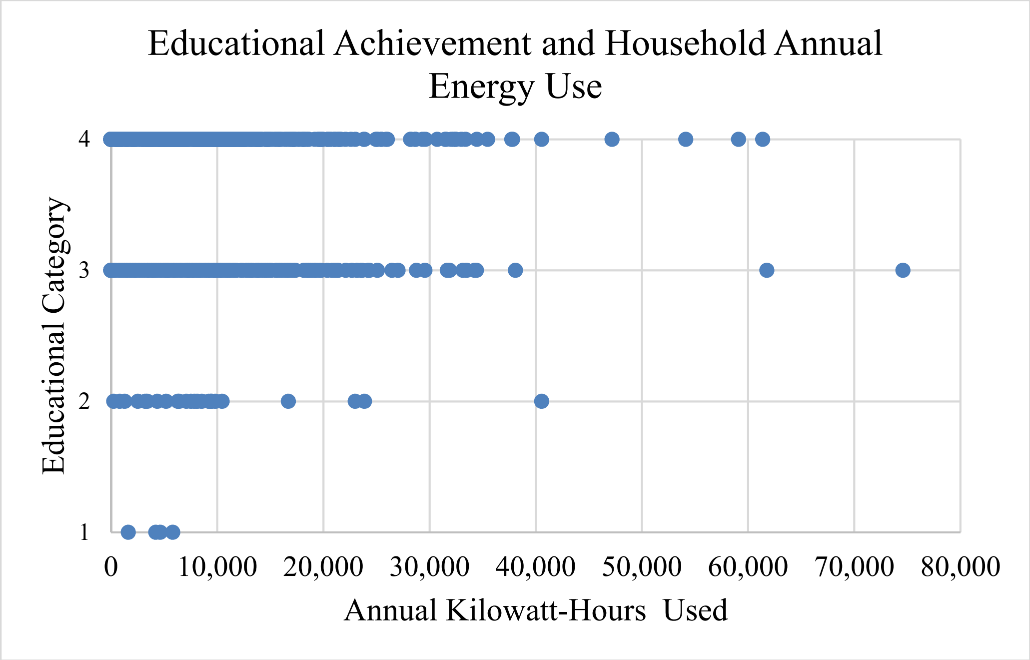


Figure 9: Scatterplot of Education Achievement Categories and Household Annual Energy Generation

Energy use also appears to generally increase with education attainment, though much of the college graduates (3) and post graduates (4) see a tapering of energy use after about 35,000 kWh per year.

Energy Use Characteristics Discussion

The difference in energy use and grid energy use between PV owners and non-owners was largely expected. Solar panels yield significant net environmental benefits in that they offset over 50% of a household's annual grid electricity use on average. Energy use for PV households is higher overall, which suggests the value of energy conservation may be associated with the energy source. This finding confirms much evidence in the literature. It also supports the rationale of the Austin Energy's transition from net metering to value of solar as discussed in Chapter 4. While the solar panels prevent these high energy users from contributing more emissions, they appear to be more liberal in their use of resources overall.

The demographic characteristics of PV owners versus non-owners is also as predicted, though the differences between the two groups are small. PV owners are slightly whiter, richer, and more educated than non-owners. While the differences are small, they do confirm concerns about the distribution of public funds in terms of subsidies for solar energy as expressed in the literature and in interviews.

Peak Energy Use

Table 22: Hourly Peak Energy Use Descriptive Statistics

	Hourly Peak Energy Use (kwh) for All Households		**Hourly Peak Energy Use (kwh) for Households with PVs**		**Hourly Peak Energy (kwh) Use for Households without PVs**
	Grid Energy	*Grid + Solar Generation*	*Grid Energy*	*Grid + Solar Generation*	*Grid Energy*
Mean	2.64	3.06	2.47	3.24	2.86
Median	2.42	2.79	2.39	2.99	2.49
Mode	2.44	3.09	1.21	2.92	4.42
Standard Deviation	2.29	2.11	2.32	1.97	2.27
Minimum	-6.42	0.00	-6.42	0.07	-2.42
Maximum	17.82	17.82	17.82	17.82	13.34
Sum	80,858	93,429	38,448	50,547	40,942
Count	30,577	30,577	15,596	15,596	14,303

Results confirm that PV owners consume less grid energy during periods of peak demand than non-owners. Yet again, PV owners use more energy overall. Though at least one owner could send 6.42 kWh back to the utility during a time of peak demand, most PV owners still drew electricity from the grid between the hours of 4:00 PM and 7:00 PM on August afternoons. Since peak demand is a critical time to reduce energy, the lower grid stress is a more important finding than the overall greater energy use, so the gains from solar panels are still worthy.

These findings do confirm the attitudes espoused by PV owners in Chapter 5 where 48% of all answers contained evidence of an economic interest. Since most Austin Energy customers do not participate in the utility's time of day pricing pilot, the cost of drawing from the grid during periods of peak demand do not translate into a personal economic experience. Furthermore, some participants specifically mentioned guilt-free afternoon energy in their responses.

Chapter 7: Conclusions

This master's thesis sought to answer the question: What are the environmental, economic, and equity values held by Austin residents and the Austin Energy electric utility concerning solar technology policy, deployment, and use? I evaluated this multi-faceted concept of value through two areas of investigation: the utility perspective and the residential perspective through four research-based chapters succeeding the introduction and literature review. Chapter 1 introduced the research topic, characterizing analysis into solar technology deployment as urgent given the local equity and environmental vulnerability posed by climate change. Chapter 2 reviewed academic literature relating to this research in four areas: ecological accounting, the economics of solar energy, perceptions of and behavior toward solar energy, and literature related to the Pecan Street project.

Chapters 3 and 4 evaluated the utility perspective. In Chapter 3 I provide a brief history of electrification of cities followed by a detailed discussion of the externalities and trade-offs present in fuel sources. I also provide an outline of residential solar programs here. In Chapter 4, I discuss Central Texas utilities and my conversations with CPS Energy and Austin Energy.

Chapters 5 and 6 evaluated residential surveys and energy usage data. Together, these areas of analysis formed a rounded exploratory portrait of the value of residential solar electricity in Austin, Texas. Chapter 5 featured a qualitative analysis of survey data coded according to the environmental, economic, and social values present in each response. Chapter 6 provided an overview of the demographic and energy usage characteristics of the households who participated in the Chapter 5 survey.

I hypothesized that economic interests dominate environmental interests and that environmental interests dominate social justice and equity interests at the scale of both the utility and the household when it comes to solar residential energy. While I did not predict that this series of dominance would sabotage the pursuit of clean, cheap, and fair electricity, I did posit that an imbalance might limit access to solar technologies and delay the rate of deployment. From the results of this research I believe this to be partially true. While the comparative case study of Austin Energy and CPS Energy showed that consumers are participating in these solar programs at a hefty volume, economic concerns surfaced frequently in the interviews and surveys and conventional energy choices continue to dominate. Residents and the electric utility have an opportunity to capture a social value in the distribution of solar energy resources that could provide more equitable distribution of resources while reducing dependency on fossil fuels.

Recommendations

Increasing Equity in Utility Rebate Structure

This rebate structure of Austin Energy may prioritize high-information, high income residents who can mobilize to purchase and install solar panels more easily than those with affordability concerns. The current rebate structure decreases the amount of money available to customers per watt as time goes on, while reserving most of the total funds for lower rebate price points.

A more just economic model focused on preserving Austin Energy's affordability mandates could change the incentive structure by establishing rebate amounts across a sliding scale based on household income. As the income level of the rebate applicant increases, the rebate per watt would decrease. Because larger houses tend to be occupied by higher income residents, their panel installation could have a greater capacity, which would balance the total amount of funds devoted to rebates. This rate structure would provide a boon to lower income households unable to mobilize for solar installation earlier or unable to afford them because of the prices. A retooling of the rate structure would also coincide nicely with falling solar panel prices, making resilient and carbon-free power sources even more accessible to lower income households.

Increasing Trust

During this research, I discovered several conflicts and tensions in the residential solar industry. Utility employees and survey participants alike noted conflicts with solar contractors and installers, demonstrating a conflict between equity and economy as politically savvy contractors lobby city councils to continue subsidies of their products. Other contractors have been accused of knowingly set up their customers with expensive system and misconstruing the return-on-investment. While the utilities claim to navigate these conflicts on behalf the customers, some survey results indicated a dissatisfaction with the utilities themselves based on changing tariff structures and rebate amounts. Working to build trust and communication across all parties may lead to a better situation that removes friction and facilitates technology deployment without requiring subsidies. Regulating contractor conduct beyond what is required through rebate policy standards may help.

Further Research

A major limitation of this research derives from the non-probability sample of Pecan Street Project data. The data comes from high-income, highly-educated, mostly white households. Low-income households and people of color are not represented in this research, despite their increased vulnerability to climate change. Extending the solar perceptions survey to a wider and more diverse sample would increase its validity and provide a stronger voice to groups historically disenfranchised by city policies. In addition, I do not know the energy use of low-income households and people of color. This research compares high-income PV owners to high-income non-owners. The findings concerning grid electricity usage during peak times among PV owners and non-owners could vary with the inclusion of a more diverse sample.

Finally, I did not tie the economic, social, and environmental interests espoused by each survey participant to their energy use data. The dataset allows further investigation into how individual household interests do or do not translate into energy use and technology adoption.

APPENDICES

Appendix A: Austin Energy Data

Table 23: Austin Energy Residential Customer Data, 2006 - 2014

Customer Class	Fiscal Year	Number of Customers	Revenue	Percentage of Revenue	Cents per kWh	Percentage of MWh
Residential	2006	338,184	$387,540,000	41%	9.499	36%
Residential	2007	345,197	$356,143,000	39%	9.112	35%
Residential	2008	352,574	$416,809,000	39%	9.863	35%
Residential	2009	363,217	$406,393,000	39%	9.633	35%
Residential	2010	368,700	$407,074,000	39%	9.604	35%
Residential	2011	372,329	$457,262,000	40%	10.024	36%
Residential	2012	376,614	$422,195,183	39%	9.637	34%
Residential	2013	383,257	$458,657,021	39%	11.019	34%
Residential	2014	391,410	$487,165,010	38.91%	11.334	30.76%

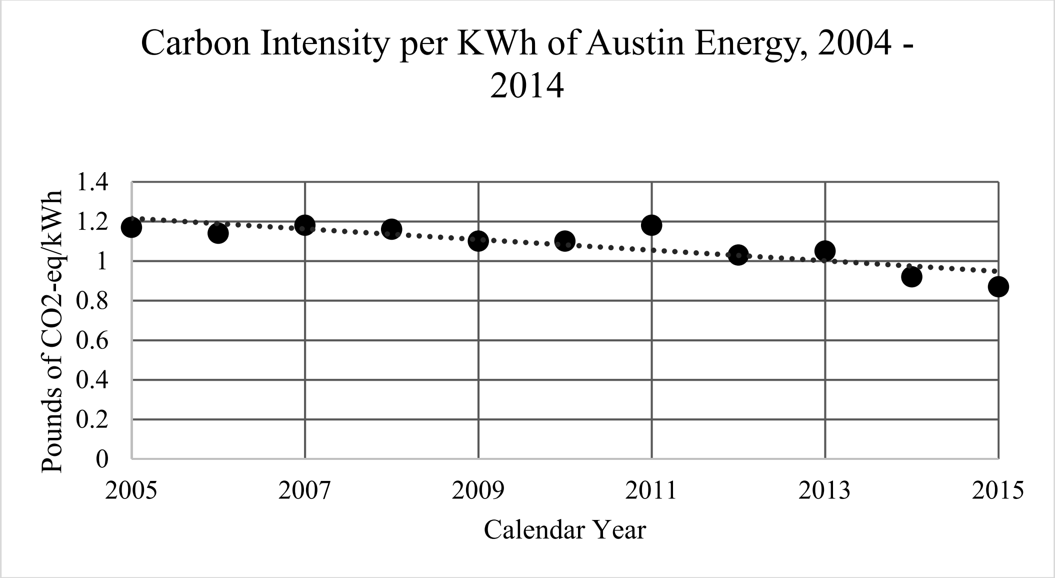
Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Austin-Energy-Customer-Data-by-Customer-Class-2006/9xdm-yhmb

Table 24: Percent Change in Austin Energy Residential Customers, Revenue, and Prices, 2006 - 2014

Customers	Revenue	Percentage of Revenue	Cents per kWh	Percentage of Total MWh
16%	26%	-5%	19%	-15%

Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Austin-Energy-Customer-Data-by-Customer-Class-2006/9xdm-yhmb

Figure 10: Austin Energy Carbon Intensity per KWh, 2004 - 2014



Source: City of Austin Open Data Portal, https://data.austintexas.gov/d/hetr-8wqd?category=Utility&view_name=Carbon-Intensity

Table 25: Austin Energy Carbon Intensity per KWh, 2005 - 2014

Calendar Year	**Pounds of CO2-eq/kWh**
2005	1.17
2006	1.14
2007	1.18
2008	1.16
2009	1.1
2010	1.1
2011	1.18
2012	1.03
2013	1.05
2014	0.92
2015	0.87

Source: City of Austin Open Data Portal, https://data.austintexas.gov/d/hetr-8wqd?category=Utility&view_name=Carbon-Intensity

Table 26: Austin Energy Generation Mix, 2006 - 2015

Fiscal Year	Coal	Natural Gas & Oil	Nuclear	Renewable Energy	Purchased Power
2006	29.7%	27.9%	27.3%	5.7%	9.4%
2007	32.2%	27.3%	25.8%	5.1%	9.6%
2008	33.2%	25.7%	27.1%	6.1%	7.9%
2009	28.3%	26.5%	26.4%	9.5%	9.3%
2010	32.5%	22.3%	25.2%	9.7%	10.3%
2011	28.9%	25.8%	21.3%	9.5%	14.5%
2012	27.0%	20.3%	21.9%	15.0%	15.8%
2013	25.9%	15.7%	22.8%	20.7%	14.9%
2014	32.1%	15.3%	26.9%	25.5%	0.0%
2015	27.0%	18.0%	29.0%	26.0%	0.0%

Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Generation-by-Fuel-Type/ss6t-rumq

Table 27: Change in Austin Energy Generation Mixes, 2006 - 2015

Coal	-9%
Natural Gas & Oil	-35%
Nuclear	6%
Renewable Energy	356%
Purchased Power	-100%

Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Generation-by-Fuel-Type/ss6t-rumq

Table 28: Austin Energy Renewable Power Purchase Agreements

Unit Name	**Fuel Type**	**Installed Capacity (MW)**	**Year Installed**	**Expiration Date**	**Location**
Sweetwater 3	Wind	34.5	2005	2017	Nolan, TX
Whirlwind	Wind	59.8	2007	2027	Floyd, TX
Hackberry	Wind	165.6	2008	2023	Shackelford, TX
Whitetail	Wind	92.3	2012	2037	Webb, TX
Los Vientos 2	Wind	201.6	2012	2037	Willacy, TX
Los Vientos 3	Wind	200.0	2015	2040	Starr County, TX
Jumbo Road	Wind	299.7	2015	2033	Castro and Deaf Smith Counties, TX
Los Vientos 4	Wind	200.0	2016	2041	Starr County, TX
Webberbille Solar	Solar	30.0	2011	2036	Travis, TX
Roserock	Solar	157.5	2016	2036	Pecos, TX
East Pecos	Solar	118.5	2017	2031	Pecos, TX
Tessman Road	Landfill Methane	7.8	2002	2017	Bexar, TX
Nacogdoches	Biomass	100.0	2012	2032	Nacogdoches, TX

Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Renewable-Purchase-Power-Agreements/i8ty-ijab

Table 29: Austin Energy Residential Customer Satisfaction, 2006 - 2015

Year	**Satisfaction Rating**
2006	75%
2007	72%
2008	76%
2009	73%
2010	74%
2011	69%
2012	68%
2013	64%
2014	68%
2015	74%

Source: City of Austin Open Data Portal, https://data.austintexas.gov/Utility/Customer-Satisfaction/aw6n-x665

Table 30: Austin Energy Time-of-Use Pricing

Time of Use Periods		
	June - September	October - May
On-Peak Hours		
2:00 PM - 8:00 PM	Monday - Friday	None
Mid-Peak Hours		
6:00 AM - 2:00 PM	Monday - Friday	
8:00 PM - 10:00 PM	Monday - Friday	
6:00 AM - 10:00 PM	Saturday and Sunday	Everyday
Off-Peak Hours		
10:00 PM - 6:00 AM	Everyday	Everyday

Source: City of Austin FY2017 Electric Tariff

Appendix B: Austin Energy and CPS Energy Interview Protocol

Basic Organization/Interviewee Questions

1. What organization do you work for?
2. Is this organization publicly-owned or private?
3. What is your role at [insert organization]?
4. How long have you worked at {organization}?
5. How long have you worked in the solar utility industry?

Role of Solar Energy at Organization

1. How does your role relate to solar PV programs?
2. Briefly, how would you describe the organizational structure of {organization}?
3. What proportion or percentage of resources for your organization would you say are dedicated to solar programs?
4. If solar programs are the minority of operations, what divisions or programs do you think receive the majority of {organization's} resources?

Solar Program Details

1. Can you briefly describe your organization's solar PV programs?
2. What is being accomplished through these programs?
3. Do these programs work? Why or why not?
4. How are these programs financed?
5. What policies, programs, mandates, fees, or grants support these programs? Which of these are generated by customer fees? Which are from outside sources? Which are taxpayer funded?

6. Do you think that these programs receive adequate financial support in terms of government subsidies—federal and state?

Customer Solar PV Financing Questions

1. How do your customers learn about {program}? How do you reach out to customers about the program?
2. How many customers would need to be involved for the program to work? Is there a maximum number of customers who can be served and a scarcity of funds?
3. Who are your target customers? What resources does a customer need to be able to participate? Who is a good fit?
4. How would an interested utility customer participate in {program}? What are the steps?
5. What are the upfront costs to the customer?
6. What are the rebates or incentives available for customers?
7. What are the benefits to the customer of the program? How does their utility bill change?
8. Does the customer encounter any risks? Financial or otherwise?
9. Do you include special considerations for lower income customers?

Benefits and Risks of Solar Expansion

1. How does expanding solar programs help the utility?
2. Hinder the utility?
3. What are your chief concerns about expanding the customer base for distributed solar generation?

4. Do you believe that there are specific policy or financing options that could relieve these concerns?
5. What might be the benefits of expanding access to solar PV programs? For the utility? For the customer?

Public Input/Participation Questions

1. What policies or protocols that encourage or regulate public involvement in how your organization works? For instance, [give example].
2. How do you gauge customer satisfaction in your programs?
3. Do you think the utility customers are satisfied?
4. Which customers are satisfied or dissatisfied?

Appendix C: Pecan Street Project 2014 Survey Protocol and Results

PV SYSTEM QUESTIONS

1. Do you own a rooftop solar photovoltaic panel system?
2. Briefly explain why you decided to acquire a rooftop solar system.
3. How satisfied are you with your solar panel system?
    a. Very Dissatisfied
    b. Somewhat Dissatisfied
    c. Neutral
    d. Very
    e. Very Satisfied
4. What features and/or aspects of your solar panel system do you like the most?
5. What features and/or aspects of your solar panel system do you wish would be changed, eliminated or improved?
6. What features and/or aspects of your solar panel system have surprised you the most based on what your expectations were prior to acquiring your solar panel system?
7. When people ask you about your solar panel system, what are the most common questions they ask?
8. When you tell people about your solar panel system, what do you say?
9. When you answer questions from others about your solar panel system or provide information about your solar panel system, what do you find, if anything, that people are most surprised to learn?

10. Which reasons have factored into why you or other decision makers in your household have not acquired a rooftop solar panel system? (Select all that apply)
    a. Not sure how much I would benefit
    b. Too expensive
    c. Don’t like the way they look
    d. Concerned with how it might affect my home's resale value
    e. Other
    f. None
11. Which of the following factors, if any, do you find appealing about solar panel systems? (Select all that apply)
    a. Independence from the utility
    b. Protection against future utility rate increases
    c. Emission-free electricity
    d. Other
    e. None
12. If you have talked to anyone who has rooftop solar panels, what have they told you?

SURVEY RESPONSES

Question 1: Do you own a rooftop solar photovoltaic panel system?

108 yes, 225 no

Question 2: Briefly explain why you decided to acquire a rooftop solar system

Table 31: Question 2 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
91	16	63
84%	15%	58%
		n = 108

Question 3: How satisfied are you with your solar panel system? (Select one)

Table 32: Question 3 Satisfaction Results

Very Satisfied	**Somewhat Satisfied**	**Neutral**	**Somewhat Dissatisfied**	**Very Dissatisfied**
81	22	2	1	1
76%	21%	2%	1%	1%
				n = 107

Question 4: What features and/or aspects of your solar panel system do you like the most?

Table 33: Question 4 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
32	4	17
30%	4%	16%
		n = 107

Table 34: Question 4 Answer Categories

Total answers indicating:				
Technology and Energy Usage Data	*Low Maintenance*	*Positive or Neutral Aesthetic*	*Negative Aesthetic*	*Frustration with Austin Energy*
28	27	4	5	1
26%	25%	4%	5%	1%
				n = 107

Question 5: What features and/or aspects of your solar panel system do you wish would be changed, eliminated or improved?

Table 35: Question 5 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
19	2	10
18%	2%	9%
		n = 107

Table 36: Question 5 Answer Categories

Total answers indicating:		
Technology/Storage	*Want More*	*Visual*
19	10	2
18%	9%	2%
		n = 107

Question 6: What features and/or aspects of your solar panel system have surprised you the most based on what your expectations were prior to acquiring your solar panel system?

Table 37: Question 6 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
16	3	3
15%	3%	3%
		n = 107

Table 38: Question 6 Answer Categories

Total answers indicating:				
Negative Surprise	*Positive Surprise*	*Education*	*Contractors/Install Process*	*Net metering change at AE*
23	32	11	4	5
21%	30%	10%	4%	5%
n = 107				

Question 7: When people ask you about your solar panel system, what are the most common questions they ask?

Table 39: Question 7 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
90	5	5
84%	5%	5%
n = 107		

Table 40: Question 7 Answer Categories

Total answers indicating:		
Hail	*Installer*	*Net Zero*
5	5	4
5%	5%	4%
n = 107		

Question 8: When you tell people about your solar panel system, what do you say?

Table 41: Question 8 Economic, Social, and Environmental Interest Results

Total answers indicating:		
Economic Interest	*Social Interest*	*Environmental Interest*
63	0	12
59%	0%	11%
n = 107		

Table 42: Question 8 Answer Categories

Total answers indicating:	
Negative (-)	*Positive (+)*
5	61
5%	57%

n = 107

Table 43: Question 8 Economic, Social, and Environmental Interests Results by Category

Breakdown of positive and negative answers						
Negative			*Positive*			
Economic	Social	Environmental	Economic	Social	Environmental	Other
5	0	0	18		5	38
5%	0%	0%	17%	0%	5%	36%
						n = 107

Question 9: When you answer questions from others about your solar panel system or provide information about your solar panel system, what do you find, if anything, that people are most surprised to learn?

Table 44: Question 9 Economic, Social, and Environmental Interest Results by Category

Total answers indicating:				
Economic Interest	*Social Interest*	*Environmental Interest*	*Negative*	*Positive*
65	0	2	11	58
61%	0%	2%	10%	54%
				n = 107

Question 10: Which reasons have factored into why you or other decision makers in your household have not acquired a rooftop solar panel system?

Table 45: Question 10 Answer Categories

Too expensive	**Unsure of benefits**	**Concerned with home value**	**Ugly**	**Other**	**None**

104	53	9	4	72	15
53%	27%	5%	2%	37%	8%
n = 197					
28 of the 225 survey participants without PV panels were removed from this analysis because they did not answer.					

Table 46: Question 10 Number of Negatives Selected

"None" selected	One negative	Two negatives	Three negatives	Four negatives	Five negatives
15	136	36	7	2	1
8%	69%	18%	4%	1%	1%

Question 11: Which of the following factors, if any, do you find appealing about solar panel systems?

Table 47: Question 11 Answer Categories

Independence from Utility	**Emission-free Electricity**	**Protection Against Utility Rate Increases**	**Other**	**None**
157	207	147	28	7
63%	82%	59%	11%	3%
n = 251				
82 participants (both PV owners and not PV owners) dropped due to incompleteness				

Table 48: Question 11 Number of Positives Selected

No Positives Selected	**One Positive Selected**	**Two Positives Selected**	**Three Positives Selected**	**Four Positives Selected**
89	57	75	99	13
35%	23%	30%	39%	5%
n = 251				
82 participants (both PV owners and not PV owners) dropped due to incompleteness				

Table 49: Question 11 Results by PV Owner versus Non-Owner

Respondent Type	**Independence from Utility**	**Emission-free Electricity**	**Protection Against Utility Rate Increases**	**Other**	**None**	**Total Respondents**
PV Owner	24	47	25	15	1	55
PV Owner	44%	85%	45%	27%	2%	51%
Non-PV Owners	133	160	122	28	6	196
Non-PV Owners	68%	82%	62%	14%	3%	77%
All	157	207	147	28	7	251
All	63%	82%	59%	11%	3%	75%

Question 12: If you have talked to anyone who has rooftop solar panels, what have they told you?

Table 50: Question 12 Economic, Social, and Environmental Interest Results by Category

Total answers indicating:				
Economic Interest	*Social Interest*	*Environmental Interest*	*Positive Response*	*Negative Response*
19	2	2	26	7
28%	3%	3%	39%	10%
				n = 67
				26% response rate

Table 51: Question 12 Answers by Category

Total answers indicating:		
Contractors/Installation	*Bad Fit (trees, etc.)*	*Haven't spoken*
2	13	14
3%	19%	21%
		n = 67
		26% response rate

Appendix D: Pecan Street Project Energy Usage Results

Table 52: Peak Energy Use (kWh) for All Households

Peak Energy Use (kwh) for All Households		
	Grid Energy	*Grid + Solar Generation*
Mean	2.64	3.06
Median	2.42	2.79
Mode	2.44	3.09
Standard Deviation	2.29	2.11
Minimum	-6.42	0.00
Maximum	17.82	17.82
Sum	80,858	93,429
Count	30,577	30,577

Table 53: Peak Energy Use (kwh) Per Person for All Households

Peak Energy Use (kwh) Per Person for All Households		
	Grid Energy	*Grid + Solar Generation*
Mean	1.16	1.35
Median	0.98	1.12
Mode	2.15	0.49
Standard Deviation	1.15	1.06
Minimum	-6.20	0.00
Maximum	11.33	11.33
Sum	34,997	40,554
Count	30,067	30,067

Table 54: Peak Energy Use (kwh) for Households with PVs

Peak Energy Use (kwh) for Households with PVs		
	Grid Energy	*Grid + Solar Generation*
Mean	2.47	3.24
Median	2.39	2.99
Mode	1.21	2.92
Standard Deviation	2.32	1.97
Minimum	-6.42	0.07
Maximum	17.82	17.82
Sum	38,448	50,547
Count	15,596	15,596

Table 55: Peak Energy Use (kwh) Per Person for Households with PVs

Peak Energy Use (kwh) Per Person for Households with PVs		
	Grid Energy	*Grid + Solar Generation*
Mean	1.02	1.36
Median	0.92	1.14
Mode	0.16	1.53
Standard Deviation	1.14	0.99
Minimum	-6.20	0.03
Maximum	9.93	10.63
Sum	15,772	21,147
Count	15,520	15,520

Table 56: Peak Energy (kwh) Use for Households without PVs

Peak Energy (kwh) Use for Households without PVs	
	Grid Energy
Mean	2.86
Median	2.49
Mode	4.42
Standard Deviation	2.27
Minimum	-2.42
Maximum	13.34
Sum	40,942
Count	14,303

Table 57: Peak Energy Use (kwh) per Person for Households without PVs

Peak Energy Use (kwh) per Person for Households without PVs	
	Grid Energy
Mean	1.34
Median	1.10
Mode	0.16
Standard Deviation	1.15
Minimum	0.00
Maximum	11.33
Sum	18,612
Count	13,869

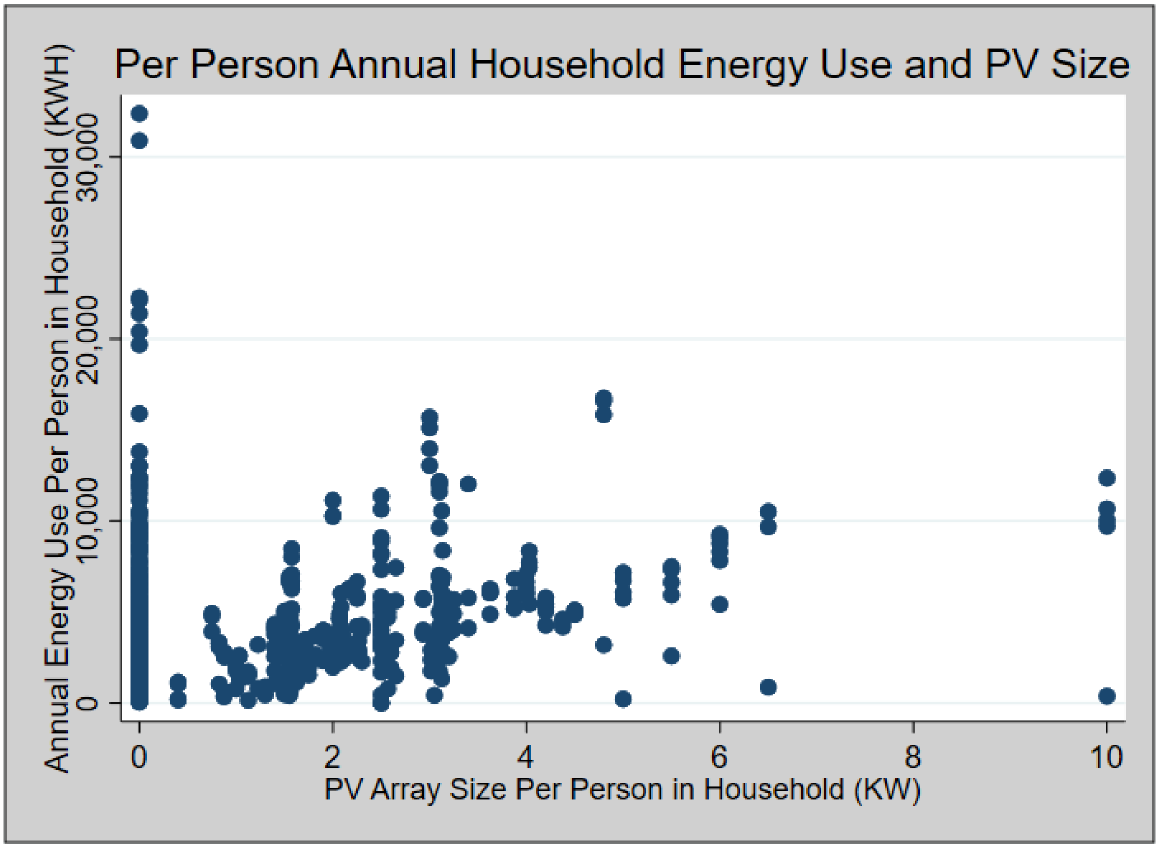


Figure 11: Relationship between PV Array Size per Person and Annual Energy Use per Person in Each Household

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