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Residential solar in Washington State

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RESIDENTIAL SOLAR UPTAKE IN WASHINGTON STATE

A Thesis

Presented to

The Graduate Faculty

Central Washington University

In Partial Fulfillment

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Master of Science

Cultural and Environmental Resource Management

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by

Samuel Edward Pfeifer

May 2018

CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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ABSTRACT

RESIDENTIAL SOLAR UPTAKE IN WASHINGTON STATE

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Electricity generated through residential solar provides a low carbon source of electricity. However, diffusion of residential solar remains low across the United States. Growing this diffusion takes an understanding of localized uptake trends, which can focus policy and business efforts to help increase residential solar market penetration. This is the first research to investigate residential solar uptake in Washington State and to examine environmental education as a potential driver of residential solar uptake. Through a snapshot analysis which considers environmental, economic, education, and cultural variables the present research fills this gap. Triangulated results include mapping of variables, ordinary-least squares multiple variable regression, and an ethnography (n = 40). Relative strength of Environmental Education was ascertained through a survey of K-12 Washington Public School Principals (n = 139). Results identified a strong disparity between the liberal/urban Western Washington and the conservative/rural Eastern Washington. Degree of awareness of residential solar emerged as the primary qualitative result driving uptake, and can also be used to explain many of the statistical correlations. Marketing and awareness campaigns targeted at overcome low solar knowledge are likely the most cost effective ways of growing residential solar in Washington State.

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CHAPTER 1

INTRODUCTION

Problem

In an era defined by the struggle against anthropogenic climate change and with consistent rhetoric championing national energy independence, solar energy has emerged as one of the most affordable and universally abundant sources of renewable energy (IPCC, 2011; DoE, 2016b). Since 2008, solar energy production has grown 17-fold in the United States, and the renewable energy sector now domestically employs more people than gas and oil combined (DoE, 2016b). However, as of 2016, solar energy still accounted for only about 0.6 percent of US energy production despite having enough potential to contribute 69 percent of US electricity demand (Fthenakis, Mason, and Zwiebel, 2009; US EIA, 2016a). Overall, production continues to increase and solar as a whole accounted for 60 percent of new electricity generating capacity in the US during the third quarter of 2016 (SEIA, 2016). That being said, growth of residential scale solar (e.g., rooftop solar panels) is slowing down, and expanding residential solar uptake beyond early adopters is a key concern in the industry (SEIA, 2016; Swift, 2013).

Residential solar refers to customer-sited photovoltaic solar arrays (Figure 1). Currently, they cost on average between $10,000 and $30,000 per typical household (Solar Power Authority, 2016). Solar technology has been available since the 1970s but has only recently dropped in price enough, due to technology improvements and governmental support, to bring it into common use (Barbose et al. 2017). Due to state and federal incentives, this upfront investment can be paid off in as little as 3-10 years after which the arrays make their owners money for the rest of their 25-30 year lifespan (Solar

Power Authority, 2016). Both personal loans and personal investments are common sources of up front financing. Depending on the season, panels in Washington can generate all the electricity needs of the average household, with sometimes more to spare. Despite this seemingly economically beneficial calculus, diffusion of residential solar remains slow in the US (Swift, 2013).

Figure 1: Residential solar. An example of solar panels on a residential roof (Pixabay, 2018).

Much research has investigated factors that influence rates of residential solar uptake (e.g., Zahran et al. 2008; Schelly, 2014; Steward et al. 2014; Robinson and Rai, 2015). State incentive structure, personal income, electricity price, solar insolation, political affiliation, installed base and attitude have all been identified as factors influencing residential solar uptake (Zahran et al. 2008; Steward et al. 2014; Chernyakhovskiy, 2015; Robinson and Rai, 2015; Graziano and Gillingham, 2015). Still the diffusion process and obstacles to more rapid adoption remained only partially understood and calls for further investigation into private solar uptake have been made by both policymakers and academics (Güler, Pinar and Afacan, 2013; Inslee, 2014; UNDP, 2016; DoE 2016b).

One promising avenue for new research is the role of attitude, which captures how likely an agent is to seek out and believe information regarding residential solar (Schelly, 2014; Chernyakhovskiy, 2015). Our understanding of what conditions shape an agent's (i.e. a homeowner's) attitude is incomplete. A potential cause of pro-solar attitude may be local public education. Research has established a link between education and attitude regarding pro-environmental behavior (Zelezny, 1999; Bonnett, 2002; Leeuw et al. 2015). However, no work has attempted to include education as a factor in residential solar uptake patterns.

Additionally, most previous research into residential solar uptake has focused on states with high uptake such as California (Mai, 2013), Connecticut (Graziano and Gillingham, 2015), and Texas (Robinson and Rai, 2015). Yet if the share of solar in the US energy mix is to rise towards its potential, more must be done in low-uptake states.

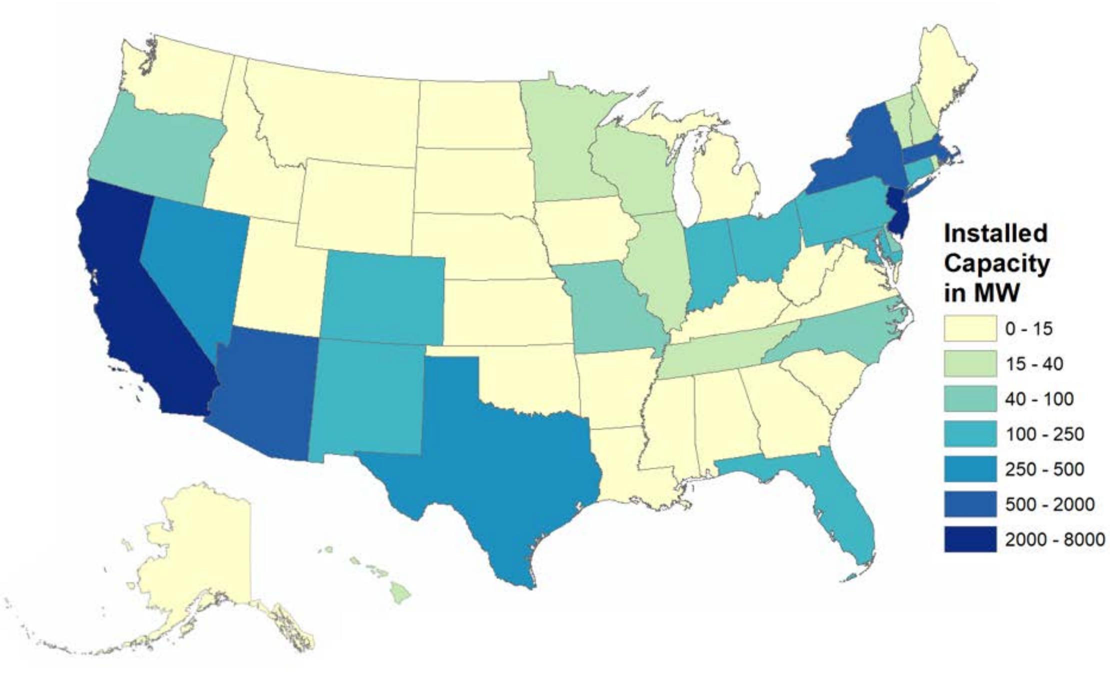

Figure 2: Solar capacity by state. Installed solar capacity by state in MW. From https://openpv.nrel.gov/rankings (NREL, 2018).

Accordingly, Washington is an appropriate focus for further research because it ranks quite poorly (39rd) in installed photovoltaic systems and therefore has massive upward potential (NREL, 2018, Figure 2). Washington State University (2014) partly attributed this low rank to Washington's incentive structure, which requires that residents front significant investments (WSU, 2014). While changing the laws governing solar incentives presents a difficult challenge, directing attention to underserved Washington populations could facilitate growth. Washington's state legislature identified residential solar as important more than a decade ago (WA Legislature, 2005); yet few studies have focused on understanding the factors and trends that shape Washington's solar uptake.

Purpose

This research is an in-depth analysis of private solar energy uptake in Washington State using both quantitative and qualitative methods. For the first time, education is examined as a potential variable influencing residential solar uptake. Specifically, the goal of this research is to answer the following questions:

1. What is the geography of residential solar installations across Washington State?
2. What factors explain the spatial variation in residential solar? The examination of education variables and the identification of features unique to Washington are central to answering this question.
3. How do households make decisions about whether or not to adopt and invest in this technology?
4. What recommendations for policy makers and business leaders can be produced from this research to increase the likelihood of private solar energy installations in Washington State?

Geographic analysis, statistical analysis, and interviews were conducted to answer these questions. First, GIS analysis was conducted using Esri's ArcGIS, revealing spatially grounded relationships and patterns (Esri, 2016). Second, statistical analysis was conducted in R and includes ordinary least squares regression to explain spatial variation in the distribution of residential solar systems (R Core Team, 2017). While inspired in part by similar analyses done in other states, this is the first analysis of residential solar adoption to include education variables. As no comprehensive dataset exists for strength of environmental education, a statewide survey of K-12 principals was conducted. Third, interviews were conducted in three locations whose rates of residential solar technology adoption were significantly over-predicted, significantly under-predicted, and accurately predicted by the regression modeling. This set of study areas allowed for what amounts to partial ground-truthing of the statistical results.

The results of the study are also analyzed using the theoretical frameworks of the theory of planned behavior and diffusion of innovation theory. These theories, as they apply to residential solar, are further outlined in the literature review. This step permits further development of a residential solar adoption framework as proposed by Wolske, Stern, and Dietz (2017). By improving conceptual understanding of pathways to residential solar adoption, greater efficiency is possible in understanding this environmentally friendly phenomena.

The combination of GIS analysis, statistical analysis, and the interviews allow for the triangulation of methods to generate recommendations, which are intended to inform public policy and business decisions.

Significance

Washington State’s energy portfolio standards call for 15 percent of electricity to be generated by non-hydro-renewable sources by 2020 (WA Legislature, 2007). However, as of October 2016, only 9.7 percent of Washington’s energy fell into this category (US EIA, 2016a). One roadblock to growing this percentage is the public pushback produced by utility-scale solar (Pasqualetti, 2011; Larson and Krannich, 2016). For example, the Iron Horse Solar Farm in Kittitas County, which would have been Washington's largest solar farm, was denied a conditional use permit due to public outcry (Buhr, 2016; Buhr, 2017). Residential solar, on the other hand, offers a politically palatable way to increase renewable energy in Washington.

Currently, Washington State’s electricity demands are 70 percent met by hydropower (Institute for Energy Research, 2010). While this source of energy certainly emits less carbon than coal or natural gas, it is not without drawbacks. Salmon and other natural resources are significantly impacted by the alteration caused by both the dams themselves and the turbines used to generate electricity (Hatten et al. 2015). More solar energy could mean more water dedicated to salmon, other important species, and to irrigation efforts.

Growing solar in Washington, especially beyond early adopters, requires an understanding of current adoption patterns that have driven Washington residents to adopt, or not to adopt, private solar energy. With this knowledge, marketing, communication, and business practices may be adapted to encourage further residential solar diffusion (Steward et al. 2014; Doris and Chavez, 2015).

Washington State’s dedication to customer sited solar was reaffirmed during the course of this study. In July 2017, the Washington State Legislature dedicated $110 million in taxpayer dollars to a new solar incentive program. The new Renewable Energy Cost Recovery Program is designed as a continuation of a similar program first instituted in 2005. This financial investment further increases the importance of identifying the places and people not responding to state solar incentives.

Furthermore, this research attempts to examine the potential role of K-12 education in fostering a culture compatible with residential solar uptake. Investigation into this link continues a rich line of research attempting to understand the connection between education and behavior (Zelezny, 1999; Bonnett, 2002; Leeuw et al. 2015). Specifically, this research adds education to a technology adoption behavior model. Understanding the relationship between education and pro-environmental consumer behavior has implications for education funding, marketing practices, and state environmental incentives.

Finally, this study is the first to investigate the uneven geographical distribution of residential solar energy in a state with relatively low uptake. Using multiple methods of analysis, this work examines the factors shaping the adoption of residential solar technology in Washington State, which, a state with significant potential for further solar growth.

CHAPTER 2

LITERATURE REVIEW

Residential Solar

Residential solar photovoltaic systems have emerged as a potentially expedient way to grow solar across Washington State and the US. This expediency stems from several aspects unique to residential solar photovoltaic systems. First, residential solar in general reduces transmission burdens on often ageing grid structures (Brewer et al. 2015; Pitt and Michaud, 2015). Second, due to high electricity output and lower cost, photovoltaic systems are a clear favorite over concentrated systems (which concentrate solar energy using a system of mirrors) (Wong, Royapoor and Chan, 2016). Third, residential solar systems contrast to utility-scale energy systems not only in size, but also in the degree to which they are not met with public pushback in the form of litigation and grassroots campaigning (Pasqualetti, 2011; Larson and Krannich, 2016). This resistance materializes despite nationwide general support for utility-scale solar and is a classic not-in-my-backyard (NIMBY) situation (Larson and Krannich, 2016). These NIMBY sentiments stem primarily from locals who see utility-scale energy as providing little local benefit while creating a distasteful change of scenery (Pasqualetti, 2011). Private solar panels, on the other hand, confer direct financial benefits to their owners and seem to generate little to no negative sentiments (Borenstein, 2015). Additionally, life-cycle assessments demonstrate that photovoltaic solar greatly reduces carbon output compared to conventional sources (Hertwich et al. 2015). Therefore, understanding residential solar uptake is important to growing low carbon energy sources. Despite all this there has been uneven adoption of residential solar across the United States (Steward et al. 2014).

While most regularly toted as low carbon and environmentally friendly, it is important to note that residential solar has negative and solar in general, requires a change in resource extraction. This change is associated with negative impacts as the result of mining and other activities (Hertwich et al. 2015; Evans, Sterzov, and Evans, 2009). This is an example of a regressive climate change mitigation effort, which often impact low income sections of society the most (Büchs, Bardsley, and Duwe, 2011). These negative impacts include worker exposer to the toxic cadmium telluride (a component of thin film solar) in Malaysia and dumping of silicon tetrachloride waste in farmer's fields in China (Mulvaney, 2013). A fair consideration of solar requires conceptualizing solar appropriately in the energy-society relationship as a low carbon source of energy that nevertheless produces far reaching cultural, economic, and environmental impacts (Calvert and Simandan, 2010; Calvert, 2016).

Furthermore, residential solar, and solar in general, is not the end all be all of electricity generation. That is to say, solar only produces electricity when the sun shines, but society takes advantage of ample electric resources during the night (Mulvaney, 2013). By generating personal energy residential solar panels take away from revenue once dedicated to maintaining the grid (Brown and Sappington, 2016; Ranalli et al. 2016). Solar technology therefore needs to be paired with either ample battery systems, a smarter grid, and/or alternative sources of electricity to fully meet society's needs (Mulvaney, 2013). That being said, residential solar energy has not yet come into wide enough use in Washington for reports of these problems to surface. Despite these drawbacks, and future issues, solar remains a low carbon source of energy that has attracted ample research from many angles.

Incentives and Economics of Solar

As solar incentives are offered by the federal and state governments, a mosaic of incentive conditions exist across the United States (Steward et al. 2014; Lee et al. 2017). These incentives come in a wide variety of forms ranging from upfront cash rebates, to tax incentives, to production incentives, and even to third party ownership (Steward et al. 2014; Swift, 2013). The effectiveness of these incentives not only shifts based on their ability to mitigate the significant upfront cost (average between $10,000- $30,000) for residential solar but also based on state electricity prices, and solar insolation (Swift, 2013; Barbose et al. 2017). Simply put, these incentives have dropped payback periods for solar to as low as 3-10 years (Solar Power Authority, 2016).

Given the significant upfront cost, it is not surprising that economics, and therefore incentives, have emerged as the most important factor governing residential solar uptake (Krasko and Doris, 2013; Steward et al. 2014; Robinson, and Rai, 2015; Lee et al. 2017). Among possible economic incentives, feed-in-tariffs are cited as one of the most effective tactics for encouraging solar uptake (Solangi et al. 2011; Bird, Reger, and Heeter, 2012). Feed-in-tariffs pay panel owners based on panel electricity production and have been identified as the incentive responsible for up to half of global solar installations (Solangi et al. 2011). Net-metering, through which utilities pay a homeowner the retail price for all electricity produced above the level at which the household consumes, is a similar incentive. A different element of the incentive structures in certain states, such as in California, allows for third party ownership of residentially sited solar (Strupeit and Palm, 2016). In this model companies lease roof space and cover all or some of the initial investment. Third party ownership has led to significant increases in total photovoltaic output in the US (Strupeit and Palm, 2016). Other research argues that many concurrent policies (e.g. feed-in-tariffs, net-metering, manufacturing tax incentives etc.), rather than any one incentive type alone, have shown the most consistent results in encouraging private solar uptake (Timilsina, Kurdgelashvili, and Narbel, 2012; Steward et al. 2014).

While policy type is important, research also shows that consumer trust in solar policy consistency and duration strengthens uptake and can be fostered through clear communication between policymakers and individuals (Bird, Reger, and Heeter 2012; Steward et al. 2014). Steward et al. (2014) conducted a state-by-state investigation into the effectiveness of state policies encouraging residential solar installations. Overall, results of this work highlight the importance of policy longevity as a means of increasing consumer trust and therefore uptake. Four groups of states were used as units of analysis in the study. States were categorized by median income, estimated technical potential for rooftop photovoltaics (PV), average electricity price, and the American Council for an Energy Efficient Economy Energy Efficiency Scorecard score (Steward et al. 2014). (Washington State was grouped in a category expected to lead the country in solar installations.) No matter the group, length of incentives consistently correlated with higher residential solar uptake (Steward et al. 2014). Longer incentives equate to longer periods to recoup residential solar investment and more time to actually earn money on systems. This result demonstrates that residential solar remains a financially driven market. Additionally, Steward et al. (2014) hypothesize that policy longevity fosters greater overall confidence. This all situates residential solar as an innovative and novel technology still in the process of earning consumer trust.

Despite the myriad efforts of state and federal government agencies, whether incentives in the US have in fact positioned residential solar as a sound investment remains up for debate (Swift, 2013). For instance, Lee et al. (2017) recently conducted an economic analysis of the feasibility of residential solar. The study analyzed the largest city from each state and the District of Columbia. Using solar radiation, electricity price, and state solar incentives, the profitability index and payback period were calculated for each city. Residential solar emerged as a wise economic decision in only 18 of the 51 cities analyzed. In Seattle, a residential solar investment in 2017 was determined to cost $9,000 in net present value (Lee et al. 2017). This result highly contradicts the popular opinion that residential solar is competitive with conventional energy sources, but is supported by some academic literature (Swift, 2013; Timilsina, Kurdgelashvili, and Narbel, 2012). These type of analyses only capture a snapshot of conditions. For instance, Lee et al. (2017), by only investigating cities, leaves out the majority of the actual potential solar sites. Further, as PV prices drop, as incentives change, and as electricity prices fluctuate, the local economic feasibility of residential solar remains in flux. Solar feasibility therefore may shift significantly from year to year and from place to place. In fact, since the publication of Lee et al. (2017) additional incentives were passed in Washington State. Partly because of those incentives and perhaps because conditions around the state vary widely from those in Seattle (the only place in Washington examined by Lee et al.) the solar industry bills a $30,000 investment into solar as a good investment (Ellensburg Solar, 2018; EnergySage, 2018). According to these latter sources, residential solar can save a resident of Washington over $8,000 in nominal terms over the course of 20 years (EnergySage, 2018). These seemingly contradictory results between scholarly and professional sources is partially the result of nominal vs net-present value calculation techniques. That is to say, a good nominal investment may actually be a bad investment in terms of net-present value and vice versa (Calculate Stuff, 2018).

Locally, Washington PV costs are the 5th lowest in the nation due to a suite of incentives (NREL, 2018). First, there is a 30 percent federal tax rebate offered on all expenditures for residential solar panel installation and purchasing, which will start incrementally decreasing after 2019 (DoE, 2016a). Locally, Washington State guarantees net-metering, in which utilities pay solar panel owners for excess electricity generated, and charges no sales tax for small solar installations (WA Legislature, 2016; WA DoR, 2013). Washington also offers a feed-in-tariff, through the Renewable Energy Cost Recovery Program, which pays per kilowatt-hour (kWh) produced based on a sliding scale that incentivizes panel purchased from Washington manufactures (WA Legislature, 2005). The original law was passed in 2005 and is set to expire in 2020. However, an amended version of the law, titled the Solar Jobs Bill, was instated as of July 1, 2017 making the incentives good through 2029 (WA Legislature, 2017). Despite this suite of incentives Washington ranks 39rd in the US total installed PV capacity, a discrepancy this research aims to reconcile (NREL, 2018).

This low ranking can be partially attributed to local electricity prices. Washington State has one of the lowest electricity rates in the country (Institute for Energy Research, 2010). Prices range from 2.95 cents/kWh in Douglas County to 13.31 cents/kWh in San Juan County (US EIA, 2016b). These low prices are due to the ample hydroelectric resources across the state, which supply Washington with 70.7 percent of its electricity

(Institute for Energy Research, 2010). Utility suppliers near the Columbia River dams, an area that coincides with the highest solar insolation, offer the lowest residential electricity prices (US EIA, 2016b).

Non-Economic Factors

In addition to economics, non-monetary factors have also been shown to affect residential solar uptake (Brody, Grover, and Vedlitz, 2012; Zahran et al. 2008; Steward et al. 2014; Schelly, 2014; Graziano and Gillingham, 2015, Robinson and Rai, 2015; Rai and Beck, 2015). For example, Robinson and Rai (2015) compared real residential solar uptake in Austin, Texas to results of an agent-based model in which economic and non-economic (e.g., attitudinal) factors were combined. Their methods worked with a rich local dataset and social interaction modeling. Impressively, their complete model accounted for 86 percent of household level spatial variations (location of homes that adopted) and 81 percent of home price variation in uptake within Austin. Home price variation means that their model predicted, at a rate of 81 percent, the value of homes which installed solar. The same model run using only economic indicators did a very effective job of modeling overall uptake rates (Robinson and Rai, 2014). However, the economic only model accounted for 55 percent of spatial variation and 74 percent of home price variation (Robinson and Rai, 2015). These results highlight economics as an effective way to understand broad uptake trends but insufficient when attempting to explain more fine scale behavior. Therefore, understanding residential solar diffusion requires the inclusion of non-economic factors.

One of these factors has emerged as personal politics. Research indicates that US counties which align with the Democratic Party are more likely to adopt residential solar

(Zahran et al. 2008). A potential cause of this trend can be seen in research investigating Americans' attitudes toward climate change and environmentally friendly action. For example, Brody, Grover and Vedlitz (2012) conducted a multiple variable regression using national phone survey responses. Their results show that people who perceive climate change to be a threat are more willing to change behavior to mitigate climate change than those who see climate change as benign or false. Additionally, Hamilton (2011), in a phone survey of Michigan and New Hampshire residents, demonstrated that Democrats are more likely to exhibit concern over the threat of climate change than Republicans in the same demographic position. Residential solar energy, as an alternative to fossil fuels, has been demonstrated as a low carbon source of energy (Hertwich et al. 2015), and the adoption of solar is commonly regarded as environmentally conscious. These results, taken with the Democratic Party's platform of climate change mitigation, seem to explain the results of Zahran et al. (2008) well.

However, in interviews of early adopters in Wisconsin, Schelly (2014) found that individuals from a broad political spectrum adopted solar. In fact, many researchers choose not to include political affiliation but rather focus on attitude, norms, and neighbor effects as a means of understanding residential solar adoption (Robinson and Rai, 2015; Rai and Beck, 2015; Graziano and Gillingham, 2015). In recent work on the subject, Graziano and Gillingham (2015) modeled residential solar uptake in Connecticut using spatial time-series analysis. Their results indicate that neighbor effects may have primacy in shaping an individual's propensity for adoption. In Connecticut, geographically central locations would first emerge as original adopters, and then adoption would spread out across the state from those locations (Graziano and

Gillingham, 2015). These results mirror findings of novel technology diffusion research which indicate that when neighbors adopt a technology, the perceived risk of adopting that technology drops (Graziano and Gillingham, 2015). Of additional note is the locus of germination for the adoption patterns identified by Graziano and Gillingham (2015). Unlike in typical novel technology adoption, the countryside, rather than the city, was identified as adopting solar first. Graziano and Gillingham (2015) hypothesize that the greater concentration of homeowners and single-family homes in the country explains this shift. Due to the payback period of 3-10 years and the continued money to be made from systems after recouping the initial investment, homeowners stand much more to gain than more transient populations. In total, these results highlight the importance of accounting for neighbor effects, homeownership, and political affiliation in understanding residential solar uptake patterns.

Locally, Washington has a positive political environment for private solar energy (Inslee, 2014). In 2014, Governor Jay Inslee issued an executive order that highlights the state’s commitment to funding and supporting renewable energy (Inslee, 2014). His 2016 re-election seems to bode well for continued gubernatorial support of private solar uptake. Additionally, Washington has voted for the Democratic presidential candidate since 1988 despite there being a split in the legislative houses between Republicans and Democrats. However, a study of the social and cultural norms governing solar in Washington State has not been conducted. Likewise, the importance of neighbor effects and homeownership patterns has not been evaluated in Washington.

Behavioral Theory

To date, work by Wolske, Stern, and Dietz (2017) is the only major attempt at situating residential solar in any of the prevailing behavior theories. Rather than proposing a primary theory, these researchers work under the premise that the theory of planned behavior, the diffusion of innovation theory, and the value-belief-norm theory all help to partially explain residential solar uptake (Wolske, Stern, and Dietz, 2017). They test this hypothesis through 1,156 surveys of non-adopters in four high-adopting US states. Rather than testing for specific residential solar adoption they use likelihood of contacting solar installers (solar interest) as their dependent variable. Using statistical analysis of the survey responses and control for demographic variables, the researchers are able to pinpoint concepts in each behavioral theory that specifically correlate solar interest and to calculate the effectiveness of each theory at explaining total interest.

The theory of planned behavior states that attitude, subjective norms, and perceived behavioral control combine to form an agent's intentions, and then behavior. Under this theory, two factors emerged as particularly significant predictors of solar interest. The first of these is belief in personal benefit from solar, categorized under attitude. Once again, this result supports the importance of economics to residential solar. The second significant factor is subjective norms, or what people believe others would think about their decision to adopt solar. This result both neatly supports the theory of planned behavior and corroborates the importance of neighbor effects in residential solar uptake. Overall, the theory of planned behavior accounted for 29 percent of the variation in solar interest.

The diffusion of innovation theory centers on new technology and how humans relate to, and come to trust it. Put simply, knowledge of a technology leads to a period of persuasion, the decision to adopt, implementation of the technology, and finally confirmation of the technology's effectiveness. Not surprisingly, personal innovativeness and novelty-seeking emerged as key characteristics in solar interest. Relative perceived advantage of solar emerged as the most important technological characteristic leading to solar interest. Trust in solar companies and observability of solar on others' homes both also aided in the persuasion step as well. Furthermore, the diffusion of innovation theory highlights consumer innovativeness a prior condition necessary for early adopters to decide to opt for a technology. Overall, the diffusion of innovation theory accounted for 31 percent of total solar interest.

The final theory discussed in Wolske, Stern, and Dietz (2017) is the value-belief-norm theory. This somewhat more complex theory combines altruism, self-interest, traditionalism, and openness to change to represent a person's values. Beliefs are created through one's ecological worldview, awareness of consequences, and ascription of responsibility. And beliefs and values combine to generate norms. For values, self-interest and altruism emerged as significant and positive in shaping solar interest. Awareness of consequences was the only significant, and positive, belief indicator. And norms also had significant effect on solar interest. This theory explained 11 percent of solar interest.

Overall, these results show residential solar to still be a novel technology whose adoption is strongly influenced by neighbor effects and whether a person believes solar will benefit them. Additionally, the writers call for further work into refining the theory surrounding residential solar uptake in order for greater academic understanding and more consistent terminology around this environmentally friendly behavior (Wolske, Stern, and Dietz, 2017).

Environmental Education as an Uptake Factor

A potential additional barrier to adoption is the level of perceived control as directly linked to quality and amount of knowledge regarding residential solar benefits (Rai and Beck, 2015). This knowledge is readily available online and from local solar installers. Whether an actor seeks out this information partially stems from their environmental concern and personal norms/attitude (Rai and Beck, 2015). Norms and attitudes regarding pro-environmental activity have been shown to be influenced through environmental education (Leeuw et al. 2015; Ajzen et al. 2011).

That being said, the existence of a connection between environmental education and pro-environmental behavior is implied through environmental education and residential solar research. First, it is argued that information alone is often not enough to influence behavior, but rather combines with attitude to influence behavior (Bonnett, 2002; Guler, Pinar and Afacan, 2013; Leeuw et al. 2015). For instance, energy-related research has found that culture, rather than policy, economics, or information access alone, influences consumer decisions (Faiers, Cook and Neame, 2007; Steward et al. 2014). Attitude is then argued to be influenced partially by educational experience (Bonnett, 2002; Leeuw et al. 2015). For example, Leeuw et al. (2014) demonstrated that students able to engage in pro-environmental behavior in an educational setting develop a more positive pro-environmental attitude. Furthermore, Zelezny (1999), in a meta-analysis, identified that classroom settings are far more likely to produce pro-environmental attitude than non-classroom educational settings.

Research highlighting the influence that children have on their parent's purchasing decisions (Brown and Venkatesh, 2005) extends the importance of environmental education from the classroom to the home. These studies find that children are most likely to encourage adoption of items they either use or are familiar with including novel technologies such as PCs and the internet (Brown and Venkatesh, 2005; Correa et al. 2015). Both technology adoption research and environmental education research call for further exploration of the potential connection between environmental education and behavior (Moloney, Horne and Fien, 2010; Cotton, Shiel, and Paço, 2016).

Chapman (2014) measured variability in environmental education through a national education survey of educators. Shortcomings in environmental education include unevenly distributed funding (which results in better environmental education for financially better-off schools) and educators who feel more pressure to teach to standardized tests than to environmental education requirements (Chapman, 2014). School principals passionate about environmental education and schools with multiple lines of environmental education (e.g., curriculum, green buildings, environmental clubs, etc.) emerged as having the strongest environmental education programs (Chapman, 2014).

Locally, Washington State law guarantees environmental education for all K-12 students (Wheeler and Ruskey, 2011). The guidelines require wide understanding of the "interconnections and interdependency of ecological, social, and economic systems" but do not explicitly address sustainable energy (Wheeler and Ruskey, 2011). However, state research demonstrates that access to environmental education is variable across state school districts (Wheeler et al. 2007; Wheeler and Ruskey, 2011). Whether environmental education, within this variable setting, fosters a local culture favorable towards private solar uptake has not yet been demonstrated or tested anywhere in the US.

Triangulation

The literature summarized above presents some contradictory findings in what ultimately motivates residential solar uptake (Zahran et al. 2008; Schelly, 2014; Steward et al. 2014). A potential way to reconcile these differences is through the triangulation of techniques (Johnson and Onwuegbuzie, 2004; Fielding, 2012; Creswell and Creswell, 2005). During the 1960s and 1970s triangulation, sometimes called mixed-methods, gained support due to the belief that qualitative and quantitative methods should be viewed as complementary techniques rather than disparate paradigms of thought (Jick, 1979; Creswell and Creswell, 2005). This applied view allows for the combination of multiple sources of analysis into a synthesized picture. Analysis of this type produces more robust results and a deeper understanding of phenomena as compared to a single method approach (Jick, 1979).

Scholars argue triangulation allows for the strengths of one method to counteract the weaknesses of the other methods (Jick, 1979; Johnson and Onwuegbuzie, 2004; Fielding, 2012). For example, a weakness of quantitative methods is the reliance on variables chosen by the researcher, which can lead to confirmation bias, while strengths are the large sample size and ability to statistically test relationships (Johnson and Onwuegbuzie, 2004). On the other hand, qualitative methods have a small sample size, do not offer the chance for rigorous statistics, but have less danger of confirmation bias clouding results (Johnson and Onwuegbuzie, 2004). To date no research has examined residential solar uptake by triangulating qualitative and quantitative techniques in the same study.

Summary

This review of the literature reveals finding on residential solar uptake which highlight the importance and impact of both cultural and economic variables. The diversity of the above results highlights triangulation of methods as a potentially proficient way to further our knowledge of residential solar uptake. To aid in informing local policy decisions, many researchers call for further analysis into residential solar uptake that includes additional variables, such as environmental education, and different scales of analysis, such as focused case studies (Wheeler et al. 2007; Zahran et al. 2008; Robinson and Rai, 2015). Additionally, Washington has established specific goals regarding renewable energy output and Governor Inslee has stated his commitment to solar (WA Legislature, 2007; Inslee, 2014). Given these goals, a more complete understanding of the trends of solar uptake in Washington would be very useful information to local lawmakers and business professionals (Hess, Mai and Brown, 2016). To shape such an understanding, methods are required that have the power to consider the multiple variables discussed above while simultaneously corroborating any patterns that are found through multiple lines of evidence.

CHAPTER 3

METHODS

In order to generate a triangulated understanding of residential solar uptake in Washington State, the methods for this paper proceed in multiple parts. First, the data listed in Table 1 was collected though archival and survey work. These variables were chosen as they were indicated as important to residential solar uptake though literature review. After data collection, variables were visually analyzed through maps using Esri's ArcGIS. These maps provide an effective means of presenting and viewing large amounts of spatially grounded data. Second, following mapping, the data was statistically analyzed using R. Ordinary least squares regression analysis identified independent variables that exert significant impact on residential solar uptake. Finally, results of the statistical analysis were ground-truthed though interviews in three locations around the state; namely, the Ellensburg School District, the Lopez Island School District, and the Garfield-Palouse School District. Conducting interviews with homeowners in two school districts that were outliers in the statistical modeling and one well-predicted school district allowed for qualitative understanding of the cultures behind the spatial and statistical results. These multiple methods were then taken as a whole to produce triangulated results.

Data Collection and Processing

The key dependent variable of this study is the number of successful solar applications to the Renewable Energy Cost Recovery Program from 2011-2014. To understand variation in this value, a suite of explanatory variables was identified through literature review. These include environmental, cultural, and economic indicators. In addition, local education metrics were also analyzed as independent variables in the residential solar technology diffusion process.

Data collection occurred mainly through archival work, including public records requests. However, the strength of environmental education was identified by conducting an original survey of K-12 public school principals. All data sources, including shapefile sources, and scales are listed in Table 1.

Successful solar applications to the Renewable Energy Cost Recovery Program (RECRP) were gathered to generate the response variable of the study - solar uptake. The RECRP was first passed by the Washington State Legislature in 2005 and was extended in 2017. This program pays successful applicants up to $0.54/kWh for power produced on their renewable energy systems (WA Legislature, 2005). A public records request was submitted to the Washington State Department of Revenue for data on this program. The request was for address level or zip-code+4-level successful applications by month since the program's 2005 inception. Monthly data at the zip code level was received.

As the RECRP allocated funds on a utility-by-utility basis, the length of fund availability is inconsistent across the state. For instance, Kittitas Public Utility District cut off applications for additional solar incentives in 2015, while many other districts continue to offer solar incentives. Unfortunately, the Department of Revenue did not have a record of utility funding availability in regards to this program. However, the president of Solar Washington, a non-profit dedicated to advancing solar in Washington, had gathered a list of utilities which had run short of funds (Nicol, 2016). The slides from a PowerPoint presentation given my Nicol in 2016, which contained this information, was

Table 1: Summary of data sources

Data	Time Range	Data Source	Scale	Shapefile Source
Solar uptake	2011-2014	Public records request (WA Department of Revenue, 2017)	Zip Code	WA OFM, 2017
Installed base	2005-2010	Public records request (WA Department of Revenue, 2017)	Zip Code	WA OFM, 2017
Average income (Per Capita Income)	2014	American Fact Finder (US Census, 2017)	Block Group	WA OFM, 2017
Percentage owner-occupied homes	2014	American Fact Finder (US Census, 2017)	Block Group	WA OFM, 2017
Percentage minority	2014	American Fact Finder (US Census, 2017)	School District	WA OFM, 2017
Education data	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Strength of environmental education	2016	Self-conducted Qualtrics survey (n = 139)	School District	WA OFM, 2017
Percentage graduated from college	2014	American Fact Finder (US Census, 2017)	School District	WA OFM, 2017
Math standardized test scores (8th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
English standardized test scores (8th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Writing standardized test scores (8th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Reading standardized test scores (8th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Science standardized test scores (10th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Biology standardized test scores (10th grade)	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Graduation rate	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Percentage remediation	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Percentage high school graduates entering college	2014	State Performance Standards (WA OSPI, 2017)	School District	WA OFM, 2017
Solar insolation	2002	National Renewable Energy Laboratory (Perez et al. 2002)	10km	Perez et al. 2002
Electricity price	2015	US Energy Information Association (EIA), 2016	Utility Service Area	WA DOR, 2018; Solar Washington, 2016
Political affiliation	2014	WA Secretary of State, 2017a	Precinct	WA Secretary of State, 2017b
Population	2010 and 2014	American Fact Finder (US Census, 2017)	School District	WA OFM, 2010

Notes: Data sources, data scales, and geographic shapefiles associated with the dependent and response variables of this study.

provided to the researcher by WA DoR (2017). To discover the exact date that funding first ran out, calls were placed to all utilities on this list. The first utility ran out of funding in January 2015. Therefore, to limit the confounding factor of disparate incentives, data from the RECRP program was trimmed to 2005 to 2014. It is important to note that funding for the RECRP was renewed in 2017. Accordingly, the findings of this research should provide insight into the factors affecting uptake in the current and consistent policy environment.

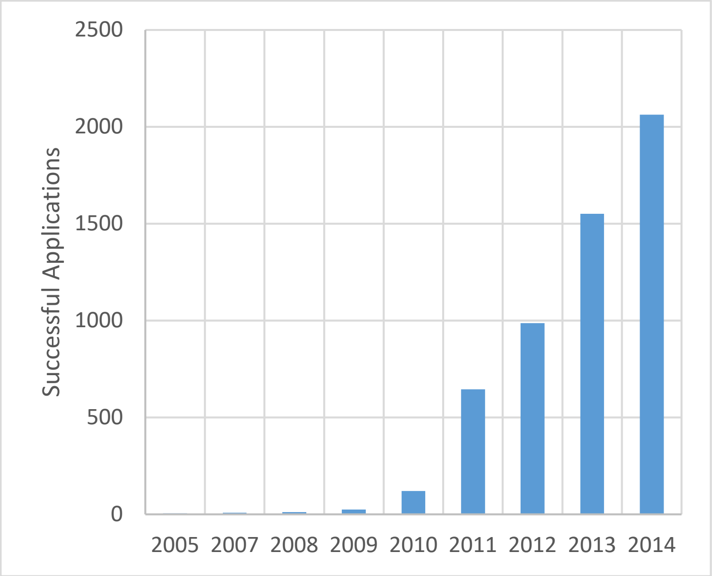

Figure 3: Successful applications per year. This graph shows all successful application to the Renewable Energy Cost Recovery Program from 2005-2014. Displays a total of 167 from 2005-2010, and a total of 5,281 from 2011-2014. These two distinct temporal trends are readily apparent in the above graph (WA DoR, 2017).

The final step taken in preparing the RECRP data was to split the dataset into uptake (2011-2014) and installed base (2005-2010). As discussed in the literature review, previous work has shown that installed base/neighbor effects are major factors shaping residential solar uptake (Graziano and Gillingham, 2015; Wolske, Stern, and Dietz, 2017). As shown in Figure 3, residential solar uptake boomed in Washington after 2010.

In fact, the RECRP only received a total of 167 applications from 2005-2010, and 5,281 applications from 2011-2014. Theoretically, it can be argued that the installed base period (2005-2010) broadly reflects the innovators described in the diffusion of innovation theory, while uptake (2011-2014) captures subsequent steps in the adoption process. Accordingly, successful applications were split into the response variable of uptake and the explanatory variable of installed base.

As identified by Swift (2013) economic variables affecting the adoption of solar panel technology include average income, electricity price, and solar insolation. Additionally, the percentage of owner-occupied homes has been included because homeowners are far more likely to install building-based-panels that include extended payback periods (Wolske, Stern, and Dietz, 2017). Both percentage homeowner and average income are easily available from the US Census at the block group level (2015). Gathering electricity price proved more difficult as, according to personal communication with the Washington State University Energy Library in July 2017 (a state funded research service), no digitized map of electricity prices exists for Washington utility areas. Therefore, one was made for this research. The digitized electricity price data layer reflects the best possible information available. This means that many utility service area boundaries are based on a jpeg map (Solar Washington, 2017), which made precise digitization difficult. Other sources included a Washington State Department of Revenue map of Public Utility Districts, boundary files for city utilities, and service area maps available on utility websites. Most residential electricity prices were obtained from the federally funded Energy Information Association, while all others were gathered from utility websites and phone calls.

The final economic variable is solar insolation. This environmentally driven variable is nevertheless economic because the more insolation a solar array receives the more electricity it produces and therefore the more economically effective it will be for its owner. Solar insolation is available for download from the National Renewable Energy Laboratory (Perez et al. 2002; NREL, 2012). Perez et al. (2002) calculated solar insolation available to PV systems for the entire US (Perez et al. 2002). The results take into account snowfall, sunshine, and cloud cover (Perez et al. 2002).

Cultural variables include installed base (as discussed above), percentage minority, political affiliation, and a suite of education variables. Installed base and political affiliation are well supported by the literature as important to understanding residential solar uptake (Zahran et al. 2008; Graziano and Gillingham, 2015). The inclusion of percent minority allows for potentially uneven uptake along ethnic divides in Washington State and for testing the conclusion of Graziano and Gillingham (2015) who found that predominantly white areas are more likely to install residential solar.

Political affiliation was calculated using methods established by the Cook Political Report (2013). For both 2012 and 2016 and for each precinct, presidential results were compared to the state presidential results. For example, in 2016, 51.2 percent of Washington voted for Hillary Clinton. If a precinct voted 61.2 percent Clinton, it would be assigned a score of 10. If a precinct voted 41.2 percent for Clinton, it would be assigned a score of -10. In this way, relative political affiliation, based on the state average, is captured for each precinct in Washington. These scores were calculated for each precinct in 2012 and 2016 and then averaged. As precinct boundaries changed over this time, areal weighting was used to produce accurate spatial averages.

A variety of education variables were assessed for their role in shaping the adoption of solar panel technology. First, the percentage of adults with a college education was included using US Census data. Second, more specific public education variables were collected from the State Office of the Superintendent of Public Instruction (WA OSPI, 2017). These include math, English, writing, reading, science, and biology scores on state-mandated standardized tests, and graduation rate, the proportion of students requiring remediation, and college entrance percentage. These variables represent all the major subjects reported by WA OSPI as well as the three graduation-related performance indicators. All WA OSPI data is for the year 2014. For all test scores, the highest grade (school year) where the subject was available was downloaded. This data is only published for districts large enough to create no privacy issues, so the data is incomplete across the state.

Third, a K-12 principal survey was conducted to assess variation in environmental education, which is not included in any readily available resource (Appendix A). The survey consisted of several parts including questions on basic school demographics and three sections on the strength of environmental education. The survey was hosted online on Qualtrics (to which Central Washington University has a subscription) and was sent to all principals on an email list of public school principals available for download on the State Office of the Superintendent of Public Instruction website (WA OSPI, 2016; Qualtrics, 2017). It is likely that not all emails on this list are up to date and there are many duplicate addresses as well. That being said 2,107 emails were sent out and 139 completed responses were received. Due to duplicated districts, this 6.5 percent total response rate represents 68 of the 295 districts in Washington. Approximately 23 percent of school districts had at least one response. Original emails were sent in June 2017, with several follow-ups over the summer into September 2017.

Several techniques were considered as means to analyze the survey responses. Initially, principal component analysis was tested as a statistically grounded way to identify an index of results. However, no components were identified. Second, variations in the responses to individual questions versus sample-wide averages could be used as variables. For example, whether staff buys into environmental education at each school could be compared to all reporting school districts. However, as only a fraction of school responded, and only one school responded for most districts that did respond, this variable would be derived from the opinion of only one principal for only one question. Ultimately, an index that considered all questions in each survey was determined to be the most scientifically robust. In other words, the opinions of a single principal are more likely to capture actual conditions in a school district when those opinions involve multiple, disparate yet related issues (Lepak and Snell, 2002; Sjoberg, 2005).

Therefore, two parts of this survey were extracted into single indexes: ten Likert scale questions centered on strengths of environmental education in the school district as identified by Chapman (2014), and six Likert scale questions regarding Washington State’s three environmental education standards. All respondents answered the first set of questions, and 120 respondents answered the second set.

The environmental education set consisted of ten questions each having possible responses from strongly disagree to strongly agree (Appendix A). The variable generated from this set is referenced herein as Environmental Education. All questions were constructed so that strongly agree implies the most favorable conditions for environmental education (e.g., “You consider environmental education to be important for students in your school.”). Therefore, strongly disagree was assigned a score of 1 and each progressively more favorable answer was assigned a higher score until strongly agree, which was assigned a score of 7. All ten answers where then totaled for each respondent to get the total index score (Environmental Education). For districts with multiple respondents, total response scores were averaged. The mean score for the environmental education set is 35, with a median of 36, a maximum of 70, a minimum of 10, and a standard deviation of 9.0.

The same methods were used for the six questions about the state learning standards, except the questions only had 5 Likert responses, so answers were scored from a 1 to a 5. The variable created from these questions is referenced herein as the State Standard score. For each of the three environmental education standards, one question addressed the standard specifically and one addressed how solar energy is taught in regards to the standard, as demonstrated in the example on the next page. The mean score for the state learning standards index (State Standard) was 17, with a median of 17, a maximum of 30, a minimum of 6, and a standard deviation of 5.7.

Unfortunately, both the dependent variable described above and most of the independent variables relate to a window ending in 2014. This leads to a three-year discrepancy between most of the data and the environmental education survey conducted here. Additionally, assigning responses from a single school to an entire district is problematic, but as funding and leadership operate at the district level perhaps not overly so. This survey represents the best available method given time and resource constraints.

State standards require K-12 education on sustainability. The Washington Office of the Superintendent of Public Instruction defines sustainability to mean "meeting the needs of the present without compromising the ability of future generations to meet their needs while ensuring long-term ecological, social, and economic health." Which statement best describes the degree to which students at your school are exposed to environmental curriculum designed to educate on this concept?

- ○ This concept is not addressed directly (1)
- ○ This concept is occasionally mentioned (2)
- ○ This concept is discussed in at least one grade level (3)
- ○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level (4)
- ○ This concept is emphasized in all grade levels (5)

Which statement best describes the degree to which students at your school are taught about solar technology as a sustainable energy source?

- ○ This concept is not addressed directly (1)
- ○ This concept is occasionally mentioned (2)
- ○ This concept is discussed in at least one grade level (3)
- ○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level (4)
- ○ This concept is emphasized in all grade levels (5)

Spatial Re-Aggregation

More than a dozen independent variables were considered in the analysis. The many disparate scales of the variables required the creation of a unified scale. This unification allows for consistent and statistically valid spatial analysis. Because isolating the impact of environmental education, and education generally, in the residential solar diffusion process is central to this work and because the education variables were collected at the school district scale, all other variables were re-aggregated to the school district scale.

Areal weighted re-aggregation was chosen as a simple re-aggregation technique. During the spatial processing and data collection, steps were taken to ensure that this method accurately captured the data despite the change in scale. First and when possible, variable data was collected at a scale smaller than the school district (e.g., precincts, block groups, 10km scale rectangles), to allow for upwards aggregation. And second, vast unpopulated areas of Washington State were removed from the calculations (Figure 4). This step ensures that the re-aggregation was only calculated using areas that are inhabited. The Figure 4 map was generated by removing all waterways, federally owned land (except military bases), state-owned land, and even large city parks. The resulting coverage is a more accurate representation of where the data in Table 1 actually comes from.

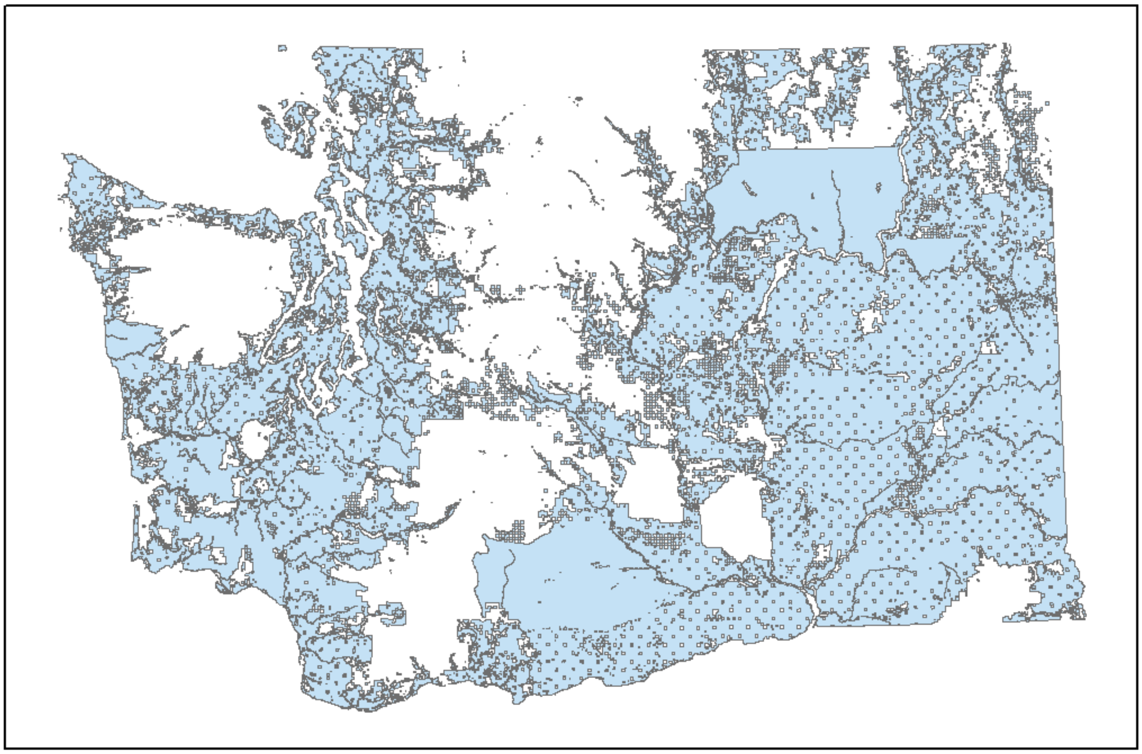

Figure 4: Inhabited areas of Washington State (WA OFM, 2017).

In a nutshell, areal weighted re-aggregation assigns the value from the variable's original polygon equal to the percentage of that polygon that falls into, or makes up, the target polygon (which in this case is the school district). First, the target polygon and the variable polygon must be intersected (see Figure 5). Intersecting takes all polygon borders from two or more layers and, keeping all data from both attribute tables, generates a layer of geometrically intersected polygons. Then a field is added to the intersected layer's attribute table to calculate the intersected polygon's variable value. He approach for calculating the field depends on whether the original data is averaged or is a count value.

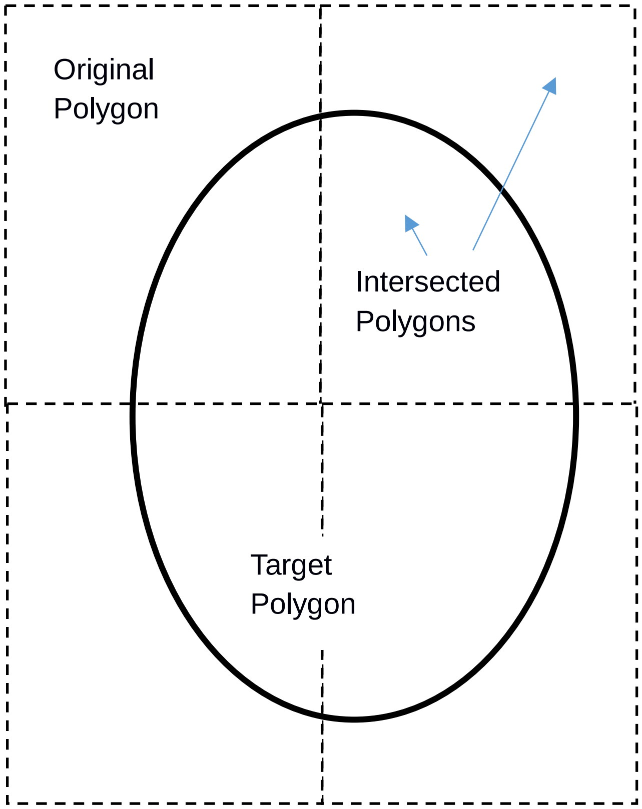

Figure 5: Re-aggregation schematic. The target polygon is the large oval, and represents a school district in the present study. The original polygons are the rectangles with the dotted lines, so there are 4 original polygons in this figure. The intersected polygons are all of the shapes generated by both shapes, so there are 8 intersected polygons in this figure. As explained in the text, the values for the four central intersected polygons are combined to produce a value for the target polygon.

For count values (e.g., solar installations) the data are assumed to be evenly spread across the original polygon area (e.g., that solar installations in zip code X are evenly spread across the zip code). Therefore, if an intersected polygon makes up 20 percent of the original polygon, then 20 percent of that polygon's count value will be assigned to that intersected polygon. Then this proportionate value is summed for all intersected polygons that fall within the enclosing school district, as below.

$$\sum_{i=1}^{k} x_i * \rho_i$$

i = intersected polygon

k = number of intersected polygons in the school district

x = data value from original scale

$$\rho_i = \frac{Area\ of\ i}{Area\ of\ original\ polygon}$$

For averaged values (e.g., income), the data is assumed to be constant across the entire polygon (e.g., that all people in a census block group have an income equal to the area's average). Therefore, the value is the same for all intersected polygons generated from the original polygon. However, these values must be converted to account for their relative importance for the target polygon, the school district. Therefore, the percentage of the school district represented by the intersected polygon is multiplied by the original value to get the value for that intersected polygon. Then all polygons that fall within the target school district are summed, as below.

$$\sum_{i=1}^{k} x_i * \rho_d$$

i = intersected polygon

k = number of intersected polygons in the school district

x = data value from original scale

$$\rho_d = \frac{Area\ of\ i}{Area\ of\ School\ District}$$

The overall validity of the areal weighted re-aggregation technique used here is displayed in Figure 6. As shown, for both count variables and average variables this method preserves many of the spatial patterns present in the data, at least at the statewide scale. For example, in the residential solar uptake map, areas of high concentration are shown to average out from the zip code scale to the school district scale well.

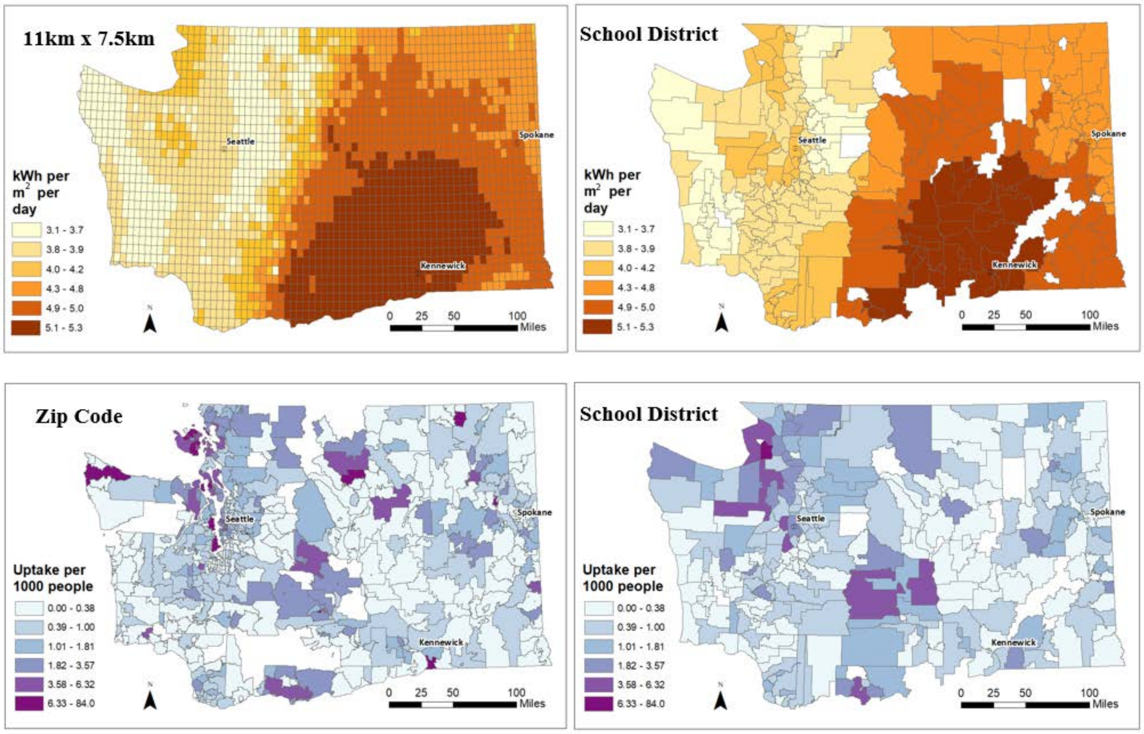

Figure 6: Re-aggregation validity. Re-aggregated maps of one averaged variable (solar insolation) and one count variable (solar installations). In both instances the before and after maps show similar overall patterns.

Despite the precautions taken in data processing, all results of the present study include the usual caveats associated with the modifiable areal unit problem. In short, the modifiable areal unit problem describes how different ways of imposing areal units upon a spatial distribution produces different patterns in the variable in question. In that same vein, changing from the areal unit of data collection to another often lowers the precision and accuracy of the data. For example, if a large city, which leads to high numbers in residential solar uptake, is located in a zip code which overlaps multiple school districts, the high value from that city will be partially and erroneously spread through all included school districts. This phenomenon emerged in the present study after aggregation. As uptake and installed base are calculated as densities, the smallest school districts in the state were getting the highest values for uptake (i.e., the small districts were getting assigned residential solar installations from nearby population centers). This result was overcome by deleting all school districts with a 2014 population below 500. As displayed in Figure 6, the remaining 263 school districts exhibited uptake patterns consistent with the original zip code pattern.

Method 1: Statistical Analysis

Analysis was conducted on the open source R software package (R Core Team, 2017). Most functions were possible using the standard R package, but additional functionality was achieved through the use of the add-on packages of ‘car’, for calculating variance inflation factors, for testing homoscedasticity, and for conducting robust standard errors (these concepts are explained more fully below), and ‘stargazer’, for exporting visually pleasing results (Hlavac, 2018). Analysis centered on ordinary least squares regression. Multiple variable regression is often used for complicated social modeling and is established as a means for understanding residential solar uptake (Shrimali and Jenner, 2013; Graziano and Gillingham, 2015; Borenstein, 2015; Wolske, Stern, and Dietz, 2017). A total of 18 models were created in this work which consider a wide range of variables and geographic distributions. The main model of the study emerged as Model 4 (Table 4, Chapter 4), because it offered the highest explanatory power for the whole state. Much of the assumption testing described below, and the discussion in Chapter 5, centers on Model 4 and the analyses derived from it.

To use ordinary least squares regression several assumptions must be met. These assumptions and the degree to which they are met by the data used in this analysis are now discussed. The validity of assuming linear relationships (upon which the ordinary least squares model is premised) was tested through the generation of scatterplots for all the variables (dependent variable – independent variable pairs). All distributions represent linear relationships, except for solar insolation, which had a strong bimodal pattern. This emerges because eastern Washington is quite sunny compared to western Washington. To test for the effect of this bimodality, in the analyses below, separate models were developed for western Washington, for eastern Washington, and for the whole state combined.

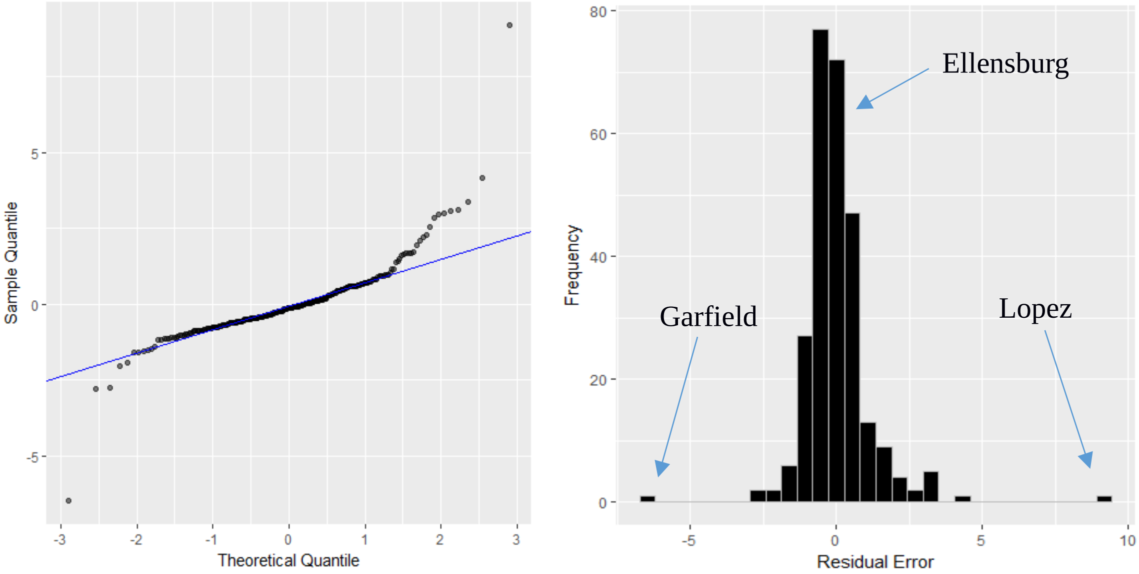

Figure 7: Graphical normality of model residuals. QQ plot and histogram of the residuals of the stepwise model (Model 4, explained in Chapter 4). Interview locations are labeled on the Histogram. These both demonstrate normal distribution of the residual error.

Multivariate normality refers to whether the model residuals are normally distributed or not. A residual equals the actual value for the dependent variable minus the predicted value derived from the values of the independent variables and the regression coefficients produced by the model. For this case, the residuals equal actual residential solar uptake minus model predicted residential solar uptake by school district. Normality is demonstrated through histograms and QQ Plots. As an example, Figure 7 shows the QQ plot of the residuals of the main model of this study (discussed further in Chapter 4) as well as the histogram for the residuals. The straight line of a QQ plot provides a benchmark for a perfectly normal distribution. By plotting the actual residuals against this line, it is possible to visually check for such a distribution. The QQ plot in Figure 7 shows a largely straight scatter with longer tails, especially on the right. A histogram graphs residuals into class bins by frequency. A normal distribution follows a bell shape, which is mostly present here, save for significant clustering of values near 0 and outliers to both the left and right.

Other tools for evaluating the degree to which a dataset fits the normal distribution include skewness (a normal distribution will have a value between -2 and 2, ideally falling as close as possible to zero), kurtosis (similar parameters to skewness), and the Wilk-Shapiro test (the test statistic W and its p-value should be close to 1). The data in this case has a skewness of 1.7, which falls within acceptable parameters. However, the data has a kurtosis of 17.5 (which captures the concentration of residuals near 0) and a Wilk-Shapiro p-value of less than 0.0000001. These two statistics both indicate a non-normal distribution. However and all told, because the QQ plot, histogram, and skewness point to normal distribution; the preponderance of evidence demonstrate a roughly normally distributed pattern of the model residual errors.

To meet the assumption of independent residuals the value of one residual should not influence the value of other residuals (i.e., they should not be auto-correlated). There is no evidence of graphical auto-correlation, indicating this assumption in met. However, as this study is spatially grounded it is important to test for the presence and nature of spatial autocorrelation (Anselin and Griffith, 1988). Therefore, testing for spatial autocorrelation was also conducted through the Global Moran's I tool on the free software program Geoda (The University of Chicago, 2018). Residuals were found to be spatially auto-correlated at a minor level (Moran's I = 0.21 for most powerful statewide model). This result is unsurprising as the social phenomenon modeled here are not strictly bounded by the school district. For example, factors such as political affiliation, solar insolation, and even residential solar uptake, are consistent over large continuous geographic areas. A Moran's I value of 0.21 is relatively minor given that there is a possible range of approximately -1 to 1. Given this result it is appropriate to investigate the results of autocorrelation as a point of departure for interpretation rather than necessarily as strong evidence for assumption violation (Shaw and Wheeler, 1985). That is to say, patterns here show relatively few areas of significant spatial autocorrelation. Considering these areas in the broader statewide context provides a means to better understand residential solar uptake patterns.

Multicollinearity refers to whether or not explanatory variables co-vary. If, for instance, political affiliation and average income varied together, it would be inappropriate to include both measures in the model. This is because they would essentially be doubling up on the same indicator. Multicollinearity was tested for all models through the variance inflation factor (VIF), available on the package ‘car’. As a rule of thumb if the VIF is over 5 for any variable, multicollinearity indicates assumption violation (Cannon et al. 2013). Variance inflation factors were calculated to be unacceptably high for various public education test score variables in certain models. This evidence for inter-variable interaction makes sense -- a high score in writing could logically also lead to a high score in reading. When appropriate, the variables with variance inflation factors significantly above 5 were removed.

To meet the homoscedasticity assumption the distribution of residuals around the line-of-best-fit must be relatively equal for all values of an independent variable. In other words, the distribution of residuals, both positive and negative, should be about the same for high values of a response variable (e.g., residential solar uptake) as for low values of that variable. This assumption was tested graphically and statistically. Graphical testing involves looking for trends other than a flat line in the model residuals vs. the predicted values. The presence of heteroscedasticity indicates untrustworthy standard errors and probability values (p-values, the most commonly used measure of statistical significance) for the explanatory variables. Heteroscedasticity was detected in several models and was shown to be statistically significant through the use of a Breusch-Pagan test. Under heteroscedastic conditions, King and Roberts (2015) advise that robust standard errors and associated p-values should be compared to normal standard errors and p-values. Robust standard errors, or heteroscedastic-consistent standard errors, take into account the residual generated by the model for each point. Robust standard errors are usually larger than the corresponding standard errors and therefore result in larger p-values (i.e., less statistically significant values). To clarify, robust standard errors take the results of the initial regression and recalculate the standard errors. This is in contrast to calculating the whole model with robust errors.

Actual statistical analysis proceeded in multiple parts due to incomplete education data. In other words, state performance indicators and the environmental education measures discussed earlier in this chapter were not available in complete statewide coverage like the other variables. As statewide analysis is central to the goals of this research, first regression was completed on all statewide variables and then on the progressively smaller datasets limited by coverage of state performance indicators and then the environmental education survey results. The initial model, hereafter termed the literature-derived model, was meant to compare the pattern of solar panel technology adoption in Washington to the findings of other researchers who have used a similar set of variables. This initial model in which all literature-derived variables were forced into the analysis was then compared to a stepwise model of the same statewide variable set. Stepwise regression tests all combinations of variables to determine the combination which most accurately models the dependent variable. Education variables were then added to the stepwise model in blocks: i. only state performance indices, ii. only environmental education survey results, and then iii. both.

To determine whether the addition or subtraction of variables significantly changes the explanatory power of the model, nested F-tests were conducted (Cannon et al. 2013). Nested F-tests take into account the number of variables in the model, the change in the adjusted coefficient of determination (R^2) between the two models, and each model’s residual standard error. Generally speaking, any nested F-test with a p-value lower than 0.05 indicates that the two models have statistically significantly different explanatory power. This test only works if the variables and data are nested. That is to say, one model must be the same as the other model but with fewer variables (e.g., performed on the same set of data response variables but with fewer explanatory variables). To perform this test on the different subsets of the data created by each set of education variables, the model chosen for comparison was run on the corresponding subset. For example, the statewide model which investigates whether environmental education has an impact on residential solar uptake only includes 68 school districts. To compare this model to a model without education variables, the statewide stepwise model was rerun, with the same variables, on the subset of 68 districts instead of the 263 school districts in the initial model.

As explained above, solar insolation exhibits a bimodal pattern with high insolation in eastern Washington and low insolation in western Washington. Additionally, spatial analysis reveals several other variables which have interesting east vs. west trends. To test the whether the state's halves are truly different environments in terms of residential solar uptake, the statistical tests described above for statewide analysis were conducted again on the data from just western Washington and then data from just eastern Washington.

Method 2: Spatial Analysis

All spatial analysis was conducted using Esri's ArcGIS 10. Many maps were generated and displayed in order to study the spatial patterns of the trends in the statistical and interview results.

Map analysis

The initial step of the spatial analysis was to map the dependent and explanatory variables. While the ultimate goal of the analysis is to determine the relationships among variables, insight can be gained from visual examination of spatial patterns that exist in each separately. These maps are particularly useful as tools to compare against the results of the statistical and qualitative analysis.

Spatial autocorrelation

Spatial autocorrelation allows for the identification of geographic clusters on the landscape. Spatial autocorrelation tests the degree to which polygons in a dataset are similar to the polygons they border. For this research, local autocorrelation was tested by comparing the target polygon to all polygons that polygon borders, or what is commonly known as the queen’s case with an order of 1. Both global autocorrelation and local autocorrelation were tested. Global autocorrelation indicates whether there is more clustering in the overall distribution than would be expected in a random distribution of data across the same set of polygons. Local autocorrelation tests how related one polygon is to its neighbors. For instance, if a group of polygons all have high relative values it is likely that those polygons will produce high autocorrelation. This is due to the similarity in the data across space. In the same logic, low values next to low values also produces high autocorrelation. Conversely, areas of randomness, so high values next to low values, produce low autocorrelation.

Autocorrelation was tested for both the dependent variable of residential solar uptake, and for the residual error of the stepwise model. High significant autocorrelation would indicate that blocks of continuity exist in the data outside of the bounds of the school district. For the response variable of uptake, high autocorrelation would indicate that the neighbor effects described by Graziano and Gillingham (2015) are present at the school district level. As described above, high autocorrelation of the residuals casts doubt on the degree to which the data meet the assumptions of ordinary least squares regression and indicates that there may be geographic bias in the results.

Method 3: Interviews

The interviews conducted here were designed to ground-truth the results of the statistical and spatial analysis while providing an additional line of evidence. Also, by investigating the question of residential solar uptake from a qualitative angle, the overall results are likely to be more robust and rich (Fielding, 2012). To identify the study area for the interviews, residuals of the statewide stepwise model were calculated (see more details about this model in Chapter 4). Figure 8 maps the residuals for this model (see Figure 7 for the histogram of residuals). Lopez Island School District and the Garfield portion of the Garfield-Palouse School District are clear outliers on the opposite ends of the spectrum; Lopez had higher solar panel technology adoption than predicted by the model (large positive residual), and Garfield-Palouse had lower adoption (large negative residual). Understanding the conditions in these outlying school districts is both a means to understanding weaknesses in the statistical model and an opportunity to explore conditions that create these outliers. In order to understand whether conditions in the outliers are truly anomalous, or extreme examples of common conditions, interviews were also conducted in a well-predicted school district. Ellensburg School District is well-predicted by the model (small residual) and was therefore an appropriate area to conduct the control group interviews. This research of human subjects was approved by exemption by the Central Washington University's Human Subjects Review Program under the approval number H17067. As outlined in the request for exemption informed consent forms were obtained for all interview participants, and no demographic (gender, ethnicity) or identifiable information was collected from participants to ensure anonymity.

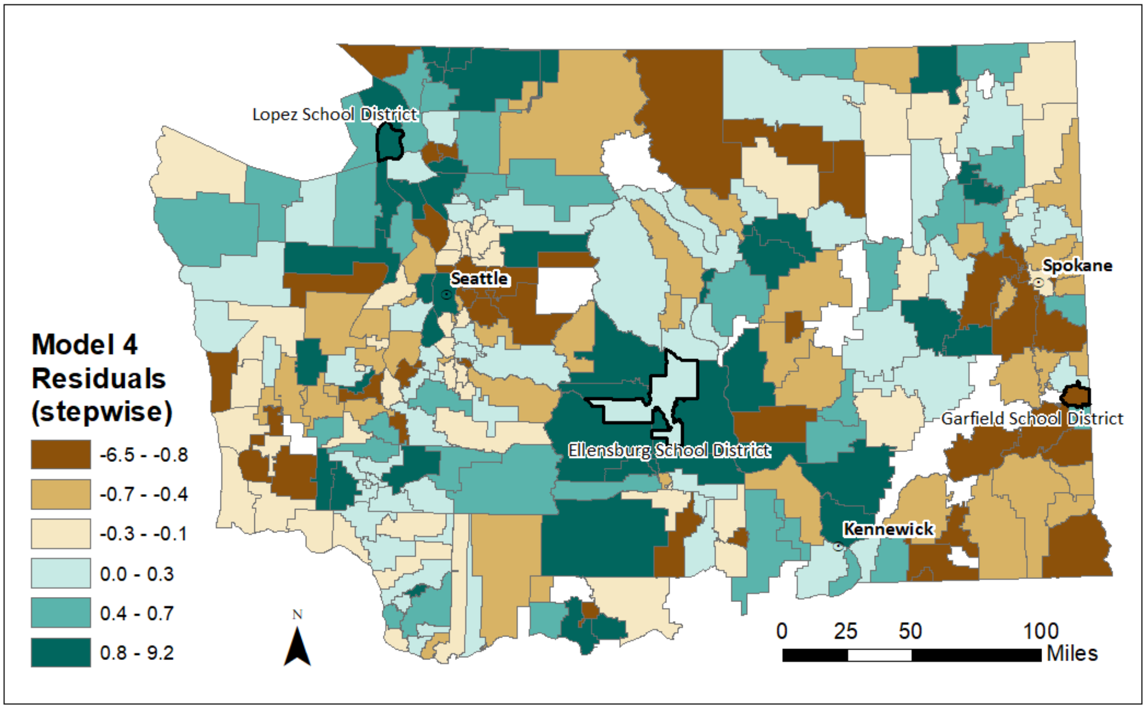

Figure 8: Residuals of Model 4. Residuals of the stepwise model (Model 4, discussed in detail in Chapter 4). Quantile breaks are used for legend.

Over the course of summer 2017, interviews were conducted using the following methods in each area. Interviewees were recruited in three ways. First, an email was sent out to local solar installers asking them to forward an interview request to their local customers. Second, residents living near the city center of the biggest town in the school district would be contacted through knocking on random doors. And third, interviewees were asked if they could recommend any potentially other interested interview subjects. Only three respondents were recruited through email, all in Ellensburg. All others were recruited through snowball interviewing and cold call door knocking. In this way, 40 people were interviewed: 11 in Ellensburg, 16 in Lopez, and 13 in Garfield.

The Garfield School District is part of a joint school district, the Garfield-Palouse school district. The state database of geographic shapefiles delineates these two districts as separate entities. Upon visiting the school district it was discovered that Garfield and Palouse share several schools and some administrative duties. Only the Garfield portion of this district emerged as an outlier. While 11 non-adopters were located in the Garfield portion of the school district, no solar adopters could be located in the Garfield portion during the interviews. In order to provide a regional baseline, two adopters from the Palouse half of the district were interviewed instead.

The questions and method used during the interviews and for interview analysis were based on similar work undertaken by Schelly (2014) and were designed to understand participants' knowledge and opinions of residential solar. Both general questions about solar energy and more specific questions about local solar incentives and solar companies were asked. Additional questions were designed to locate interviewees with respect to the explanatory variables. These questions regarded employment, political affiliation, and local environmental education. Finally, all participants were asked for their opinions on how to grow residential solar in their region. All interviews were done by with participants who allowed the interview to be recorded. Interviews were recorded using a handheld audio recorder and took between 5 minutes and 30 minutes. The full question guide is included in Appendix B.

All recorded interviews transcribed. Three text documents of these interviews, one for each school district, were uploaded to NVivo, a qualitative data analysis software (QSR International Pty Ltd., 2012). Then they were analyzed in two ways. First, interviews were coded using simple yes or no metrics. This included whether or not the interviewee installed solar, whether they (he or she) know about the local solar incentives, if they know about the relatively short payback period, whether they are environmentally friendly, whether they are politically liberal, if they think residential solar will have a positive economic impact, if they have a positive opinion of energy independence[1], whether they know others with solar, and what they know about local environmental education. These categories correlate with many of the questions shown on the interview guide in Appendix B. The purpose of this step is to provide an easily interpreted summary of conditions in each school district.

The second technique involved the generation of two narratives for each school district. Specifically, the main roadblocks to adoption and the main pathways to adoption were identified. The terms “roadblock” and “pathway” are novel to this work and represent suitable ways of conceptualizing solar under the goals of this research. Specifically, as producing advice which may grow solar is central to this work, understanding the major factors leading to adoption and the major factors blocking adoption provide a solid foundation on which to build recommendations.

Roadblocks are defined as the conditions that are indicated as prohibitive for the adoption of solar technology. Pathways are defined as the conditions that interviewees describe as leading them to adopt residential solar. These narratives were created by first coding the interviews in NVivo based on the main terms and concepts discussed in this thesis (Figure 9). Figure 9 shows parent nodes which split responses into several categories. Due to space, only two parent nodes are expanded here. A full node list is

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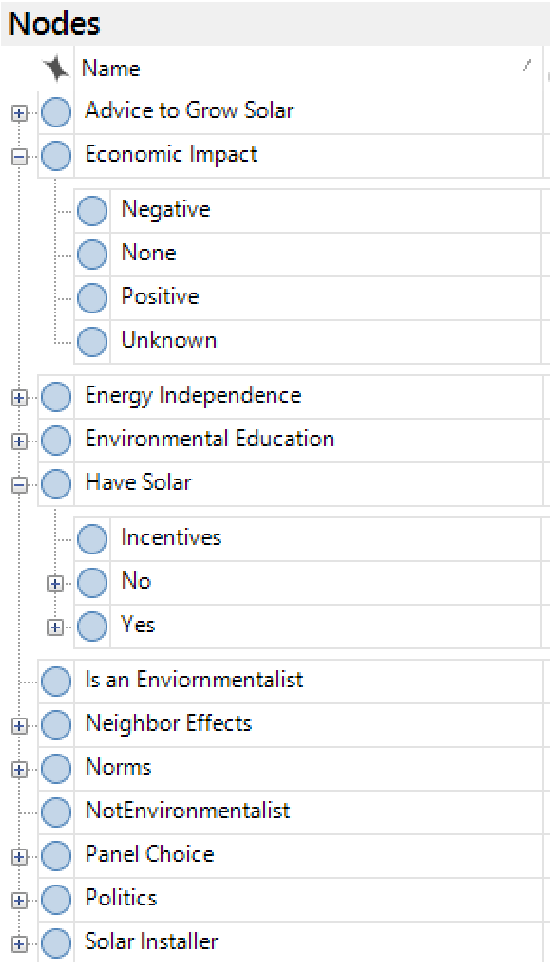
[1] See Appendix A for the wording of this question. Many interviewees were confused whether this meant national or personal independence. When asked to clarify I would tell them either/both and to answer in the way they felt most appropriate.



Nodes

Name

- Advice to Grow Solar
- Economic Impact
  - Negative
  - None
  - Positive
  - Unknown
- Energy Independence
- Environmental Education
- Have Solar
  - Incentives
  - No
  - Yes
- Is an Enviornmentalist
- Neighbor Effects
- Norms
- NotEnvironmentalist
- Panel Choice
- Politics
- Solar Installer

Figure 9: Main code nodes. The main nodes used to code the transcribed interview responses. Due to space constraints a full breakdown is not provided here.

available in Appendix C. This coding technique allowed for easy identification of consistencies in thought among adopters and non-adopters in each district. For instance, the node heading labeled ‘Have Solar’ was used to identify all respondents that both have, and do not have solar There is an additional node coding for when respondents specifically mentioned incentives in regard to their decision to adopt, or not adopt, solar. Then, and as an example, the node labeled ‘Economic Impact’ was used to determine the type of economic impacts each respondent believes residential solar will have. Each school district was analyzed separately. By replicating this process for all the aspects included in the interviews the results in Chapter 4 are produced. Finally, indicative quotes were isolated from both adopters and non-adopters to illustrate patterns which where highlighted using the above methods.

When appropriate, assertions and assumption made by the interview participants were tested for accuracy through archival work. This involved visits to websites and phone calls to local unity companies and residential solar installers. This internal triangulation of the interview responses allows for identifying cases where perceived and actual conditions do not line up.

The results generated through these two techniques are synthesized in the conclusions using two behavioral theories laid out in Wolske, Stern, and Dietz (2017) on the theory of solar technology diffusion. Additionally, the results are compared to previous results of residential solar uptake work.

Triangulation

To generate final results and conclusions, results from the spatial analysis, the statistical analysis, and the interviews are analyzed side by side. Results which emerge from all three methods are highlighted as primary relative to results indicated by only one or two investigation strategies.

CHAPTER 4

RESULTS

This chapter has three main sections. First, descriptive results are discussed for the main variables of the study. Second, inferential statistical modeling results are presented for the entire state and the state split into two halves. Finally, the main roadblocks and pathways to residential solar adoption are laid out for each of the three investigated school districts.

Descriptive Results

This section displays descriptive statistics and spatial results for most of the variables investigated in the present study. Initial observation of these maps show a striking inconsistency in Washington State patterns for variables that other researchers have found to encourage solar uptake. Take, for instance, the school district which includes Kennewick, Washington. Of all the variables mapped here, only political affiliation exhibits the characteristic that would strongly predict low residential solar uptake. Some of the other variables are about average but some others, like solar insolation, and electricity price, should lead to very high residential solar uptake. However, the school district around Kennewick, Washington exhibits very low solar uptake (0.3 successful applications to the RECRP per 1000 people). This example highlights the necessity of statistical analysis, which can evaluate the simultaneous interplay of the diverse factors at work here. First, however, it is useful to consider each of the variables individually.

Unless otherwise specified, each map below includes all school districts with a 2014 population over 500. All legends use Jenks' natural breaks algorithm, as calculated by Esri's ArcGIS. Observable patterns are discussed with each map along with basic descriptive statistics. One of the major trends apparent in the following maps is a divide well known to Washington locals. Eastern Washington and western Washington are very different in terms of political culture, climate, wealth, and a variety of other variables.

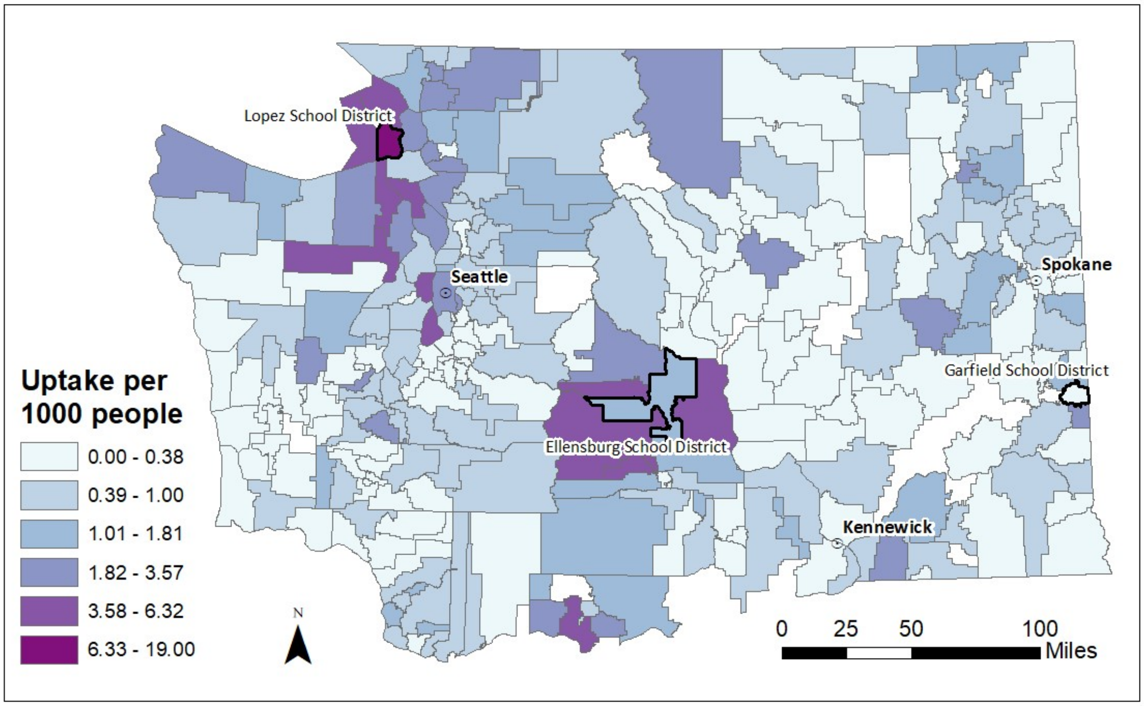


Figure 10: Residential solar uptake in Washington State. Uptake = successful solar applications from 2011-2014 to the Renewable Energy Cost Recovery Program/ 2014 population / 1000 (WA DoR, 2017).

Figure 10 depicts the response variable of this study, residential solar uptake per 1000 people. The areas around Seattle, northern Puget Sound, central Washington, and a single school district in south central Washington exhibit the highest statewide uptakes. Areas of low uptake cover the rest of the state in a seemingly patchwork pattern. Overall, it seems that the western half of Washington has more consistent uptake than eastern Washington.

Uptake per 1000 people has a mean value of 0.97 and a median of 0.50. The maximum value is 19 while the minimum value is 0. This indicates a strong right skew, which is supported by the trend displayed in Figure 11. This type of skew demonstrates that uptake of residential solar is still in the early adopter/innovator stage discussed in the diffusion of innovation theory. Therefore, the results of this study are particularly relevant when applied to areas where solar, and perhaps other expensive technologies, are still relatively new. Additionally, Figure 11 shows how strong of an outlier the Lopez Island School District is. The interview results in the final section of this chapter identify factors that help to explain this school district’s record.

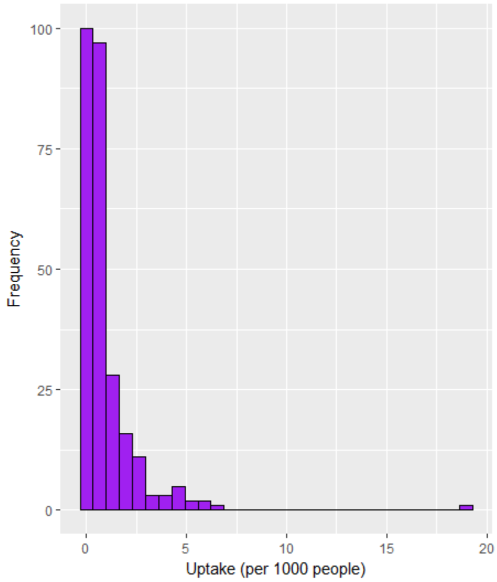


Figure 11: Histogram of residential solar uptake. This represents successful applications per 1000 people to the Renewable Energy Cost Recovery Program from 2011-2014 by school district.

Average income shows higher values around Seattle, Spokane and near Kennewick (Figure 12). Other than a few districts in the Seattle area, average income does not seem to correlate well with areas of high residential solar uptake. Average income has a mean of $28,354, and a median of $27,247. There is a much higher average income on the western side of the state. However, this correlates with a higher cost of living; therefore disposable income and/or money available to be invested in home improvement may not differ as much between east and west as this map suggests.

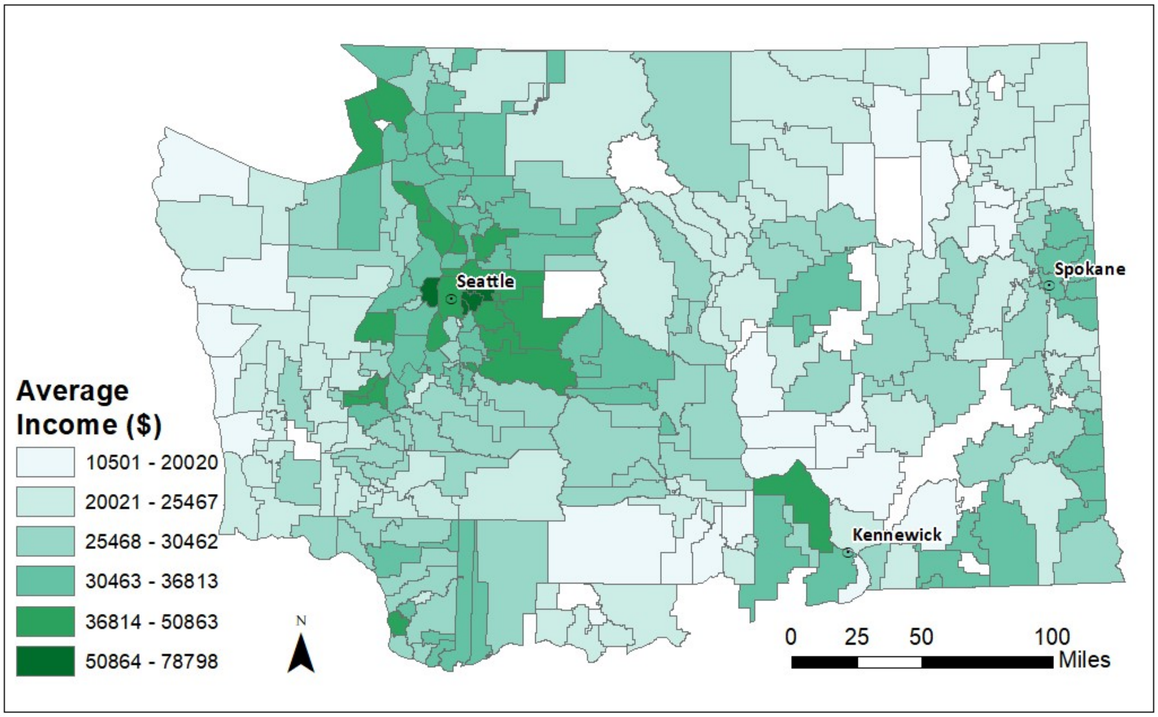


Figure 12: Per capita income. Average per capita income in dollars for 2014, as reported by the school district by the US Census Bureau (US Census, 2017).

While uptake seems to be clustered, solar insolation shows a clear and consistent pattern with insolation increasing from the northwest of the state towards the southeast (Figure 13). Solar insolation has a mean of 4.3 and a median of 4.0. This data compares to national insolation that maxes at about 6.5 kWh/m2/day in areas of the American Southwest (Perez et al. 2002). Interestingly, areas with the highest insolation generally coincide with the areas of the lowest uptake. This general trend, which is apparent by comparing Figure 12 to Figure 10, is contradicted by the statistical results (displayed below) which show a positive relationship between insolation and uptake. This means that despite the mapped patterns, when other important variables are held constant in the statistical analysis, solar insolation still exerts a positive effect on uptake. Importantly, visual analysis of this map compared to Figure 10 (residential solar uptake) demonstrates that solar resources are being poorly exploited by residential systems across Washington.

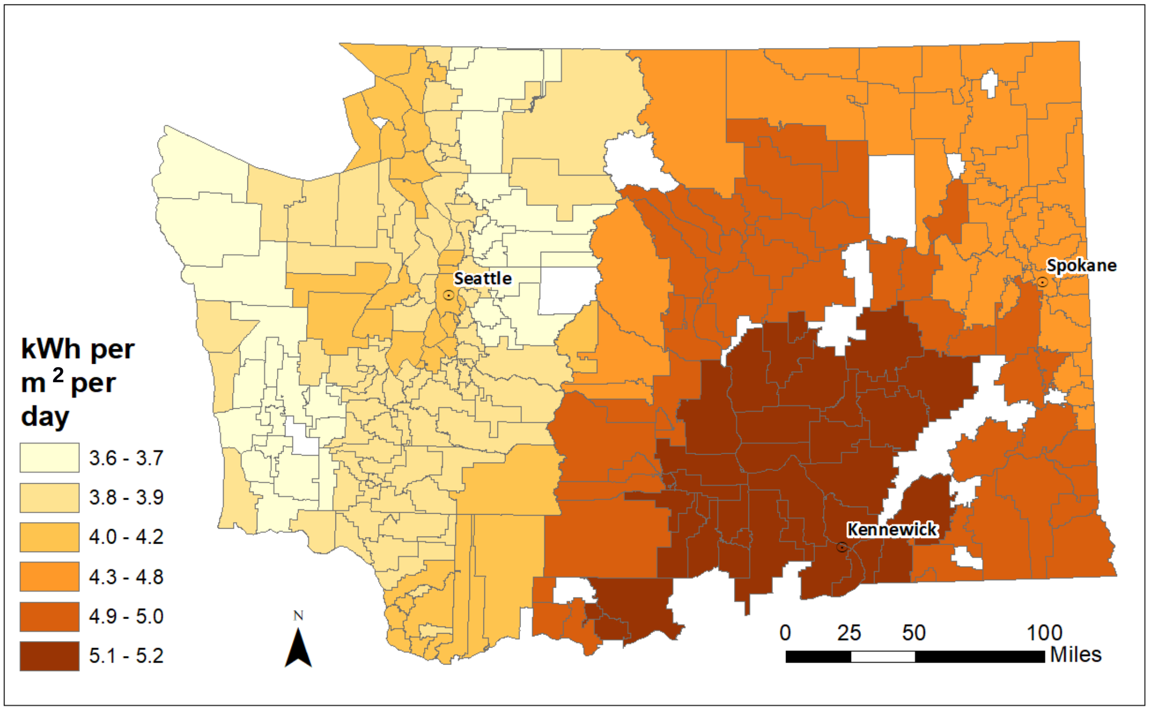


Figure 13: Solar insolation. Average solar insolation as available to residential solar photovoltaic systems as calculated by Perez et al. (2002) and reported by NREL (2018).

Electricity price displays a rather eclectic pattern across Washington (Figure 14). The areas of high price near Seattle, Puget Sound, and southern Washington are generally associated with high uptake on Figure 10. On the other hand, the area of high price near Kennewick is associated with low uptake. Visual analysis of this map is particularly useful when employed to identify areas with the most to gain from the adoption of solar. In other words, high electricity price means that solar would be more profitable! The mean price of electricity in Washington is 8.2, and the median is 8.4. The max is relatively close to this at 10.75 (San Juan County), and the minimum is at a very cheap 3 (Douglas County). These numbers compare to a national average of 12.58 cents/kWh (Institute for Energy Research, 2010). The relatively high average shows that electricity price has a leftward, or negative, skew. In other words, while electricity can be very inexpensive in Washington, it generally is offered at the higher end of the range.

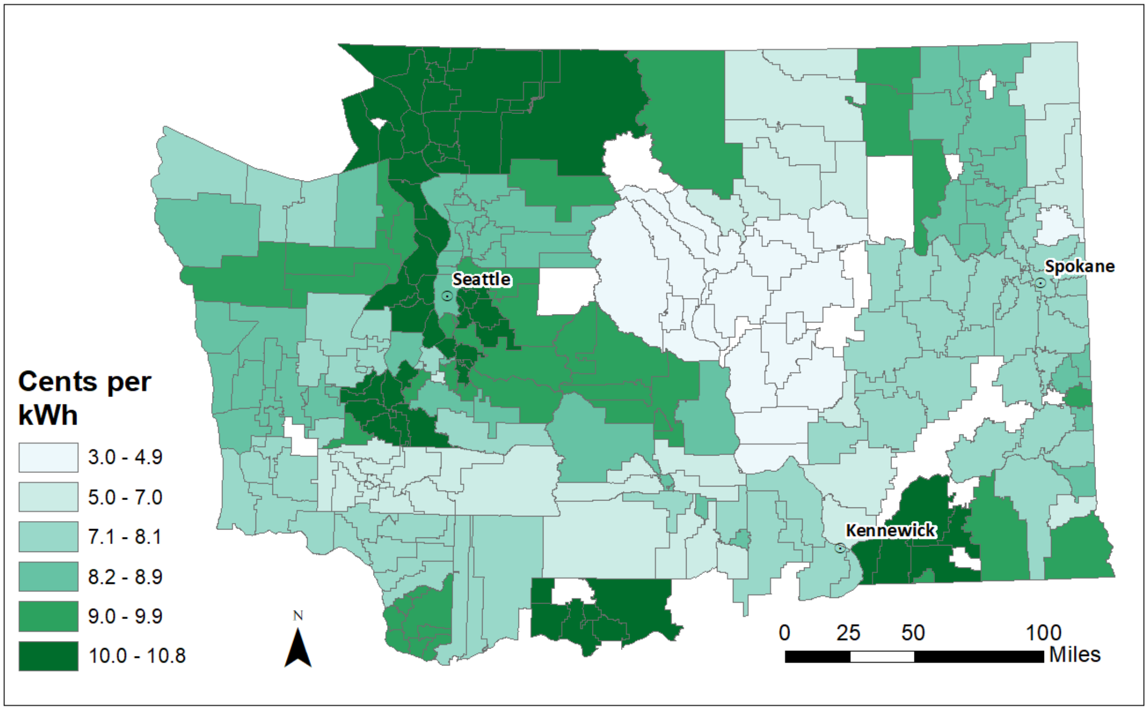


Figure 14: Residential electricity price. Residential electricity price in Washington State as reported by the Energy Information Association (US EIA, 2016b).

The map of installed base (Figure 15) displays no strong spatial pattern. There are clusters of high installed base in the east and in the west. This implies that from 2005-2010 adoption of residential solar was relatively even across the state. There are a few concentrations of installed base in the east, west, north, central, and south. The highest concentration of higher values does appear to be around the Seattle area. All told, installed base is very low across Washington from 2005-2010.

Comparing Figure 15, installed base, alongside Figure 10, residential solar uptake, displays a significant difference between eastern and western Washington: school districts in the west that got off to a strong start with a substantial installed base (2005-2010) tend to have high uptake during the study period (2011-2014), while school districts in the east with a high installed base tend not to have built upon that head start. The areas chosen as the locations for the interviews highlight these disparate outcomes. Specifically, the Garfield School District and the Lopez Island School District are the only two districts with an installed base over 0.63/1000 people. This is surprising in that uptake subsequently boomed on Lopez, while staying very low in Garfield. This disparate pattern, which is consistent across each side of Washington, potentially points to a cultural difference between the two state sides.

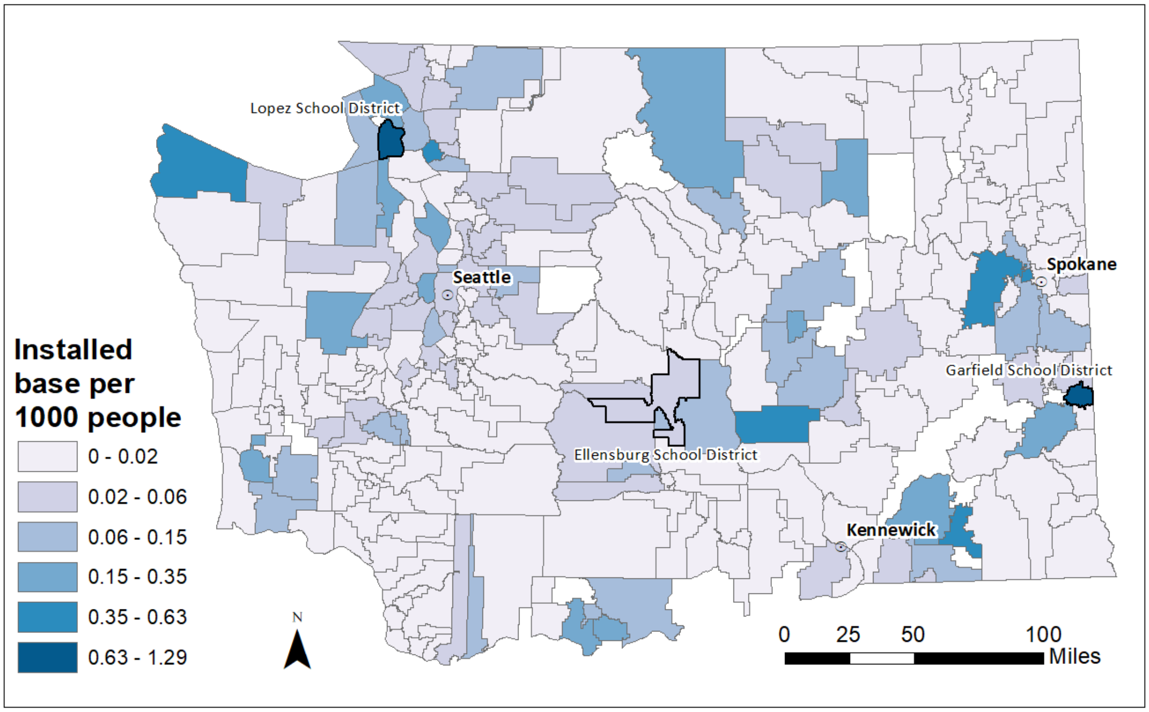


Figure 15: Installed base. Installed base is defined as all successful applications to the Renewable Energy Cost Recovery Program that occurred 2005-2010 (WA DoR, 2017).

Installed base has a mean value of 0.05, and a median value of 0.002. The max is 1.29 and the minimum is 0. As clearly shown by the large number of low values, this data has a strong right skew (Figure 16). However, this skew is more pronounced than the one for uptake (Figure 11). The trend of less right skew implies that, if and when solar becomes more common, the histogram of uptake may become more similar to a normal distribution.

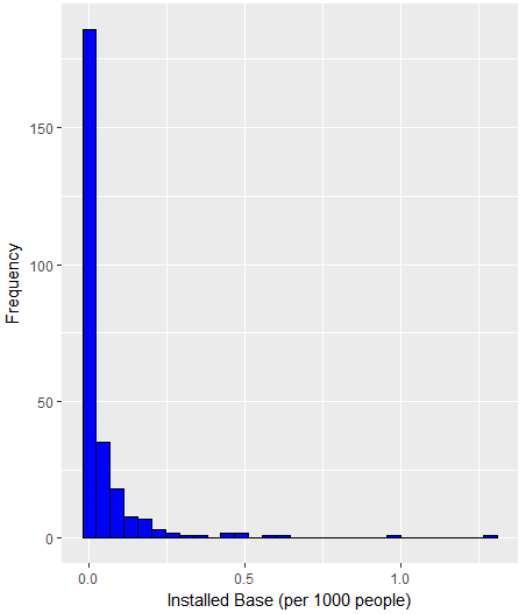


Figure 16: Histogram of installed base. This represents successful applications to the Renewable Energy Cost Recovery Program from 2005-2010 by school district.

Political affiliation displays a pattern surprisingly similar to the one depicted in solar insolation (Figure 17). The mean political affiliation is -15.4, while the median is -16.0. These negative values indicate that the geographic area of Washington is mostly Republican. That is to say while Democratic candidates have dominated presidential races in Washington State, the landscape is mostly covered by relatively low population areas that lean Republican. This explains why Democratic candidates generally capture Washington’s electoral votes. The northwest is the most Democratic-leaning, while the southeast is the most Republican-leaning. Many of the high adopting school districts are in fact also quite Democratic but some of the high adopting districts are also strongly Republican, especially those on the eastern side of the state. The trend here may help explain the different reactions to high installed base, as discussed in the above paragraph. Overall, Washington displays very polarized political affiliation based upon region.

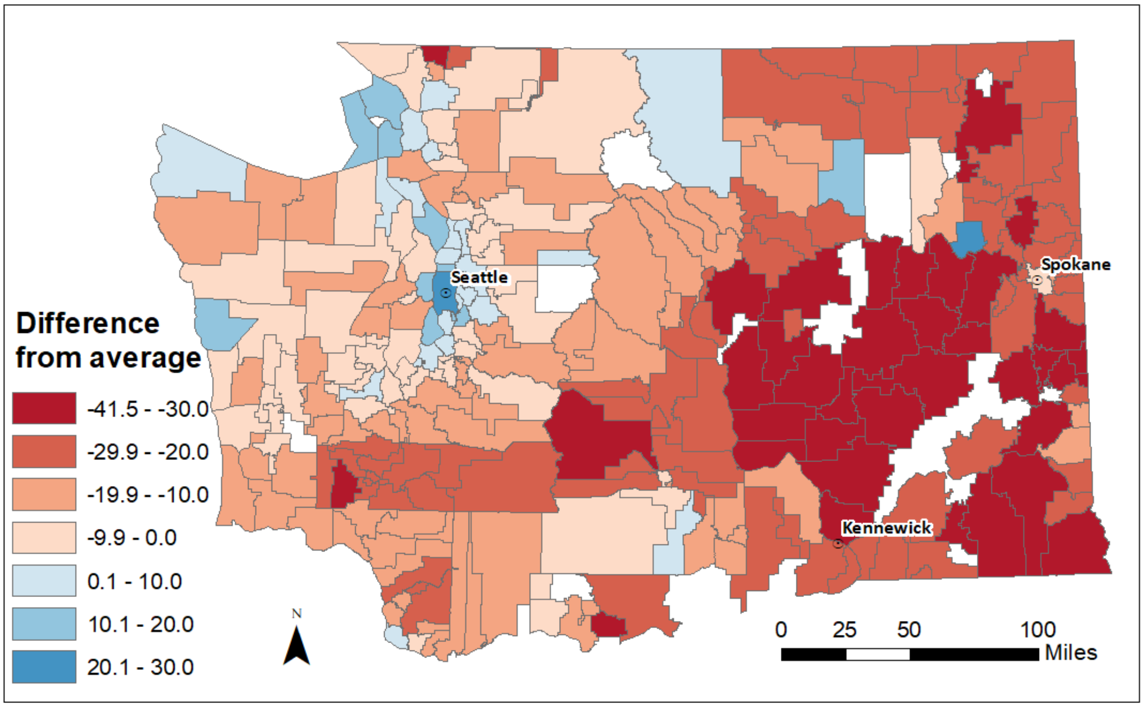


Figure 17: Political affiliation. Political affiliation in Washington State normalized against statewide results. On this scale, a value of zero indicates that a school district voted in the same way as the state averaged over the 2012 and 2016 presidential elections. Blue areas voted more strongly for the Democratic presidential candidate while red areas voted more strongly for the Republican presidential candidate. The breaks in this map were se manually (WA SoS, 2017a).

Percentage ethnic minority (Figure 18) displays a pattern which is unlike those in the previous maps. The area around Seattle, the Native American reservations, and the Columbia agricultural plateau have the highest percentage of minorities, though which group actually comprises the minority population in these areas differs of course. Both areas of high and low minorities display high residential solar uptake. Minority percentage has a mean of 15.8 percent and a median of 10.5 percent; so most areas in Washington are predominantly white.

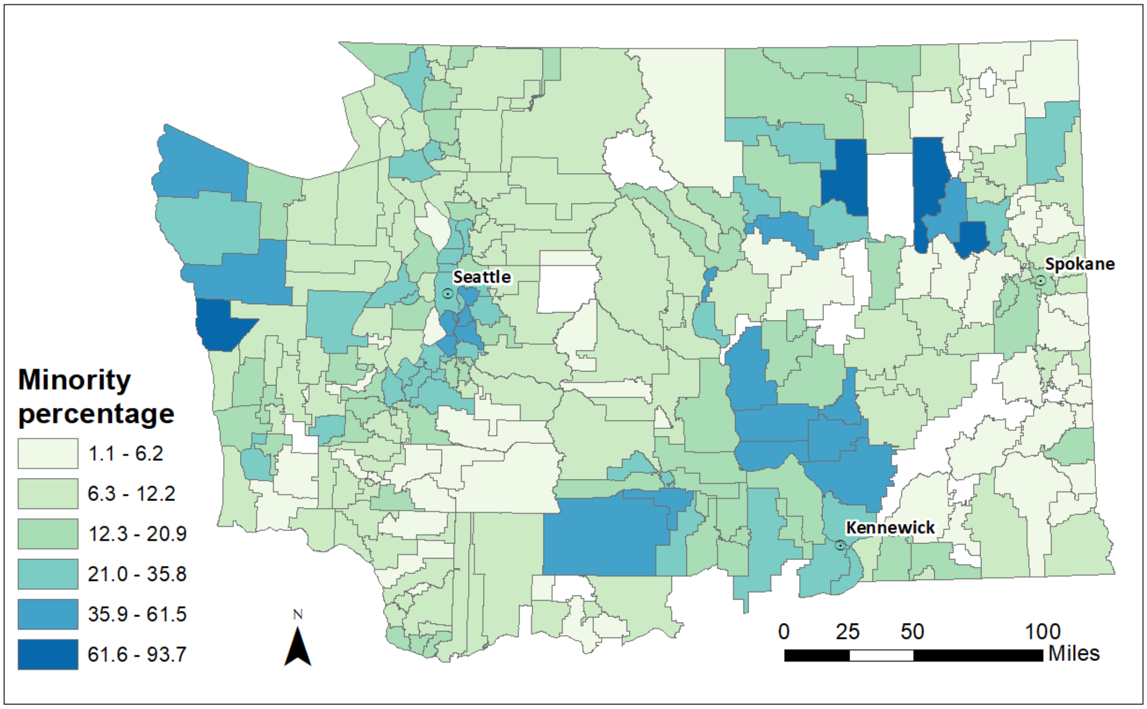


Figure 18: Percentage minority. Percentage minority as reported by the US Census Bureau for 2014 (US Census, 2017).

Figure 19 shows that high concentrations of college graduates are present in pockets throughout the state. Areas with both high and low residential solar uptake have a high percentage of college graduates. For instance, areas such as southeast Washington have a relatively high concentration of college graduates but low uptake while the area around Seattle has a high number of college graduates and high uptake. If residential solar uptake is influenced by percentage of college graduates, it is clearly in tandem with other factors as well. Both Lopez and Ellensburg have relatively high percentages of college graduates for their region. Garfield, on the other hand, has a lower percentage for its region. College graduates and average income show similar patterns across the state. Percent college graduates has a mean of 33 percent and a median of 31 percent, the maximum is 81 percent, and the minimum is 8 percent. Compared to all the variables mapped here, this distribution is relatively wide.

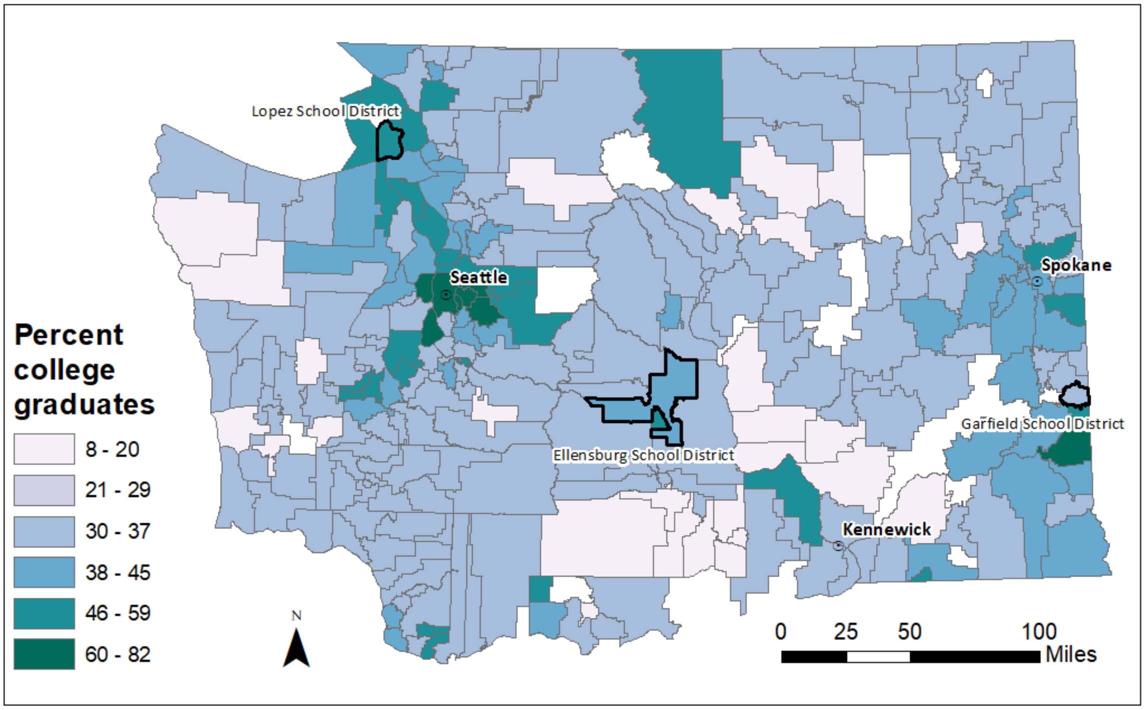


Figure 19: College graduates. Percent college graduates as reported by the US Census Bureau for 2014 (US Census, 2017). These statistics include all adults over 25 with at least an associate's degree.

School district population is unsurprisingly higher in western Washington and around urban areas (Figure 20). Most of the high adopting school districts are in high population areas, but this is not universally the case. Uneven population density could explain the eastern-western disparity in the effect of installed base. That is to say, higher population leads to higher population density. Therefore, residents of higher population areas are more likely to come across neighbors with solar in their day-to-day lives, perhaps amplifying the effect of installed base. The mean population per school district is 25,615 while the median is 8,343. The positive skew in the distribution shows that population is concentrated in a few areas, and most school districts have relatively low populations.

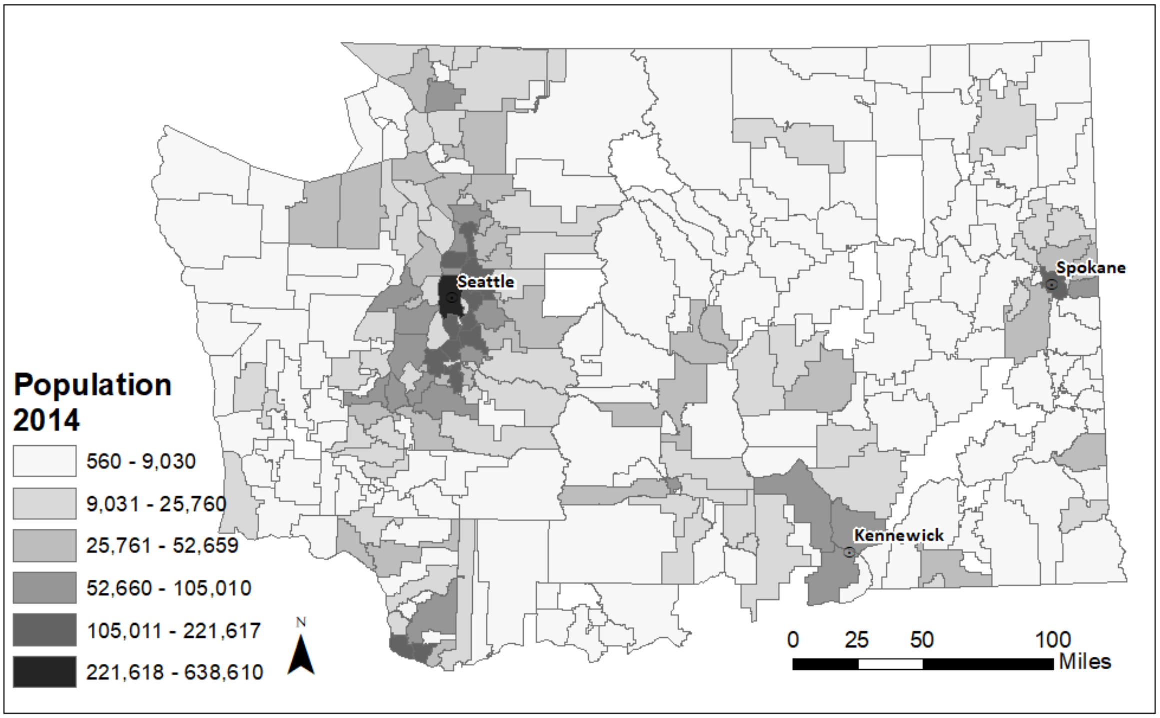


Figure 20: Population. School district population in 2014 as reported by the US Census Bureau for 2014 (US Census, 2017).

The major takeaways from Figure 21, which displays the Environmental Education score from the environmental education survey (refer to Chapter 3 for more details) are, first, that while coverage is quite low, it is relatively well spread out across the state. That is to say, no area is overrepresented or underrepresented. This implies that the statistical models (next section) which consider this variable, are not overly confounded by geographic constraints. Additionally, there does not appear to be a particular high concentration of good environmental education as measured this way in any particular sector of the state. Interestingly, the highest value of any response comes from the Kittitas School District in central Washington. This district neighbors one of the interview study areas, Ellensburg School District. This survey-derived variable has a mean of 34.76 and median of 36. The minimum value is 10 and the maximum is 70. The spread-out nature of this variable, and the nearness of the mean and median, help position this variable as an appropriate addition to the following statistical models. (The State Standards index did not produce any significant statistical results and so is not mapped here).

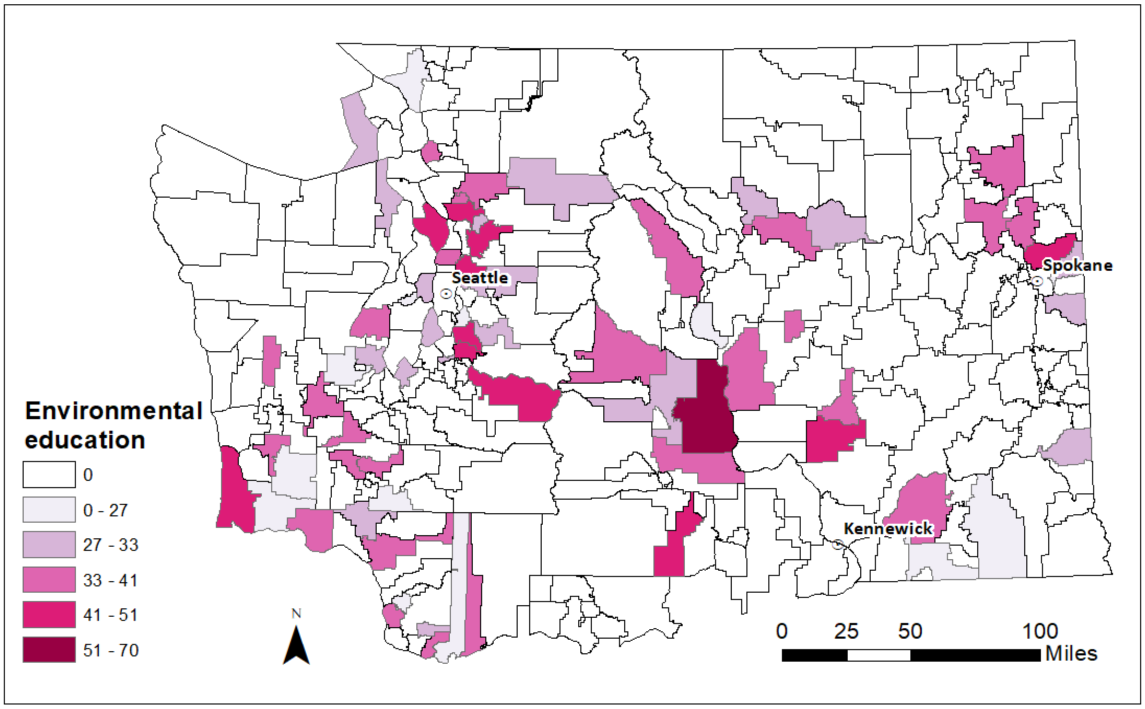


Figure 21: Environmental education. Value for the Environmental Education Score from the K-12 public school principal survey. Higher scores are associated with conditions more favorable to environmental education.

Statistical Results

This section presents the results of statistical analyses. Statistical results include a correlation matrix, several statewide regression models, and the same regression models rerun separately for eastern Washington and western Washington.

The literature shows that multiple variables are necessary to understand residential solar adoption. Table 2 displays the covariate matrix of the main variables of this study. The specific parameters of each variable are laid out in Chapter 3. Of the explanatory variables, only average income and percent college graduates have a cross-correlation higher than 50 percent. Most other explanatory variables have low cross-correlation. Installed base and college graduates have the highest correlation with residential solar uptake. Table 2 shows that the many variables here interact with uptake, and each other, in diverse ways.

Table 2: Correlation matrix

	U	AI	EP	SI	PH	IB	PA	MP	CG	POP
U	1.00	0.25	0.30	-0.03	0.09	0.56	0.23	-0.17	0.35	-0.06
AI	0.25	1.00	0.32	-0.32	0.30	0.05	0.39	-0.21	0.81	0.36
EP	0.30	0.32	1.00	-0.39	0.13	0.14	0.39	-0.11	0.41	0.14
SI	-0.03	-0.32	-0.39	1.00	-0.28	0.06	-0.55	0.10	-0.21	-0.18
PH	0.09	0.30	0.13	-0.28	1.00	-0.07	-0.07	-0.46	0.17	-0.20
IB	0.56	0.05	0.14	0.06	-0.07	1.00	0.09	-0.04	0.14	-0.09
PA	0.23	0.39	0.39	-0.55	-0.07	0.09	1.00	0.34	0.37	0.41
MP	-0.17	-0.21	-0.11	0.10	-0.46	-0.04	0.34	1.00	-0.22	0.20
CG	0.35	0.81	0.41	-0.21	0.17	0.14	0.37	-0.22	1.00	0.36
POP	-0.06	0.36	0.14	-0.18	-0.20	-0.09	0.41	0.20	0.36	1.00

Notes: Cross-correlation matrix of the main literature derived variables in this study. U = Residential Solar Uptake. AI = Average Income. EP = Electricity Price. SI = Solar Insolation. PH = Percentage Homeowner. IB = Installed Base. PA = Political Affiliation. MP = Minority Percentage. CG = Percentage of College Graduates. POP = Population in 2014.

To account for the effects of each variable, ordinary least squares multiple linear regression is well-suited to uncovering the relationships among many interacting factors. By keeping all other variable values constant, this technique is used to identify variables which are statistically correlated to residential solar uptake.

In this section, the data are analyzed in three subsets: the whole state, the eastern half of the state, and the western half of the state. First, and for each subset, forced regressions and stepwise regression are done on all of the variables identified and collected as suggested by the literature review. These models provide a standard useful for basing recommendations on how to grow residential solar uptake across all of Washington. Then, three series of education variables are added to the stepwise model. The education variables are added in a separate step because, due to data availability, they have less coverage than the literature-identified variables. For instance, the full statewide model employs a sample of 269 school districts, while the smallest set of education variables for the state only considers 68 districts. Also, it can be determined if education variables significantly change the amount of variability in residential solar uptake explained by each model.

The test used to determine whether the additional of extra variables actually adds explanatory power, is the nested F-test (explained more thoroughly in Chapter 3). As the education variables limit the sample size of the study, the education models are compared to a model generated on the same subset of the data, but only using the variables selected in the stepwise model. By examining R^2s of each model alongside the p-values of the nested F-test, it can be determined whether the additional variables truly improve model specification.

A critical part of using ordinary least squared regression is ensuring that model assumptions are met, and understanding, if they are not met, how to interpret the results. Chapter 3 presents an assessment of whether the following models meet those assumptions. These assumptions include: 1) linear relationships between the explanatory and independent variables, 2) multivariate normality, 3) no multicollinearity among the independent variables, 4) independent residuals, and 5) homoscedasticity (constant variance). The data meet assumptions 2 and 3 fairly well, conform to assumptions 1 and 4 less well, and are most problematic with respect to assumption 5.

A discussion of the source of the heteroscedasticity is provided below as almost all models generated here are heteroscedastic. This means that a model is significantly better at predicting uptake of certain values (e.g., better at predicting uptake per 1000 near zero than uptake per 1000 closer to 15). One negative outcome of heteroscedasticity is that the standard error of the correlation coefficients cannot be trusted. Therefore, robust standard errors are displayed for some models. This step demonstrates that installed base and population are the cause of the heteroscedasticity found here.

To understand these statistical outputs, it is easiest to focus on the adjusted R^2 value for the overall model and then the regression coefficients and associated p-values for individual independent variables. The adjusted R^2 value indicates the overall variability in residential solar uptake explained by the model; the higher the value, the better the model.

The asterisk(s) next to a regression coefficient indicate that the variable is statistically significant. The p-values associated with these asterisks are displayed at the bottom of each table. Essentially, the more asterisks, the more statistically significant the variable is in its correlation to the response variable, residential solar uptake. A negative regression co-efficient means that as the explanatory variable increases, residential solar uptake decreases and vice versa. The number in parentheses below each regression co-efficient is the standard error of the regression coefficient. The smaller the ratio of the standard error to the coefficient the more certain we can be of the influence that variable has on the model. Interpretation of these variables comes with the danger of making an ecological fallacy. For instance, just because school districts with high electricity price adopt solar at a higher rate, does not mean that individuals within that district with higher electricity prices adopt solar more often.

Statewide Literature-Derived Model

Table 3 displays the statewide literature-derived models. As the default Model 1 exhibited heteroscedasticity, robust standard errors were calculated on the variables (Model 2), and installed base was tested as a binary variable (Model 3). Installed base was transformed to a binary value by assigning a 1 to all school districts that had any installed base by 2010, and assigning a zero to all school districts that had no installed base. Below, the default model (Model 1) is first discussed followed by the additional results provided by Model 2 and Model 3.

The default standard errors in Model 1 show all explanatory variables as statistically significant, save for average income and percentage homeowner. These results are surprising given the literature suggesting that economic limitations are a major reason for low residential solar adoption. It is possible, and given the high cross correlation of average income and college graduates (Table 2) that college graduates is simple masking the impacts of average income. That being said, the economic indicators of solar insolation and electricity price both emerge as significant. All three cultural variables - political affiliation, minority percentage, and installed base - emerge as significant as well.

For Model 1, and as indicated by the regression coefficient, installed base has perhaps the largest effect on predicted uptake. For every one unit increase in number of installed base per 1000 people in a school district from 2005-2010 is associated with an increase of 5.9 in residential solar uptake per 1000 people between 2011 and 2014. Following this in magnitude of impact is percentage college graduates. For every 1 point increase in the percentage of college graduates, uptake is predicted to increase by 2.3.

Table 3: State literature derived models

	Default (1)	Robust (2)	IBB (3)
Average Income	0	0	-0.00001
	(0.00002)	(0.00002)	(0.00002)
Solar Insolation	0.600***	0.600***	0.824***
	(0.186)	(0.149)	(0.213)
Electricity Price	0.104**	0.104**	0.107*
	(0.048)	(0.048)	(0.058)
Percentage Homeowner	0.74	0.74	0.009
	(0.989)	(0.886)	(1.142)
Installed Base	5.632***	5.632	
	(0.578)	(4.163)	
Political Affiliation	0.038***	0.038***	0.051***
	(0.009)	(0.011)	(0.01)
Minority Percentage	-2.054***	-2.054***	-2.642***
	(0.654)	(0.637)	(0.753)
College Graduates	2.288**	2.288*	3.179**
	(1.141)	(1.22)	(1.32)
Population	-0.00000***	0	-0.00001***
	(0)	(0)	(0)
Installed Base Binary			0.455**
			(0.194)
Constant	-2.993**	-2.993***	-2.985**
	(1.276)	(1.081)	(1.479)
Observations	269	269	269
R^2	0.471	0.471	0.291
Adjusted R^2	0.452	0.452	0.267
Residual Std. Error (df = 259)	1.181	1.181	1.366
F Statistic (df = 9;259)	25.575***	25.575***	11.823***
Note:	*p<0.1;	**p<0.05;	***p<0.01

Model 1 and 2 VIF

AI	SI	EP	PH	IB	PA	MP	CG	POP
3.6	2.0	1.4	1.6	1.1	2.6	1.8	3.6	1.5

Model 3 VIF

AI	SI	EP	PH	PA	MP	CG	POP	IBB
3.6	1.9	1.5	1.6	2.5	1.8	3.6	1.4	1.3

Notes: Literature derived ordinary least squares regression models of residential solar uptake in Washington State, along with the variance inflation factors for all models. IBB = Installed Base Binary.

Next is minority percentage. For every 1 point decrease in percentage minority, uptake is predicted to increase by 2.1. The coefficient for solar insolation indicates that for every kWh/m2/day increase in sun strength an additional 0.6 is predicted for uptake. All variables exhibit the sign (positive or negative) predicted though the literature review. Overall this model explains 45.2 percent of the variation in the concentration of residential solar uptake in Washington State.

These results do change under robust standard errors (Model 2). Specifically, the standard error of installed base grows by over 7-fold from 0.56 to 4.17 and the variable is no longer statistically significant. All other model parameters exhibit little to no change. This drastic change in installed base standard error indicates that effect of installed base is less reliable across uptake values as compared to the other model variables.

The heteroscedasticity of Model 1 can be removed by reassigning installed base as a binary variable (Model 3). However, the explanatory power of the binary installed base model is reduced, as shown by the R^2 (0.27) of Model 3. These results imply that the impact of installed base, while important, should be cautiously evaluated.

Figure 22 shows residual vs. the fitted value graphs for Model 1 and Model 3 along with corresponding Breusch-Pagan p-values (p-values below 0.05 strongly indicate the presence of heteroscedasticity). Residual vs. predicted plots graph the residual error (or the actual minus the predicted value) against the predicted values. Homoscedastic models exhibit a random pattern around zero for low and high predicted values. The trend line in the first graph in Figure 22 indicates that, as the predicted values get larger the residuals become increasingly negative. However, it is important to note that for the main concentration of observations nearer the left side of the graph, the distribution of residuals is more balanced. This result indicates that the heteroscedastic nature of the model is only problematic for areas of very high uptake, not for most values. The comparably flat line, and much higher p-value, displayed in the second graph in Figure 22 shows that by simplifying installed base, the heteroscedasticity is removed. In other words, when installed base is transformed to a binary variable, the heteroscedastic misspecification of the model is considerably reduced.

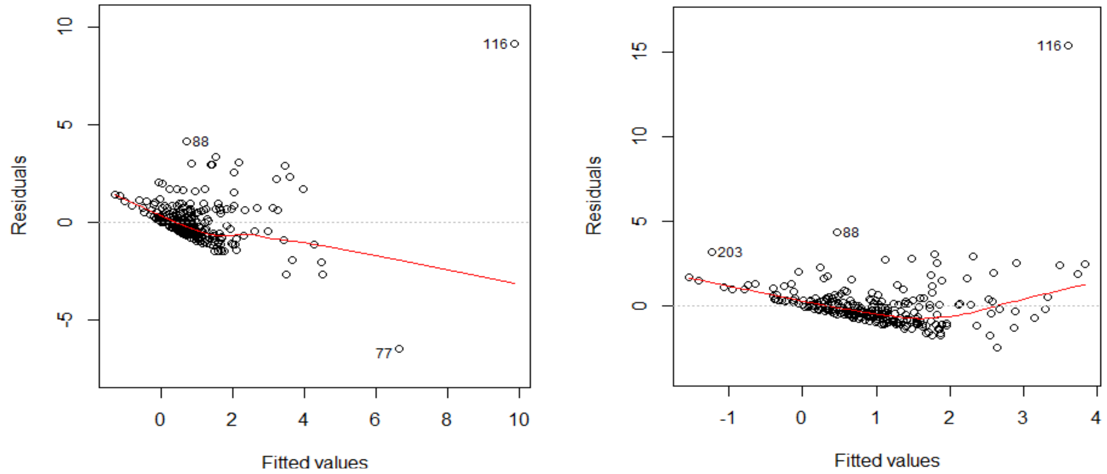


Figure 22: Residuals vs. fitted graphs. Residuals vs. predicted (fitted) values for the literature derived model. The left image shows results for Model 1, and the right shows Model 3. The first graph shows clear heteroscedasticity as evidenced by the non-horizontal fitted line. The associated Breusch- Pagan p-value = <2.2e-16, which verifies the non-random nature of the model error. For the second graph, the line of best fit is far more linear, and the associated Breusch-Pagan p-value = 0.11, demonstrating homoscedasticity.

Statewide Stepwise Model

A common means of improving the efficacy of regression modeling is to use a stepwise selection process that chooses from a given set of independent variables to construct the most powerful model (in terms of the R^2). As the variables identified through the literature review are by no means the hard and fast way to understand residential solar uptake, stepwise selection of variables allows for a statistically grounded identification of the most important indicators. Both the variables that are chosen and the variables that are left out, provide important clues for improving our understanding of residential solar uptake.

Table 4: State stepwise models

	Default Model 4	Robust Model 5
Solar Insolation	0.565***	0.565***
	(0.178)	(0.139)
Electricity Price	0.103**	0.103**
	(0.048)	(0.046)
Installed Base	5.585***	5.585
	(0.572)	(4.146)
Political Affiliation	0.038***	0.038***
	(0.009)	(0.011)
Minority Percentage	-2.195***	-2.195***
	(0.623)	(0.654)
College Graduates	2.320***	2.320***
	(0.774)	(0.813)
Population	-0.00000***	0
	(0)	(0)
Constant	-2.303***	-2.303***
	(0.857)	(0.766)
Observations	269	269
R^2	0.469	0.469
Adjusted R^2	0.455	0.455
Residual Std. Error(df = 261)	1.178	1.178
F Statistic (df = 7 ;261)	32.980***	32.980***
Note:	*p<0.1; **p<0.05; ***p<0.01	

Model 4 and 5 VIF

SI	EP	IB	PA	MP	CG	POP
1.8	1.4	1.1	2.6	1.6	1.7	1.4

Notes: Stepwise ordinary least squares regression models of residential solar uptake in Washington State and variance inflation factors for those models.

To accomplish this the models displaying in Table 4 select from all of the variables from the literature derived model. The same model is displayed with default standard errors (Model 4), and with robust standard errors (Model 5). The robust standard errors are calculated on the already stepwise selected variables (in contrast to rerunning selection under different conditions). For this reason, non-significant variables appear in Model 5.The results of the models in Table 4 are similar to the literature-derived model. Average income and percentage homeowner were not selected. All other variables were selected as significant. For the selected variables, the coefficients are very similar in Model 1 and Model 4 (e.g., 0.565 for solar insolation in Model 4 and 0.600 in Model 1). The changes improved the explanatory power from 45.2 percent to 45.5 percent.

As Model 4 is nested within Model 1 a nested F-test is appropriate to see if the removal of variables improves the model significantly. This test produces a p-value of 0.75 which indicates that the explanatory power of the models cannot be said to be statistically different. However, Model 4 is preferable due to its comparable simplicity.

Once again, the default model exhibits significant heteroscedasticity with a Breusch-Pagan p-value of nearly 0. And once again, the robust standard errors only change significantly for the case of installed base and population (Model 5). Therefore, the discussion provided above on this heteroscedastic result holds true to this case as well.

Model 4 emerged as the model which produced the highest R^2 for the entire state. Therefore, the residual errors of this model were investigated to locate the locations for conducting the interviews. A map of these residuals was provided in Chapter 3 but is reproduced below (Figure 23).

Figure 23 demonstrates the model residual error for each school district. Each residual is computed as actual uptake minus predicted uptake. For instance, areas with strongly negative residuals are predicted to have substantially higher residential solar uptake than is actually present.

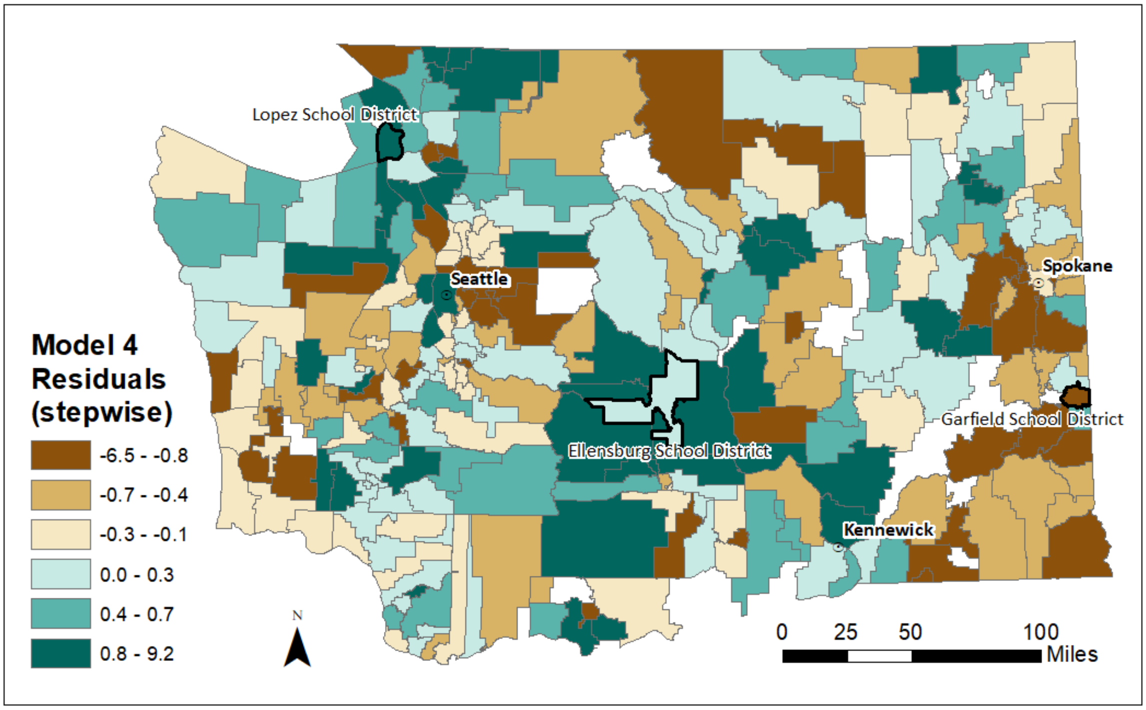


Figure 23: Model 4 residuals (reproduced). Residuals of the stepwise Model 4. In this case the residuals are the values of uptake minus the value produced by Model 4 for each school district.

A few trends emerge, including clusters of high residuals near Seattle and central Washington, and the lowest residuals all in eastern Washington. To investigate the cause of the residuals identified in Figure 23, autocorrelation maps are presented below. Both the response variable of residential solar uptake and the Model 4's residual are examined for autocorrelation.

Figure 24 displays the local autocorrelation results for the response variable of residential solar uptake. The appearance of several spatially auto-correlated uptake regions shows non-random spatial patterns in the uptake variable. This means that neighbor effects, as predicted by the literature review, and as shown by the importance of installed base, likely extend across school district borders. Alternatively, the autocorrelations shown in Figure 24 capture cultural sub-regions which extend outside the bounds of the school district. The existence of this inter-district effect is a possible cause of the residual patterns displayed in Figure 23. That is to say, Model 4 does not account for inter-district effects so is more likely to misjudge certain districts. Figure 23 has a global Moran's I of 0.28 with an associated p-value of less than 0.000001. Therefore, the pattern here is very unlikely to be random.

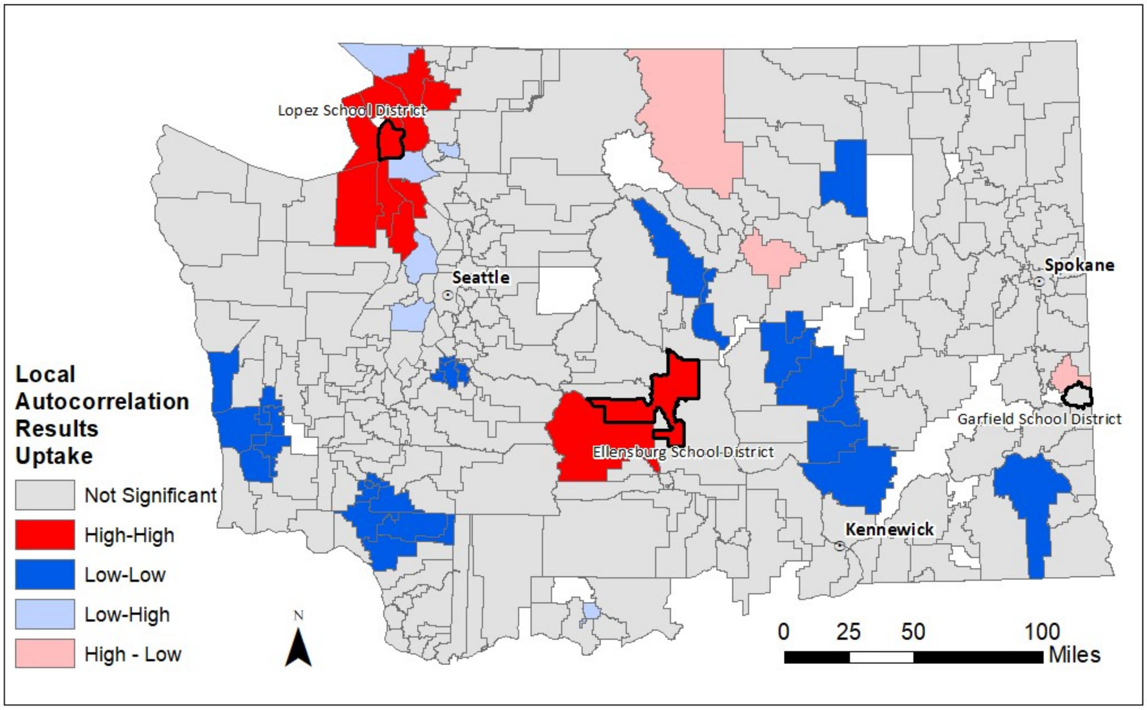


Figure 24: Local autocorrelation of residential solar uptake. Local Moran's I results for concentration of residential solar uptake. All colored polygons have a local indicators of spatial association (LISA) statistic p-value of less than 0.05. The global Moran's I associated with this map is 0.28, which has a p-value of less than 0.000001.

Figure 25 shows the autocorrelation of the residuals of the stepwise Model 4. A few clusters are displayed. High-high clusters are clear in central Washington and in northwest Washington. Low-low clusters are near Seattle, the southeast, and a few districts in the southwest. It is odd that the two low-low clusters and the two main high-high clusters are in rather different areas of the state. Each state half has one high-high and one low-low cluster. A few clusters are consistent across both Figure 24 and Figure 25, such as the positive cluster including Ellensburg School District. These consistencies show that the original response variable likely produces some of the autocorrelation shown by the residual of Model 4. The cluster of low-low uptake to the immediate east of Washington is associated with dense trees and many hills, indicating that the solar insolation variable may not be fine scale enough to capture change in that area.

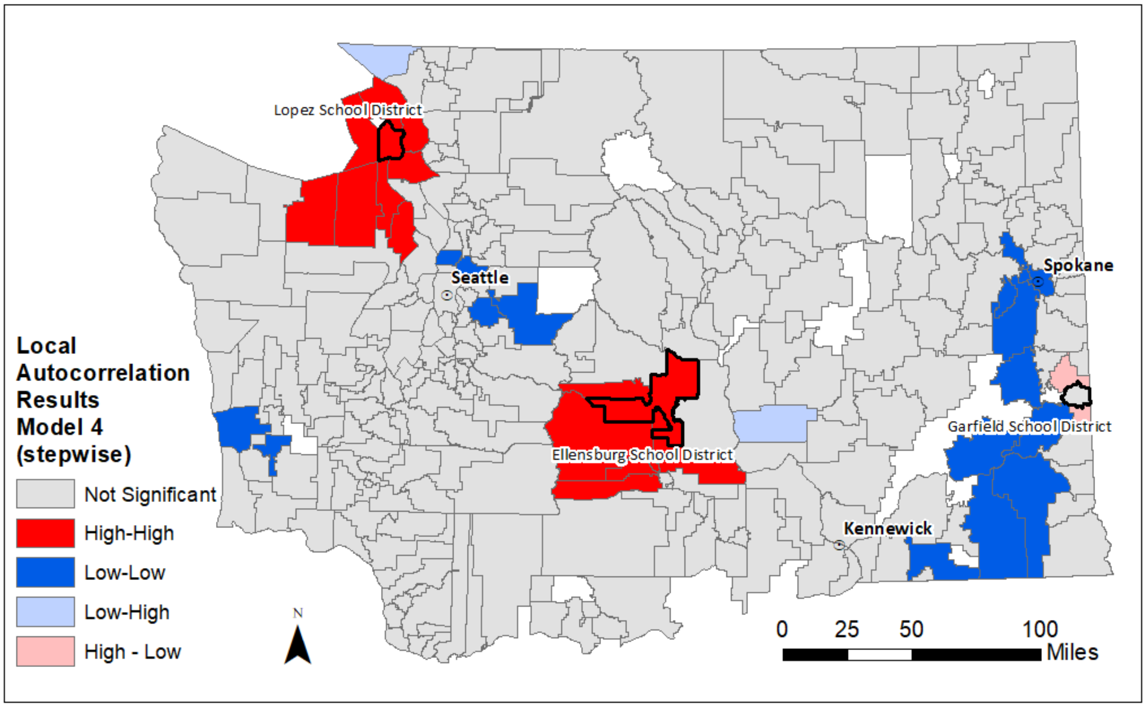


Figure 25: Local autocorrelation of Model 4 residuals. Local Moran's I results for the residuals of Model 4 (which are mapped in Figure 23). All colored polygons have a LISA statistic p-value of less than 0.05. The global Moran's I associated with this map is 0.21, which has a p-value of less than 0.000001.

Overall, the global Moran's I value of 0.21 indicates moderate, but not severe, clustering. The p-value associated with this outcome is less than 0.000001 so there is essentially no chance that the pattern here emerged from random chance. Instead, the results imply that cross border effects not modeled are potentially influencing the residuals of Model 4. A graph of the local autocorrelation statistics is provided in Figure 26.

While the interdependence of residuals violates an assumption of ordinary least squares regression, the degree of autocorrelation is minor. This is evidenced by the relatively low global value of 0.21 and corroborated by the visually random pattern of autocorrelation demonstrated across most of Figure 24 and in Figure 25.

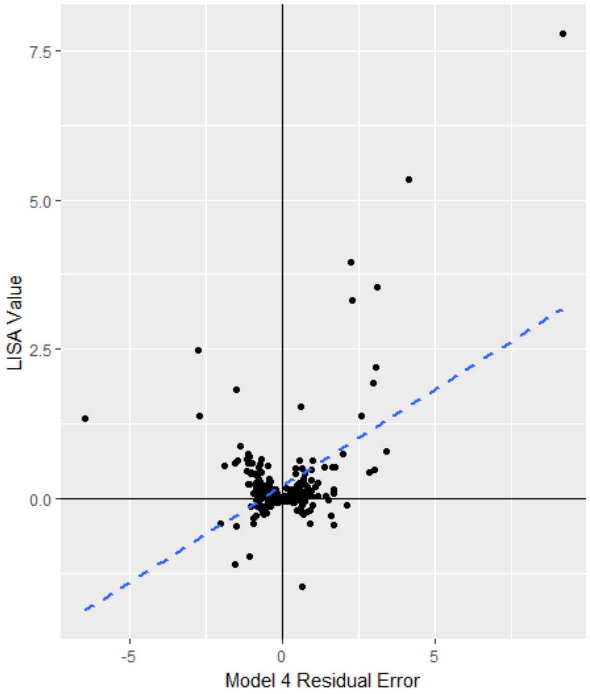


Figure 26: Scatterplot of local autocorrelation for Model 4. Local area statistical auto-correlation (LISA) value of all school district residuals. A relatively random pattern is present. The dotted blue line is the line of best fit, it has a slope of 0.21 which is the means for deriving the Moran's I value.

When investigating social phenomenon, such as residential solar uptake, socially consistent areas may extend outside of the chosen polygons. Alternatively, consistent conditions, in terms of the variables identified here, may be present in several adjacent polygons without the underlying inter-district social networks. This research does not attempt to model or understand breadth of social networks, which could account for Figure 25's autocorrelation, and is more concerned with testing the impact of education on uptake. Therefore, understanding areas of high residual autocorrelation provides an additional avenue of analysis on which to base conclusions.

Adding Public Education Indicators

Next, three models were explored with public school indicators added. These models were constructed by adding sets of education variables to the stepwise Model 4. The first model adds graduation rate, percentage remediation, and college entrance percentage. The second model adds average tests scores in biology, science, math, and writing. The third model adds the results of the environmental education survey (see Chapter 3). In this way each model tests whether a set of education indicators helps in explaining residential solar uptake. As shown, each subsequent model has different degrees of freedom due to data coverage. While all models exhibit heteroscedasticity, the discussion on this topic above applies here as well in that robust standard errors only change the significance of installed base and population.

These three statewide models are displayed in Table 5. Model 6 exhibits a decrease in explanatory power over the statewide models (42 percent compared to 45 percent). The three performance indicators are insignificantly related to residential solar uptake and do not aid in model performance. In fact, a nested F-test indicates that the addition of these variables does not significantly change the explanatory power of the model ($p = 0.22$).

Model 7 has an even worse explanatory power at 40 percent. No test score relates to residential solar uptake on a statistically significant level. These results indicate that public school test scores are not an effective way to predict residential solar uptake. A nested F-test has a p-value of 0.10 indicating that the addition of test scores are not especially helpful in understanding residential solar uptake.

Table 5: State models incorporating education variables

	(6)	(7)	(8)
Solar Insolation	0.678***	0.479***	0.789***
	(0.164)	(0.147)	(0.295)
Electricity Price	0.116**	0.128***	0.149*
	(0.046)	(0.038)	(0.077)
Installed Base	3.716***	3.199***	2.35
	(0.857)	(0.686)	(1.47)
Political Affiliation	0.032***	0.036***	0.052***
	(0.008)	(0.007)	(0.013)
Minority Percentage	-2.424***	-2.268***	-0.631
	(0.629)	(0.529)	(1.228)
College Graduate	3.247***	2.307***	3.403***
	(1.092)	(0.832)	(1.144)
Population	-0.004***	-0.004***	-0.016***
	(0.001)	(0.001)	(0.004)
Graduation Rate	-0.017		
	(0.011)		
Percentage Remediation	-0.081		
	(0.701)		
College Entrance	-1.118		
	(0.946)		
Science		-1.242	
		(0.919)	
Biology		0.519	
		(0.632)	
Math		-1.548	
		(1.026)	
Writing		1.486	
		(1.061)	
Environmental Education			0.028**
			(0.013)
State Standards			0.017
			(0.022)
Constant	-1.2	-1.831**	-4.967***
	(1.254)	(0.881)	(1.438)
Observations	188	228	68
R^2	0.448	0.432	0.637
Adjusted R^2	0.417	0.404	0.58
Residual Std. Error	0.875(df = 177)	0.864(df = 216)	0.878(df = 58)
F Statistic	14.4***(df = 10; 177)	15.0***(df = 11; 216)	11.3***(df = 9;58)
Note:	*p<0.1;**p<0.05;***p<0.01		

Notes: Test of education variables using ordinary least squares regression models of residential solar uptake in Washington State (variance inflation factors in Table 6).

Table 6: Variance inflation factors for Table 5

Model 6 VIF

SI	EP	IB	PA	MP	CG	POP	GR	PR	CE
2	1.7	1.1	2.6	1.6	4.7	1.5	1.6	1.9	2.5

Model 7 VIF

SI	EP	IB	PA	MP	CG	POP	Science	Biology	Math	Writing
2	1.5	1.1	2.8	1.7	3.1	1.5	4.9	2.4	4.6	3.4

Model 8 VIF

SI	EP	IB	PA	MP	CG	POP	EE	SS
2	1.8	1.3	2.5	1.8	2.2	2.1	1.1	1.2

Notes: GR = Graduate Rate. PR = Percentage Remediation. CE = Percent College Entrance. EE = Environmental Education. SS = State Standard Score.

Model 8, which is presented in Table 5, adds the results of the environmental education survey. The explanatory power of this model actually increases to 58 percent. However, this comes with the caveat of a decrease in degrees of freedom. Therefore, this increase in model power could simply be due to a favorable subset of the data. A nested F-test test demonstrate that the addition of the environmental education variables does not greatly improve model explanatory power (p = 0.114). In fact, when the environmental education indicators are removed from the same subset of data (i.e. the 68 school districts for which the environmental education survey results are available) the explanatory power of the model is 56 percent.

Nevertheless, the Environmental Education score from the survey is statistically related to residential solar uptake. This result shows that strength of environmental education is positively correlated to residential solar uptake which implies that environmental education may influence residential solar uptake. Taken together, the results of Model 8 call for further investigation into a link between residential solar uptake and environmental education.

Several significant results emerged from this initial statewide statistical analysis. Surprisingly, average income did not emerge as a useful variable for explaining residential solar uptake. Otherwise, the literature review seemed to provide an effective list of variables to create the models shown here. Installed base, while responsible for model heteroscedasticity, also emerges as an important factor leading to higher uptake. Following this in importance are percentage college graduates and percentage minority. These three variables all measure cultural factors. Of all the added education variables, only the Environmental Education score, which measures environmental education, emerged as significantly related to residential solar uptake. All in all, the best statewide model accounted for 45.5 percent of the variation in the data.

Eastern Washington Compared to Western Washington

In an effort to account for the patterns of Washington's residential solar uptake, the data set was split into east and west and the analyses were rerun. Table 7 shows a summary of population and uptake in each state half. Figure 27 maps the split in the state, which more or less coincides with the crest of the Cascades. Western Washington exhibits almost double the uptake rate compared to eastern Washington.

Table 7: Summary of eastern and western Washington

	East	West
Total Uptake	714	4,463
Total Population	1,519,044	5,371,332
Uptake per 1000	0.47	0.83
Number of School Districts	123	146

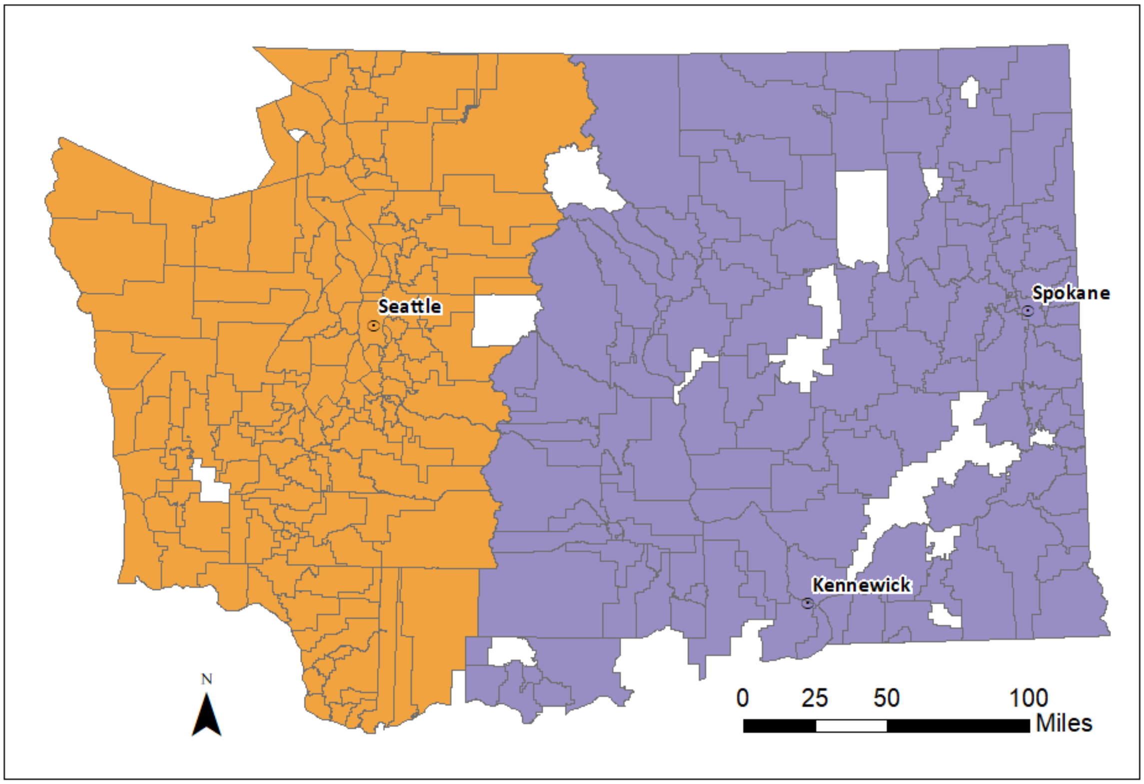


Figure 27: East/West divide. Map of how the state was split for the analysis in this section.

Literature Derived Model by Region

Table 8 displays the results for the literature-derived model for the west and the east, alongside the original statewide literature-derived model. The R^2 for the eastern half of the state is 0.18 while the R^2 for the western half of the state is 0.77. This disparity demonstrates that the effectiveness of the original model is almost entirely driven by the western half of the state of Washington. Electricity price and solar insolation are the only variables that persist as statistically significant in all three models. Installed base, political affiliation, minority percentage, and college graduates are not statistically significant in the east despite their significance in the whole state model and the model for the west. Population is not significant in the west while it is significant for the whole state and the east. This result indicates that residential solar payoff may be the primary driver of uptake in eastern Washington but not the rest of the state. That is, the two economically

Table 8: East/west literature derived models

	Whole State (9)	East (10)	West (11)
Average Income	0	0.00001	-0.00001
	(0.00002)	(0.00003)	(0.00002)
Solar Insolation	0.600***	0.981**	1.893**
	(0.186)	(0.475)	(0.747)
Electricity Price	0.104**	0.144***	0.130*
	(0.048)	(0.049	(0.073)
Percentage Homeowner	0.74	0.724	-0.193
	(0.989)	(1.111)	(1.431)
Installed Base	5.632***	0.674	10.482***
	(0.578)	(0.68)	(0.666)
Political Affiliation	0.038***	0.013	0.035***
	(0.009)	(0.01)	(0.011)
Minority Percentage	-2.054***	-0.01	-0.045***
	(0.654)	(0.00)	(0.009)
College Graduates	2.288	0.015	0.021
	(1.141)	(0.013)	(0.015)
Population	-0.00000***	-0.00001**	0
	(0)	(0)	(0)
Constant	-2.993**	-5.628**	-7.031**
	(1.276)	(2.596)	(3.418)
Observations	269	123	146
R2	0.471	0.239	0.783
Adjusted R2	0.452	0.178	0.769
Residual Std. Error	1.181(df = 259)	0.980(df = 113)	(0.925(df = 136)
F Statistic	25.575***(df = 9;259)	3.943***(df = 9;113)	54.497***(df = 9;136)
Note:		*p<0.1;**p<0.05;***p<0.01	

Model 9 VIF

AI	SI	EP	PH	IB	PA	MP	CG	POP
2.8	1.3	1.2	1.5	1.1	1.4	2.0	2.5	1.2

Model 10 VIF

AI	SI	EP	PH	IB	PA	MP	CG	POP
4.7	1.3	1.5	2.3	1.2	2.7	1.9	5.9	1.6

Notes: Literature-derived results of eastern Washington and western Washington alongside the entire state and associated variance inflation factors.

driven variables emerged as statistically significant for the east, while none of the non-economic variables is significant. This implies that the non-economic variables identified here are more important in the west.

While the west model remains heteroscedastic, like the whole state model, robust standard errors do not change the significance of any of the variables. The east side model is homoscedastic, a result perhaps of its poor explanatory power. In other words, Model 9 is equally poor at explaining areas of high residential solar uptake and low residential solar uptake. These results show that the literature-derived variables are much more effective for explaining residential solar uptake in western Washington than in eastern Washington.

Table 9 displays the stepwise results of the whole state and each state half. The trends established in the east/west literature-derived models are strong enough to emerge in this model as well. Eastern Washington is poorly modeled ($R^2 = 0.17$) while western Washington is well-modeled ($R^2 = 0.77$). Solar insolation, installed base, political affiliation, and college graduates are not selected as significant variables for eastern Washington. Stepwise regression failing to select installed base in the east corroborates the trend identified in the Figure 15 map. This trend implied that installed base led to high uptake in the west but seems to have impacted uptake much less in the east. Nested F-tests demonstrate that neither stepwise model is statistically better at explaining residential solar uptake when compared to the corresponding literature derived model ($p = 0.84$ for west, $p = 0.26$ for east).

Table 9: East/west stepwise models

	Whole State	East	West
	(4)	(11)	(12)
Solar Insolation	0.565***		1.964***
	(0.178)		(0.685)
Electricity Price	0.103**	0.186***	0.130*
	(0.048)	(0.044)	(0.072)
Installed Base	5.585***		10.544***
	(0.572)		(0.65)
Political Affiliation	0.038***		0.035***
	(0.009)		(0.011)
Minority Percentage	-2.195***		-0.044***
	(0.623)		(0.008)
College Graduates	2.320***		0.015*
	(0.774)		(0.009)
Population	-0.00000***	-0.00001**	0
	(0)	(0)	(0)
Average Income		0.00004**	
		(0.00002)	
Constant	-2.303***	-1.425***	-7.538***
	(0.857)	(0.544)	(2.689)
Observations	269	123	146
R^2	0.469	0.187	0.782
Adjusted R^2	0.455	0.166	0.771
Residual Std. Error	1.178(df = 261)	0.987(df = 119)	0.919(df = 138)
F Statistic	32.980***(df = 7; 261)	9.099***(df = 3; 119)	70.872***(df = 7; 138)
Note:	*p<0.1;**p<0.05;***p<0.01		

Model 11

EP	POP	AI
1	1.1	1.1

Model 12

SI	EP	IB	PA	MP	CG	POP
1.1	1.5	1.2	2.5	1.6	2.2	1.5

Notes: Stepwise regression results of eastern Washington and western Washington alongside the regression results for the entire state, and associated variance inflation factors.

Table 10 displays the three successive additions of state public education variables for eastern Washington (variance inflation factors in Table 11). When compared to Model 11 with a nested F-test, Model 13 generates a p-value of 0.235, so is statistically no better at explaining residential solar uptake. Additionally, only graduation rate is statistically related to residential solar uptake. In fact, as graduate rate drops residential solar uptake is predicted to increase, but only at a very marginal rate. The other two state performance indicators (percentage remediation, and college entrance percentage) are not significantly correlated to residential solar uptake.

Model 14's nested F-test p-value is 0.08, and so indicates that Model 14 is statistically slightly different from Model 11. As in the statewide model, no standardized tests score exhibits a significant correlation with residential solar uptake in the east.

Model 15, on the other hand, produces a nested F-test p-value equal to 0.004. Therefore, for eastern Washington the inclusion of environmental education variables significantly change model accuracy. In this model, the Environmental Education score is shown to be highly correlated with uptake. This correlation is positive in that each ~0.1 increase in Environmental Education score is associated with one more residential solar uptake per 1,000 people. This result is particularly interesting because Model 8, the statewide model which explored the impact of environmental education on the statewide dataset, was statistically no better at explaining residential solar uptake than Model 4 as evidenced by the nested F-test p-value discussed above. Therefore, strength of environmental education is statistically a more potent factor distinguishing high uptake from low uptake school districts, especially for eastern Washington.

Table 10: Eastern WA models incorporating education variables

	(13)	(14)	(15)
Electricity Price	0.177***	0.192***	0.221***
	(0.048)	(0.045)	(0.065)
Population	-0.00001**	-0.00001**	-0.00002*
	(0)	(0)	(0.00001)
Average Income	0.00004*	0.0001***	0.00004
	(0.00002)	(0.00002)	(0.00003)
Graduation Rate	-0.007*		
	(0.004)		
Percentage Remediation	(0.509)		
	(0.726)		
College Entrance	0.566		
	(0.562)		
Science		-1.095	
		(0.662)	
Biology		-0.096	
		(0.436)	
Math		-0.056	
		(0.81)	
Writing		-0.34	
		(0.767)	
Environmental Education			0.055***
			(0.014)
State Standards			0.03
			(0.034)
Constant	-0.799	-0.896	-4.096***
	(0.687)	(0.612)	(1.059)
Observations	123	123	23
R^2	0.216	0.244	0.655
Adjusted R^2	0.175	0.198	0.554
Residual Std. Error	0.982(df = 116)	0.968(df = 115)	0.710(df = 17)
F Statistic	5.320***(df = 6;116)	5.296***(df = 7;115)	6.466***(df = 5;17)
Note:	*p<0.1;**p<0.05;***p<0.01		

Notes: Regression results of public school education indicators for eastern Washington. Model 13 includes the stepwise results for eastern Washington as well as the state performance indicators of graduation rate, percentage remediation, and college entrance rate. Model 14 includes the stepwise results for eastern Washington as well biology, science, math, and writing average test scores. Model 15 investigates the results of the K-12 principal survey designed to identify relative strength of environmental education (Appendix A).

Table 11: Variance inflation factors for Table 10

Model 13						
EP	POP	AI	GR	PR	CE	
1.2	1.2	1.2	1.1	3.1	3	
Model 14						
EP	POP	AI	SCIENCE	BIOLOGY	MATH	WRITING
1.1	1.1	1.2	2	1.9	1.8	2.3
Model 15						
EP	POP	AI	EE	SS		
1	1.1	1.7	1.1	1.6		

Table 12 displays the three successive additions of state public education variables for western Washington (corresponding variance inflation factors are in Table 13). When compared to Model 12, Model 16 generates a nested F-test p-value of 0.013. This result implies that the addition of graduation rate, percentage remediation, and college entrance percentage significantly improves the model’s ability to predict residential solar uptake. Both graduation rate and percent entering college are identified as statistically significant. Surprisingly, the more students who go to college after graduation the lower the predicted uptake is. Another surprising result is that graduation rate which has a negative relationship with uptake in the east exhibits a positive relationship in the west.

Model 17 generates a nested F-test p-value of 0.66. Therefore, Model 17 is not statistically more successful than Model 12 in predicting uptake. Additionally, no test scores are identified as statistically associated with residential solar uptake in the west.

When compared to the subset of Model 12, Model 18 generates a nested F-test p-value of 0.752. Therefore, the addition of environmental education indicators does not generate a model statistically better at understanding residential solar uptake. Neither the Environmental Education score nor the State Standard score are statistically related to residential solar uptake.

Table 12: Western WA models incorporating education variables

	(16)	(17)	(18)
Solar Insolation	2.328***	1.975***	1.839*
	(0.68)	(0.698)	(1.061)
Electricity Price	0.153**	0.132*	0.064
	(0.071)	(0.073	(0.147)
Installed Base	9.695***	10.305***	1.741
	(0.683)	(0.684)	(1.65)
Political Affiliation	0.035***	0.035***	0.079***
	(0.011)	(0.011)	(0.017)
Minority Percentage	-0.043***	-0.041***	-0.052**
	(0.008)	(0.008)	(0.022)
College Graduates	0.028**	0.018	0.029*
	(0.012)	(0.011)	(0.015)
Population	0	0	-0.00001
	(0)	(0)	(0.00001)
Graduation Rate	0.011**		
	(0.004)		
Percentage Remediation	0.53		
	(0.806)		
College Entrance	-2.014***		
	(0.699)		
Science		0.77	
		(0.894)	
Biology		-0.256	
		(0.395)	
Math		-1.853	
		(1.216)	
Writing		-0.411	
		(0.889)	
Reading		1.569	
		(1.144)	
Environmental Education			-0.013
			(0.019)
State Standards			0.001
			(0.024)
Constant	-9.569***	-7.830***	-5.708
	(2.694)	(2.776)	(4.365)
Observations	146	146	45
R2	0.799	0.788	0.788
AdjustedR2	0.784	0.768	0.734
Residual Std. Error	0.893(df = 135)	0.925(df = 133)	0.764(df = 35)
F Statistic	53.680***(df = 10;135)	41.091***(df = 12;133)	14.470***(df = 9;35)
Note:		*p<0.1;**p<0.05;***p<0.01	

Notes: Regression results of public school education indicators for western Washington. Model 16 includes the stepwise results for western Washington as well as the state performance indicators of graduation rate, percentage remediation, and college entrance rate. Model 17 includes the stepwise results for western Washington as well biology, science, math, and writing average test scores.

Model 18 investigates the results of the K-12 principal survey designed to identify relative strength of environmental education (Appendix A).

Table 13: Variance inflation actors for Table 12

Model 16 VIF

SI	EP	IP	PA	MP	CG	POP	GR	PR	CE
1.2	1.5	1.4	2.6	1.6	4	1.6	2.7	3	5.8

Model 17 VIF

SI	EP	IP	PA	MP	CG	POP	SCIENCE	BIOLOGY	MATH	WRITING	READING
1.1	1.5	1.3	2.7	1.6	3.2	1.5	4.9	1.9	6.9	4.5	5.7

Model 18 VIF

SI	EP	IP	PA	MP	CG	POP	EE	SS
1.2	2.3	1.6	2.7	3.3	2.9	4.1	1.5	1.3

Overall, education indicators are not very effective at improving the understanding of residential solar uptake for western Washington. The surprising sign on college entrance (Model 16) is hard to interpret without a theory explaining why a lower propensity for students to go on to college entrance would lead to more residential solar uptake. More research could be appropriate in this area.

Statistical investigation into each side of the state corroborates the trends identified during the map analysis. That is, eastern and western Washington are very different. The variables reported here are far less effective in modeling eastern Washington as compared to western Washington. The sign of graduation rate switching from negative in the east, to positive in the west indicates that yearly pattern of school indicators may be too sporadic to properly predict residential solar uptake. Perhaps, more long term averaging could produce more reliable statistics. On the other hand, the associated p-value for graduation rate in Model 13 is 0.1, this indicates a 10 percent chance of correlation being statistically significant without correlation actually existing. The p-value for graduation rate in Model 16 is 0.05, indicating a 5 percent chance of false correlation. Ultimately, the small correlation coefficient for both of these values, the switching sign, and the statistical potential of a Type I error (e.g., that there is no relationship between the variables under study despite evidence to support a relationship), position graduation rate as a difficult variable to interpret in either case. Perhaps eastern and western Washington high school graduates react differently to solar advertising and solar incentives. Or perhaps high school graduates in the east are more likely to leave town and settle in other locations. Either way, these results add evidence to separate conditions in eastern as compared to western Washington.

While most of the results produced by the above statistical analysis are readily explained by prevailing theory and logic, there are several results that do not lend themselves to simple interpretation. This begs for other methods of analysis, such as interviews to shed light on confusing numerical results.

Interview Results

The statistical and spatial analyses quantify the decisions made by homeowners in Washington State and the conditions shaping those decisions. The interviews provided in this section aims to help in understanding the actual perspectives of those people. This allows for grounding the statistical and spatial results in the on-the-ground reality.

The interviews were conducted in the Ellensburg School District, the Lopez Island School District, and the Garfield-Palouse School District. A total of 40 interviews were conducted: 11 in Ellensburg, 16 on Lopez, and 13 in Garfield-Palouse School District. Table 14 displays the variables for the five most over-predicted school districts (i.e., districts where uptake of solar technology was substantially lower than predicted), the five most under-predicted school districts, and five of the most accurately predicted school districts. This set includes the three interview locations.

Table 14: Selected school district data

School District Name	RES	U	AI	EP	SI	PH	IB	PA
Garfield	-6.48	0.13	28,275	9.1	4.7	73.69	0.96	-20.9
Great Northern	-2.77	1.8	27,751	8	4.7	64.02	0.63	-21.3
Waitsburg	-2.74	0.76	32,174	10	4.9	72.41	0.44	-32.7
La Conner	-2.04	2.39	31,819	10.4	3.9	80.21	0.51	1.9
Reardan-Edwall	-1.9	1.7	24,742	8	4.7	80.97	0.49	-33.5
Shelton	-0.03	0.35	23,314	7.6	3.8	74.5	0	-7.9
Queets-Clearwater	-0.01	0	10,501	9.7	3.7	66	0	-1.9
Franklin Pierce	0	0.12	26,964	6.8	3.9	63.16	0.01	-3.9
Inchelium	0.01	0	15,589	9.2	4.7	65.29	0	-3.7
Ellensburg	0.03	1.33	28,802	9.3	5	75.89	0.02	-24
Naches Valley	3.05	3.85	26,498	8.3	5	80.18	0.03	-31.9
Damman	3.11	5.24	36,813	9.5	4.8	82.08	0.09	-21.9
Quilcene	3.37	4.84	30,189	9.7	3.8	84.26	0.04	-7.8
Highland	4.14	4.83	26,211	6.2	5	72.16	0.12	-28.3
Lopez	9.17	19	35,504	10.3	4.1	74.48	1.29	12.7

School District Name	MP	CG	POP	EE
Garfield	1.11	32	632	na
Great Northern	9.09	38	968	na
Waitsburg	2.7	36	1,295	na
La Conner	21.77	45	4,631	36
Reardan-Edwall	1.34	41	4,909	na
Shelton	19.67	25	23,526	24
Queets-Clearwater	46.77	13	789	na
Franklin Pierce	33	25	51,245	na
Inchelium	77.43	23	1,183	na
Ellensburg	11.68	44	26,774	30
Naches Valley	9.42	30	8,394	na
Damman	5.29	50	756	na
Quilcene	10.79	39	1,659	na
Highland	27.25	25	5,388	na
Lopez	7.8	55	2,604	na

Notes: Values for key variables for the five most over-predicted, five most under-predicted, and five of the ten most accurately predicted school districts according to results of Model 4. EE= Environmental Education. RES = Model 4 residual.

Summarization Table

Results from the interviews are presented below in the following order. First, a presence/absence coded table of results is shown. Second, conditions are laid out for the major roadblocks and pathways to adoption in each school district. This second technique creates a narrative using indicative quotes gathered during the interviews. The results presented here are triangulated with the other methodologies in the last section of this chapter.

As described in Chapter 3, categorical presence/absence coding was applied to the interviews transcripts for each district (Table 15). The coding included whether or not the interviewee installed solar, whether they knew about the local solar incentives, whether they knew about the relatively short payback period, whether they self-described as environmentally friendly, whether they are politically liberal, whether they think residential solar will have a positive economic impact, whether they have a positive opinion of energy independence, whether they know others with solar, and whether they know about local environmental education.

Table 15: Interviews summary

School District	Have solar (%)	Know incentives (%)	Know financial story (%)
Ellensburg	36%	91%	91%
Lopez	38%	69%	82%
Garfield	15%	31%	31%
School District	**Are environmentally friendly (%)**	**Are liberal (%)**	**Believe solar has positive impact on economy (%)**
Ellensburg	91%	55%	73%
Lopez	100%	75%	38%
Garfield	85%	54%	85%
School District	**Are favorable to energy independence (%)**	**Know others with solar (%)**	**Know of local environmental education (%)**
Ellensburg	82%	82%	36%
Lopez	81%	94%	81%
Garfield	69%	38%	31%

Notes: All interviews were coded for presence of the above indicators.

The information in Table 15 supply a rudimentary but useful synopsis of the interviews. For many measures, there is little difference between the three school districts (like whether people are environmentally friendly). However, a few numbers stand out. As a practical matter, and as demonstrated by the data, it was very difficult to find interview subjects who had adopted solar in the Garfield School District, while it was much easier in the other two districts. In fact, as no solar adopters could be located within the Garfield half of the school district, interviews with solar adopters were conducted in the Palouse portion of the Garfield-Palouse School District. Garfield also shows far lower knowledge regarding incentives with only 31 percent of the interviewees knowing that there are incentives, and that they lead to a short payback period. Garfield is also unique in that only 38 percent of the interview respondents knew others with solar, while 82 percent and 94 percent know others in Ellensburg and Lopez, respectively. The most unique value from Lopez is the 81 percent who know of the presence of environmental education in the school district. Also, Lopezians did not believe that solar would necessarily have a positive impact on the economy at the rate the other districts did. This finding may imply that greater familiarity with the technology fosters skepticism about its economic impacts. Ellensburg did not show any strikingly unique response trends, befitting its well predicted position in the statistical models. In the following subsections the major roadblocks and pathways to adoption are examined for each district.

Ellensburg School District

Eleven interviews were conducted in the Ellensburg School District. The statistical model accurately predicts uptake in Ellensburg. Therefore, there is reason to believe that the experience and knowledge regarding solar and the economic and cultural conditions of Ellensburg are relatively average for Washington State. As a central tenet of this research is to investigate uptake under consistent incentive structure it is important to note that the incentive conditions are equal across the study sites save for the city incentive provided in Ellensburg. The existence of this city incentive was not discovered until the interviews were conducted. Importantly, the city incentive was not offered until fall 2017 so does not correspond to the data used for the spatial and statistical results, and was not present during the interviews conducted here. Therefore, and due to the well predicted nature of Ellensburg, the responses of the Ellensburg interviewees can be considered a baseline to compare Lopez and Garfield to.

Roadblocks to adoption

The major roadblock in Ellensburg can be summarized as incomplete information about solar incentives and payback period. Specifically, the non-adopters in the Ellensburg community have the attitude that solar is too expensive, and are not fully aware of any possible personal benefit possible through solar. While Ellenburgers are generally aware that incentives exist for residential solar (Table 15), the consensus among non-adopters is that residential solar is too costly. All interviewees provided their employment status, and it is true that some interviewees' income would make the upfront cost of solar prohibitive (such as an unemployed interviewee). However, most non-adopters had <u>not</u> sought out an actual quote from an installer or explored financing options. For example, when an interviewee without solar who had a good job at the local university solar was asked if they knew about solar incentives, they responded by saying:

> "I know nothing too specific about Washington incentives but I try to keep up with solar and I know that there are incentives for purchasing panels, but I have not asked anyone about it locally."

The interviews suggest that many residents in Ellensburg do not know the full story regarding solar, and are forced to make assumptions about the cost and incentives. Despite the 70 percent of non-adopting interviewees who said that they did not seek out quotes from solar installers, Ellensburg interviewees have a positive opinion of solar. One resident states this well when they say, "I am all for solar, I just can't afford it." Only one interviewee expressed a worry that solar would be an eyesore to neighbors. All other subjects predicted that they would receive no social pushback from installing solar.

In fact, almost every non-adopting interview subject knew others with solar and many even expressed the knowledge that their friends and acquaintances had had positive solar experiences. For example one non-adopting interview subject said:

> "I know one person who has installed solar and is totally off the grid and they are very proud and happy with that. I know another family that installed solar and is waiting for the five year payback, because they thought it would be a good financial investment."

Non-adopting people in Ellensburg are aware of others with solar (Table 15), support solar, and even think solar is a good financial decision for those that can afford it. However, they think that solar is expensive, but do not often take the extra effort to research solar for their own situation. Knowledge of this shortcoming has not escaped Ellensburg interviewees. Over 50 percent of the individuals interviewed recommend more education as a means towards growth of residential solar. One non-adopter, who showed particularly good knowledge regarding the incentives and payback period of solar, said:

> "More education, you know if you show people that this little time is all it needs, and you're going to see extra money in your pocket every month. If you show people that money, they'll know that it helps people."

Someone who adopted solar expressed a similar opinion with the following quote:

> "The information is out there and available, it is just the matter of whether they want to take the effort to go out there and find it."

In fact, finding information on the average cost of solar, and the average payback period, is as simple as a Google search. In Ellensburg, a local installer has an easy-to-locate website that lays out the financial situation of residential solar (Ellensburg Solar, 2018). The information provided on this site mirrors what is laid out in the above literature review. That is to say, the cost of residential solar is about ~$30,000, there is a 30 percent federal tax rebate, a renewable energy cost recovery program rebate that pays for all electricity produced (which amounts to a maximum of $5,000/year depending on system production), a net-metering payoff (~$130/year), and energy savings for not having to buy from the utility company (varies on household use).

While this financial story seems quite favorable, Ellensburg companies who install solar say they rely on word of mouth to advertise their product. It is possible that this passive means of marketing fails to reach all those that could be interested in residential solar. Despite the ease of accessing solar information, it seems that many Ellenburgers believe solar to be too expensive so therefore do not bother doing research for themselves.

Taken together these quotes highlight that locals who are knowledgeable about solar options and incentives believe that active investigation into residential solar would reveal solar to be more of a possibility than some Ellensburg residents believe it to be. In fact, understanding the low solar uptake in Washington, despite the favorable economic calculus of solar, is central to the goals of the current work.

Through these indicative quotes taken from non-adopting Ellensburg residents it seems that a lack of solar knowledge is the main roadblock to adoption in Ellensburg. However, "reduce the upfront costs", was a simple piece of advice offered by just under 50 percent of those interviewed when asked how to grow solar locally. This makes sense, as the initial investment of approximately $30,000, as touted by local installers, is a prohibitory upfront cost for many (Ellensburg Solar, 2018). While local installers also advertise the option to get loans to cover this (Central Wind & Solar, 2018), and the incentive process will even pay off those loans as they come due, it still takes individual research to discover this.

As evidenced through the interviews it seems that the perception of many Ellensburg locals is that solar remains prohibitively costly. Overall, a belief in financial constraints and poor knowledge emerge as the main roadblocks to growing solar in the Ellensburg School District.

Pathways to adoption

On the other hand, the main path to adoption in Ellensburg involved active research. Those that did install solar took personal effort to seek out knowledge on the subject. This is a relatively easy process as well, as there as at least two active solar installers in Kittitas County. For example one early adopter said:

> “I remember reading about the solar incentives, and I guess Audubon [Kittitas Audubon Society] also had some stuff about it, too, in one of their newsletters. I saw it in various sources. Then we started researching.”

This highlights that solar energy is most accessible to those that actively seek novelty and are unafraid of doing their own research. Additionally, those that have installed solar, have a very positive opinion of the state incentives. For example, one solar adopter said:

> “I think that our state has done a fantastic job trying to get solar established here. By fantastic I mean that the state incentive pays us to make electricity. And the only way that it makes sense to have solar is to have incentives.”

This opinion was consistent even though each individual who had installed found that their payback period was longer than they first had anticipated. This does indicate overselling by local installer. However, and despite the increase in payback period, adoptees still believed they would pay off and even make money off their solar systems. The disparity between what adopters had expected and the actual repayment period resulted from overestimates during the projection process but mostly from utilities falling short on feed-in-tariff tax credit funding associated with the Renewable Energy Cost Recovery Program. More specifically, for the original 2005 bill each utility only was funded to distribute credit equal to “one-half percent of the light and power business' taxable power sales, or one hundred thousand dollars, whichever is greater (Washington Legislature, 2005). This legislative decision proved to be problematic, as utilities reached these limits they were forced to either stop accepting new applications or to reduce payment to existing applicants. Some utilities cut off new applications, while others reduced the payback and kept accepting applications. For example, of the three utilities in Ellensburg, Ellensburg Utilities stopped accepting new applications in 2015, Puget Sound Energy reduced payments from $0.54/kWh to $0.51/kWh in 2015, and Kittitas PUD stopped accepting applications in 2015. It is important to note that the 2017 renewal of the Renewable Energy Cost Recovery Program addressed these problems directly by locking applications into their original payback rate for at least 8 years, or until 50 percent of the original investment was paid off, and allocated significant additional funding to the program. This allows utilities to re-open application for the incentive and to guarantee a payback rate.

The continued appreciation of solar, despite the change in payback period, could be explained by the environmentally friendly reasons adopters cite for their decisions. These non-financial motivations always came with a financial caveat, as demonstrated in the following quote:

> “We also wanted to do it to be green, to provide clean energy. If we produced excess we’d help the community have cleaner energy. That is a philosophical incentive, but we would not have done it if the payback period was too long.”

Likewise this quote shows how environmentally friendly motivation may open the door to residential solar, but financial prudence encourages people to take the step through.

> “I want to be more green, but I don’t go out of my way to call myself a green person or anything like that. It is a selfish thing, too, because I wanted to generate more electricity for myself and at the same time…. Going green is great, but not if it costs twice as much as not, then it is not worth it.”

While those that adopted experienced no resistance or negative reactions from fellow community members, more than one adoptee did experience resistance from local municipal permitting agencies. After being asked whether they received any support or resistance to their decision to adopt solar, one adoptee said:

> "Actually several people commented that we were putting solar up. We experienced no resistance from neighbors. That being said, there are resistant elements from people who work with the city because this is a state program, so people were not particularly excited about it."

While resistance may be the impression of a few interviewees, this is not the opinion of the official interviewed on the phone from Ellensburg Utilities. They claim that the Ellensburg City Council, which runs the utility that services a large percentage of the Ellensburg School District's population, is very pro-solar. In 2008, they put in a community solar project and in 2017 they went so far as to allocate $75,000 in additional incentives. Residents could receive up to $5,000 in one-time incentives if they decided to install solar. This plan was hyper effective and the entire budget was used up in a few weeks, skyrocketing the total of adopters in the town of Ellensburg from 21 to 51. This incentive was initiated after these interviews were conducted.

Overall, adopting interviewees expressed positive experiences with their residential solar and are happy to be saving money, despite their reported extension in payback period (often from a predicted 5 years to an actual 7-8 years). However, they warn that the new incentives from the state will not cut it to encourage additional adoption. For example one interviewee said the following.

> “Now there is a new program initiated by the state. This will take a lot longer to pay back than the old incentive structure. At least 2.5 times longer. The costs of the system just haven’t come down enough for those materials without a better incentive program.”

This statement is partially correct. That is to say, the incentives have been reduced, but according to the Ellensburg Utility employee, the cost of panels has also come down. The original bill, passed in 2005, provided up to $0.54/kWh of feed-in-tariff tax incentive. The new bill, passed in 2017, provides up to $0.21/kWh. However, in 2008, panels in Ellensburg cost 7.7¢ per watt while today they can be purchased for a fraction of that at 1.3¢ per watt (Ellensburg Utility, 2018). Additionally, the new bill also locks the panel owner into the rate at which they start, but only for up to 50 percent of the cost of the system. Therefore, the incentive can no longer be used as a money-making enterprise. The new incentives are lower, but as evidenced by the recent jump in solar for Ellensburg not prohibitively so.

To summarize, adoptees in the Ellensburg School District are most unique in that they were willing to do the extra effort to clarify that solar was a good decision for them. They identify economics as the primary motivator, with environmental concerns as the secondary motivator.

Lopez Island School District

A primary reason for visiting the Lopez Island School district was understanding the conditions which led this unit to being so under-predicted by the statistical model. In other words this part of the interviews attempted to answer the question, ‘Why are there so many solar installations on Lopez Island?’ To properly answer to this question, both the roadblocks and pathways to adoption are examined below. Incentive conditions on Lopez are the same as Ellensburg save for the fact that there is no additional municipal incentive. Below, special attention is paid to ways that Lopez differs from Ellensburg.

Roadblocks to adoption

Once again, the main roadblocks to adoption expressed by non-adopting Lopezians were ignorance and funding constraints. However, a few interviewees also expressed issues of control and a desire to wait for solar technology to mature further. For example, one non-adopting couple said the following when asked what they knew of incentives:

> "Not much. The payback is too long for us old folks. I understand that the payback is about 25 years."

This quote shows how poor information actually leads to an issue in perceived control. Perhaps a 5 to 7 year payback period would have been more within this couple's means. Additionally, non-adopters often expressed interest in solar, but had not adopted due to other priorities. One interviewee said the following.

> "We don't have any money in solar. But this house is r-factored out the kazoo when we need to heat. We walk and bike. We are low on the scale for energy consumption".

A potential reason for not prioritizing solar is expressed in the following quote from a non-adopter after they were asked if they had solar:

> "No. I have been spending my money on other things. We spent money on the [goat dairy] and spent money on another building, and we built a yurt, and spent some on the barn. So I have been busy spending money on other things and would

> just as soon wait. It seems like things just keep getting better. There is technology now that didn’t exist five years ago.”

With a few exceptions, non-adopting Lopezians were very favorable of solar and most of them knew the incentive situation quite well. As Lopez has the highest concentration of uptake in the state of Washington, this is not particularly surprising. Solar was visible and common on the island, and a point of pride. One non-adoptee seemed excited when they said:

> “I do not [have solar]. I have only lived in this house for a few years and this is the first house that I have owned that solar is actually an option!”

In contrast with Ellensburg, only 25 percent of respondents recommended more education as a means towards growing solar. This difference is interesting as both Lopez installers and Ellensburg installers indicate that they rely on word of mouth to engage new customers. Despite this similarity, it seems that Lopezians generally feel that solar knowledge has saturated the community. Instead, 75 percent of respondents called for more incentives, innovation, and cheaper installations as the way to grow residential solar installations.

Pathways to adoption

A few features of the community stood out as possible catalysts for high solar adoption. These include very visible community development which has residential solar, a strong culture of environmental education led by organic farmers, several local solar installation companies, and the isolation caused by being an island community. Additionally, it should be noted that several adopters interviewed here were financially well off and had retired to the island after successful Seattle area careers.

In many of the interviews, Lopezians brought up the Lopez Island Community Land Trust as a place on the island with solar. For example one non-adopter said the following when asked if they knew others with solar.

> "Just up the road here there is a community land trust that has it. They worked hard with that group of homes to have a lot of independence that way. Those are straw bale houses with a mud overlay."

After several interviewees talked about the land trust, an interview was done with a person who has intimate knowledge of the land trust's workings. The Lopez Island Community Land Trust (LICLT) was first established in 1989 and has been interested in solar since then. Community land trusts purchase land and make it available for cheap housing to the community, in perpetuity. It was not until 2007, however, that the financing for solar came together (Figure 28). With the help of an outside grant, the LICLT took advantage of the state subsidies and installed solar near seven sweat-equity straw bale homes. The date of 2007 is the earliest date recorded during the interviews of someone taking advantage of the state Renewable Energy Cost Recovery Program, which started in 2005.

As demonstrated by the above quote, and the frequency in which the LICLT was referenced, this land trust is a visible and important place for residential solar on Lopez island. The early adoption date recorded here also means that this land trust, located near the city center on the island, has been imparting neighbor effects for more than a decade. That is to say, the visible solar on the land trust keeps residential solar present in the mind of Lopez locals.

Figure 28: Lopes Island Community Land Trust. Photo of the Lopez Island Community Land Trust. Photo Credit: Chris Greacen (courtesy of LICLT personal e-mail communication May 2017).

Another source of pro-solar sentiment seems to come from the healthy community of small solar-powered family run farms on the island. There are over 35 small organic farms on the island. One farm, which had four total solar installations, also participated in community outreach. An interview subject said the following when asked about environmental education:

> "Fifteen years ago we went to the school and said that we wanted to start a farm-to-school program where kids would grow vegetables from seed to table and they would grow it, take care of it, harvest it, take it to the kitchen, prepare it, and eat it. At first there was a great deal of resistance from the administration, because

> they didn’t have time, there was no room in the curriculum, and from the parents who were worried that we were promoting organics and then the people on the island who could not afford organic food were going to feel criticized….but these days the “O” word, the organic word, isn’t even considered as a bad thing anymore.”

Another part of the program mentioned above was regular visits to the interviewee’s solar powered farm. For fifteen years high school students on Lopez have been taking field trips to the farm. Additionally, the high school itself has solar installations, made possible through effort from the local utility company OPALCO in combination with local donors. One interviewee mentioned how their child helped with the process of bringing solar to the local high school:

> “They had solar panels on the school and my daughter even helped to solicit money by giving the whole spiel about how it would benefit the school.”

Another interviewee also noted this initiative when asked about environmental education in the area:

> “OPALCO set up a program where anybody can put up solar on the school. You had to pay $1,000 to finance solar on schools throughout the islands. The payback was that the school, as they saved themselves money, would send you a check every year. And it would pay back the $1,000. I think that it will take 10 years.”

OPALCO (Orcas Power & Light Cooperative) is the utility company which services the San Juan Islands (of which Lopez Island is a part). The above quote demonstrates that the local utility is friendly to solar, and makes solar-related environmental education a reality for local children. Additionally, and according to many interviewees, OPALCO is currently exploring options to initiate a local community-owned solar farm.

Even outside of the public schools, interviewees expressed multiple times that the island culture was very environmentally friendly. They said that a visit to the farmers market would help to get a "feeling for the community." Several interviewees also suggested that the isolated do-it-yourself island culture led to the environmental concern:

> "Lopez has always been farmers and fishermen. But now we are retired folks and artists. We had a do-it-yourself ambulance that we would use. We are pretty isolated with three ferries a day. You had the resources you had but they were hard to replace. So I think that concern is kind of a natural thing."

In addition to their environmentally friendliness, Lopezians also mentioned the high level of community engagement several times. This was summed up well by a non-adopting interview participant who said the following when asked about environmental education:

> "There are a hell of a lot of people on this island that are into community, so there are a ton of organizations and non-profits for whether it is housing or food, as well as some of the more entertaining quality of life issues. You can join anything you want, whether it is a chess club, or something else, but not everybody does. So there are several environmental groups too, as well as education at the school."

Environmentally friendly, community-oriented, with a solar friendly utility company; what a place to be a solar installer. In addition to these cultural traits, it would be remiss to not mention how many of the Lopez locals are economically very well off (see Table 14). For instance, another organic farmer, who had semi-retired to the island from a successful mainland career, said the following about why they adopted solar:

> “The incentives helped, but we appreciate the ethics of it and we are fortunate enough to have the money to afford it, and it seemed intriguing, and the right thing to do. [The system] never has to pay itself off as far as I am concerned. “

This lack of financial concern was relatively rare as most solar adoptees on Lopez were still very concerned with the incentives and payback periods and very aware of their timeline for break-even. Although not explicitly mentioned during the interviews, Lopez Island has some of the highest electricity prices in Washington (Figure 14). This price likely led to more favorable calculus when individuals were deciding to adopt solar. As in Ellensburg, Lopez adopters also expressed a willingness to do their own research regarding solar. Additionally, many Lopezians knew the name of a local solar installer that they would contact if they decided to install. Overall, however, Lopez Island was most unique in its environmental concern, level of environmental education, and community engagement. Overall, Lopez locals know a lot about solar, are well exposed to solar, and have a relatively easy pathway to adoption.

Garfield School District

As high adoption was the primary reason for studying Lopez, the primary reason for visiting Garfield was low adoption. The statistical model greatly over-predicted the rate of adoption in the Garfield school district. To help understand the reason for this outlier, interviews were conducted in this school district. Incentive conditions are the same as most of the state, and Lopez Island, meaning that the only state and federal incentives are available. As before, attention is paid to ways that Garfield differs from Ellensburg.

Roadblocks to Adoption

The primary roadblock in Garfield is well displayed in Table 15. Less than a third of those interviewed actually know about solar incentives and the payback period associated with solar. In fact, no non-adopting participant could name a local installation company. This is unsurprising as a Google search for solar installers in Garfield Washington revealed no options closer that Spokane, WA (this is a 1 hour drive). Without proper information, many Garfield residents assumed that they could not afford solar even without knowing the cost. For example:

> "No we do not [have solar]. I have not done any research. We made up our minds that we could not afford it so never did research."

The relative ignorance regarding solar in this area possibly stems from the very low adoption rate. That is to say without many neighbors who had adopted solar, curiosity about solar is naturally lower. Among the interview subjects who did know others with solar, almost all mentioned the neighboring community of Palouse. For example, when asked if they knew others with solar one non-adopting interview subject said:

> "Not here. Palouse has it I know, but not here in Garfield."

Another difference between Garfield and Lopez is the ownership structure of the utility. Avista Corp., the Garfield utility, is a private for-profit company, while OPACLO, the Lopez utility is publically owned. While Lopezians had favorable things to say about their utility, Garfield residents were less pleased with AVISTA. For instance, one non-adopter said the following when asked about energy independence:

> "I would love nothing more than to be independent. It galls me nothing more than to write checks to Avista and then read about the big wigs up there getting millions and millions of dollars of salary and bonuses. I think it is stupid. If I could get away from that, I would."

While this opinion was expressed by interviewees, there seems to be no direct evidence of anti-solar sentiment at Avista. For example, the Avista website offers a residential solar calculator. The calculator asks for your location, electricity cost, and roof type and predicts the electricity offset and payback of solar installations (Avista, 2018). While the outputs are a bit confusing, there is a 1-800 number available for contacting an Avista solar representative.

Additionally, a few non-adopting interviewees also expressed the worry that adopting would create negative sentiments from neighbors. For example, one non-adopter, who did not know the price or incentives of solar, said the following when asked if they would get resistance if they installed solar:

> "In this community I would. Any change in this community is a no go. I wouldn't let it deter me especially if I found solar to be something that I could actually afford. I wouldn't care what anyone thought. It is my house, it is my property, and I will do what I want. If it required a permit, I would be challenged. Our mayor and others wouldn't go for something outside of something that they have been doing for the last 60 years"

The above quote was out of the ordinary, however, with most non-adopters saying that others would regard a decision to adopt solar with nothing more threatening than curiosity. That being said, small roadblocks such as potentially negative norms associated with solar, the lack of local solar installers, and very low visibility of solar could add up.

As in Ellensburg, over half of those interviewed suggest more education and solar knowledge as main means of growing solar locally. Several interviewees specifically suggested some sort of informative town hall meeting. All in all, Garfield is most unique in the low level of knowledge regarding solar installations, and the lack of local visible solar infrastructure. This low level of solar knowledge is likely the result of the combination of factors displayed here such as the absence of a local installation company, a privately owned utility, and potential resistance from the community.

Pathways to Adoption

As mentioned above, no adopters could be found in the Garfield portion of the Garfield-Palouse school district. To provide a baseline comparisons, interviews were conducted with two adopters from the neighboring Palouse school district. No unique results were identified from these interviews. They were environmentally concerned, knew the exact timeline for panel payoff, and are proud of their installations. Both adoptees recommended more incentives as the main way to grow solar in Washington.

Summary of Interview Results

A presence/absence table combined with the examination of the primary roadblocks and pathways to adoption are examined above for the Ellensburg, Lopez Island, and Garfield-Palouse school districts. The results of the interviews show different cultural conditions in each of these three school districts. These results provide an effective means for understanding residential solar uptake in the terms of the theories and mechanisms outlined in the literature review. A brief synopsis of these results, especially in relation to theory, is provided below.

Poor information on solar options and incentives is the primary roadblock to adoption in these interviews. This finding supports the results of Rai and Beck (2015) who identified gaps in information as a major obstacle to residential solar adoption. Likewise, knowledge of a technology is critical in the diffusion of innovation theory, as outlined in relation to residential solar uptake by Wolske, Stern, and Dietz (2017). That being said, level of knowledge could also be construed to shape an agent's attitude and perceived behavior control towards a behavior (tenants of the theory of planned behavior).

Both the Garfield and Ellensburg adopters are novelty-seeking and are interested in conducting their own research. Schelly (2014) found a very similar trend in novelty seeking among Wisconsin early adopters. Both these results fit the importance of consumer novelty seeking to early adoption as proposed in the diffusion of innovation theory (Wolske, Stern, and Dietz, 2017). The high residential solar uptake, and high residential solar knowledge in the Lopez Island School District, indicate that this area may have moved further along the knowledge-persuasion-adoption-confirmation process as described by the diffusion of innovation theory (see Chapter 2). It may be that the visible/early installed base and pro-environmental education on the island combined to speed up the process of residential solar diffusion. The results from Lopez imply that solar, once established in an area, builds on itself by increasing solar visibility and familiarity.

On the other hand, the theory of planned behavior focuses on attitude and subjective norms as major factors in the decision to adopt solar. Solar attitudes are demonstrated as positive by these interviews, not a single adopter regretted their decision to install solar, and 97.5 percent of non-adopters expressed positive attitudes as well. Additionally, 95 percent of the interview participants do not believe that solar would contradict local cultural norms. These results likely stem from the positive financial experience adoptees have with solar and the fact that at least 85 percent of interview subjects expressed that they are environmentally friendly.

Finally, both Lopez and Garfield have local utilities that are actively taking steps to encourage solar use. There is no evidence of community level solar effort in the Garfield-Palouse School District. Engaged utilities could logically increase consumer knowledge of a technology and produce a positive attitude regarding a technology. This result highlights the potential importance that local institutions and organizations have in encouraging adoption of novel technologies.

Altogether, both the diffusion of innovation theory and the theory of planned behavior can be framed to explain the results of these interviews. The dual effectiveness mimics the results of Wolske, Stern and Dietz (2017) who found saliency in both theories. Furthermore, primary mechanisms for adoption laid out by other researchers, such as novelty-seeking, propensity for pro-environmental behavior, and the influence of economic factors, are compatible with both theories. Chapter 5, the following conclusion section, includes a discussion which attempts to partially reconcile whether the diffusion of innovation theory or the theory of planned behavior best fits residential solar uptake in

Washington. This discussion includes both the results discussed in this interview section, alongside the statistical and spatial results.

CHAPTER 5

CONCLUSIONS

The flipping of a light switch conceals a complex system in which power is drawn from water or wind moving a turbine, the burning of fossil fuels, a nuclear reaction, or – increasingly – the light of the sun. The shift to solar is fueled by multiple forces. Primarily, government agencies recognize solar as an efficient way to increase homegrown low carbon energy and so have heavily subsidized this energy source in particular. In Washington, solar energy allows residents to become more self-sufficient, and to lower their reliance on hydropower. A shift from hydropower to solar power could allow water and fisheries managers more freedom in resource allocation and decision-making. A good example of what is at stake is the central Washington Yakima Basin Integrated Plan. This multi-decade, multibillion dollar effort is directed at changing the way water is used in the region to increase drought resilience, prepare for climate change, and make more water available for salmon and other threatened species (YBIP, 2018). Increasing reliance on solar energy has the power to aid in reaching these same ends. Water that isn’t required to spin hydroelectric turbines can be dedicated instead to irrigation and wildlife interest.

Perhaps with this consideration, Washington State has subsidized solar to the point where it is the 5th cheapest in the nation. This thesis asks, given such low prices, why does Washington rank 39rd in the nation in total solar capacity? And, after understanding the cause of this discrepancy in the realm of residential solar, what can be done to grow residential solar further? To understand the patterns of residential solar uptake in Washington, three separate methods were employed. These include spatial analysis, statistical analysis, and qualitative investigation. By examining residential solar uptake from these three different perspectives, the conclusions presented below are richer and more certain than what would be possible by employing just one technique.

The statistical results are a solid foundation to build conclusions upon. The best statewide statistical model produced in this work accounted for 45.5 percent of the variation in residential solar uptake across Washington[2]. This falls between the 21 percent modeled by Graziano and Gillingham (2015) and the 86 percent modeled by Robinson and Rai (2015); the former modeled residential solar diffusion using time-series analysis in Connecticut and the latter modeled residential solar uptake using time-series analysis coupled with social modeling in Austin, Texas. Variables found to be statistically significant in the current study include solar insolation, electricity price, installed base, political affiliation, minority percentage, college graduates, population, and environmental education. Installed base, while emerging as the most powerful variable in several models, is problematic in that its inclusion violates an assumption of ordinary least squared regression analysis. This implies that understanding the impacts of installed base and neighbor effects may be a worthy avenue for further research. Surprisingly, average income is generally determined to be non-significant in its correlation to residential solar uptake.

Altogether, several salient conclusions and objects of discussion are identified during this thesis and discussed below. First, a potential urban/liberal bias in residential solar uptake academic study is revealed through this research. Second, triangulated

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[2] Model 4 emerged as the main model of this study and derived many of the conclusions discussed in this chapter. However, the most salient conclusions are supported by the many other statistical models discussed in detail in Chapter 4.

conditions which lead to residential solar uptake in Washington are described and analyzed. Third, evidence has emerged which indicates that public school environmental education is associated with increased residential solar uptake. Fourth, and within the above conclusions, recommendations on how to grow residential solar in Washington State are presented. These conditions are then couched in terms which continue the theoretical conversation on residential solar started by Wolske, Stern, and Dietz (2017) and Schelly (2014). Following these points is a discussion on the shortcomings of this work, a few potential avenues of further research, and final remarks.

Eastern and Western Washington: a telling divide

A stark conclusion drawn from the current analysis is the divide between eastern and western Washington. Even when all the factors included in the statistical analysis are controlled for, the state halves had drastically different R^2s. In the best western Washington model, more than three-quarters of variation was accounted for ($R^2 = 0.77$), and while the best eastern Washington model explained about a sixth ($R^2 = 0.17$). Prior to the statistical modeling, the first indicator of this binary difference is the variable solar insolation. The clear bi-modal pattern of this variable (Figure 13), neatly correlates to the halves of Washington as split by the Cascade Mountains. However, the east-west divide is not isolated to environmental trends. Specifically, political affiliation, population, electricity price, and average income, show a similar pattern (See maps in Chapter 4). Even the interviews from western and eastern Washington show very different results.

What conditions are leading to such polar statistical results? The bimodal solar insolation would be a good first guess. However, eastern Washington, the half of the state with more sun, adopted solar at a rate half that of western Washington (Table 8). Other, less obvious, reasons are clearly also driving this result.

The variables of this study where chosen through literature review. And frankly, they did a very effective job at modeling the liberal, relatively urban, wealthy western Washington. However, the literature-derived variables were poor at modeling the conservative, relatively rural, and poorer eastern Washington. While previous research has included a diverse set of areas, including the whole nation (Zahran et al. 2008), California (Mai, 2013; Strupeit and Palm, 2016), and Wisconsin (Schelly, 2014), recent research has focused on areas more similar to western Washington like Connecticut (Graziano and Gillingham, 2015), Austin, TX (Robinson and Rai, 2014), and cities in general (Lee et al. 2017). Taken together this implies that rural America is being neglected in terms of residential solar work.

There are some clues as to the cause of this divide in the statistical models from Table 8 and Table 9. For the literature derived models in Table 8, eastern Washington uptake is only correlated to electricity price and solar insolation, two economic variables. These variables are also important for the west, but the non-economic variables of installed base, political affiliation, minority percentage, and college graduate are also important. The importance of economics to eastern Washington is further highlighted by Table 9. Average income is selected through stepwise regression as the most important variable to understanding uptake in the east, but not in the west or for the full state. This implies that economics, rather than culture, may be the driving factor to residential solar uptake in eastern Washington. That being said, it is just as likely that cultural variables not included in this study would increase the R^2 of the model for the east.

One variable, installed base, calls for additional unpacking in terms of the state divide. Figure 13, the map of installed base across Washington, shows that successful applications to the renewable energy cost recovery program are relatively even in the west and the east from 2005-2010. This trend clearly does not persist to the period of 2011-2014 (the period defined as Uptake in this study). Graziano and Gillingham (2015) establish installed base as a means of imparting neighbor effects and therefore increasing residential solar uptake. These neighbor effects, and the impact of installed base, seem to express differently in the east as compared to the west. A few explanations for this difference emerged from the interviews. First, while the data demonstrates that residential solar must exist in the Garfield school district area, no interview subject knew of local installations and none were in the town center. The lower population density may, therefore, be responsible for the different impact of installed base. Second, perhaps the lower level of awareness, in terms of residential solar options and incentives, in the east leads to the corresponding lower uptake. That is to say, if you see your neighbors with solar, but do not know the incentives that they took advantage of, the neighbor effects may be slackened. Additionally, and as mentioned above, differences in population density may cause installed base to impact areas in different ways. Targeted investigation could attempt to determine the differences in neighbor effects in rural and urban areas to help explain this result.

Whatever the cause for the east/west divide, this conclusion is particularly problematic given that sunny sparsely-treed eastern Washington has a far lower concentration of residential solar than cloudy well-treed western Washington (Table 7).

Therefore, the area with the most potential for growth in residential solar, is the least understood.

Only, population, electricity price, average income, and strength of environmental education were identified as positively correlated with residential solar uptake in eastern Washington. This provides a baseline of variables but far from the entire picture. Further research could focus on rural-conservative America or the academic community researching solar risks leaving a large segment of the population behind.

This finding of an east/west divide also calls into question previous studies that have established best practices in terms of residential solar incentives (e.g., Steward et al. 2014). Due to the population concentration in urban/liberal areas, large portions of the US are likely overshadowed in statistically driven conclusions. The danger of this is apparent in the present work. The whole state model still accounted for a good portion of residential solar uptake, produced several significantly correlated variables, and could easily have led to fertile conclusions. Only by purposely dividing the state did the east/west-urban/rural divide become apparent. Accounting and controlling for this divide should at least be considered when attempting to understand residential solar uptake and potentially the use of other environmentally friendly technology.

Conditions Leading to Residential Solar Uptake

In line with previous research, awareness of residential solar emerged as one of the most pervasive conditions that lead to higher residential solar uptake in Washington (Graziano and Gillingham, 2015; Rai and Beck, 2015). This awareness came in both specific knowledge of incentives and payback, and in the form of imparted neighbor effects.

Degree of knowledge regarding residential solar uptake was a distinguishing factor among the interview locations. Over 90 percent of Lopez respondents knew about the solar payback period and incentive structure. This contrasts to only 38 percent of the Garfield respondents. This knowledge gap neatly correlates to residential solar uptake. That is to say, areas with higher solar knowledge seem to adopt more residential solar and vice versa. Furthermore, the interviews determined poor knowledge of solar to be a main roadblock to adoption in both Garfield and Ellensburg.

Awareness of residential solar is also imparted in terms of neighbor effects. The variable specifically designed to account for neighbor effect is installed base. While a problematic variable to analyze, as discussed above, installed base is still strongly and positively correlated to residential solar uptake (e.g., Table 3 and Table 4). Neighbor effects are a classic way of increasing technology awareness. The theory is that, a neighborhood solar array is a visible, large reminder that solar is a local, feasible option. For instance, Graziano and Gillingham (2015) found a strong correlation between the presence of solar installations in a neighborhood and additional adoption in the following timeframe. Two of the three interview locations highlight this same result well. The Lopez Island School District had several visible locations (including a high profile community land trust; see Figure 28) where solar was installed early during this study period. These neighborhood installations were demonstrated to be well known locally and very visible from the town center. This is likely part of the reason that Lopez adopted residential solar at such a high rate. On the other hand, solar has such low visibility in Garfield School District that few locals who had installed could be located for the interviews. Both the quantitative variable of installed base, and the qualitative observations, corroborate the importance of installed base at encouraging residential solar uptake.

Both installed base, in the form of neighbor effects, and solar specific knowledge, combine as avenues for increasing awareness of residential solar. Understanding that this awareness is a key factor separating high uptake areas from low uptake areas provides an important first step in understanding how to grow residential solar in Washington. As discussed, residential solar uptake has a payback period that can be as short as 3-5 years (Solar Power Authority, 2016). It stands to reason that as awareness of residential solar as an option increases, so will the percentage of those who take advantage of residential solar. Therefore, marketing and awareness campaigns could be relatively straightforward ways to grow residential solar uptake in Washington State.

However, marketing is not free or easy. Fortunately, this analysis reveals several statistically grounded variables which can help to focus marketing efforts. These statistically significant variables include: solar insolation, electricity price, political affiliation, minority percentage, college graduates, and population. Conclusions derived from the analysis of single variables sometimes contradict each other, and the interplay of the many variables should ideally be considered.

Some of these variables are simple to interpret. For instance, solar insolation and electricity price both increase residential solar payoff. Therefore, it is no surprise that these variables positively correlate to increased residential solar uptake. This correlation corroborates the importance of economics in residential solar uptake identified by the literature review. From this information, marketing of solar could focus on the under-adopting areas (Figure 10) that have high solar insolation and high electricity prices

(Figure 13 and Figure 14). For instance, the Kennewick area seems to be a prime location in Washington for economically efficient solar growth.

College graduates and population are also significantly related to residential solar uptake. Areas with higher college graduates and lower population adopt solar more. From this results, it would be logical for solar installers to focus on well-educated areas with lower population (Figure 19 and Figure 20) to increase solar uptake. Alternatively, the same results may indicate the need for a shift in policy. Specifically, the fact that highly educated areas have adopted solar at higher rates reinforces the need for new forms of public education/outreach to reach less well-informed/more skeptical populations.

Both political affiliation and minority percentage are very interesting variables which also correlate significantly with residential solar uptake. Specifically, the statistical models provided in Chapter 4 demonstrate that more Democratic areas, and less diverse areas, have been more likely to install residential solar. The correlations persist even when controlling for per capita income, and percentage of college graduates (e.g., Table 3 and Table 4). These statistical correlations imply that, for some reason, residential solar uptake is either more efficiently communicated to certain sections of society, or residential solar is more culturally accepted or common for certain sections of society. Alternatively, it may be possible that un-even access to wealth is being masked due statistical averaging, and it actually responsible for these trends.

Take for instance the issue of political affiliation. The literature explains how Democrats are more likely to be concerned about the effects of climate change, and to subsequently take steps to lower their carbon footprint (Brody, Grover, and Vedlitz, 2012). As the correlations within the statistical model aligns with this predilection, it is unsurprising that Democratic-leaning school districts install more solar than Republican-leaning school districts. However, solar offers traits that should be appealing no matter ones party affiliation. Residential solar improves one's financial situation and one's independence.

That being said, solar is often discussed as a primarily environmentally friendly decision. This is well outlined in a memo by Democratic Washington Governor Jay Inslee. He calls for the growth of solar in Washington as a move grounded in environmental preservation and to combat climate change, mentioning the personal finances of solar as almost an afterthought (Inslee, 2014). Even the academic community champions solar primarily as environmentally friendly. Analyses of solar energy (and this thesis is no exception) spring from the same premise. Essentially, they argue that residential solar, and solar more generally, should be a priority of our society because it is environmentally friendly.

Perhaps this rhetoric could be shifted to being more universally palatable. Sell solar as a way to gain independence, as a means towards saving more money, or even as a way of increasing salmon runs and preserving irrigation interests. In Washington, this shift in strategy could be most effective in those areas identified as conservative in Figure 17. In short, understanding that political affiliation influences buyer opinions of solar helps to situate marketing efforts and lends credence to the idea of framing solar as a non-partisan path to personal gain and independence.

Likewise, less diverse areas also install residential solar at a higher rate. Even while controlling for average income and percentage homeowner, and a bevy of other variables, percentage minority was found to be negatively correlated to residential solar uptake. This may mean that the state government, and solar installers, are communicating the advantages of solar best to white Washingtonians. It may even mean that income inequality exists at too fine a scale to be captured in the per capita income variable used in this study. That is to say, income access may be lower in certain communities despite not appearing in the data used to control for such factors. Alternatively, it has long been known that access to personal loans are uneven based on race, color and origin (Rice, 1995; Hurley and Adebayo, 2016). It is unlikely that loans for residential solar are immune to this problem. As mentioned above, solar installers often advertise access to personal loans as a means to affording this expensive technology, but we do not know how access to such financing varies with minority status. The interviews undertaken in this study did not specifically assess minority perspectives regarding residential solar. Work tailored to do so would provide more well-grounded conclusions as to specific minority experiences with this low carbon source of energy.

To the degree that low adoption in such communities is the result of poor information or attitude, rather than structural problems such as financing, the fact that areas of high minority percentage adopt solar at a lower rate is useful knowledge in terms of efficient solar marketing. Steps could be taken to overcome this gap in adoption, Such as Spanish language solar advertising or information. Alternatively, framing solar not as a luxury, but as a necessity for those looking to save money on power cost and establish independence could address this issue. It could even be possible to reach out to Native American communities through environmentally conscious programs such as the Indigenous Environmental Network (IEN, 2018).

There are many sectors of Washington society that under-adopt solar. One things ties most of these people together – their electricity bills. A household's utility communicates, on a monthly basis, about the cost of electricity. There seems to be no better avenue for universally spreading the word about residential solar. As evidenced by the interviews, utility activity is also shown to be a factor in residential solar uptake. Both Ellensburg and Lopez had utility companies that have taken active steps to encourage the use of solar. Ellensburg Utilities was instrumental in installing and managing a community solar project starting in 2008. OPALCO, the Lopez Island utility, helped support solar panels on the high school and has plans for a community solar project in the works. On the other hand, Avista, Garfield's utility, did not resist solar per se, but they did not participate in any active steps to encourage solar either. Legislated or subsidized utility-driven solar advertising could quickly fill gaps in solar knowledge.

While understanding the impacts of each of the many explanatory variables is important, it is most efficient to understand all the variables together. One interpretation of the map of the residuals of Model 4, reproduced here in Figure 29 provides that overview. All the school districts with negative residuals are places where the model over-predicted residential solar uptake. Therefore, the demographic conditions exist in those places with the potential of further adoption of solar technology.

Overall, residential solar uptake remains low in Washington State. The highest concentration of residential solar installations in any district included in this study is 19 installations per 1000 people. The conditions that lead to residential solar uptake discussed above are therefore most appropriate when applied to areas of similar uptake levels. However, it is likely that the general recommendations drawn here would apply to a wide range of cultural and geographic conditions. That is to say, it is important to take into consideration political views, race, electricity price, and solar insolation, when targeting residential solar-related marketing and information efforts.

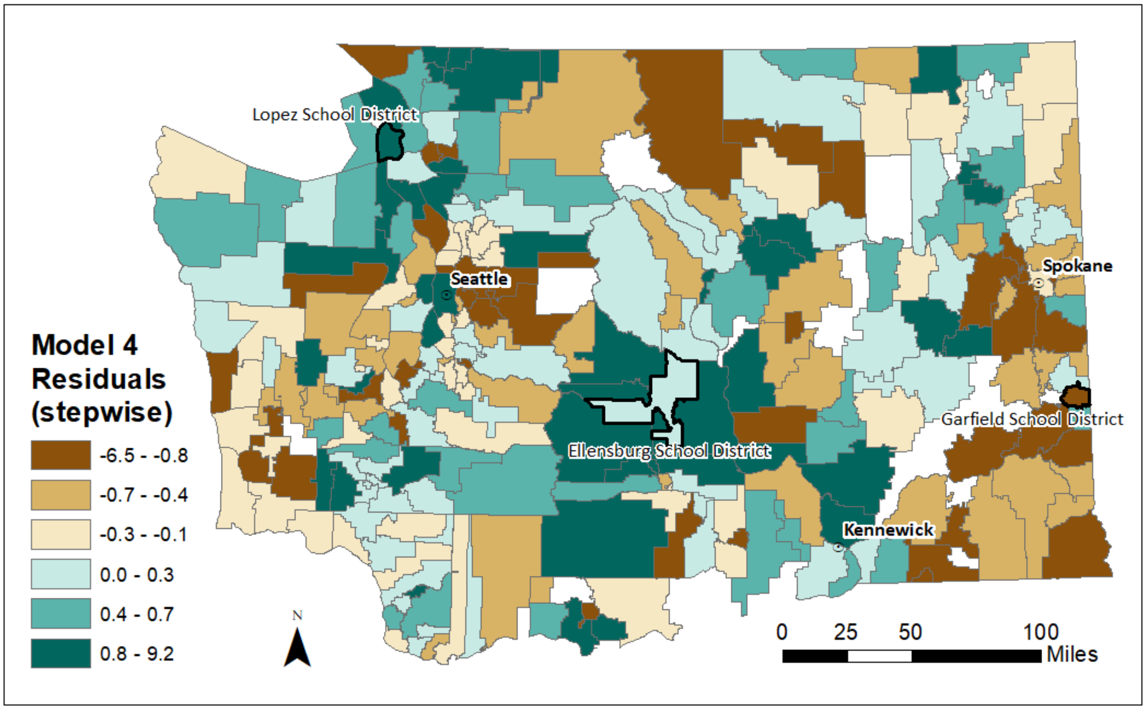


Figure 29: Residual errors of Model 4 (reproduced). Under-adopting areas, or those shaded brown, are indicated as the areas with the most potential for residential solar uptake by the statistical results.

Environmental Education: A potential catalyst for residential solar uptake

The statistical analysis and the interview results both provide evidence that environmental education helps to foster a culture favorable to residential solar uptake. Combining these sources of evidence generates a solid foundation on which to base future research.

The K-12 environmental education survey conducted in the course of this research measured strength of environmental education in 68 school districts across Washington State. For both the entire state, and for eastern Washington, the primary variable derived from this survey was positively correlated to residential solar uptake. That is to say, areas with better environmental education (as assessed by the input of school principals) also have higher levels of residential solar uptake. However, the inclusion of the environmental education variable significantly limited the sample size of the data; and in most cases, only a single survey per school district was received. The limited data warrants caution in interpreting the influence of environmental education and points to the need for further research.

Additional evidence linking strength of environmental education and residential solar uptake was uncovered during the visit to the Lopez Island School District. The decision to visit Lopez Island was driven because of the very high residential solar uptake present on the island. Uptake was so high that the model under-predicted uptake per 1000 people by 6.5 installations (which made the Lopez Island School district an extreme outlier, see Figure 29). Interviews with Lopez residents revealed that environmental education, and specifically education exposing students to residential solar, is strong on Lopez Island. The local high school has solar panels on its roof, and visits to a local solar-powered organic farm have long been part of the curriculum. It is hard to discount the association discovered here as a random one. That being said, it is possible that conditions exist on Lopez Island that lead to both strong environmental education and high residential solar uptake without one of these being the cause of the other.

This is the first work to look for a link between residential solar uptake and strength of public school environmental education. While the results presented here are compelling, further research needs to be conducted to corroborate these findings.

Theory of Residential Solar Uptake

As discussed in Chapter 4 in context of the interview results alone several potential behavior frameworks and theories could be used to explain residential solar uptake. In work by Wolske, Stern, and Dietz (2017), which was specifically tailored to understanding diffusion of solar technology, the theory of planned behavior and the diffusion of innovation theory emerged as the most effective means of understanding residential solar uptake. To continue this line of consideration, both of these theories are now deployed as lenses through which to understand residential solar uptake patterns in Washington State produced through the spatial, statistical, and interview analyses. To a degree, the results of this study fit both frameworks. All told, and as explained more fully below, the diffusion of innovation theory seems to most appropriately account for residential solar uptake in Washington State. (Please see Wolske, Stern, and Dietz (2017) and Chapter 2 for more in-depth description of these theories.)

The theory of planned behavior states that attitudes, subjective norms, and perceived behavior control combine to form an agent's decision making/behavior. This theory more heavily weights the cultural situation of an actor. In this vein, attitudes and subjective norms can be used to explain the statistical results of less solar adoption in Republican and minority areas. In terms of political affiliation, this supposition is supported by earlier research indicating that Democrats adopt residential solar at higher rates and care more about engaging in environmentally friendly behavior (Zahran et al. 2008; other Brody, Grover and Vedlitz, 2012). While less research has specifically investigated minority perspectives on residential solar uptake, it is possible that the subjective norms and/or attitudes of minority communities are less favorable to residential solar uptake. While these conclusions are logical, no corroborating evidence was produced in this research. That is to say, the statistical methods were not designed to specifically test the theory of planned behavior, and interview participants were not chosen for their political views or racial background. While the theory of planned behavior does encompass mechanisms which explain the phenomenon here, research attempting to understand residential solar related decision-making in conservative and minority areas would be an appropriate way to more accurately understand this correlation.

As the influence of subjective norms on a person's decision-making is a pillar to the theory of planned behavior, the importance of installed base can also be interpreted to fit the theory of planned behavior framework. This is because local installed base can be viewed as a rough manifestation of subjective norms regarding residential solar. That is to say, local solar installations clearly would increase positive subjective norms regarding solar, as seeing solar in your neighborhood proves that local people support the decision to use this technology. Furthermore, while two of the 40 interview participants worried that residential solar would upset the norms of their community (one in Garfield and one in Ellensburg), most participants felt that neighbors would support and be curious about a decision to install residential solar. The theory of planned behavior thus provides an effective conceptual basis for understanding what leads neighbor effects to being such an impactful variable.

Overall, the theory of planned behavior consists of several aspects which demonstrate consistencies with the results of this study. However, when the diffusion of innovation theory is turned to understanding these same statistical correlations, it is also effective. This effectiveness is joined by ample support stemming from the interviews. While the following discussion should not be considered conclusive, it provides an argument that the diffusion of innovation theory most appropriately accounts for the present results on residential solar uptake in Washington State.

The diffusion of innovation theory focuses on how knowledge of a new technology spreads, and how people come to trust that technology. To summarize the theory, knowledge of a technology leads to a period of persuasion, the decision to adopt, implementation of the technology, and finally confirmation of the technology's effectiveness. As knowledge was found to be critical to adoption, the diffusion of innovation theory fits the evidence well. Perhaps the starkest evidence for the importance of awareness is the difference in degree of solar knowledge in the two outlying school districts investigated in the interviews. Garfield, an outlier because so little solar was adopted there, was discovered to have residents who know very little to nothing about solar options and incentives. Lopez, an outlier because of the high residential solar adoption, has residents who are very knowledge about solar options and incentives. The discovery of this difference, which was directed by statistically grounded outliers, supports the diffusion of innovation theory. If Garfield residents were aware of solar options and incentives, but chose not to adopt for other reasons, the theory of planned behavior would have more closely matched the evidence. As that is not the case, the diffusion of innovation theory seems to most accurately fit this portion of the interview results.

Importantly, the statistical results demonstrate that non-economic grounded variables like installed base, political affiliation, and minority percentage influence residential solar adoption. That being said, it is likely that the financially prudent decision to adopt residential solar could cross over societal boundaries underlying these datasets. Rather than cultural norms, low solar knowledge could explain the low adoption in conservative and minority communities. Simply put, avenues of information which disseminate residential solar may not be as prevalent in those communities. For example, the interviews demonstrates that many residents adopted solar both for the environmental benefits and the financial benefits. Perhaps environmental awareness may have increased solar awareness, like the interviewee who heard about solar from their Audubon newsletter. Under this framework, environmentally conscious communities would have higher initial installed base, and greater solar awareness, which would snowball to higher residential solar uptake. Overcoming this barrier would simply involve finding innovative ways to establish solar and disseminate solar information in lower adopting communities.

Taken from the perspective of the diffusion of innovation theory, growing residential solar requires overcoming the sequential barriers to adoption. Increasing knowledge of a technology like solar, which directly benefits its users, should then lead to a shorter period of persuasion to adopt. As those that adopt, as supported by the interviews, are pleased with their decision, the effectiveness of solar is being confirmed. This confirmation then helps persuade others to adopt, which creates a snowball effect of technology diffusion. When the results of this study are investigated in terms of the diffusion of innovation theory, increasing knowledge is the most effective ways to grow residential solar.

While both the theory of planned behavior and the diffusion of innovation theory hold water with the results of this study, the diffusion of innovation most solidly fits the results as discussed above. That is not to say that further targeted research into how the theory of planned behavior explains residential solar would not lead to interesting results. Rather, the results of this study indicate that the diffusion of innovation theory best holds for residential solar uptake in Washington State.

Further Research

Several avenues of further research are discussed in above. These include: 1) targeted ethnographic and/or interview research could attempting to understand specific mechanisms that lead to lower solar adoption in minority and conservative areas, 2) further investigation into the reasons for the stark east-west divide, 3) investigation into installed base/neighbor effects could be a rich avenue for future research, and 4) more targeted research on the effects of environmental education on pro-environmental behavior at the scale of society.

In addition to these already discussed recommendation several additional changes and additional work could add significant value. These are: 1) it would be worthwhile to investigate additional/finer scale variables, 2) spatially grounded consideration of Model 4's residual spatial autocorrelation, 3) the use of time series analysis of the residential solar adoption phenomenon in Washington, and 4) specific investigation into the potential impact that residential solar, utility-scale solar, and even other renewables could have on the environment of the Columbia Basin.

The addition and/or use of more finely scaled/additional variables would likely create both different and more accurate study results. Additional variables could include, more finely scaled environmental conditions (such as variations in tree cover), population density, number of and proximity to local solar installers, the location of community solar projects (including their visibility as evident in GIS-produced viewsheds) and the neighbor effects they engender. As mentioned in Chapter 3 the results of this study come with the caveat of the Modifiable Areal Unit Problem (MAUP). Including more finely scaled variables could be used to verify results found here. This verification could use zip code level polygons, polygons that specifically split the urban and rural areas across the state, and/or another other scale of investigation. Additional analysis could also include the environmental variables more specific to Washington State's scale and conditions, this could possible account for some of environmental conditions discussed in association with Figure 25.

In another sense the spatial frame of analysis could be changed to specifically account for areas of autocorrelation of model residuals. The autocorrelation revealed in investigated in this study reveals similar patterns in the Model 4 residuals and the response variable of solar uptake (Figure 24 and Figure 25). This implies that there are cross-border cultural areas and effects that this study does not capture. That is to say, the impact of neighbor effects and other variables likely spill over the bounds of a school district. For instance, the high-high area identified near the Ellensburg School District could be the result of the local visible community solar project. As part of the aim of this research was to understand how residential solar uptake and public education may be connected, the school district was chosen as a strict scale of study. An investigation without this goal could tailor polygons to more appropriately match areas of similar conditions, as identified by spatial autocorrelation. More in depth social network modeling also has the potential to account for some of the spatial autocorrelation. That is to say, by accounting for the flow of information across polygon barriers perhaps some areas of high autocorrelation could be modeled within the statistical analysis and therefore controlled for. Alternatively, the addition of a geographic dummy variable could account for these issues.

A time-series approach would be particularly valuable in assessing neighbor effects. In this research, successful applications to the Renewable Energy Cost Recovery Program were split into two timeframes, installed base (2005-2010) and uptake (2011-2015). Rather than this snapshot analysis, gathering time series data in all of the variables would allow for more rigorous analysis, somewhat like Graziano and Gillingham (2015) in Connecticut, which could more appropriately account for the changing conditions over time and incremental effects of installed base. An analysis such as this would likely identify patterns overlooked by the current snapshot analysis.

Finally, it is posited here that increasing the use of residential solar energy could free up water resources for environmental benefit and irrigation interest. Having the freedom to turn off turbines and reallocate river flow could truly change political, social, and environmental considerations in Washington. Without specific research quantifying the potential effect of additional solar electricity exploitation and interviews with industry experts on that effect, it is hard to understand what is truly at stake. Research specifically designed to understand this issue could be very interesting and impactful.

Final remarks

The recommendations and results drawn here have the power to grow solar in Washington State. Growth of residential solar decreases the carbon footprint of electricity generation, and increases personal financial stability and independence. In Washington, taking the onus of electricity generation off dams can free up water for allocation to fisheries and irrigation. State policymakers have expressed their support of solar time and time again and solar business professionals have an obvious vested interest in solar growth.

While understanding best practices to grow residential solar uptake in Washington is the central goal to much research on this topic, growth in this technology does not come without drawbacks (Mulvaney, 2013). As discussed in Chapter 2, supply chain impacts associated with the resource extraction and production of solar panels can have toxic and detrimental effects – often on poor communities.

The primary barrier to solar continues to be economic. Without state and government incentives residential solar would remain economically expensive (Swift et al. 2017). Lowering the price of panels or increasing their efficiency is still therefore the greatest hurdle to increasing growth of this technology. Also, the 2018 tariffs imposed by the Trump administration increase the cost of solar technology (Swanson and Plumer, 2018).

Recommendations on how to Grow Residential Solar: summarized

- Tailor marketing messages regarding residential solar to under-adopting sections of society, like minorities and conservatives.
- Increase awareness of residential solar options and incentives. This could take the form of utility bill-based marketing, more aggressive public service campaigns, or installer-sponsored public forums.
- Increase the quality of environmental education to include the benefits and options regarding residential solar.

- Use Figure 29 to identify locations most ripe for further residential solar adoption by combining all the factors statistically analyzed here. That is to say, the cultural and economic conditions exist in the areas depicted in brown that could lead to easy customer acquisition for solar installation companies.

As a financially wise investment residential solar has the power to be appealing to people from a wide range of cultural situations. Therefore, the diffusion of innovation theory, which focuses on how technology spreads with knowledge and trust of that technology, is most appropriate for the results drawn here. Given that, targeted and/or widespread information and marketing campaigns would likely result quicker diffusion of residential solar technology.

REFERENCES

Ajzen, I., N. Joyce, S. Sheikh, and Nicole Gilbert Cote. 2011. Knowledge and the prediction of behavior: the role of information accuracy in the theory of planned behavior. *Basic and Applied Social Psychology* 33 (2): 101–17. 6.

Anselin, L. and D. A. Griffith. 1988. Do spatial effects really matter in regression analysis? *Papers of the Regional Science Association* 65(1): 11-34.

Avista. (2018). Solar Power. https://www.myavista.com/about-us/energy-innovations/solar-power (last accessed 9 March 2018)

Barbose, G. L., N. Darghouth, D. Millstein, K. Lacommare, N. Disanti, R. Widiss. 2017. Tracking the sun 10: the installed price of residential and non-residential photovoltaic systems in the United States. Lawrence Berkeley National Laboratory. https://cloudfront.escholarship.org/dist/prd/content/qt5h90b3j4/qt5h90b3j4.pdf?t=ownbjt (last accessed 4 April 2018)

Bird, L., A. Reger, and J. Heeter. 2012. Distributed solar incentive programs: recent experience and best practices for design and implementation. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy13osti/56308.pdf (last accessed 4 April 2018).

Bonnett, M. 2002. Education for sustainability as a frame of mind. *Environmental Education Research* 8(1), 9–20.

Borenstein, S. 2015. The private net benefits of residential solar PV: and who gets them. Energy Institute at Haas Working Paper. https://ei.haas.berkeley.edu/research/papers/WP259.pdf (last accessed 23 February 2017)

Brewer, J., D. P. Ames, D. Solan, R. Lee, and J. Carlisle. 2015. Using GIS analytics and social preference data to evaluate utility-scale solar power site suitability. *Renewable Energy* 81 (September): 825–36.

Brody, S., H. Grover, and A. Vedlitz. 2012. Examining the willingness of Americans to alter behavior to mitigate climate change. *Climate Policy* 12 (1): 1–22.

Brown, D. P., and D. E. M. Sappington. 2016. Designing compensation for distributed solar generation : is net metering ever optimal ? United States Associate for Energy Economics. Paper No 16-234.

Brown, S., and V. Venkatesh. 2005. Model of adoption of technology in households: a baseline model test and extension incorporating household life cycles. *MIS Quarterly* 29 (3): 399–426.

Büchs, M., N. Bardsley., and S. Duwe. 2011. Who bears the brunt? Distributional effects of climate change mitigation policies. *Critical Social Policy* 31 (2): 285–307.

Buhr, T. 2016. Big crowd shows up for solar farm hearing. The Daily Record. https://www.dailyrecordnews.com/news/big-crowd-shows-up-for-solar-farm-hearing/article_7a4c9aa4-bbce-59d2-93d9-61f43d61b121.html (last accessed 17 April 2018).

Buhr, T. 2017. County commissioners deny solar farm permit near Kittitas. The Daily Record. http://www.dailyrecordnews.com/news/county-commissioners-deny-solar-farm-permit-near-kittitas/article_408ef8f5-6339-5a1d-9ee2-2a33485a00dc.html (last accessed 25 January 2017)

Calculate Stuff. 2018. Net Present Value (NPV) Calculator. https://www.calculatestuff.com/financial/npv-calculator?initial_investment=30000.00&discount_rate=5.000&cash_flows%5B%5D=1900&cash_flows%5B%5D=1900&cash_flows%5B%5D=1900&cash_flows%5B%5D=1900&cash_flows%5B%5D=1900&cash_flows%5B%5D=1900&cash_flows%5B%5D=19 (last accessed 21 June 2018).

Calvert, K., and D. Simandan. 2010. Energy, space, and society: a reassessment of the changing landscape of energy production, distribution, and use. *Journal of Economics and Business Research* 16, no. 1: 13-37.

Cannon, A. R., G. W. Cobb, B. A. Hartlaub, J. M. Legler, R. H. Lock, T. L. Moore, A. J. Rossman, and J. A.Witmer. 2013. *STAT2: Building Models for a World of Data*. New York, NY: W.H. Freeman.

Central Wind & Solar. 2018. Central Wind & Solar - Home. www.centralwind.net (last accessed 4 April 2016).

Chapman, P. 2014. Environmental Education and Sustainability in U. S. Public Schools. Inverness Associates. http://projectgreenschools.org/wp/wp-content/uploads/2014/08/USGreenSchools12114.pdf (last accessed November 25, 2017).

Chernyakhovskiy, I. 2015. Solar PV adoption in the United States: an empirical investigation of state policy effectiveness. Masters Theses. 141. Department of Resource Economic, University of Massachusetts Amherst. https://scholarworks.umass.edu/masters_theses_2/141 (last accessed 21 June 2018).

Correa, T., J. D. Straubhaar, W. Chen, and J. Spence. 2015. Brokering New Technologies: The Role of Children in Their Parents' Usage of the Internet. *New Media & Society* 17 (4): 483–500.

Cook Political Report, The. 2013. Introducing the 2014 Cook Political Report Partisan Voter Index. http://cookpolitical.com/story/5604 (last accessed 29 March 2017).

Cotton, D., C. Shiel, and A. Paço. 2016. Energy saving on campus: a comparison of students' attitudes and reported behaviours in the U.K. and Portugal. *Journal of Cleaner Production* 129: 586–95.

Creswell, J. W., and J. D. Creswell. 2005. Mixed methods research: Developments, debates, and dilemmas. *Research in organizations: Foundations and methods of inquiry*: 315-26.

Department of Energy (DoE). 2016a. Residential renewable energy tax credit. http://energy.gov/savings/residential-renewable-energy-tax-credit (last accessed 5 November 2016).

Department of Energy (DoE). 2016b. Solar energy in the United States. Accessed http://energy.gov/eere/solarpoweringamerica/solar-energy-united-states (last accessed 18 October 2017).

Doris, E., and J. Chavez. 2015. Are incentives the thing? Presented at the Renewable Energy World Conference & Expo. Orlando, Florida. December 9. https://www.nrel.gov/docs/fy15osti/63059.pdf (last accessed 17 April 2018).

Ellensburg Solar. 2018. Ellensburg Solar. https://www.ellensburgsolar.com/ (last accessed 4 April 2018).

EnergySage. 2018. 2018 cost of solar panels in Seattle, Washington. EnergySage. https://news.energysage.com/how-much-do-solar-panels-cost-seattle-washington/ (last accessed 4 April 2018).

Esri. 2016. ArcMap 10.5.1.Ink. Redlands, CA: Environmental Systems Research Institute.

Evans, A., V. Strezov, and T. J. Evans. 2009. Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews* 13 (5): 1082-88.

Faiers, A., M. Cook, and C. Neame. 2007. Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. *Energy Policy* 35 (8): 4381–90.

Fielding, N. G. 2012. Triangulation and mixed methods designs. *Journal of Mixed Methods Research* 6 (2): 124–36.

Fthenakis, V., J. E. Mason, K. Zweibel. 2009. The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. *Energy Policy* 37 (2): 387-99.

Graziano, M., and K. Gillingham. 2015. Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. *Journal of Economic Geography* 15 (4): 815-839.

Güler, D., M. Pinar, and Ö. Afacan. 2013. The impact of field trips on attitudes and behaviours related to sustainable environmental education. *World Applied Sciences Journal* 23 (8): 1100–1105.

Hamilton, L. C. 2011. Education, politics and opinions about climate change evidence for interaction effects. *Climatic Change* 104 (2): 231–242.

Hatten, J. R., T. R. Batt, J.J. Skalicky, R. Engle, G.J. Barton, R.L. Fosness, and J.

Warren. 2016. “Effects of dam removal on Tule fall chinook salmon spawning habitat in the White Salmon River, Washington.” *River Research and Applications* 32: 1481–1492.

Hertwich, E. G, T. Gibon, E. A. Bouman, A. Arvesen, S. Suh, G. A. Heath, J. D. Bergesen, A. Ramirez, M. I. Vega, and L. Shi. 2015. Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies. *Proceedings of the National Academy of Sciences of the United States of America* 112 (20): 6277–82.

Hess, D. J., Q. D. Mai, and K. P. Brown. 2016. Red states, green laws: ideology and renewable energy legislation in the United States. *Energy Research and Social Science* 11: 19–28.

Hlavac, M. (2018). stargazer: well-formatted regression and summary statistics tables. R package version 5.2.1. https://CRAN.R-project.org/package=stargazer (last accessed 18 June 2018).

Hurley, M., and J. Adebayo. 2016. Credit scoring in the era of big data. *Yale Journal of Law & Technology* 148: 148–216.

Indigenous Environmental Network (IEN). 2018. Indigenous Environmental Network. http://www.ienearth.org/ (last accessed 30 April 2018).

Inslee, J. 2014. Executive order 14-04: Washington carbon pollution reduction and clean energy action. http://www.governor.wa.gov/sites/default/files/exe_order/eo_14-04.pdf (last accessed 1 November 2016).

Institute for Energy Research. 2010. Washington energy facts. http://instituteforenergyresearch.org/media/state-regs/pdf/Washington.pdf (last accessed 26 January 2018).

Intergovernmental Panel on Climate Change (IPCC). 2011. IPCC special report on renewable energy sources and climate change mitigation summary for policymakers. http://www.uncclearn.org/sites/default/files/inventory/ipcc15.pdf (4 April 2018).

Jick, T. D. 1979. Mixing qualitative and quantitative methods : triangulation in action. *Administrative Science Quarterly* 24 (4): 602–11.

Johnson, R. B., and A. J. Onwuegbuzie. 2004. Mixed methods research: a research paradigm whose time has come. *Educational Researcher* 33 (7): 14–26.

King, G., and M. E. Roberts. 2015. How robust standard errors expose methodological problems they do not fix, and what to do about It. *Political Analysis* 23 (2): 159–79.

Krasko, V. A., and E. Doris. 2013. State distributed PV policies: can low cost (to government) policies have a market impact? *Energy Policy* 59 (C): 172-181.

Larson, E. C., and R. S. Krannich. 2016. A great idea, just not near me! Understanding public attitudes about renewable energy facilities. *Society & Natural Resources* 29 (12): 1436-51.

Lebowitz, A., and D. Trudeau. 2017. Digging in: lawn dissidents, performing sustainability, and landscapes of privilege. *Social & Cultural Geography* 18 (5). Routledge: 706–31.

Lee, M., T. Hong, C. Koo, and C. Kim. 2017. “A break-even analysis and impact analysis of residential solar photovoltaic systems considering state solar incentives. *Technological and Economic Development of Economy 4913* (February): 1–25.

Leeuw, A. de, P. Valois, I. Ajzen, and P. Schmidt. 2015. Using the theory of planned behavior to identify key beliefs underlying pro-environmental behavior in high-school students: implications for educational interventions. *Journal of Environmental Psychology* 42 (June): 128–38.

Lepak, D. P., and S. A. Snell. 2002. Examining the human resource architecture: the relationships among human capital, employment, and human resource configurations. *Journal of Management* 28 (4): 517–43.

Mai, S. Y. 2013. Political attitudes toward the environment : the politics of residential solar panel installations in California. Masters Thesis. Department of Political Science, University of California San Diego. https://polisci.ucsd.edu/_files/undergrad/Thesis%202013%20Political%20Attitudes%20toward%20the%20Environment%20The%20Politics%20of%20Residential

%20Solar%20Panel%20Installations%20in%20California.pdf (last accessed 17 April 2018).

Moloney, S., R. E. Horne, and J. Fien. 2010. Transitioning to low carbon communities – from behavior change to systemic change: lessons from Australia. *Energy Policy* 38 (12): 7614–23.

Mulvaney, D. 2013. Opening the black box of solar energy technologies: exploring tensions between innovation and environmental justice." *Science as Culture* 22 (2): 230–37

National Renewable Energy Laboratory (NREL). 2012. Solar Data. https://www.nrel.gov/gis/data-solar.html (last accessed 4 April 2018).

National Renewable Energy Laboratory (NREL). 2018. "State Rankings." The Open PV Project. Accessed April 4, 2018. https://openpv.nrel.gov/rankings.

Nicol, D. 2016. The state of solar in Washington (state). Washington State Solar Summit, October 15, 2016. President of Solar Washington.

Pasqualetti, M. J. 2011. Opposing wind energy landscapes: a search for common cause. *Annals of the Association of American Geographers* 101 (4): 907–17.

Perez, R., P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George, and F. Vignola. 2002. A new operational satellite-to-irradiance model - description and validation. *Solar Energy* 73 (5): 307–17.

Pitt, D., and G. Michaud. 2015. "Assessing the Value of Distributed Solar Energy Generation." *Current Sustainable/Renewable Energy Reports* 2: 105–13.

Pixabay. 2018. Solar panel array roof home. https://pixabay.com/en/solar-panel-array-roof-home-house-1591358/ (last accessed 18 April 2018).

QSR International Pty Ltd. 2012. NVivo qualitative data analysis software. https://www.qsrinternational.com/nvivo/home (last accessed 16 May 2018).

Qualtrics. 2017. Qualtrics. Version May-September 2017. Provo, Utah, USA. https://www.qualtrics.com (last accessed 15 May 2018).

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/ (last accessed 21 June 2018).

Rai, V., and A. L. Beck. 2015. Public perceptions and information gaps in solar energy in Texas. *Environmental Research Letters* 10; 0704011

Ranalli, J., M. B. Boz, K. Calvert, and J. R.S. Brownson. 2016. Assessing demand impact of solar capacity growth in Philadelphia. In American Solar Energy Society National Solar Conference 2016, SOLAR 2016. American Solar Energy Society, 2016.

Rice, W. E. 1995. Race, gender, 'redlining,' and the discriminatory access to loans, credit, and insurance: an historical and empirical analysis of consumers who sued lenders and insurers in federal and state courts, 1950-1995. *San Diego Law Review* 107 (1993).

Robinson, S. A, and V. Rai. 2015. Determinants of spatio-temporal patterns of energy technology adoption: an agent-based modeling approach. *Applied Energy* 151: 273–84.

Schelly, C. 2014. Residential solar electricity adoption: what motivates, and what matters? A case study of early adopters. *Energy Research and Social Science* 2 (August). 183–91.

Shaw, G., and D. Wheeler. 1985. *Statistical Techniques in Geographical Analysis*. Wiley, Chichester, Sec. 11.4-11.8; 364.

Shrimali, G., and S. Jenner. 2013. The impact of state policy on deployment and cost of solar photovoltaic technology in the U.S.: A sector-specific empirical analysis. *Renewable Energy* 60: 679-690.

Sjoberg, R. L. 2005. Obesity, shame, and depression in school-aged children: a population-based study. *Pediatrics* 116 (3): 389–92.

Solangi, K. H., M.R. Islam, R. Saidur, N.A. Rahim, and H. Fayaz. 2011. A review on global solar energy policy. *Renewable and Sustainable Energy Reviews* 15 (4): 2149–63.

Solar Energy Industries Association (SEIA). 2016. Solar market insight report 2016 Q4. http://www.seia.org/research-resources/solar-market-insight-report-2016-q4 (last accessed 23 February 2017).

Solar Power Authority. 2017. How much do solar panels cost to install? https://www.solarpowerauthority.com/how-much-does-it-cost-to-install-solar-on-an-average-us-house/ (last accessed 18 January 2018).

Solar Washington. 2017. Utilities in Washington. http://www.solarwa.org/utilities_washington_state (last accessed 4 April 2018).

Steward, D., E. Doris, V. Krasko, and D. Hillman. 2014. The effectiveness of state-level policies on solar market development in different state contexts. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy14osti/61029.pdf (last accessed 4 April 2018).

Strupeit, L., and A. Palm. 2016. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. *Journal of Cleaner Production* 123: 124-36.

Swanson, A., and B. Plumer. 2018. Trump slaps steep tariffs on foreign washing machines and solar products. The New York Times. https://www.nytimes.com/2018/01/22/business/trump-tariffs-washing-machines-solar-panels.html (last accessed 16 April 2018).

Swift, K. D. 2013. A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States. *Renewable Energy* 57: 137–43.

Timilsina, G., R, Kurdgelashvili, and P.A. Narbel. 2012. Solar energy: markets, economics and policies. *Renewable and Sustainable Energy Reviews* 16 (1): 449–65.

United Nations Development Programme (UNDP). 2016. Sustainable Energy. http://www.undp.org/content/undp/en/home/ourwork/climate-and-disaster-resilience/sustainable-energy.html (last accessed 23 January 2017).

United States (US) Census. 2017. American factfinder - guided search. https://factfinder.census.gov/faces/nav/jsf/pages/guided_search.xhtml (last accessed 23 February 2017).

United States Energy Information Administration (US EIA). 2016a. EIA's energy in brief:

what are the major sources and users of energy in the United States? http://www.eia.gov/energy_in_brief/article/major_energy_sources_and_users.cfm (last accessed 12 October 2016).

United States Energy Information Administration (US EIA). 2016b. 2015 utility bundled retail sales. https://www.eia.gov/electricity/sales_revenue_price/pdf/table6.pdf (last accessed 2 February 2017).

University of Chicago, the. 2018. Geoda. https://spatial.uchicago.edu/software (last accessed 30 April 2018).

Washington Department of Revenue (WA DoR). 2013. Sales/use tax exemption on purchases of renewable energy systems extended; thermal heat systems added; annual tax incentive survey required for refund applicants. http://dor.wa.gov/Docs/Pubs/SpecialNotices/2013/sn_13_EnergyHeatSurvey.pdf (last accessed 25 January 2017).

Washington Department of Revenue (WA DoR). 2017. Public records request submitted December 2016. Research and Fiscal Analysis Division. https://dor.wa.gov/contact-us/public-records (last accessed 21 June 2018).

Washington Department of Revenue (WA DoR). 2018. Property tax data downloads. https://dor.wa.gov/find-taxes-rates/property-tax/property-tax-data-downloads (last accessed 4 April 2018).

Washington (WA) Legislature. 2005. WAC 458-20-273: renewable energy system cost recovery. http://apps.leg.wa.gov/WAC/default.aspx?cite=458-20-273 (last accessed 4 April 2018).

Washington (WA) Legislature. 2007. RCW 19.285: energy independence act. http://apps.leg.wa.gov/rcw/default.aspx?cite=19.285&full=true (last accessed 15 January 2017).

Washington (WA) Legislature. 2016. Chapter 80.60 RCW: net metering of electricity.

http://app.leg.wa.gov/rcw/default.aspx?cite=80.60&full=true (last accessed 25 October 2016).

Washington (WA) Legislature. 2017. Engrossed substitute senate bill 5939. http://lawfilesext.leg.wa.gov/biennium/2017-18/Pdf/Bills/Senate%20Passed%20Legislature/5939-S.PL.pdf#page=1 (last accessed 4 April 2018).

Washington Office of Financial Management (WA OFM). 2017. Census geographic files. 2017. https://ofm.wa.gov/washington-data-research/population-demographics/gis-data/census-geographic-files (last accessed 4 April 2018).

Washington Office of the Secretary of State (WA SoS). 2017a. Election results and voters pamphlets - elections & voting. https://www.sos.wa.gov/elections/research/Election-Results-and-Voters-Pamphlets.aspx (last accessed 31 January 2017).

Washington Office of the Secretary of State (WA SoS). 2017b. How to make a request for Secretary of State records. Submitted June 2017. https://www.sos.wa.gov/office/public-records.aspx (last accessed 4 June 2018).

Washington Office of Superintendent of Public Instruction (WA OSPI). 2016. Education directory. https://eds.ospi.k12.wa.us/DirectoryEDS.aspx (last accessed 21 February 2017).

Washington Office of the Superintendent of Public Instruction (WA OSPI). 2017. State testing. http://www.k12.wa.us/assessment/StateTesting/ (last accessed 8 February 2017).

Washington State University (WSU) Energy Program. 2014. Solar energy in Washington State. Washington State Utilities and Transportation Commission. http://www.energy.wsu.edu/documents/WSU%20Energy%20Program%20Report%20and%20Questions_Solar%20Energy%20in%20WA_June%2026%202014.pdf (last accessed 4 April 2018).

Wheeler, G., and A. Ruskey. 2011. Washington State environmental and sustainability literacy plan. Superintendent of Public Instruction and E3 Washington. http://www.k12.wa.us/EnvironmentSustainability/pubdocs/WAESLPFinalJuly2011.pdf (last accessed 4 April 2018).

Wheeler, G., C. Thumlert, L. Glaser, M. Schoellhamer, O. Bartosh. 2007. Environmental education report. http://www.k12.wa.us/EnvironmentSustainability/pubdocs/EEReport.pdf (last accessed 4 April 2018).

Wolske, K. S., P. C. Stern, and T. Dietz. 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: toward an integration of behavioral theories.” *Energy Research and Social Science* 25: 134–51.

Wong, J. H., M. Royapoor, and C. W. Chan. 2016. Review of life cycle analyses and embodied energy requirements of single-crystalline and multi-crystalline silicon photovoltaic systems. *Renewable and Sustainable Energy Reviews* 58: 608-18.

Yakima Basin Integrated Plan (YBIP). 2018. The Yakima basin integrated plan. http://www.yakimariver.org/ (last accessed 4 April 2018).

Zahran, S., S. D. Brody, A. Vedlitz, M. G. Lacy, and C. L. Schelly. 2008. Greening local energy: explaining the geographic distribution of household solar energy use in the United States. *Journal of the American Planning Association* 74 (4): 419–34.

Zelezny, L. C. 1999. Educational interventions that improve environmental behaviors: a meta-analysis. *The Journal of Environmental Education* 31 (1): 5-14.

APPENDIX A

K-12 Washington Principal/Administrator Survey

Start of Block: Information

This survey is designed to assess environmental education generally, and solar energy education specifically, across Washington State. It has been e-mailed to almost all Washington K-12 public school principals. Your answers will be aggregated by school district to ensure anonymity and confidentiality.

This survey is part of a larger research project designed to better understand decisions about installing residential solar panels. Your responses will allow us to test whether K-12 environmental education fosters a culture favorable to residential solar adoption. You may not directly benefit from taking part in this research.

Reasonable and appropriate safeguards have been used in the creation of this web-based survey to maximize the confidentiality and security of your responses; however, when using information technology, it is never possible to guarantee complete privacy.

End of Block: Information

Start of Block: Demographics

School District____

Number of Students in your school____

Grade Levels in your school (e.g., K-6 or 9-12 ect.)__________________________________

End of Block: Demographics

Start of Block: Environmental Education

In 2014, the Office of the Superintendent of Public Instruction published the most recent "Washington State K-12 Integrated Environmental and Sustainability Education Learning Standards." These standards are designed to meet WAC 392-410-115 and RCW 28A.230.020 which require that instruction on conservation, natural resources and the environment be presented in an interdisciplinary way to all grade levels.

For the following section please choose strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, or strongly agree, based on your opinion of the statement.

Before reading the above passage you were familiar with these state laws and graduation requirements.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Students at your school are exposed to environmental education during STEM education.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Students at your school are exposed to environmental education during humanities and social science education.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Your school has sufficient funding to meet state environmental education goals.

- Strongly disagree
- Disagree
- Somewhat disagree

- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Teachers at your school have sufficient time in the curriculum to meet state environmental education goals.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Your school has sufficient staff to meet state environmental education goals.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Staff at your school accept and support state environmental education goals.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Your school board is sufficiently committed to furthering environmental education to meet state goals.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

Teaching to standardized tests undermines your school's ability to meet state environmental education goals.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

You consider environmental education to be important for students in your school.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

End of Block: Environmental Education

Start of Block: Other questions

Does your school have a dedicated environmental education leader?

○ Yes

○ No

○ Don't Know

Please choose all environmental education infrastructure available at your school.

☐ Waste reduction program

☐ Recycling program

☐ Composting program

☐ Installed wind energy

☐ Installed solar energy

☐ Other installed renewable energy

☐ Environmentally friendly purchasing policy

☐ Student garden

☐ Other ____

End of Block: Other questions

Start of Block: State Learning Standards

The following state standards are taken from the "Washington State Learning Standards: Integrated Environmental and Sustainability" which were updated in 2014. The full document can be accessed at the following link (http://www.k12.wa.us/EnvironmentSustainability/pubdocs/ESEStandards.pdf). State standards require K-12 education on sustainability. The Washington Office of the Superintendent of Public Instruction defines sustainability to mean "meeting the needs of the present without compromising the ability of future generations to meet their needs while ensuring long-term ecological, social, and economic health."

Which statement best describes the degree to which students at your school are exposed to environmental curriculum designed to educate on this concept?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

○

Which statement best describes the degree to which students at your school are taught about solar technology as a sustainable energy source?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

A second state standard requires education that fosters students to think "critically about how the human-built environment can be designed or modified to promote ecological health and better serve quality of life for all humans."

Which statement best describes the degree to which students at your school are exposed to environmental curriculum designed to educate on this concept?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

Which statement best describes the degree to which students at your school are taught about solar energy as an aspect of the human-built environment designed to promote ecological health and human quality of life?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

A final state standard is designed to encourage students to take "an active role as responsible citizens to create positive solutions for present and future generations."

Which statement best describes the degree to which students at your school are exposed to environmental curriculum designed to educate on this concept?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

Which statement best describes to the degree to which students at your school are taught about solar energy as a potentially positive environmental solution?

○ This concept is not addressed directly

○ This concept is occasionally mentioned

○ This concept is discussed in at least one grade level

○ This concept is emphasized (e.g., the focus of one or more modules or courses) in at least one grade level

○ This concept is emphasized in all grade levels

End of Block: State Learning Standards

Start of Block: Comments

Do you have any questions, comments, or criticisms about this topic or survey?

____

End of Block: Comments

APPENDIX B

Solar Interview Guide

1. Do you have solar on your home? Have you considered installing solar?
2. Why did (or did not) you install solar on your home?
3. What factors influenced this decision?
    - a. Economic factors
        - a.i. What do you and your family do for a living?
        - a.ii. Do know a lot about residential solar options in your area?
        - a.iii. Did you take advantage of state subsidy? How did you find out about those subsidies? Or what do you know about state solar subsidies?
        - a.iv. Do you expect your system to pay for itself over time? If so, how long do you expect this to take? If not, why not? Or do you know that solar can pay for itself in a short amount of time?
        - a.v. How did electricity price play into your calculations?
    - b. Political factors?
        - b.i. Do you consider yourself an environmentalist? Why or why not?
        - b.ii. What impact do you think residential solar will have on the economy?
        - b.iii. What are your thoughts on energy independence?
    - c. Environmental Education
        - c.i. Are there or did any school age children live with you while you were considering or installing solar panels?
        - c.ii. Did the curriculum that they were exposed to influence your decision to install or not install solar in any way?

    d. Neighbors
        d.i. Do you know anyone else who installed solar on their homes or property?

        d.ii. How important was knowledge of them in your decision making process?

        d.iii. Did you experience any support or resistance when you were considering installing solar?

        d.iv. Did you ever discuss solar with neighbors or community members?

4. How did you hear about solar energy as a privately owned option?

5. How did you find your installation company? Or do you know of any local installation companies?
6. How did you choose your panels?

7. Do you have any advice for what it would take for more of your neighbors to adopt solar energy?

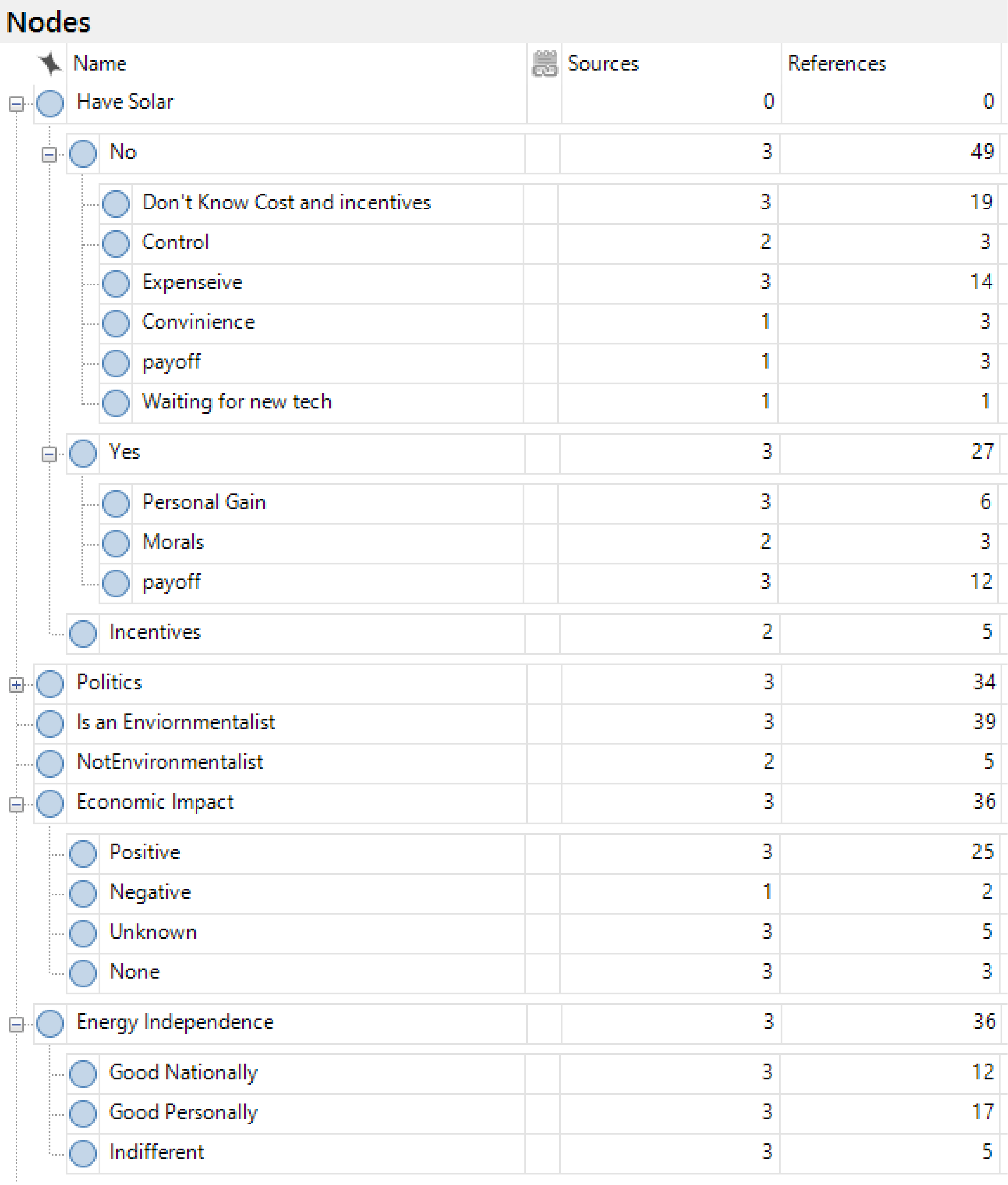
8. Is there anything else you would like to tell me about your decision to adopt (or to not adopt)?

9. Are there any other opinions about solar energy technology that you would like to share?

APPENDIX C

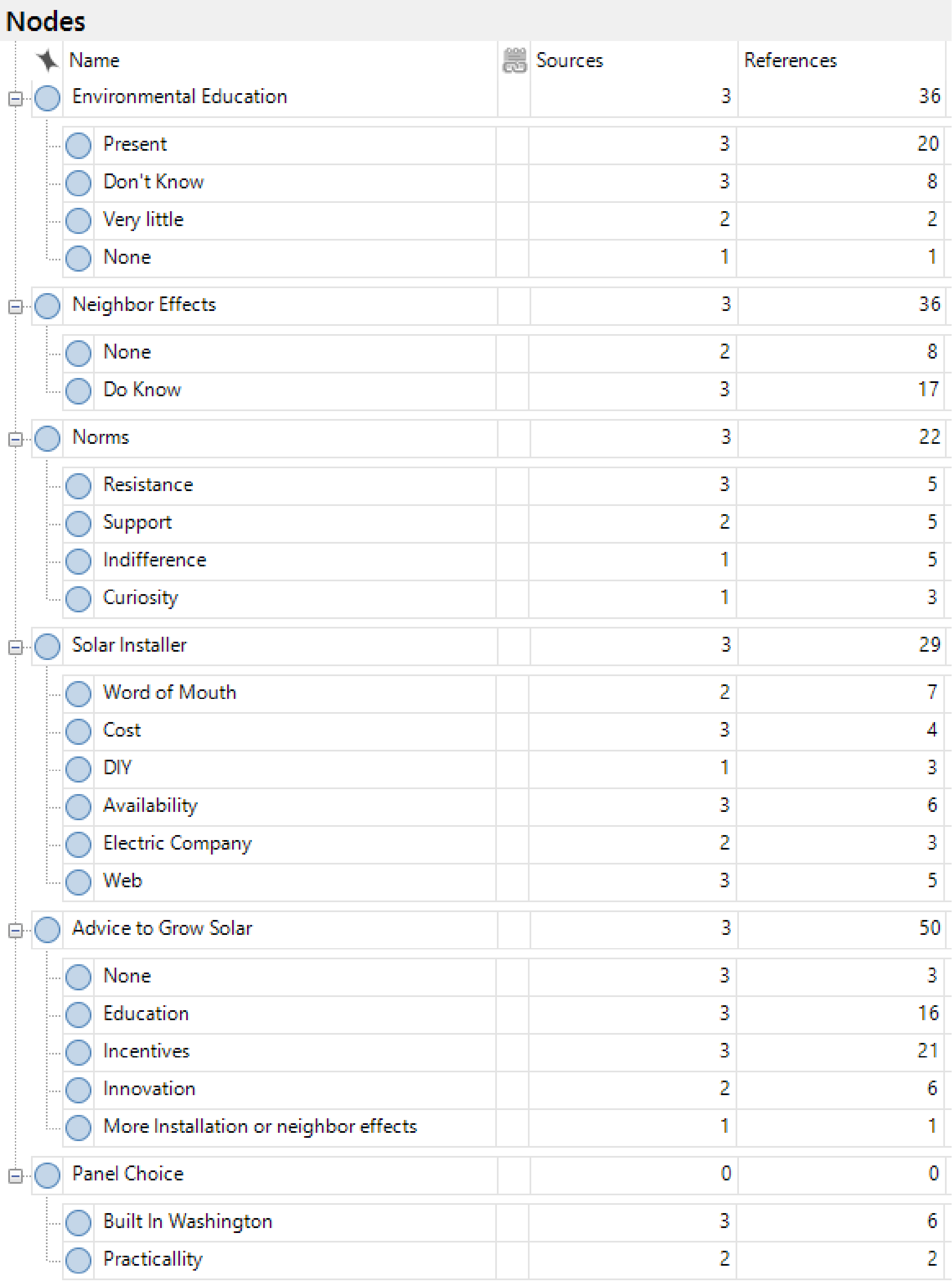
Coding Nodes

The heading ‘Sources’ references to the number of sources the node is found in, there is one source each for the Ellensburg, Lopez Island, and Garfield school district transcriptions. The heading ‘References’ refers to the number of total times each node was coded within all three sources.



Nodes

Name	Sources	References
Have Solar	0	0
No	3	49
Don't Know Cost and incentives	3	19
Control	2	3
Expenseive	3	14
Convinience	1	3
payoff	1	3
Waiting for new tech	1	1
Yes	3	27
Personal Gain	3	6
Morals	2	3
payoff	3	12
Incentives	2	5
Politics	3	34
Is an Enviornmentalist	3	39
NotEnvironmentalist	2	5
Economic Impact	3	36
Positive	3	25
Negative	1	2
Unknown	3	5
None	3	3
Energy Independence	3	36
Good Nationally	3	12
Good Personally	3	17
Indifferent	3	5



Nodes

Name	Sources	References
Environmental Education	3	36
Present	3	20
Don't Know	3	8
Very little	2	2
None	1	1
Neighbor Effects	3	36
None	2	8
Do Know	3	17
Norms	3	22
Resistance	3	5
Support	2	5
Indifference	1	5
Curiosity	1	3
Solar Installer	3	29
Word of Mouth	2	7
Cost	3	4
DIY	1	3
Availability	3	6
Electric Company	2	3
Web	3	5
Advice to Grow Solar	3	50
None	3	3
Education	3	16
Incentives	3	21
Innovation	2	6
More Installation or neighbor effects	1	1
Panel Choice	0	0
Built In Washington	3	6
Practicallity	2	2