Exploring Solar Housing Dynamics in the Western United States

Toward Socially Sustainable Solar PV

by

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ABSTRACT

Solar energy is a disruptive technology within the electricity industry, and rooftop solar is particularly disruptive as it changes the relationship between the industry and its customers as the latter generate their own power, sell power to the grid, and reduce their dependence on the industry as the sole source provider of electric power. Hundreds of thousands of people in the western United States have made the decision to adopt residential rooftop solar photovoltaic technologies (solar PV) for their homes, with some areas of western cities now having 50% or more of homes with solar installed. This dissertation seeks to understand how rooftop solar energy is altering the fabric of urban life, drawing on three distinct lenses and a mixed suite of methods to examine how homeowners, electric utilities, financial lenders, regulators, solar installers, realtors, and professional trade organizations have responded to the opportunities and challenges presented by rooftop solar energy. First, using a novel solar installation data set, it systematically examines the temporal, geographic, and socio-economic dynamics of the adoption of rooftop solar technologies across the Phoenix metropolitan area over the decade of the 2010s. This study examines the broad social, economic, and urban environmental contexts within which solar adoption has occurred and how these have impacted differential rates of solar uptake. Second, using survey and real estate data from the Phoenix metropolitan area, it explores how solar energy has begun to shape important social and market dynamics, illuminating how decision-making in real estate transactions, including by buyers, sellers, agents, lenders, and appraisers is shifting to accommodate houses with installed solar systems. Lastly, the study explores patterns of rooftop solar adoption across major electric utilities and what those can tell us about the extent to

which corporate social responsibility and sustainability reporting have affected the practices of investor-owned electric utilities (IOU) within the western US.

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CHAPTER 1

DIFFUSION AND ADOPTION OF SOLAR PV IN A DESERT CITY

Introduction

In *Do Artifacts have Politics?* Langdon Winner argued that technologies are not just tools that serve narrow, instrumental purposes. Rather, as people use them, they become part of their lives and help create the places and systems that people inhabit. Moreover, because different people adopt and use technologies in different ways, and at different rates, inequalities can emerge or become exacerbated, and technology can come to "embody specific forms of power and authority". (Winner, 1980)

Informed by this idea, this study presents an initial exploration of how solar energy technologies are being taken up by urban residents and becoming part of what shapes the patterns of urban life (e.g., in Chapter 2, how they are becoming part of real estate markets) and the patterns of power and inequality (e.g., in this chapter, how they are being taken up differentially in different parts of the urban landscape). Several studies have looked at the adoption of rooftop solar energy in urban communities. This study goes further to provide the first systematic analysis of the patterns of solar energy development across an entire urban geography over the course of a decade of solar installations. This longitudinal study uses a comprehensive spatial analysis to compare residential solar PV installations both across geographies within one-year snapshots and across time over the decade of the 2010s. This is important to help us understand patterns of inequality in detail as they play out in an urban geography, interacting with other dimensions of city experience, demographics, economics, and history. A key finding of this study is that the social dynamics of solar photovoltaic (solar PV) adoption have changed significantly over time. Certain patterns and trends that were significant and notable during early adoption phases of solar PV have become greatly diminished and are no longer statistically significant today. Conversely, patterns that were not easily detectable or statistically significant in the early days of solar PV adoption are now quite significant and have changed the landscape of how people interact with this technology.

Between 2010 and 2020, rooftop solar PV in the United States grew from close to zero to nearly 20 GW of total solar generation potential. This represents about 2 million solar installations nationwide. Many studies have looked at the adoption of rooftop solar PV systems in terms of their rate of diffusion, including comparatively across different cities and counties. To date, however, no studies have systematically examined how solar PV adoption has occurred across different parts of a metropolitan region (e.g., between downtown districts, inner and outer ring suburbs, and exurbs or across gradients in socio-economic variables, such as income, race, or home ownership rates) and over time, as rooftop solar energy markets and policy have evolved. For example, as incentive programs have declined, zero-down leases have grown into a major market segment. This gap is significant. Insights into the urban dynamics and geographies of rooftop solar adoption have the potential to provide critical information for future energy policy development, especially as cities seek both to accelerate clean energy transitions and ensure that they are just. In this chapter, I explore these questions drawing on data from rooftop solar energy adoption in the Phoenix metropolitan region from 2011 to 2019.

This study contributes to a substantial body of literature on solar technology adoption in cities, which have looked at a number of questions regarding the contribution of solar energy to urban sustainability, the technical potential of urban solar deployments, and social, policy, and economic factors involved in solar adoption.

Examining the adoption of solar PV in different parts of the United States as a form of distributed generation, recent studies have highlighted that distributed rooftop solar solutions have significant potential to contribute significantly to developing sustainable, carbon neutral energy systems for US cities (Brown et al., 2021) and that current patterns of adoption across states are shaped strongly by social and political values and policies that drive adoption in some states more than others. (Pretnar & Abajian, 2021) Similarly, looking across counties in California, another recent study used a generalized Bass model to examine social trends in solar PV distribution and adoption, showing that the pace of adoption varies from place to place and raising a number of important questions about what kinds of social and policy factors might influence differential adoption rates. (Kurdgelashvili et al., 2019)

In seeking to explain differential uptake of solar energy, studies have explored a number of different variables. Graziano et al, for example, researched solar adoption in a region within the state of Connecticut to examine some of the social and policy factors that come into play for solar PV adoption, including spatial peer effects. (Graziano & Gillingham, 2014) (Graziano et al., 2019) Their research found that social factors such as the visibility of solar within a region and word of mouth conversations among neighbors have greater influence over solar PV adoption than income or education. They further suggested that both policy and the built environment influence solar PV adoption. Studies of regional variations in solar adoption in Germany similarly showed that variation in policy and economic incentives were important, while also showing peer effects between neighboring regions and suggesting that social attitudes were more ambiguous. (Dharshing, 2017) Mundaca and Samahita studied solar PV adoption in Sweden and came to slightly different conclusions from the previous authors. Mundaca and Samahita's research suggests that people's social interactions with each other have a greater influence. (Mundaca & Samahita, 2020)

Building on these previous studies, researchers have recently observed trends of racial and ethnic inequities in residential solar PV diffusion patterns within the US as recently as 2013. (Sunter et al., 2019) Using data on the adoption of solar by Census tract from Google Project Sunroof, their study showed that Hispanic and African American-majority Census tracts showed significantly less solar deployment than neighborhoods that were White or Asian majority. They suggest that these differences result from both differences in income and home ownership as well as differences in peer effects, with lower initial adoption rates compounding over time due to slower effects from social networking.

Given these findings, it is somewhat surprising that no systematic appraisal of how rooftop solar energy has developed over time and geographically within a major urban area has been published. Such a study offers the opportunity to explore a number of important questions, both about the factors that explain solar adoption and also with respect to its relationship to and impacts on urban inequality. Within an urban geography, do some areas see accelerated solar adoption in comparison to others? Do rates of adoption stay the same over time, or do they change? What do those differences tell us about the different kinds of social, economic, and policy factors that shape the uptake of technology?

To begin to answer these questions, this study developed a unique database of rooftop solar energy technology adoption across the Phoenix metropolitan region by year, by zip code, for the years 2011-2019. Using this data set, the study examined the socio-economic determinants and social dimensions of solar PV within the Phoenix region, including, over time, how solar adoption correlates spatially with income, race, housing construction, community characteristics, and other factors. As I will discuss in more detail below, the results shed interesting light on solar PV adoption trends, confirming some facets of the literature reviewed here (e.g., that at early points in the adoption of solar in Phoenix, there were measurable disparities in the rate of solar installations in primarily white neighborhoods vs largely black or ethnically Hispanic neighborhoods, even after accounting for wealth and housing prices) while at the same time demonstrating that solar adoption is a more nuanced, heterogeneous, and complex phenomena than revealed in less comprehensive studies.

Methodology

This inquiry is grounded in a uniquely constructed assemblage of data sets constructed for this study for the Phoenix metropolitan statistical area (MSA) at the zip code level. The data sets illuminate the following variables over time from 2011-2019: a) the distribution of solar PV installations, b) socio-economic status, c) demographics, and d) characteristics of residential housing. Using these datasets, this study pursues several analyses that are motivated by and seek to answer the following high-level research questions:

- How has rooftop solar energy developed, geographically, across the Phoenix MSA over time over the course of 2011-2019?
- How do these patterns of solar development correlate to important socio-economic, demographic, and housing patterns across the MSA (e.g., housing density, income, race, retirement, new construction, etc.)?
- How equitable has the development of rooftop solar in Phoenix been as a function of time?
- How have major trends in solar business models and housing markets impacted solar development in Phoenix (e.g., the rise of third-party ownership (TPO) models, the integration of solar into new home construction, etc.)?

To answer these questions, the study pursues a number of specific analytical exercises, which answer these detailed questions:

1. Where is solar PV installed and what does the geospatial distribution look like within Arizona's main Metropolitan Statistical Areas (MSAs) as a function of time?
2. What does this distribution look like controlled for the number of owner-occupied housing units per zip code? To achieve this goal, I created a metric called the solar housing ratio (SHR). See below for more details on this metric.
3. What can be said about the zip codes with the average, least, or the most solar PV installs, both in terms of demographics and market forces?

4. What percentage of the solar PV installs are leased or third party-owned (TPO) and how can these trends be explained?
5. What percentage of the solar PV installs are on newly constructed homes (NC) and how can these trends be explained?
6. How does the SHR compare to wealth, both in terms of household income and housing prices? I compare SHR to both median income and median housing prices.
7. How does the SHR compare to retirement status? I compare median age, percentage of families with retirement income, and the Old Age Dependency Ratio, which is the proportion of working aged adults compared to non-working age adults, excluding children.
8. How does the SHR compare to various racial and ethnic percentages in each zip code? I compare percentages of the standard major Census demographic categories of White, Black, American Indian, Asian, Pacific Islander, Other, and Hispanic or Latino of any race.

To explore these questions, one must rely on data that is available. The form and structure of this data influenced the structure of my own study. These data sets are not always structured in ways that easily match up. That said, I was able to sample at the most granular level available for data on solar PV installations over space and time: individual installations, by date, aggregated at the zip code level. For the socio-economic and demographic variables, I relied primarily on US Census data from the American Community Survey (ACS) aggregated by their own version of the zip code called Zip Code Tabulation Area (ZCTA). Lastly, for housing prices, I sampled the historical database from Zillow.com. Working with each of these somewhat disparate data sets presented a great deal of opportunities and challenges. See below for more details.

Geography

I started with the Phoenix metropolitan area as this comprises the vast majority of the population of the state of Arizona. I chose the Metropolitan Statistical Area (MSA) as a boundary set because this was both available and fairly simple to grasp. The MSA for the Phoenix metropolitan region comprises both Maricopa and Pinal counties, which accounts for the vast growth of the Phoenix-Mesa metropolitan region. The US Federal Office of Management and Budget (OMB) officially designates the Phoenix metropolitan area as the Phoenix-Mesa-Chandler Metropolitan Statistical Area (MSA). (OMB BULLETIN NO. 18-04 Revised Delineations of Metropolitan Statistical Areas, Micropolitan Statistical Areas, and Combined Statistical Areas, and Guidance on Uses of the Delineations of These Areas, 2018) Rather than just using Maricopa County, to make observations, I wanted to expand to neighboring Pinal County to capture the large housing growth that has occurred in that portion of the metropolitan region over time. Using this MSA allows for this, as it is wholly comprised of Maricopa and Pinal counties. By contrast, the Tucson MSA is just Pima County and Flagstaff includes just Coconino County.

Data Set Construction

In 2010, when I first began this study, there were very few reliable, publicly available datasets on the geospatial distribution of solar PV in Arizona as a whole, and none of them were centralized. While the electric utilities had this information, the data was not freely available to citizens or researchers in ways that were useful for detailed analysis. The closest thing to a reliable and complete source at that time was the ArizonaGoesSolar.org website, which listed details for residential solar PV installations aggregated by zip code. This database was curated by the Arizona Public Service (APS) electric utility and commissioned by the Arizona Corporation Commission to help inform the public about solar PV. The major Arizona utilities supplied their installation data, and it was made public through this site, but the underlying data sets were not always available from every utility. In my initial explorations, I data-mined that resource and others for publicly available data sufficient to compile a grand total for all the solar PV in Arizona, both residential and non-residential.

Using this early, highly-limited data, I made some initial observations and discovered that there were high numbers of installations in some western neighborhoods of the metropolitan Phoenix region. This was particularly true among the retirement communities in the western reaches and within the wealthier neighborhoods in more central parts of the metropolitan region. This led to a number of questions about the socio-economic distributions of solar, which I was unfortunately not able to answer, nor was I able at the time to do a robust analysis of the spatial distribution of solar installations in Phoenix. Later, however, I was able to turn to an alternative source for solar data.

Solar data

The data for solar PV installations in this study derives from a dataset that was created and curated by the Lawrence Berkeley National Lab's Berkeley Lab. (*Tracking* *the Sun | Electricity Markets and Policy Group*, n.d.) This data relies on utilities to self-report the solar installations. It has dozens of fields to enter, though not all utilities fill them in. For instance, Tucson Electric Power utility (TEP) failed to enter anything in the "city" or "county" fields. They only included zip code and state for the geographic fields. The city and county can be filled in by matching with other zip code databases, but it is unnecessary for this study. This data set also appears to have some data entry errors, as some zip codes show up as being in other states, well outside of the specific utility territories, even though they're designated as being within Arizona. Some of the zip codes in this dataset do not match up with the zip codes in the historical data sets for Census data. Some of this could be margins of error that don't match up with the way the Census calculated their ZCTAs, but those numbers are relatively small. More of the mismatches from other zip code databases have to do with the fact that some of the zip codes are historical. In other words, they were either created or deleted by the USPS within the past 10 years. For example, the USPS added 7 zip codes at various times during those intervening years. Those 7 zip codes were excluded from this analysis because their solar installation counts were low due to only being in existence for a relatively short period of time. Ideally, these new zip codes might be accounted for in a more robust manner, perhaps in future studies.

These issues of zip codes which do not match the historical Census ZCTAs nor current Zillow databases errors account for about 260 issues out of roughly 157,000 installations state-wide so this is a very small percentage, overall. I was able to match most of the zip codes with historical USPS zip codes to fill in the city, county, and MSA where applicable. Three Arizona counties are so small that they are not assigned to an

MSA. Those are Apache, Greenlee, and La Paz counties. Most of the zip codes could be matched with a county, but for nearly 100 records in some historical zip codes - such as Queen Creek, for example - it is unclear if they were in Maricopa or Pinal counties. Either way, they definitely fall within the Phoenix-Mesa-Chandler MSA, so were assigned that designation, at least. After matching with the USPS database, and fixing partial matches, as explained above, this left just 17 problem zip codes yet to be resolved. This is an extremely small portion of the 157,000 Arizona installations in the solar installation dataset.

Many of these problem zip codes still do not match any of the Census records within the 9-year period being analyzed. Therefore, without information such as the number of homes in said zip codes, it is impossible to create a Solar Housing Ratio for them or any other analyses which require matching to Census data. That said, they can still be used for geographic grand totals and for descriptive data, including running totals for cities and counties.

Solar Housing Ratio (SHR)

I created the SHR in order to easily compare the number of solar installations across zip codes while controlling for variable number of homes within each zip code. This metric is important because some zip codes have many homes, and some have far fewer. While the USPS periodically creates or deletes zip codes to adjust for changes in population, there is still a great deal of variability in housing numbers between zip codes at any given time. The SHR is obtained by simply dividing the number of solar installations in any given zip code by the number of owner-occupied homes (OOH) and then multiplying the result by 1,000.

The OOH represents single-family homes under one roof which are also occupied by the owner. By using the OOH from the US Census ACS data, the SHR controls for several variables all at once: home ownership, vacancy rates, and housing type. *Ownership* means these homes are owned by the current residents, not rented. *Occupied* means that these homes are currently occupied, not vacant. *Home* defines this as a single-family residence or at least a home that constitutes only one roof. This is important for residential rooftop solar because it indicates agency of decision-making about the building as being solely in the hands of the current residents. Virtually all residential rooftop solar installations in Phoenix are on owner-occupied homes.

By using the SHR to compare solar across zip codes, rather than just raw solar installation numbers, we can control for things like the number of homes in a neighborhood as well as vacancy rates which change over time. By using owner-occupied homes, we can control for the ownership rate within each zip code. If we were to use the raw number of homes, regardless of ownership status, this might make the distinctions between zip codes even more stark than they already are, because some zip codes have a higher rate of rental homes. This is important because it is unlikely that home renters will have the same agency and decision-making power to put solar on their homes as homeowners do. There would otherwise be little incentive for landlords to put solar on a rental home. While some landlords may still do so if they were to charge a flat rate for utilities, for instance, this is likely a rare scenario.

Demographics and Solar Data

I used the United States Census as the primary source for socio-economic and demographic data. While the decennial census is most well-known by most people, the American Community Survey (ACS) plays an important role in collecting and estimating data on a yearly basis in between every the 10-year census. I collected ACS 5-year data from the Census for the years 2011-2019 and used this as a baseline for building the entire database for this study. The ACS 5-year data tables are the only ones with Zip Code Tabulation Areas (ZCTA), so this is a sample of necessity. (Bureau, n.d.) ZCTAs are not exactly the same as zip codes used by the US postal service (USPS), so some allowance must be made for the fact that the USPS does change the boundaries of said zip codes from time to time over the years. While the census estimates also contain some zip codes with high margins of error for the data observed and imputed, those are fairly uncommon outside of rural areas and not a significant portion of the data sets used in this study. The more populous regions within Maricopa and Pinal counties generally have a lower margin of error for the variables pulled from the datasets of interest for this study. However, without actual street addresses as data points for the solar installations, it is impossible to match up any of the Census datasets with a high degree of accuracy. Thus, zip code aggregation is our most granular level of observation.

The Census includes 405 zip codes within the State of Arizona and this list of zip codes remains stable across the nine-year range of 2011-2019. This list is more stable and more reliable than the LBNL data for solar installations, which is self-reported by electric utilities. The LBNL dataset contains dozens of reporting errors as well as some Zip codes that don't exist or are outside of Arizona. It is likely that many of these are due to data-entry errors by the utilities when reporting. Sorting out and verifying every one of these dozens of errors would be difficult and also possibly subject to researcher-error, so this is the main reason why it was necessary to use another dataset as the basis for zip codes within Arizona. Fortunately, as discussed above, these reporting errors represent only a few dozen unusable entries out of tens of thousands of solar installations, so the percentage of installations omitted from this study due to reporting error is extremely small.

For the most recent list of zip codes, I downloaded all Arizona zip codes from the USPS website. (*Arizona ZIP Codes List, Map, Demographics, and Shipping*, n.d.) I then included only "Standard" types of zip codes, omitting "PO Box" and "Unique" zip codes. Unique zip codes are mostly campuses for universities, schools, and hospitals, for example, where no owner-occupied residential housing exists. PO Box zip codes do not represent actual observed properties, so they were also excluded from this study.

Single-Family Homes Time Series by Zip Code

The ZHVI stands for Zillow Housing Value Index. This "Zestimate" as they call it, essentially measures the estimated median value of single-family residences that fall within the geography and time series specified. In this case, zip codes and the month of December for each year from 2011-2019. However, the calculation is more complicated than recent median sales and also includes some hedonic modeling where they consider various attributes of the homes when making their calculations. The latest model from 2019 has been used to recalculate all the home sales back into the 1990s which provides plenty of data for this study.

The main reason for choosing the ZHVI rather than using the median value home estimate from US Census ACS table DP04 (selected housing characteristics) is consistency and reliability. The ZHVI uses a stable methodology applied consistently over time. This sits in contrast to the US Census ACS data for which they changed the methodology significantly in 2015. Unlike Zillow, the Census data cannot be matched up or easily and reliably compared to their own data for years prior to that.

Results and Discussion

Solar Housing Ratio (SHR), socio-economic and demographic variables

To show the results from the study, I start with annual plots of the geographic distribution of solar installations (measured as the SHR) across the Phoenix MSA for the years 2011-2019. The full set of color maps can be found in Appendix A. Here, for illustrative purposes, I show the resulting maps for 2011, 2015, and 2019. The full set are plotted with a consistent color code, so that SHR can be compared across the maps as well as within them.

The first significant observation from these maps is the rapid growth in solar adoption observed across the entire time period. Darker blue colors represent areas with very low solar housing ratios. Darker red colors represent areas with very high solar housing ratios. As can be seen in the quantitative results under each map, the average SHR was 11.6 in 2011, representing just over 1% of owner-occupied houses with solar. By 2019, the average SHR was 96.5, or just less than 10% of owner-occupied houses with solar across the entire MSA. Overall, this reflects a 10-fold increase in solar installation in less than a decade. The maximum individual zip code SHR in 2011 was

105, while the maximum rose to 537 by 2019, for a 4-fold growth. In the maximum zip code, (zip code 85396, in the city of Buckeye) by 2019, over 53% of owner-occupied houses had solar installed.

The second significant observation from these maps is the heterogeneity of solar installations across the Phoenix geography. In 2019, the latest year in the study, some zip codes still had an SHR of less than 10 (less than 1% of houses with solar), in comparison to 53% in the highest penetration zip code, with zip codes ranging considerably in between. This heterogeneity is interesting because it suggests that local variability is very high across zip codes. In fact, as I show in the next section, many different factors contribute to shaping the heterogeneity of solar adoption across the MSA.

The third significant observation from these maps is the broad patterning, in 2011, of lighter blue in the north and west areas of Phoenix, with darker blue in the central, east, and south parts of the MSA. This pattern continues in 2015 and 2019, with the exception that the far southern areas of the MSA catch up to their north and west counterparts by 2019, leaving the lighter pink and bluer areas in central Phoenix and in the eastern suburbs (Mesa, Tempe, Chandler). While this pattern was not quantitatively analyzed, it broadly corresponds (at least for much of the MSA) with the territorial areas of the two Phoenix utilities, APS and SRP, with APS in the north and west and SRP in central Phoenix and the eastern suburbs. From a policy perspective, APS had for most of this period more favorable rooftop solar incentives than SRP, which likely helps explain the higher rates of adoption in its territories. At the same time, the heterogeneity in solar adoption within each of the territories indicates that other variables are also important.

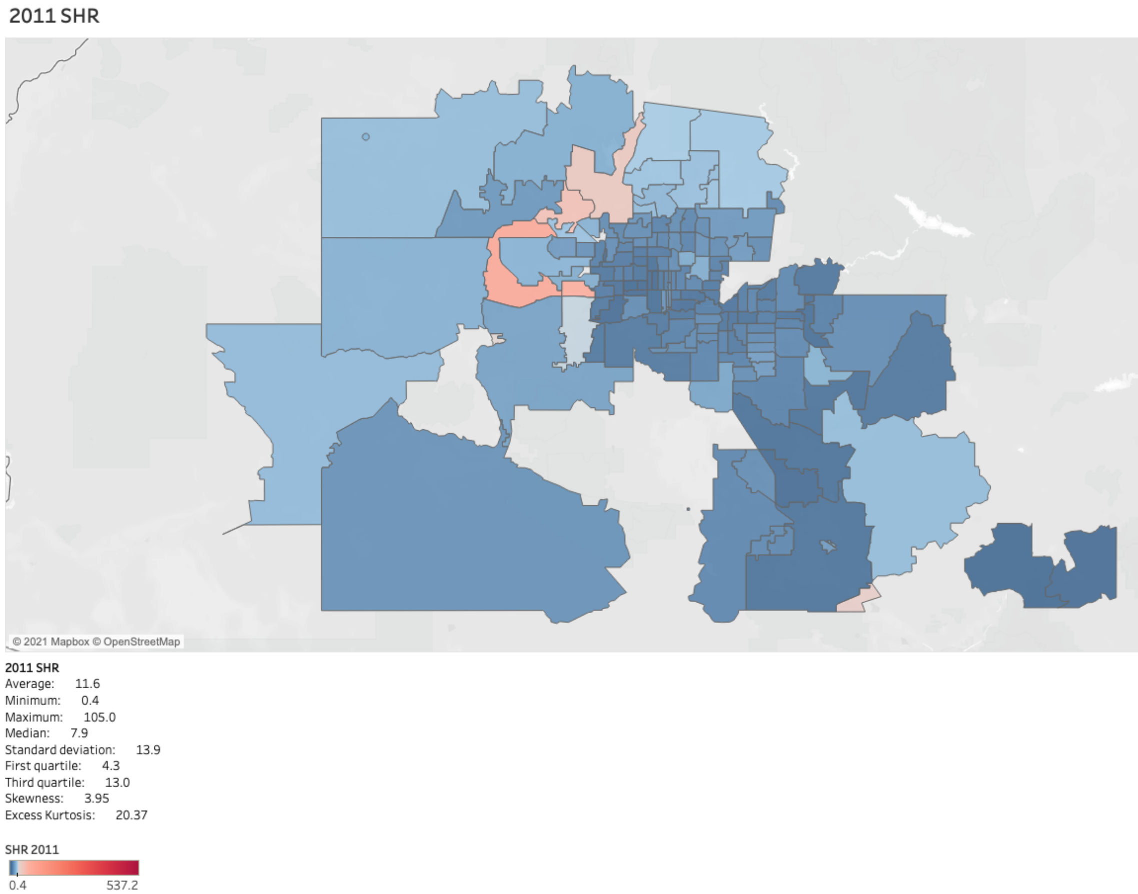


Fig. 1.1. SHR by zip code for 2011

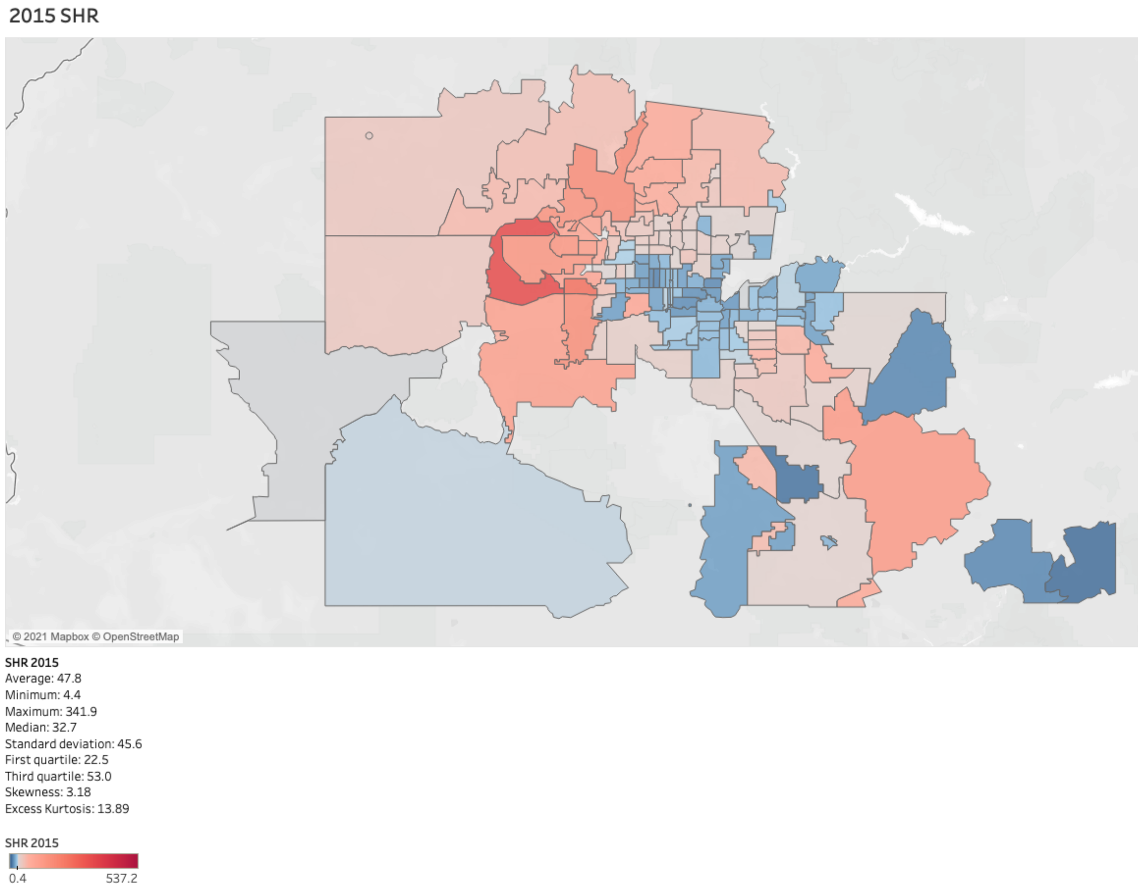


Fig. 1.2. SHR by zip code for 2015

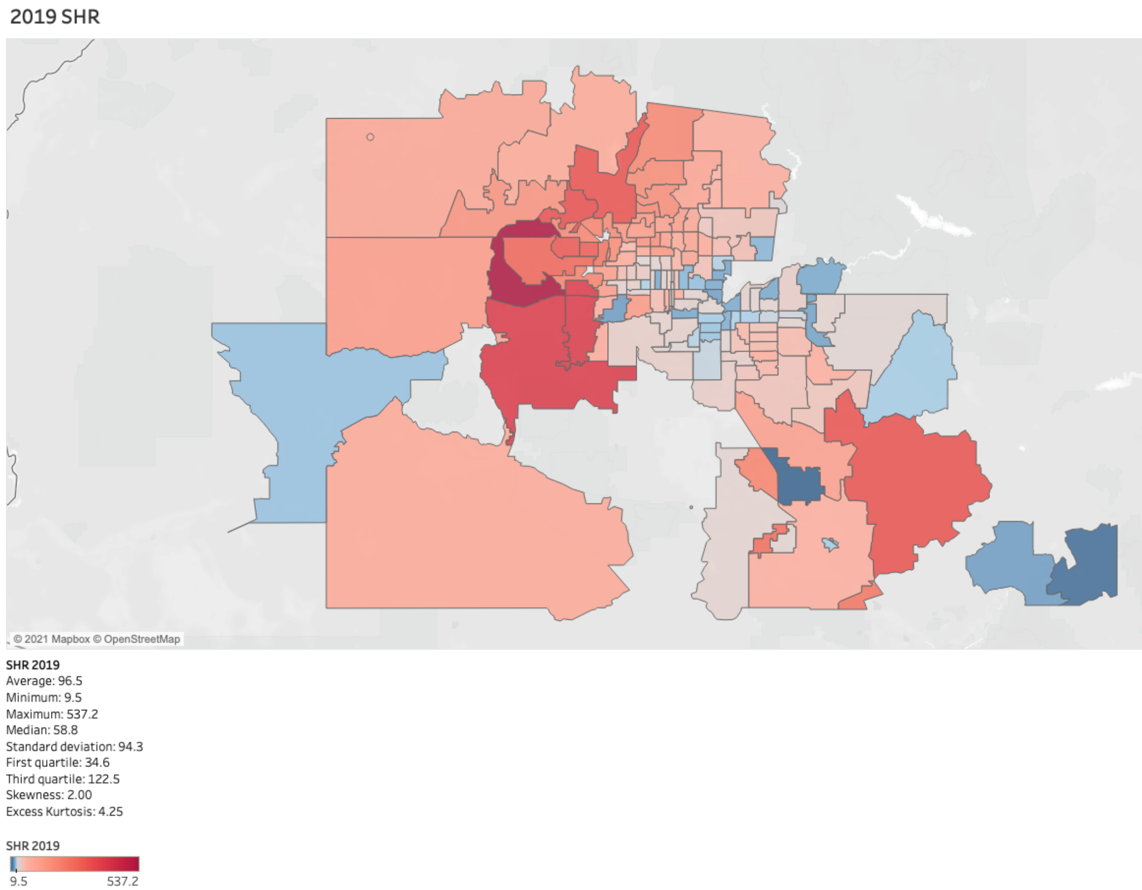


Figure 1.3 SHR by zip code for 2019

Results from Correlation Analysis

To analyze the various factors that impact solar adoption, I used a Spearman Correlation Analysis to analyze the SHR in relation to a number of socio-economic, demographic, and housing variables (as described above in the methods section), with the results for each year comparing the same variables across the same zip codes.

In table 1.2, I present the results from this analysis for each of the years from 2011-2019, note the changes over time, and discuss the implications. Please see the inline color-coded table in figure 1.4 for details on these results. Note the legend on how the table is color coded for easy reference. Also see Tables 1.2, 1.3, and also 1.4 in the Appendix for more information on the names of coded variables and detailed results of this analysis.

When I first began this research, I had some basic hypotheses about how SHR would correlate to wealth and retirement status but did not have specific predictions about race and ethnicity. Specifically, based on anecdotal stories within the solar community in Phoenix, I hypothesized that the data would show that wealthier households and retiree households were more likely to adopt solar. My hypotheses were borne out in the statistical analysis, but only in the early years. Over time, many of these correlations became weaker or disappeared entirely. This overall trend was both drastic and a surprise. I even went back to spot-check the accuracy of my input data and assured that it was indeed correct. Again, see the color-coded Figure 1.4 and Table 1.1 for specific results from the Spearman correlation analysis. The shaded red and blue boxes indicate a statistical significance with p-values of $<.05$. The white boxes had p-values of $>.05$ and did not show a significant correlation. The shading represents the power of this effect with the darker colors being larger effect sizes and the lighter colors being smaller effect sizes. Note the change over time from 2011 to 2019. By 2019, the majority of correlations disappear, and the remaining are all reduced to low effect sizes, save for the TPO variable. This variable started out as insignificant in 2011 and became the strongest statistically significant indicator by 2019.

In 2011, there was a statistically significant positive correlation to both wealth and all the age/retirement indicators. The correlation for wealth was stronger in terms of median housing price than it was for median income. There was also a statistically significant correlation (positive or negative) in all the race and ethnicity categories except for Asian. This could be due to small percentage in sample size, but it is also notable that Asian families tend to be very close to White families in terms of median income. This just may not be apparent within these demographic distributions within these observed geographies. One of the strongest positive correlations was to housing value, followed by percentage of White race, and median income. One of strongest negative correlations was with Hispanic/Latin ethnicity, followed by American Indian race, and, with low effect sizes, for Black race. Income and housing value also had large effect sizes in the 2011 analysis, while age and retirement status specifically had moderate to small effect sizes.

In 2019, many of the correlations, including for median age and housing value, both disappeared, while the correlations for income and retirement status were greatly diminished. This indicates that, while early adopters were wealthier and many were also concentrated in retirement communities, later adopters have been much more widely distributed across not only geography but also socio-economic, demographic, and housing type variables.

Spearman correlation analysis

Phoenix-Mesa-Chandler Metropolitan Statistical Area

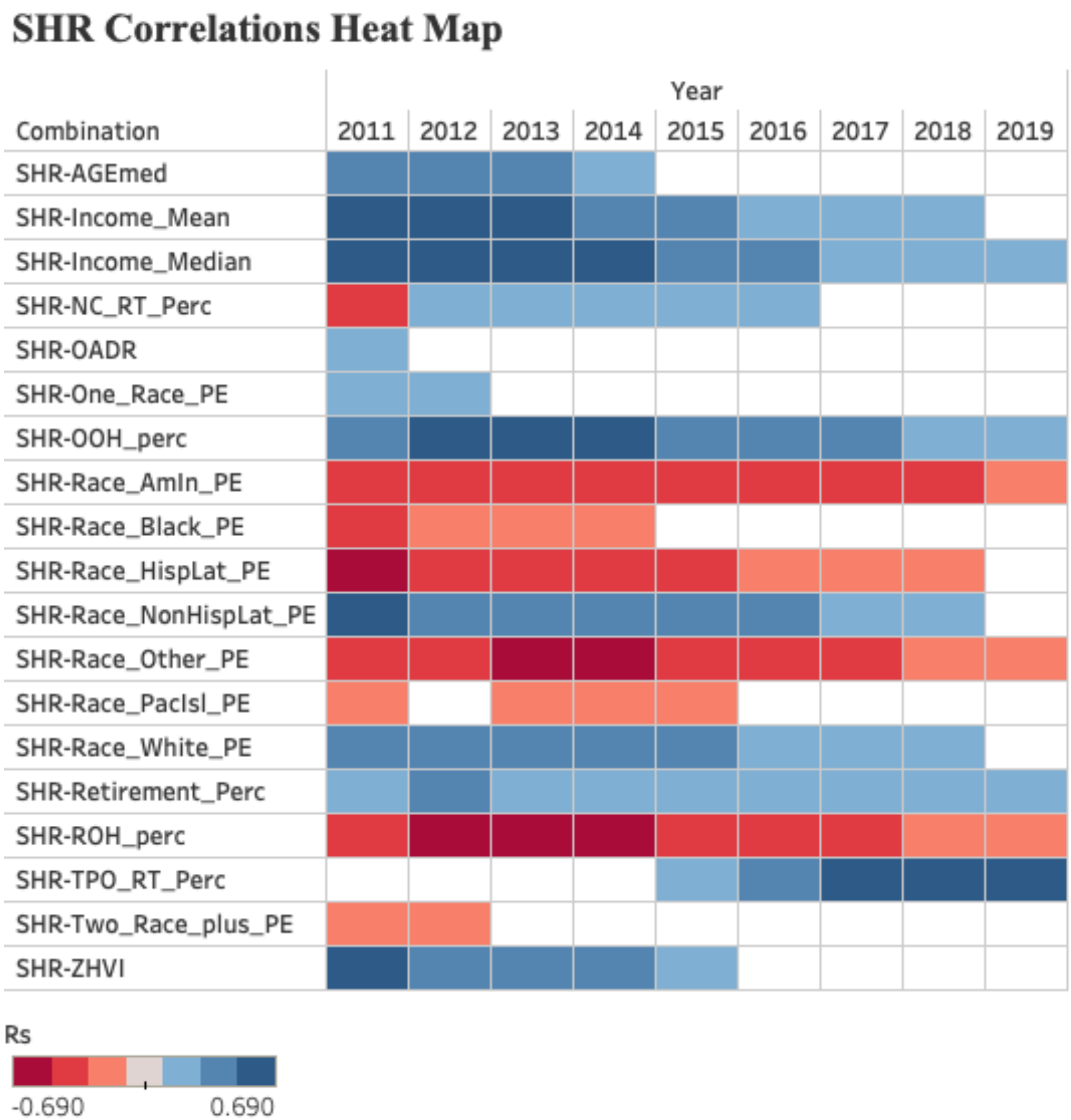
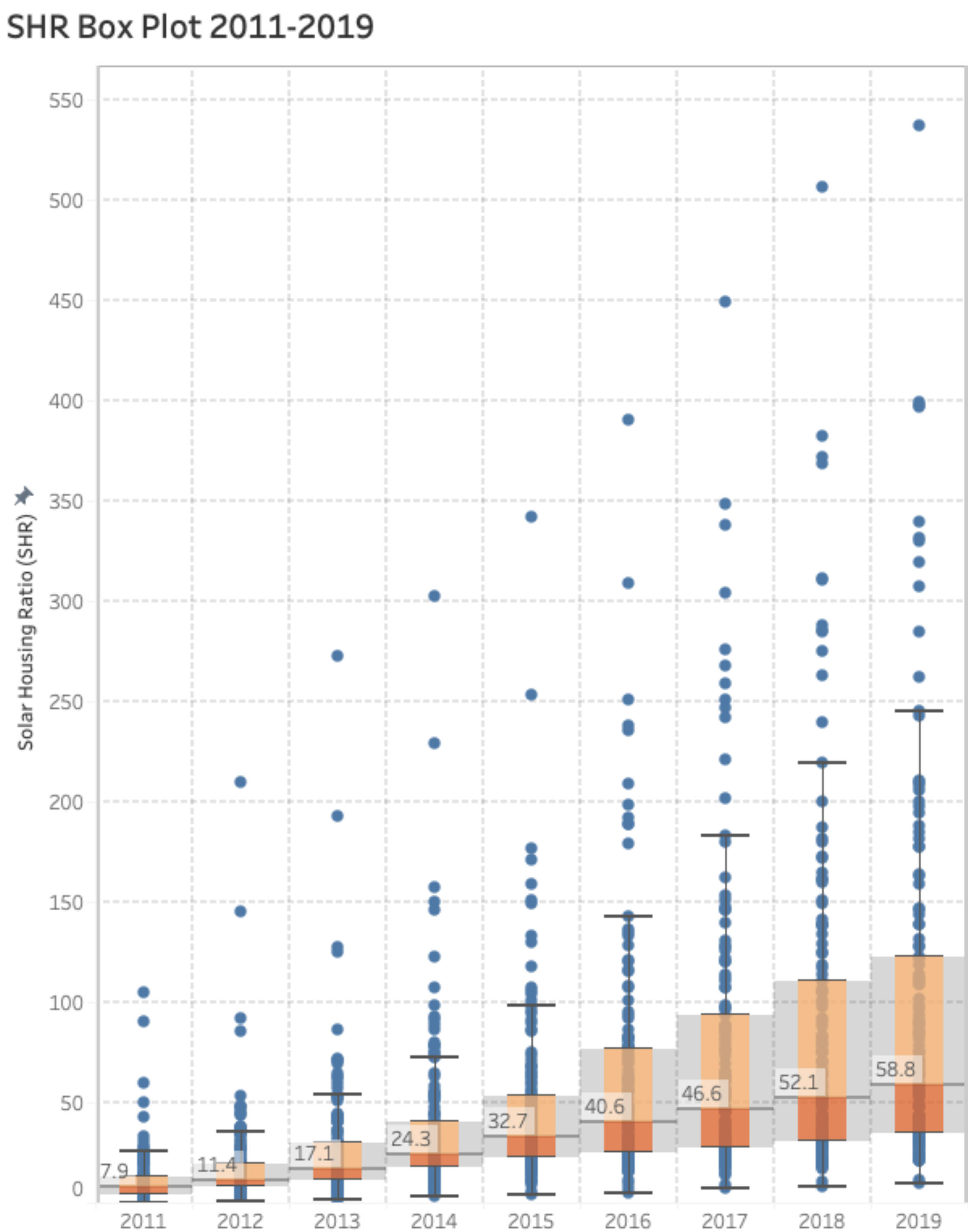


Figure 1.4 SHR Correlations Heat map. This heat map displays correlations between combination variables and the solar housing ratio (SHR) broken down by Year. The colors relate to the power of the Correlation Coefficient. Red equals a negative correlation, while blue equals a positive correlation. The colors are also graded to represent the effect sizes of small (.10-.29), medium (.30-.49), and large (>5.0) The view is filtered to only include P-values of <.05. Any p-value > .05 displays as an empty white box on this table. See SHR Correlations Table 1.1 for actual numeric values. See Table 1.4 in the appendix for variable definitions.

SHR Correlations Table

Combination		2011	2012	2013	2014	2015	2016	2017	2018	2019
		Year								
SHR-AGEmed	P	0.001	0.001	0.001	0.013	0.154	0.540	0.524	0.507	0.538
	Rs	0.410	0.370	0.300	0.200	0.120	0.050	0.050	0.060	0.050
SHR-Income_Mean	P	0.001	0.001	0.001	0.001	0.001	0.002	0.015	0.033	0.176
	Rs	0.510	0.500	0.510	0.450	0.370	0.250	0.200	0.180	0.110
SHR-Income_Median	P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.011
	Rs	0.500	0.520	0.550	0.510	0.460	0.360	0.290	0.260	0.210
SHR-NC_RT_Perc	P	0.001	0.004	0.001	0.001	0.001	0.028	0.148	0.225	0.265
	Rs	-0.370	0.240	0.280	0.290	0.280	0.180	0.120	0.100	0.090
SHR-OADR	P	0.036	0.053	0.137	0.324	0.536	0.755	0.640	0.567	0.563
	Rs	0.170	0.160	0.120	0.080	0.050	0.030	0.040	0.050	0.050
SHR-One_Race_PE	P	0.001	0.005	0.190	0.190	0.760	0.231	0.171	0.437	0.412
	Rs	0.270	0.230	0.110	0.110	-0.030	-0.100	-0.110	-0.060	-0.070
SHR-OOH_perc	P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Rs	0.490	0.550	0.580	0.550	0.490	0.360	0.330	0.290	0.280
SHR-Race_AmIn_PE	P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Rs	-0.350	-0.380	-0.380	-0.380	-0.390	-0.380	-0.340	-0.320	-0.290
SHR-Race_Asian_PE	P	0.647	0.493	0.187	0.187	0.166	0.332	0.552	0.438	0.750
	Rs	0.040	0.060	0.110	0.110	0.120	0.080	0.050	0.060	0.030
SHR-Race_Black_PE	P	0.001	0.001	0.007	0.007	0.344	0.820	0.932	0.804	0.695
	Rs	-0.300	-0.260	-0.220	-0.220	-0.080	-0.020	0.010	0.020	0.030
SHR-Race_HispLat_PE	P	0.001	0.001	0.001	0.001	0.001	0.001	0.007	0.020	0.057
	Rs	-0.510	-0.480	-0.460	-0.460	-0.350	-0.270	-0.220	-0.190	-0.160
SHR-Race_NonHispLat_PE	P	0.001	0.001	0.001	0.001	0.001	0.001	0.007	0.020	0.057
	Rs	0.510	0.480	0.460	0.460	0.350	0.350	0.220	0.190	0.160
SHR-Race_Other_PE	P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.019
	Rs	-0.450	-0.480	-0.520	-0.520	-0.430	-0.360	-0.300	-0.260	-0.200
SHR-Race_PacIsl_PE	P	0.022	0.087	0.004	0.004	0.013	0.244	0.749	0.641	0.813
	Rs	-0.190	-0.140	-0.240	-0.240	-0.210	-0.100	-0.030	-0.040	-0.020
SHR-Race_White_PE	P	0.001	0.001	0.001	0.001	0.001	0.003	0.012	0.042	0.086
	Rs	0.440	0.450	0.420	0.420	0.310	0.240	0.210	0.170	0.140
SHR-Retirement_Perc	P	0.014	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.004
	Rs	0.200	0.300	0.280	0.260	0.250	0.270	0.250	0.250	0.240
SHR-ROH_perc	P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Rs	-0.490	-0.550	-0.580	-0.550	-0.490	-0.360	-0.330	-0.290	-0.280
SHR-TPO_RT_Perc	P	0.445	0.187	0.265	0.265	0.038	0.001	0.001	0.001	0.001
	Rs	0.060	0.110	0.090	0.090	0.170	0.390	0.510	0.590	0.690
SHR-Two_Race_plus_PE	P	0.001	0.005	0.190	0.190	0.760	0.231	0.171	0.437	0.412
	Rs	-0.270	-0.230	-0.110	-0.110	0.030	0.100	0.110	0.060	0.070
SHR-With_retirement_in..	P	0.379	0.893	0.864	0.399	0.196	0.239	0.332	0.407	0.364
	Rs	-0.070	-0.010	0.010	0.070	0.110	0.100	0.080	0.070	0.080
SHR-ZHVI	P	0.001	0.001	0.001	0.001	0.007	0.167	0.374	0.532	0.912
	Rs	0.530	0.470	0.410	0.340	0.220	0.120	0.070	0.050	0.010

Table 1.1 SHR Correlations Table. Correlations between combination variables and the solar housing ratio (SHR) broken down by Year. Rs represents the Correlation Coefficient with effect sizes of small (.10-.29), medium (.30-.49), and large (greater than 5.0). The p-values represent the probability of obtaining the result with $p < .05$ being statistically significant. P values of < .001 are listed as .001.



SHR distributions of Zip Codes in the Phoenix Metropolitan Statistical Area.for the years 2011 -2019. The median SHR for each year is displayed on its reference line within the box.

Figure 1.5 SHR Box Plot 2011-2019 SHR distributions of Zip Codes in the Phoenix Metropolitan Statistical Area for the years 2011 -2019. The median SHR for each year is displayed on its reference line within the box.

Change	Trend assessment	Combination	Changes over time
<	Good	SHR-Income_Median	Median income weakened from a large to a small effect size.
<	Good	SHR-ZHVI	Housing value weakened from a large effect size to no significant correlation.
<	Good	SHR-AGEmed	Median age weakened from a moderate effect size to no significant correlation.
Constant	Neutral	SHR-Retirement_Perc	Percentage of households receiving retirement income stayed nearly the same with a positive correlation and small effect size.
<	Good	SHR-OADR	Old Age Dependency Ratio weakened from a small effect size to no significant correlation.
<	Good	SHR-Race_White_PE	White race weakened from a moderate effect size to no significant correlation.
>	Good	SHR-Race_Black_PE	Black race strengthened from a negative correlation with moderate effect size to no significant correlation.
>	Good	SHR-Race_AmIn_PE	American Indian race strengthened from a negative correlation with moderate effect size to a negative correlation with only a small effect size.
Constant	Neutral	SHR-Race_Asian_PE	Asian race remained virtually the same with no significant correlation.
>	Good	SHR-Race_PacIsl_PE	Pacific Islander race strengthened from a negative correlation with small effect size to no significant correlation.
>	Good	SHR-Race_Other_PE	Other race strengthened from a negative correlation with moderate effect size to a negative correlation with only a small effect size.
>	Good	SHR-Race_HispLat_PE	Hispanic ethnicity strengthened from a negative correlation with large effect size to no significant correlation.
<	Good	SHR-Race_NonHispLat_PE	Non Hispanic ethnicity weakened from a positive correlation with large effect size to no significant correlation.
>	Good-Neutral	SHR-TPO_RT_Perc	Third Party Owned strengthened from no significant correlation to a positive correlation with large effect size.
>	Good-Neutral	SHR-NC_RT_Perc	New Construction strengthened from a negative correlation with moderate effect size to no significant correlation.

Table 1.2 SHR trends and how they change over time.

Race and solar adoption

On the whole, metropolitan Phoenix already has a majority white population (Min. >50%) in every zip code examined within this MSA. That said, some areas do have large representations of black and Hispanic/Latino populations, for example. Early on in this study, in 2011, those zip codes showed some more significant disparities in solar adoption. Neighborhoods with the greatest numbers of Hispanic/Latino also had the strongest negative correlation with SHR scores. In fact, this was the strongest negative correlation out of all the variables examined for that particular year. As solar began to diffuse more evenly throughout society over the years, this correlation lessened and completely disappeared from statistical significance by 2019.

The declining relevance of wealth to solar adoption

One of the more interesting findings has to do with the correlation between wealth and the SHR. While there is, in early years, a correlation between wealth and the amount of solar PV in neighborhoods, this correlation falls off over time, as can be seen in Figure 1.4. What is going on here, and what is the explanation for this decline? While looking at the statistical outliers in Figure 1.5, the zip codes that are represented by the upper most dots in each year (which are above the top quartile of zip codes in terms of SHR/solar adoption) exhibit housing prices above the median income for the MSA. However, they are not the highest income or housing price zip codes, and their median SHR is proportionally much higher than their median income (in comparison to the rest of the metropolitan area).

This could potentially be explained by several factors. One explanation, offered by DOI theory (Rogers, 2014) could be that early on in this study, adoption was still the purview of early adopters who, Rogers notes, are often more wealthy, better educated, and have better access to information about innovations. On the other hand, there was also a significant business model shift in the middle of these years with the adoption of TPO financing (see TPO section).

It is worth noting that these findings run counter to our expectations about what should have happened during this time period, given the hypothesis that solar adoption is primarily a phenomenon of wealthy neighborhoods and households. During the great recession and the subsequent decade of the 2010s, wealth disparities in the US grew dramatically. On first blush, this should have made it even easier for wealthy families to go solar and harder for lower-income families. But the correlation statistics went the other direction. The adoption rate for the wealthiest zip codes was not as high as that of zip codes of more modest means. In fact, the zip codes with the highest wealth had only very modest growth in SHR while zip codes with only modest wealth had far higher rates of growth in SHR over time.

First, there's the uneven economic recovery following the great recession of the late 2000s. People in the upper and middle end of the wealth spectrum gained wealth at far faster rates than those of the lower and middle end of the spectrum. The power of compound interest and other socio-economic factors also likely contributed to this wealth gap increasing over time. Yet, the adoption rate for the wealthiest zip codes was not as high as that of zip codes of more modest means. In fact, the zip codes with the highest wealth had only very modest growth in SHR while zip codes with only modest wealth had far higher rates of growth in SHR over time.

Third-party ownership (TPO) solar financing

Early on in this study, TPO financing played a very small role and actually showed no statistical correlation with the SHR scores. However, the policies that enabled TPO were fairly new and this financing model was just beginning to take hold in the market. Contrary to all the other measured variables, TPO correlation actually began to go up by 2015 and by 2019 it was the strongest correlation of all. The fact that TPO financing allowed people with modest incomes to adopt solar with low or zero-down financing, it may help explain some of the trends where factors such as wealth began to play less of a role. While TPOs may have been less profitable over time when compared to owning the solar installation outright, there's little doubt that this innovative financing structure helped democratize solar in this metropolitan region.

Retirement and other trends – how theory fits the observations

Looking at the various neighborhoods, some of the largest SHR values are in retirement communities, most in the western parts of Maricopa County. One example of these early trends is the retirement community of Pebble Creek in Goodyear, Arizona. Starting in 2008, they saw early solar adoption and, subsequently, saw a rapid increase in installations over the next four years. I did an interview with a local retired engineer who lived in that community and still lives there today. His name is Drury (Dru) Bacon. Dru started an environmental club in his Pebble Creek community with limited attendance of maybe 35 people. That is until people became interested in Solar PV. Suddenly the attendance rate more than doubled, then tripled and quadrupled from the original 35, as more and more people from this one retirement community crowded into the clubhouse to hear about putting solar on their own rooftops. At first, he first successfully advised people on what to look for and how to not get taken advantage of by installers. As people began to get discounts and referral bonuses, they began to consult him less and simply recommend whichever company they received the bonuses from. Some folks received bad deals as a result. Over the years, Dru continued to consult with local residents and still does to this day.

Within Diffusion of Innovation (DOI) theory, one main element in the adoption of technology is the presence of a change agent. (Rogers, 2014) These individuals are often early adopters themselves and are highly motivated to adopt a particular technology. Their presence in a system can have a dramatic effect on the uptake of technology adoption. Dru Bacon can be seen as a change agent in Pebble Creek, though he was not alone. The city of Goodyear - where Pebble Creek was located - worked with a solar community organization called SmartPower to increase the adoption of solar PV in their community. SmartPower recruited local and regional residents to be solar ambassadors. These solar ambassadors worked in very similar roles to Dru Bacon, both advising and promoting solar PV. Although Dru continued to advise local residents on solar long after SmartPower discontinued their work in Goodyear, these solar ambassadors can also be viewed as change agents.

Changes over time: SHR Delta, Skewness, and Kurtosis

In addition to the various changes over time in the demographic correlations, I have also observed some notable changes in patterns of diffusion within the observed Phoenix metropolitan area as a whole. To measure SHR trends over time, I created a cross-tabulation of the SHR scores for all the zip codes over each of the years between 2011 and 2019. Then to find the rate of change over time, I first subtracted the 2011 SHR scores from the 2019 SHR scores for each zip code resulting in the Delta. Using that Delta, I calculated a percentage of change in SHR scores from 2011 to 2019. While this is a useful metric, it is also relative. Some zip codes saw massive percentages of change over time, but if they started out with very low SHR scores, they still had only moderate SHR scores at the end of the time scale. Other zip codes – particularly those in Buckeye and Sun City West, for example - also saw large increases, but they started out with high SHR numbers to begin with. Thus, it is relative, but still significant.

One of the summary statistics that changed significantly over time is the skewness. Skewness shows whether the distribution of data is symmetrical or asymmetrical, shifting either to the left or the right, leaving a long tail of outliers in its wake. Any skewness score over 2.0 shows that it is not a normal distribution (bell curve). In 2011 the skewness was 3.95 and in 2012 it was 4.89. By 2019 the skewness came down to 2.0, which is borderline. This indicates two things. First, a high positive skewness score means that the distribution skewed to the left (low SHR scores) with a long tail to the right. Over the course of the decade observed in the data, the distribution shifted more toward the center. This means that the SHR scores are slightly more evenly distributed than before and also suggests that solar PV adoption is more evenly distributed across the various sectors of society, though it is still just outside a normal distribution as of 2019. While some inequities do remain in the distribution, they are now far less statistically significant.

Another important summary statistic to note here is kurtosis. Kurtosis shows how likely you are to see outliers in the distribution of data. Larger kurtosis scores produce fat tails on a distribution curve. This fat tail means a greater likelihood of outliers. The larger excess kurtosis scores in 2011-2013 indicates steeper bell curves with a lot of outliers in the data. The fact that the kurtosis scores came down so significantly over time indicates that there is also a significantly lower likelihood of outliers in the data. This is a significant and notable change over time, as it means that the Phoenix Metropolitan region is approaching a more normal distribution of SHR as solar diffuses through society at different socio-economic levels.

Summary Statistics Table for Interval and Ratio Variables

Variable	*M*	*SD*	*n*	SE_M	Min	Max	Skewness	Kurtosis	*Mdn*	Mode
SHR_2011	11.58	13.87	145	1.15	0.37	104.98	3.95	20.37	7.91	9.76
SHR_2012	18.52	24.12	145	2.00	0.94	209.84	4.89	31.27	11.38	37.04
SHR_2013	26.83	32.56	145	2.70	1.80	273.08	4.44	26.11	17.09	18.21
SHR_2014	37.52	39.56	145	3.29	3.37	302.62	3.55	16.85	24.35	19.26
SHR_2015	47.76	45.56	145	3.78	4.36	341.93	3.18	13.89	32.71	16.87
SHR_2016	61.85	60.71	145	5.04	4.97	390.49	2.51	7.69	40.63	24.81
SHR_2017	75.94	76.21	145	6.33	7.62	449.45	2.22	5.45	46.57	32.62
SHR_2018	87.10	87.55	145	7.27	7.96	506.80	2.11	4.84	52.07	39.66
SHR_2019	96.54	94.31	145	7.83	9.50	537.23	2.00	4.25	58.75	41.61

Note. '-' indicates the statistic is undefined due to constant data or an insufficient sample size.

Table 1.3 Descriptive statistics for the Phoenix metropolitan region.

Conclusion

This chapter reviewed solar trends over time in terms of the amount of solar, housing stock, solar financing, socioeconomics, and demographics. While some trends were stark and significant in the early years of this study, many of them became statistically insignificant and less easy to observe over time. These trends include high concentrations of solar PV installations in retirement communities and in primarily white neighborhoods, for example. That said, those trends did indeed exist and the stories around the people who helped drive those trends are no less relevant for having occurred in the early stages of solar PV adoption in the Phoenix Metropolitan region. In fact, the actors involved, and trends observed fit quite well with Diffusion of Innovation theory, where we see early adopters and innovators playing significant roles in easing adoption among their neighbors and peers.

Looking at the raw numbers and percent increases over time of solar installations added to wealthy neighborhoods versus the far more modest numbers that were added in low-income neighborhoods, one might be tempted to say that the rich just keep getting richer, while the poor remain mostly poor. This would not be entirely wrong, though this statement also lacks nuance. Absent robust policies to promote solar in low-income neighborhoods or multi-family housing in Arizona - compared to California's solar tariff (California Solar Initiative, n.d.) and low-income carve-outs for single-family homes (CSI Single-Family Affordable Solar Homes (SASH) Program, n.d.) as well as virtual net-metering (CSI Multifamily Affordable Solar Housing (MASH) Program, n.d.), for example - we do see low numbers of solar PV installations within low-income communities, even to this day. Even California regulators had challenges in getting landlords to adopt solar on their multi-family housing properties, leading to iterative program adjustments over time. However, those households in Arizona who do adopt solar in low-income neighborhoods and who are happy with the arrangement may have a networking effect with a long tail. Those who adopt solar leases may have more poor opinions of solar PV and there have been some unethical solar installers who seemingly took advantage of people, giving them poor deals. But that is for a different analysis.

Note that while race and ethnicity are represented in the demographic statistics, it's important to remember that these are abstract representations of populations based on Census estimates from their 5-year American Community Survey. These numbers do not measure the specific characteristics of individual solar homeowners or solar PV adopters, merely the characteristics represented within the zip codes in which they reside. Thus, one may only infer the likelihood that these demographics represent those of actual solar homeowners in those neighborhoods. This is an area that needs further study with more granular data. To what extent do zip code level aggregates reveal or hide underlying racial, income, or other demographic patterns?

That said, there may very well be structural inequalities at play in the unequal distribution of solar PV throughout these observed populations. O'Shaughnessy correctly notes that discussions of solar PV and energy justice in which structural inequalities are not included in the narratives are themselves incomplete. (O'Shaughnessy, 2021) He notes, for example, that some utilities have used the idea of inequity to promote utility-friendly regulations which actually had the effect of curtailing solar PV adoption in that region. Other examples of structural inequalities may include the legacy of red-lining neighborhoods to segregate populations and manipulate real estate property values. This, in turn, may show up in the current distortion of solar PV as well.

The next chapter presents more granular data about solar home ownership and contains demographic information gathered from the survey that I conducted in 2015 of recent buyers of pre-equipped solar homes. The data set is far smaller than in this chapter, so different methods were required for analysis. But the survey data also offers some rich narratives as we hear stories directly from the survey respondents about their behaviors and attitudes toward residential rooftop solar PV.

CHAPTER 2

SOLAR PV DYNAMICS IN THE REAL ESTATE MARKET: TPO LEASING AND PRE-PAID SOLAR FINANCING MODELS IN INTERRELATED SYSTEMS

A. Introduction

This chapter presents an initial exploration of the extent to which the growing presence of solar energy systems on household rooftops is re-shaping the dynamics of housing markets and real estate transactions and the processes through which this reconfiguration is happening. Specifically, the chapter presents three analytical contributions: the development of a conceptual socio-technical systems dynamics model of real estate transactions and how solar alters those dynamics; the results of a survey conducted with home buyers who purchased a “solar home” with a rooftop solar system already installed; and a statistical analysis of how solar financing models impact different facets of real estate transactions, including home prices. The chapter situates the dynamics of household decision making about solar PV within the larger context of the real estate market as affected by various trade groups, including realtors, real estate housing assessors, and home purchase financing institutions.

In the United States, by 2020, more than 2.5 million total houses had rooftop solar on them, amounting to 1.8% of the national total of houses. (US Census Bureau, 2021) (US Energy Information Administration, 2021) In some areas, however, the fraction of solar homes is significantly higher. As we showed in the previous chapter, for example, in some parts of Maricopa County, AZ, the ratio of owner-occupied houses with solar on them has risen to higher than 50%. As a result of these trends, “solar homes” are a growing portion of the overall housing market, and this portion can be expected to continue to grow in the future. Hence, it is important to better understand how the presence of solar impacts decision-making about the sale and purchase of homes and the relatively complex market, administrative, financial, and legal processes through which home sales occur.

The existing literature on the impact of solar systems on the housing market is not extensive but has explored several different dimensions. Some of the earlier studies of solar energy in the housing market focused on environmental attitudes among home buyers. This work showed that, while early adopters of the technology were keen on the positive perceived environmental impacts of solar, financial and economic considerations were still significant barriers to adoption (Faiers & Neame, 2006) (Wüstenhagen et al., 2007). The Faiers study was conducted in the UK just as utility regulators in the US began to adopt renewable energy standards to promote solar adoption in the US.

Following on this initial work, Hoen and Dastrup examined the price premiums commanded in the marketplace for homes with existing solar PV installations from 2003-2010. They found that solar added about 3%-4% to the value of most homes and up to 7% for homes in markets without any other solar installations on their block. Like other US solar adoption research prior to 2014, they focused on California. This is likely because California had more solar installations than any other single state, and it also had a robust solar data set to draw upon. (Dastrup et al., 2012) (Hoen et al., 2015) (Gaur & Lang, 2020) Arizona, by contrast, was largely missing from these studies until 2016 when Adomatis and Hoen used a hedonic regression model to address the challenges that solar homes pose to real estate appraisers and the market in general. They included Arizona in their six-state study *Selling Into the Sun* (Adomatis & Hoen, 2016) in which they conducted an analysis to determine price premiums for solar homes across a multi-state dataset. While far more complicated than a paired-home methodology, their hedonic model is quite robust. That said, while the hedonic regression model has proven accurate in comparison to other methodologies and actual sales, it is also a methodology which is somewhat difficult to learn and perform for average real estate assessors, and thus not as commonly used by most assessors who traditionally rely on a paired-home model to compare similar homes and produce a valuation. However, especially in the early years, with only a small percentage of homes having solar installed on them, the paired analysis did not work very well. This gap in research and applied best practices led to the search for more viable methodologies to assess and value solar homes.

Separately, researchers pursued the question of how financing models in the rooftop solar industry were shifting, which could have significant implications for home sales. Virtually all early rooftop solar systems were owned by the homeowner, which meant that they were an asset in the sale that also transferred ownership. By the mid-2010s, however, third-party ownership (TPO) solar financing was rapidly emerging in the solar market (as we observed in Chapter 1 for Phoenix), and its implications garnered attention from researchers and regulators alike. Kollins et al presented the main legislative and regulatory challenges associated with the TPO model that were present in 2010. (Kollins et al., 2010) For instance, under some states' utility regulations, TPOs would have fallen within the definitions of electric utilities and service providers, which would have required them to be regulated in similar ways as utilities. Another issue was whether TPOs could utilize net metering which was a big incentive and a keystone to this financing model. Since then, many states have passed TPO-friendly regulations and made determinations that enable customers to take advantage of third-party solar leases and for developers to operate without the same regulatory oversight as traditional electric utilities. As we saw in Chapter 1, this led both to significantly more rapid growth in solar rooftop adoption and, also, to solar becoming more broadly distributed across homes of all value, rather than concentrated solely on higher-value houses.

A more recent study conducted interviews in 2014 to examine consumers' stated preferences and attitudes toward solar, including assessing whether changing ownership models impacted those preferences. They found that home buyer preferences varied depending upon the form of solar financing used by the homeowner selling the home: namely whether the system was owned outright by the homeowner or had been obtained through a third-party ownership model (Pless et al., 2020). Specifically, they found that the TPO solar homeowners sought out more information on in things like risks associated with installing solar and operations and maintenance issues. Alternatively, the owned-solar homeowners were primarily interested in financial returns. This body of literature demonstrates that solar financing models matter significantly in home sales outcomes, but it did not address even newer financing approaches, such as pre-paid leasing.

Building on that literature, this chapter explores three important questions about solar energy in the housing market. First, I build a conceptual systems model of the complex ways that the presence of a solar energy system on a house plays into the decision-making of different actors who participate in that market, including buyers, sellers, real estate agents, appraisers, and financers. Buying and selling a home is a complex process, and solar enters into and interacts within this system in a number of different ways. Understanding how solar impacts the real estate market thus requires a deeper analysis of these dynamics. I present my model in the first section that describes the complex process of buying and selling homes and how solar impacts it.

Second, I build on the studies reviewed above to develop new insights into the decision-making of buyers, who occupy a central place in real estate transactions and whose choices impact the value of solar in housing market transactions. To develop a richer understanding of their choices, including how they understood their purchase and whether or not their decisions were impacted by different forms of rooftop solar ownership and financing, I conducted a survey of recent solar home buyers from January, 2014 through July, 2015 in Maricopa County, Arizona. I present a summary of the survey results, in terms of descriptive statistics, in the second section. A primary goal of the survey was to determine which of three solar financing arrangements was in place for the home each buyer purchased at the time the homes were sold. These arrangements included solar leases with “payments” remaining at the time of sale, “prepaid” solar leases, and “owned” solar PV systems. Housing practices and standards are constantly evolving as both governmental bodies and trade organizations build capacity within their networks to accommodate green technologies such as solar PV. The survey data and responses also show that solar homeowners care about other issues such as home energy storage. This is particularly notable in respondents’ expressed price sensitivity toward utility rate schemes and their perceptions of demand-side management.

Finally, building on the survey results, I used MLS data to quantify the impact of different ownership and financing models on home sales price, which I present in the third section. Research has shown that solar homes command a higher value in the real estate marketplace than comparable non-solar homes (Dastrup et al., 2012) and even homes with leased solar third-party ownership (TPO) also hold their price premiums over non-solar homes, though at a smaller premium (Hoen et al., 2017). However, in their 2017 study *Leasing into the Sun*, Hoen et al were unable to find statistically significant correlations between pre-paid solar lease financing and other kinds of solar financing within their sample (years 2011-2013), partially due to an insufficient sample size. By contrast, our study was conducted later (years 2014-2015) and has a sufficiently larger sample size, thus giving us the ability to produce statistically significant results comparing pre-paid solar lease financing to other solar financing models, albeit using a different statistical analysis (ANOVA). Also note that our study was conducted in 2015, two years before Hoen et al published their report, so we were conducting our studies in in the same time frame, albeit with different data sets. (Hoen et al., 2017)

B. Modeling the Solar Home Sales Process

When purchasing a home that already has solar PV pre-installed, there are many moving parts that make up the system dynamics involved (see the systems dynamics diagram in Figure 2.1 for the main dimensions and factors that affect the buyers and sellers' choices surrounding solar homes within the real estate market). The systems dynamics chart uses a network model with different kinds of nodes and arrows to represent different kinds of interactions between actors and institutions in this market. At the very center of this model is the blue box representing the experiences of individuals within the real estate market, who include home owners, buyers, and sellers. Surrounding this box are all the other nodes which influence those experiences visa vis residential solar. The experiences of these individuals produce information which flows outward to the other nodes within this system (blue arrows) and are affected by information from the other nodes as well (red and purple arrows). The red circles to the right represent realtors and housing assessors.

These accredited professionals are critical to the valuation, marketing, financing, and shepherding of solar homes through the real estate market. They also operate within the boundaries of professional organizations and are subject to various rules and regulations to maintain their licenses and accreditations. The stories and experiences of the realtors and assessors (red arrows) flow out to their professional organizations who, in turn, provide best practices, guides, rules and regulations for them to follow. By contrast, social networks and media create a different set of interactions. The experiences of individuals in the real estate market flow through these green nodes and they produce and circulate a variety of stories about what solar means for buyers and sellers (green arrows). Those stories flow into the purple node where homeowners make decisions about what kind of solar financing model to use when adopting solar. Their homes are now transformed into a different entity and become solar homes. Their experiences then cycle back through the network and affect potential buyers of solar homes (purple arrow). When solar homeowners and potential buyers begin the process of working together, their experiences are situated within this larger systems network.

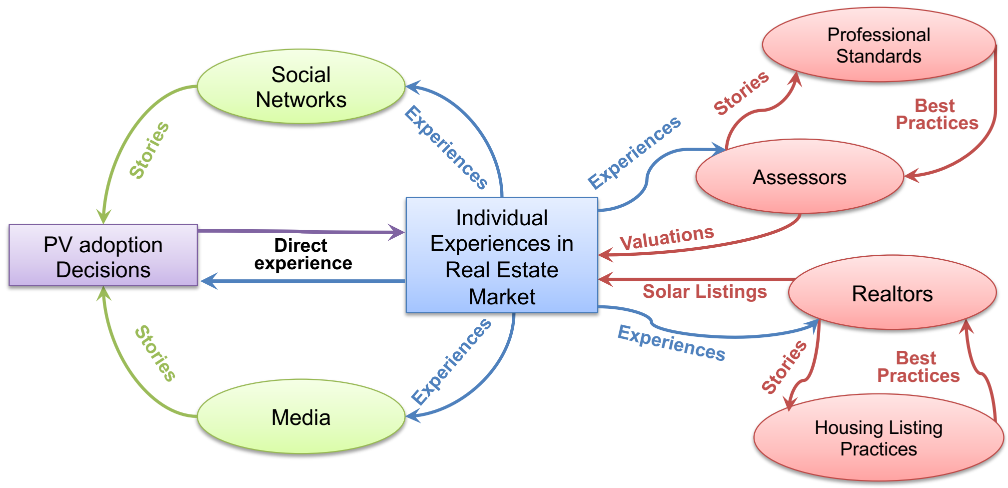


Figure 2.1 – System dynamics of solar housing in the real estate market

During the early stages of solar PV adoption in Arizona, as defined in the previous chapter, consumers had limited financing choices if they wanted to adopt residential rooftop solar PV. As third party owned (TPO) solar lease financing arrangements became plausible and more widely adopted, people began to experience some unique challenges when they attempted to buy or sell a solar home. (Wade, 2014) If the solar installation was owned by the homeowner, then it appeared as an asset on the balance sheets. If the solar installation was leased with remaining payments to a third party, then it could be listed as a liability, depending upon the appraisal policies in place at the time and as set by the home loan lender. (Adomatis & Hoen, 2016) This was often true regardless of the fact that solar was a physical upgrade to the property in the same way that a pool or an upgraded kitchen might be viewed as an upgrade. The Federal Housing administration (FHA) was still issuing guidance to assessors that prohibited leased solar valuation, while the Veteran's Administration omitted solar valuation altogether. (U.S. Department of Housing and Urban Development, 2014) (U.S. Department of Veterans Affairs, 2008) While these policies have since been modified, they were the rules in place at the time of this study.

Thus, solar leasing arrangements had to be accounted for and resolved before the home could be sold. This sometimes resulted in questions about the buyer's credit or their desire to assume the lease payments, which sometimes resulted in delays or scuttling of the home deal altogether (and which, in turn, created stories that circulated through social media). Eventually, Solar City, one of the biggest solar leasing installers, agreed that if a consumer could qualify for a home loan, then they would allow them to automatically qualify to take over the leases. (*Selling or Buying a Home with Solar Panels | SolarCity*, 2017) Still, it did not quell public perception that solar leasing was risky when it came to the future sale of a solar home. (Brady, 2014)

Issues such as these prompted questions about other types of solar financing arrangements and how they were treated in the housing market. The main alternative to leasing or owning solar PV is the pre-paid leasing arrangement. Under these arrangements, solar homeowners would pay off the remaining lease payments in full, either using cash or obtaining a loan to do so, thus transforming a potential liability into a solid asset. This still allowed the solar homeowners the benefit of operations and maintenance risk abatement inherent in solar leasing (and also the potential cost reductions for installing solar achievable via the TPO model due to the lower cost financing and tax incentives available to the TPO entity) while reducing some of the transactional risk of solar leasing when it came time to sell their home.

Yet, there was still some uncertainty about how these pre-paid leasing arrangements would hold their value in the housing market compared to owned or leased systems. Realtors did have some access to listings of solar home transactions during that time through the Arizona Regional Multiple Listing Service (ARMLS) system, including both leased and owned systems. However, realtors in Arizona had only recently adopted the use of solar PV fields in the ARMLS and their use was spotty, as they were optional prior to 2015. It had been shown that solar PV systems held their value in the real estate market (Hoen et al., 2015), but the value of pre-paid lease arrangements remained unverified in the literature at that time.

C. A Survey of Buyers Who Purchased Solar Homes

Combined with ongoing public uncertainty about solar leasing, these factors comprised the main motivation for conducting our survey of home buyers who had purchased a home with solar already installed. (O'Leary, 2017) The survey was conducted in 2015 and mailed to 1418 recent solar home buyers who purchased their homes between January 2014 and July 2015. This resulted in 280 valid responses. For the complete set of survey questions and more explanatory information, see the Appendix.

1. Results of the Survey: Solar Financing

When people purchase solar PV for their residential homes, they have several financing options. They could purchase the solar outright (owned), lease it through a third-party owned company (TPO), or even buy out their lease through a pre-paid option. Each one of these financing options has up sides and down sides. Owned systems have the advantage of becoming an asset when viewed as part of the house, just a pool or a kitchen upgrade might. It directly affects the value of the home for potential buyers. However, the downside is that the homeowner must come up with the funding themselves and they are also responsible for the cost of maintenance and repairs.

Leased solar financing options have the advantage of little to no-money down up front and the TPO solar leasing company bears the responsibility for maintenance and repairs. However, solar leases must be transferred to new homeowners when the home is sold, and this has caused complications in the past. The solar leasing option has also been problematic for housing assessors who are bound by the rules of the lender used by potential buyers. Such rules took years to update and during this study period they were still in flux, depending on the lender.

Many solar homeowners opted to purchase the lease in a prepaid arrangement to avoid some of the potential problems upon sale of the home. The disadvantage is that they need to finance the cost of the entire solar lease up front, which is often done through a separate loan product. But the advantage is that prepaid solar leases may be treated differently by assessors and lenders. The idea is that prepaid leases would show up in the asset column on an assessment, while leases that need to be transferred may show up as a financial liability that the new homeowner would have to take on themselves.

The results of the survey showed that 54% of homes in this study were leases of some kind (n=151), while 45.7% were owned (n=128) and one data point was missing this information (n=1).

2. Results of the Survey: Home Financing

There are four main kinds of home loans present in the results of this survey. Those are: Conventional, Cash, Federal Housing Administration (FHA), and Veterans Administration (VA). The dynamics in the home financing market also include home loan institutions, real estate assessors, and realtors. Assessors are constrained in the ability to properly assess the value of solar homes by their ability to assess solar PV installations on those homes. (U.S. Department of Housing and Urban Development, 2014) (U.S. Department of Veterans Affairs, 2008) This is based in part on the kind of solar financing arrangements that are in place. See Table 2.1 for a typology. The assemblage of solar PV technologies installed on the home and the legacy of its originating solar financing structure is what makes such ontological objects "solar homes". In turn, realtors need good data in order to inform their clients about the risks and rewards inherent in particular solar housing assemblages. Traditionally, if the solar installation is owned outright, then it shows up as an asset in the assessment. If the solar is leased, then it shows up as neutral or even as a liability, as explained in the previous section. So, to help construct our data set, we included housing financing as one of the questions on the solar housing survey. See table 2.2 for the distribution of home loan types among survey respondents. It does appear that homes purchased with conventional and cash loans tended to have owned solar financing while those purchased with FHA and VA loans were more likely to have leased solar financing. See methods and results sections below for more details.

Home loans	Guidelines for valuing solar PV

Cash	No restrictions
Conventional	No restrictions
FHA	Prohibits leased solar PV valuation
VA	Omits solar PV valuation

Table 2.1: Home Loan Typology characterizing rules for valuation of solar PV during the timetable of this study, 2014-2015. Sources: FHA Handbook 4000-1 (2014) and VA Pamphlet 26-7 (2008).

Home Loan type	**n**	**%**
a) Conventional	137	48.93
b) FHA	33	11.79
c) VA	32	11.43
d) Cash	74	26.43
e) Other	4	1.43

Table 2.2: Home loan types and distribution for survey respondents.

3. Results of the Survey: Matrix of Attitudes and Beliefs Toward Solar

The survey presented respondents with a matrix of 10 questions that asked the respondents how various factors related to the solar installation influenced their decision to purchase the property. These questions dealt with the categories of environmental concerns, economic factors, social network effects, maintenance and repair, and going off-grid. A summary of the responses is presented in Table 2.3. Overall, the respondents viewed the environmental factors positively, the economic factors moderately positively, the social networking factor neutrally, and the off-grid independence factor neutrally. It is notable that the maintenance and costs factor received the most negative responses, and this may be partially explained by the difference between owned and leased solar.

To explore the differences between responses from those with owned and leased solar, I used a Chi-Square test of independence to measure differences between solar ownership and these 10 variables. When comparing the results of owned solar to leased solar, only two questions showed statistically significant differences in observed frequency from those expected, given the number of respondents in each category. The first was the question dealing with maintenance and repair. This showed that a slightly higher number of leased solar homeowners considered this factor more highly and more positively than those with owned solar (p=.031). This result is consistent with the literature (Pless et al., 2020) in which people who had leased solar were more interested in finding information about maintenance and repair than those who owned their solar outright. The next was the question about whether solar added value to the home. This question showed a large difference (p=<.001) for the owned solar respondents who considered this factor more highly and more positively than the leased solar respondents. This makes sense, since the owned solar group would be responsible for the costs of maintenance and repair, while the leased solar group would not be directly responsible for these costs.

Question	Very negative	Somewhat negative	Neutral	Somewhat positive	Very positive
Q10_1 Good for the environment	1	1	67	86	125
Q10_2 Concerned about climate change	6	2	132	70	70
Q10_3 Cleaner energy	2	1	54	96	127
Q10_4 Lower electricity bills	2	0	15	37	226
Q10_5 Earn extra money from net-metering	2	3	153	64	58
Q10_6 Planning to rent the property	20	3	246	7	4
Q10_7 Someone I know had solar	8	3	213	34	22

Q10_8 Maintenance and repair costs	7	38	180	32	23
Q10_9 Adds value to the home	5	8	71	115	81
Q10_10 Would like to go off-grid	7	4	187	47	35

Table 2.3 Detailed distributions of responses for Matrix of attitudes and beliefs toward solar when considering the purchase of their solar home.

Question	Somewhat or very Negative	Neutral	Somewhat or very Positive
Q10_1	2	67	211
Q10_2	8	132	140
Q10_3	3	54	223
Q10_4	2	15	263
Q10_5	5	153	122
Q10_6	23	246	11
Q10_7	11	213	56
Q10_8	45	180	55
Q10_9	13	71	196
Q10_10	11	187	82

Table 2.4 Simplified distributions of responses for Matrix of attitudes and beliefs toward solar when considering the purchase of their solar home.

4. Results of the Survey: Solar Storage

We also asked respondents about their potential interest in adding battery storage to their solar system. The main finding here is that a plurality (36.43%) of the respondents had never heard of solar battery storage when they answered this survey. 23.2% of them were either somewhat or very familiar with solar battery storage, while another 34.65% were only a little or vaguely familiar with this technology. Around 53% said it would have had no influence on their decision to purchase a solar home, while 40% said they would be more likely to buy and just 2% said they would be less likely to do so.

Question variable	N	%
a) Very familiar	15	5.36
b) Somewhat familiar	50	17.86
c) A Little familiar	40	14.29
d) Vaguely familiar	57	20.36
e) Never heard of it	102	36.43
Missing	16	5.71

Table 2.5 Respondents familiarity with solar battery storage technology

One interesting finding is that, among those respondents who answered this question, women seemed showed a preference for utilizing the solar battery storage systems for backup power rather than for the economic incentives of cycling through and net metering the power.

Note that one of these solar battery storage questions was invalidated due to many improperly recorded answers by the respondents (rank choice) but the other questions are still valid.

5. Results of the Survey: Demographics

The demographics questions covered gender, age, income, race/ethnicity, and education. The majority of respondents were well-educated white men with household incomes over $100,000 and a median age of 55. See table 2.3 in the appendix for the distribution of these variables.

6. Results of the Survey: Open-Ended Questions

At the end of the survey, I also included two qualitative questions with space for respondents to write in about their own experiences. The two questions were:

Q11: Has the Solar PV arrangement lived up to expectations before purchasing this home? Why or why not?

Q12: Please tell us anything else you would like to share about your experience purchasing a solar home?

I performed a qualitative analysis of these questions to determine what the respondents thought of the process. While they only occasionally referenced the process of purchasing their solar home, they did talk a great deal about their overall experience with their solar home since moving in.

Generally, the responses were positive (n=169) though some were decidedly negative (n=34) and some were mixed (n=28). Still others were unsure (n=24), often because they had not been in the house for long enough to determine their savings. See table 2.6 for the breakdown of these impressions.

Impression	n	%
Positive	169	66.3%
Negative	34	13.3%
Mixed	28	11%
Unsure	24	9.4%
Total	255	100%

Table 2.6 Main themes in the qualitative responses to open-ended questions Q11 and Q12.

One of the biggest themes seemed to be a general and strong dissatisfaction with their solar leasing companies. This was not universal, but among those who were unhappy, it was very often because of poor communication or customer service from their solar leasing company or because they had poor access to information about the output and productivity of their solar installation. Others were unhappy due to economics of a bad deal on their lease. Still others were simply unhappy with politics and large government and how solar fit into that narrative. These examples below illustrate the main themes in these qualitative responses.

These respondents had issues with the appraisal of the solar home and essentially got their solar for free.

"Yes. In the 6 months we have lived in the house, it's estimated that the solar PV has saved us over $900.The sellers expected that the solar panels had a value that would be considered by the appraiser. They were not so the appraised value was less than the contract price. We required them to reduce the contract price to the appraised value."

This respondent particularly liked the prepaid lease and how it was built into their mortgage.

"Absolutely. Previous owners pre-paid 20 year of lease. Panels added to value of home. Decreased energy bill and renewable energy were large factors in purchase of this particular home. Was very easy as everything was built into mortgage. Did not cost us any additional money and has saved us thousands to where I have considered solar plus batteries."

This respondent was pleasantly surprised with how well solar was working for them.

"Yes, APS bill for 1500+ sq ft home has been just $22-28 during the Jun-Jul-Aug bills, so the solar is a bargain. Neighbors in similar homes are paying over $200/mo without solar. Solar was not something on my must-have list when looking for a home. It was more of a bonus that the home I chose happened to have solar. I would now definitely seek solar if I were ever to purchase a different home."

Some respondents had good experiences with their lease, but it appears they also tended to have good access to information and data about their solar installation.

"Yes. The system is meeting expectations with no issues in the past 1.5 years we have owned the home. Through APS the solar credits we earn each month allow us to run our AC at high peak hours with little effect on our bill or being charged at peak rates. I enjoy tracking our solar use through Solar City's website. Many complain that solar hurts re-sale value but we plan to stay in this house long term so it was of little concern. While I would rather own them, the up-front costs is pretty significant and I would rather have a company having to maintain them with no charge to me if something does go wrong..."

These respondents were uncomfortable with the degree of uncertainty in their prepaid lease. They have a perception of leases being negative for the resale value of their home, even though the lease was prepaid.

"This was a new home and the builder had already installed pre-paid 20-year lease solar system. I would prefer to have had a owned solar system... Concerns and difficulty with leases that are collecting monthly payments. These types of solar leases can create issues when selling a home. Another concern is when a prepaid lease is toward the end how is that going to affect the sale of a home. Concern is what are we going to do with outdated systems? How expensive and what kind or environmental issues will there be?"

Asymmetric information and reported bad customer service experiences play a big role in the qualitative comments of those who reported having a negative view of the solar aspect of their home and how it did or did not live up to their experiences.

"I have no data as to what my APS bill would be if I did not have solar. From talking to people, not convinced that solar lease is worth it, purchasing was not an option when I purchased the house 1.5 years ago. I have no data available, do not trust APS or the solar company."

By contrast, this respondent likes the ability to have easy access to information about their system.

"Yes, it is a nice benefit. Lowered electric bills by $100-$150 / month. The phone app is a very nice addition to the system. It also produces hot water and exchanges air if the outside temp is cooler than the house."

Even when the respondents had a good experience with solar overall, they still tended to dislike the solar leasing companies.

"We love having solar power, but we very much dislike the company the lease is through. We could not (and have not) confidently recommended leasing solar panels. Other than that, most everything has been great. We love having lower energy bills. We have an electric car that we charge at home and it doesn't cost anything. We purposely purchased electric appliances for our kitchen and laundry in order to maximize the use of our solar panels."

This respondent really likes the economic benefits of solar but is actually a climate change skeptic.

"Yes, the pre-paid lease has made this a good investment. We paid slightly more for the house. I look at it as mortgaging some of the energy cost. I doubt I would have leased it directly myself. The difference would have been negligible. The house was being sold for 20K higher, but it did not appraise. The price was lowered after it did not appraise. Solar as with pools are nice to have but do not raise the price anywhere near this investment. I do not put any weight on environmental concerns. I do not think humans are impacting climate change at the degree some would think."

D. Quantitative Analysis of Solar Market Data

1. Methodology

This section defines the methodology for the quantitative data analysis. The analysis combined key questions from the solar home survey described above in Section C with data from the Arizona Multiple Listing Service (MLS). We use zip-codes as a boundary unit because that is the level at which many key components are aggregated, including overall Solar PV installations from the electric utilities within Arizona. The geographic boundaries for this study include all the zip codes bounded by Maricopa County, Arizona. The sampled time period was 18 months between January, 2014 through July, 2015. There were 88,281 home sales within this time period and the geographic boundary of Maricopa County. The number of sales that included homes with pre-existing solar PV installations was 1,637. There were over 280 respondents to the survey. Some were excluded for various sampling errors or incomplete survey data, leaving 273 respondents.

All housing sales within the time period of January, 2014 through July, 2015. All housing sales within the zip codes within by Maricopa County, Arizona.

a. Definition of variables

- Solar Housing (SH) - houses with pre-existing solar PV installations at the time of sale
- Non-solar housing (NSH) - all other houses with no solar PV installations at the time of sale
- Solar Housing with solar owned outright (SHow)
- Solar Housing with lease payments (SHlp)
- Solar Housing with pre-paid leases (SHpp)

b. Solar financing

The primary question for the solar financing dimension is: How do solar PV installations with pre-paid leases (SHpp) compare to solar PV installations with leases that transfer payments to new owners (SHlp) and solar PV installations which are owned outright (SHow)? The null hypothesis states: There is no difference between pre-paid, leased payments, and owned systems. The alternative hypothesis states: Pre-paid systems perform similarly to owned systems and less like other leased systems.

c. Home financing

The primary question for the Housing financing dimension was: How are the four main home financing arrangements associated with different solar financing arrangements? The home financing variables are: Cash, Conventional, FHA, and VA. These being nominal variables, I used a Chi-test to determine the differences between expected distribution and the observed distribution on these variables. See the results section for more details.

d. Days on market (DOM)

Another question we explored was the timing of home sales: Do the leased and pre-paid solar PV installations delay closing time on real estate deals more than owned solar PV installations? To measure this, we examined the Days on Market (DOM) metric which shows how long houses were on the market from the time they were listed to the time they were sold. We determined early on that there were too many other confounding variables which affect DOM and thus make it an unreliable indicator when measuring solar PV financing. Two examples of this unreliability are: a) Houses often go on and off the market for seller's personal reasons. b) The DOM may be affected by other problems with the property including the lenders or the buyers. There is a good degree of variability in reasons for DOM changing which may have nothing to do with the solar financing.

2. Data Analysis

The dependent variable in this analysis is the housing price per square foot (PPsqFt) (Ratio data). The independent variable is Solar financing (Nominal data). I use an analysis of variance (ANOVA) to determine the difference between the following variables to determine whether prepaid solar leases behave similarly to owned solar financing, or if prepaid is more similar to regular leased payment solar financing. The analysis makes comparisons amongst all three variables concerning solar financing.

However, before this analysis could take place, we first need to account for variability in housing prices. I control for this by creating a ratio based on the price per square foot for both solar housing and non-solar housing, as a control. This is achieved through the following steps.

First, I calculate the median PPsqFt for all zip codes on all sales of all homes during that 18 month time period 2014-2015. Calculation: PPsqFt

Next, I designate the individual SH sales price per square foot as SHPPsqFt. Then I repeat this process using the median non-solar housing PPsqFt for all other non-solar home sales within each zip code to produce NSHPPsqft. NSH_Median_PPSqFt_byZip

Then I calculate the difference between SHPPsqFt vs. NSHPPsqft within each zip code. This is done by using the NSH median for each zip code (NSH_Median_PPSqFt_byZip) as the denominator and each individual sale's PPsqFt (SH_PPsqFt) as the numerator to create a ratio called: SHvNSH_Ratio_PPsqFt. This produces a ratio of individual SH data points vs NSH median for each zip code.

Important note: SHvNSH_Ratio_PPsqFt is one of the most important metrics in this chapter. By controlling for relative price within each zip code, this ratio normalizes the data so that we can now compare the solar housing data across all zip codes, regardless of how much median home prices differ between different zip codes.

Lastly, using the Intellectus statistics platform, I conducted an analysis of variance (ANOVA) to determine whether there were significant differences in SHvNSH_Ratio_PPsqFt by comparing leased, pre-paid, and owned solar installations. (*Intellectus Statistics [Online Computer Software]*, 2021)

These are the steps in this analysis:

- Compare Pre-paid to Leased payments (SHpp vs SHlp)
- Compare Pre-paid to Owned (SHpp vs SHow)
- Compare Leased payments to Owned (SHlp vs SHow)

3. Results and Discussion of Quantitative Analysis

a. Solar financing

The results from the ANOVA listed below represent a statistically significant finding, as predicted by my hypothesis. It shows that the pre-paid solar PV installations were indeed treated the same as owned solar PV installations in terms of price per square foot upon sale of the solar home. See figure 2.2, and tables 2.7 and 2.8 for details of the ANOVA. This data analysis shows that prepaid leases are treated nearly the same as owned systems in the real estate market in terms of price per square foot. These results are statistically significant with $p= <.001$.

The greater significance of this finding is that, despite anecdotes reported in media and spread through social networking, it appears that prepaid lease arrangements are a safe investment when it comes to the resale value of solar homes. While negative experiences do still exist and have been shown in the qualitative data from the solar housing survey in the previous section, the sales statistics appear to suggest that they do not outweigh the positive experiences and efficient sales of solar homes.

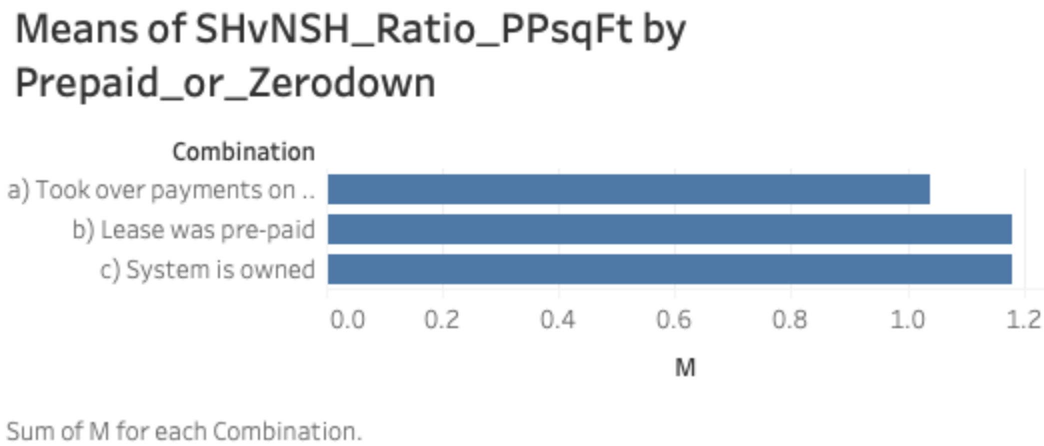


Figure 2.2 Results of the ANOVA analysis of solar financing categories

Combination	M	SD	n
a) Took over payments on the lease	1.04	0.19	94
b) Lease was pre-paid	1.18	0.27	54
c) System is owned	1.18	0.27	125

Table 2.7 Mean, Standard Deviation, and Sample Size of SHvNSH_Ratio_PPsqFt by Q6_Prepaid_or_Zerodown

Term	SS	df	F	p	ηp2
Prepaid_or_Zerodown	1.14	2	9.40	< .001	0.07
Residuals	16.36	270			

Table 2.8 Analysis of Variance (ANOVA) for SHvNSH_Ratio_PPsqFt by Q6_Prepaid_or_Zerodown showing Sum of Squares, degrees of freedom, F-ratio, p-value, and partial Eta-squared

b. Home financing

Using a Chi-square test, which yielded statistically valid results (p=.006), I determined that homes purchased with conventional and cash loans tended to have owned solar financing while those purchased with FHA and VA loans were more likely to have leased solar financing. This suggests that there is a connection between the type of home loan used and the type of solar financing.

Home Loan type	a) Leased solar	b) Owned solar	$\chi 2$	df	p
d) Cash	33[39.51]	40[33.49]	14.48	4	0.006
a) Conventional	72[74.15]	65[62.85]			
b) FHA	23[17.86]	10[15.14]			
c) VA	23[17.32]	9[14.68]			
e) Other	0[2.16]	4[1.84]			

Table 2.9 Results from the Chi-squared test showing the type of home loan vs leased and owned solar loans. The values in the leased and owned solar columns are the observed and [expected] frequencies. The other values are Chi-squared, degrees of freedom, and the p-value.

E. Conclusion

In the past, some solar home sales suffered in the real estate marketplace due to assessments that did not – indeed were not permitted to – account for the full value of leased solar PV or sometimes even owned solar PV systems. We have learned that while buying and selling solar homes is more complicated than non-solar homes in the real estate markets of Maricopa County, AZ, there are identifiable nodes within the system and factors that often influence these sales. Home loan lenders dictate terms, assessors integrate those terms into their calculations, realtors identify and market solar homes within their modified MLS database, and buyers and sellers negotiate a real estate market sometimes fraught with difficulties. However, through adjustments to real estate best practices, updated and disseminated professional standards for assessors using different assessment methods for solar PV that integrate updated standards from major housing lenders, solar home sales have become easier and more reliable over time. This has allowed people to adopt solar through an assemblage of home financing and solar financing combined. That said, when people move into homes where solar already exists, and when the solar system was obtained via a TPO solar financing model, they are still in a relationship with the solar company that owns and maintains the leased solar on their rooftops. The degree to which the solar system was properly sized, expectations managed, and customer service adequately performed goes a long way toward influencing people's attitudes toward their solar homes. Future research could focus on obtaining better data about prepaid solar financing as well as running robust housing assessments through hedonic modeling. Better data combined with better analytical tools could yield even more useful results.

CHAPTER 3

REORIENTING FROM SHAREHOLDERS TO STAKEHOLDERS: RENEWABLE PORTFOLIO STANDARDS AND SUSTAINABILITY REPORTING FOR RENEWABLE ENERGY

Introduction

100% carbon neutrality by 2050 is rapidly becoming a widely adopted target within the electricity industry, with some measures showing a large majority of US electric utilities and electricity customers now covered by such a commitment. Arizona's largest electric utility, for example, APS, recently set a voluntary commitment to achieve 100% carbon neutrality on its generation fleet by 2050, while SRP has established a target of reducing the carbon emissions intensity of their generation fleet by 90% on the same timetable. Given the rapid upswing in the number of utilities making such commitments, one of the biggest current questions in US energy transition policy is whether or not electric utilities setting such targets can be trusted to achieve those goals, operating under the oversight of shareholders and stakeholders, or whether state or national regulators should mandate the achievement of these goals through some sort of new renewable portfolio standard. While this chapter does not provide a definitive or comprehensive answer to that question, it does seek to inform it by exploring the extent to which the robustness of utility sustainability practices correlates with progress toward climate action. Specifically, the chapter develops independent measures of the robustness of utilities' sustainability reporting efforts and the adoption of rooftop solar PV within their territories—and the chapter finds that these measures are correlated, illustrating that those companies that adopt more rigorous internal sustainability processes and practices, including more ambitious stakeholder engagement and materiality assessment initiatives, are also the companies that see (and perhaps facilitate) greater adoption of rooftop solar PV.

The broader context for this study is the generally heterogenous and haphazard adoption of renewable energy policies and standards by regulators in the United States, including both the absence of national renewable energy adoption targets and highly variable state renewable portfolio standards (RPS) and policies to facilitate distributed solar adoption. (Carley & Miller, 2012) This problem is compounded by the current weakening of state RPS standards, which historically played a key governance role during the early days in driving renewable energy (RE) adoption, but which are increasingly being allowed to lapse or being weakened by regulators for a wide variety of reasons (Barbose, 2021), at just the moment where citizen demand for strong climate action is ramping up significantly in the US.

In this context, the rise of environmental, social, and governance (ESG) standards and corporate social responsibility (CSR) in industry is being offered by many as an alternative governance mechanism that might serve to help continue to drive progress on strong climate action. I undertook this study to conduct an initial simple empirical test of the impact of ESG and CSR governance approaches on concrete sustainability outcomes. In particular, the study examined whether more robust forms of sustainability reporting, as a practice, signaled greater movement toward the adoption of renewable energy technologies. Several factors influenced my choice, including the fact that sustainability reporting has recently become much more prevalent in the electric utility industry, that there are very different levels of commitment to it among utilities, and that the more robust forms of CSR reporting include holistic, stakeholder-focused approaches to corporate governance here in the United States, compared to the business-as-usual shareholder-focused approaches so common during the past 30-40 years. Similarly, I chose solar photovoltaic (PV) technologies as a focus because, as a very visible, local, and tangible manifestation of renewable energy solutions, solar PV potentially taps into public sentiments in favor of RE in ways that large, distant wind power projects, for example, do not. In other words, rooftop solar PV adoption is a very local, tangible move towards carbon neutrality that local stakeholders give high preference to as a signal of utility friendliness toward strong climate action. Finally, I chose to focus on investor-owned utilities (IOUs) because these are some of the largest corporations and electricity service providers in the country, serving the vast majority of households and energy users. While most IOUs are highly regulated monopolies, they also cross state boundaries and are therefore subject to heterogenous regulations, even within the same region.

Motivation

Research reported in this paper is motivated by a general shift in the renewable energy governance landscape for investor-owned electric utilities. This shift is epitomized by a general decline in the use of RPS policies at the same time that we see a rapid rise in voluntary adoption of carbon neutrality targets by companies, as well as perhaps early signs of a shift in electric utility governance from primarily an investor or shareholder orientation to more of a stakeholder orientation. This last has been driven by broader trends in US industry, especially in the financial sector, where, overall, many investors are now adopting much more rigorous ESG commitments and standards, including increasing citizen calls for greater transparency, corporate accountability to the environment, and attention to social justice issues.

One prime example of this trend is BlackRock, Inc., the world's largest investment manager. For the past several years, BlackRock's CEO Larry Fink has released consistent statements in his annual letter to investors that advocate strongly for corporate sustainability and push companies within their portfolio to do more on this front. Indeed, in January 2020, Fink went so far as to argue that “the transition to a low-carbon economy,” is now “the center of our investment approach … Sustainability is driving a profound reassessment of risk and asset values … In the near future, sooner than most anticipate, there will be a significant reallocation of capital. As a fiduciary, our responsibility is to help our clients navigate this transition.”

The question that I pose in this chapter is whether these trends in corporate governance correspond, in any meaningful way, with rooftop solar adoption. To do this, I propose new methods and metrics for measuring and understanding potentially relevant changes in renewable energy adoption and for measuring success in adopting renewable energy technologies and strategies. While in the past scholars have used RPS rules as an indicator of policies driving solar adoption among electric utilities, and therefore a measure of progress toward decarbonization, it appears that RPS standards are increasingly less viable as a metric for solar adoption. This is not to say that RPS policies have not had value as a policy tool, nor that they might not again in the future, but just specifically that their usefulness as a measure of solar adoption by utilities has become very limited, at this time. (Barbose, 2021) Additionally, it is unlikely that they would capture or explain any changes that would result from companies' shift to more of a stakeholder orientation or adoption of strong internal ESG standards and practices. Instead, I propose to explore whether the CSR reporting produced by electric utility corporations correlates to measurable sustainability outcomes, e.g., increased solar PV adoption.

Measuring the Robustness of CSR Reporting Practices

The choice to focus on CSR reporting was motivated by two key ideas. First, CSR reporting is a public and visible activity of the company whose robustness can be measured through the choices the company makes about what to include and how to conduct its reporting exercises. My approach is underpinned by a model that suggests that the most important element of a robust CSR or ESG effort is the shift from a shareholder orientation to a stakeholder orientation. This can be classified by a progression through stakeholder theory and measured by assessing the nature and quality of sustainability reporting that companies produce. For example, GRI and other sustainability reporting standards recommend or require a materiality assessment as evidence of good faith and demonstration of action on the front of identifying, prioritizing, and engaging with stakeholders. (Manetti, 2011)

Other scholars have used Maturity Modeling to track companies' progression through various levels of effectively integrating stakeholder engagement into corporate governance. (Silvius, 2015) (Baumgartner & Ebner, 2010) (Machado et al., 2017) The scale runs from low to high integration with milestones along the way. Low integration includes tactics such as using sustainability reporting as a marketing tool or a tool for managing stakeholders, without giving them meaningful opportunities to provide input to or oversight of corporate decisions. High integration includes stakeholders having far more agency in the operations and decision-making processes that affect the company's work as well as its impacts in society or on the environment.

The ultimate goal is for CSR reporting to be developed into more of a holistic approach, which is internalized within corporate decision-making, rather than simply compliance with prescribed reporting requirements imposed by regulatory bodies. Organizations are often required by governmental institutions to disclose certain sustainability-related impacts and risks that companies do by producing official reports and filings such as annual reports or disclosures to shareholders. For example, a call for disclosure and reporting could come from the United States Securities and Exchange Commission (*Public Utility Holding Company Act of 1935: 1935-1992*, n.d.) or it might come from activist investor groups who have a stake in the company. They may also voluntarily decide to disclose, for instance by engaging in the process of sustainability reporting. (*TITLE 6 - CHAPTER 50E. Certification of Adoption of Transparency and Sustainability Standards by Delaware Business Entities*, n.d.)

CSR is thus a set of practices intended to measure corporate performance on key Environmental Social and Governance (ESG) indicators and then communicate the resulting information to shareholders and stakeholders through periodic CSR reports or sustainability reports as a tool for holding companies accountable to meeting their targets. (*GRI Standards English Language*, n.d.) While such reporting is legally required in some countries, and while reporting standards have been institutionalized, these standards are numerous and diverse. (Van der Lugt et al., 2020) The practice of selecting from and following them remains largely voluntary and unregulated within the US (see methods for a more detailed account of variations in quality of CSR reporting).

Methodology

This study conducts a correlation analysis between two variables: a metric of the robustness of CSR or ESG reporting by an electric utility and a metric of distributed (rooftop) solar adoption within its territory. I describe each metric below.

Sample Selection: Electric Utilities

I have chosen to look at investor-owned electric utilities (IOUs) within the Western Electricity Coordinating Council (WECC) region within the United States for several reasons. First, there are several different kinds of utility ownership including municipal, political subdivision, and co-operatives, to name a few. Further, a low number of large, investor-owned utilities (IOUs) serve more residential customers nationwide than the many smaller, non-investor-owned utilities. This is due in part to economies of scale and path dependence. Lastly, the utilities located within the western states carry some similar geospatial and demographic characteristics, especially within each of the three sub-regions (southwest, northwest, and California). As such, this study examines the robustness and comprehensive qualities of CSR reporting within the IOU sector, rather than the particular results that they disclose within those reports.

There are many different types of ownership models for electric utilities in the United States, including cooperatives, investor-owned, municipal, and political subdivisions, just to name a few. Nationally, Investor-owned Utilities (IOUs) account for only 9% of the total number of utilities, yet they serve 67% of residential customers nationwide, compared to non-IOUs. Within the western region of the U.S., this trend is even more pronounced, as IOUs still represent only 9% of all electric utilities in this region, yet they serve 71% of all residential customers. IOUs have had the lion's share of utility customers for over one hundred years, in part because of their economy of scale and in part because of their regulated monopoly status wherein customers are assigned to the utilities based on geographic territories.

The sample used in this study consists of all IOUs within the Western Electricity Coordinating Council (WECC) and within the United States, excluding Canada and Mexico. WECC is one of eight regional entities managed by the North American Electric Reliability Corporation (NERC), which exists to help maintain reliability across the entire continental grid. While the WECC region does include some parts of Canadian and Mexico, we have excluded both in order to focus on the United States where utilities are regulated by geographically smaller statewide public utility commissions. This distinction controls for the geographic and institutional frameworks that are seen in the US, such as state-level public utility commissions, which institute renewable portfolio standards.

We have also selected the WECC IOUs because of the nature of issues that western utilities face as compared to those within states in central and eastern U.S. Specifically, patterns such as recently seen in California typify challenges of some utilities: Extreme drought, forest fires, flooding when the rains do return, and landslides. These issues are relevant for utilities in nearly all of the western states, but especially in California, where a combination of these events has led to interruptions in service and actual financial liability for the utilities in that state. The stock price of Pacific Gas and Electric (PGE) initially dropped by nearly half in the quarter during which the above events occurred and the company has since gone through bankruptcy proceedings as a result of this liability.

Solar Ratios

In order to measure the amount of solar and distributed generation (DG) resources that each utility has adopted, I've created four ratios, which use the number of residential customers within each utility's service territory to control for population. These ratios are drawn from categories in the 2016 U.S. Energy Information Administration (EIA) form 861 Net Metering data and are listed as follows:

- Solar PV Total ratio;
- Solar PV Residential ratio;
- DG All Capacity Customer Ratio;
- DG All Residential Capacity Customer Ratio

Ratio 1 accounts for all solar generation sources from all sectors, including residential, commercial, and utility scale. Ratio 1a accounts for just residential scale solar sources. Ratio 2 accounts for all DG sources (including solar PV) from all sectors, including residential, commercial, and utility scale. Ratio 2a accounts for just residential forms of DG sources (including solar PV). The calculations are listed below:

- Solar Total Ratio: (PV_Capacity_MW_Total / Total_RESIDENTIAL_Customers) * 1000000 = watts of solar PV per customer
- Solar Residential Ratio: (PV_Capacity_MW_Residential / Total_RESIDENTIAL_Customers) * 1000000 = watts of residential solar PV per customer
- DG_All_Capacity_Customer_Ratio: (All_Capacity_MW_Total / Total_RESIDENTIAL_Customers) * 1000000 = watts of DG per customer
- DG_All_Residential_Capacity_Customer_Ratio: (All_Capacity_MW_Residential / Total_RESIDENTIAL_Customers) * 1000000 = watts of residential DG per customer

The reason for including a DG ratio in this analysis is that some geographic regions may have less solar resources (solar insolation) available to draw from, but more wind and hydroelectric resources naturally available. While wind and hydroelectric generation is largely utility-scale, it may also be deployed at smaller scales as well. Thus, while solar may not be an ideal indicator to compare all utilities within diverse geographies and local climate conditions, the designation of distributed generation does encapsulate the ideals of decentralization and resilience which are important to sustainable power systems.

I use residential customers as a constant in order to control for the size of the companies in a fairly standard way. For instance, Tucson Electric Power (TEP) has less than 400,000 residential customers, while Pacific Gas and Electric (PG&E) has over 4 million. Even though TEP may have stronger solar resources within its territory than a typical PG&E sample, PG&E may also have higher gross levels of solar PV overall because they have so many customers. Thus, the ratio exists to give a better relative indication of how much solar is within each utility's territory when controlling for population size within said territories.

Sustainability Reporting Scores

I then used various components of utility sustainability reporting and corporate governance to create my own CSR reporting score. I've created two relevant categories in this study for independent variables and they are called "Governmental" and "Marketplace". Each of these categories has representative tools for the governance of solar PV and other emerging distributed generation technologies. The governmental category includes interventions and regulations by state public utility commissions (PUC) such as renewable portfolio standards (RPS). The marketplace category includes an instrument for evaluating the quality of CSR/ corporate sustainability reports.

I used a distilled set of components of CSR reporting and corporate governance to create a CSR reporting score to evaluate the basic quality of CSR and sustainability reports without using the many dozens of components that other organizations use to evaluate corporate compliance to sustainability standards. These components are drawn from the publicly available methodologies of RobecoSAM and the Global Reporting Initiative (GRI). (*CSA Methodology | S&P Global*, n.d.) (*GRI Standards English Language*, n.d.) Now part of the S&P Dow Jones Indices, RobecoSAM created their own comprehensive sustainability and corporate responsibility indexes. This includes the Down Jones Sustainability Index (DJSI), which is one of the most well-known. However, the DJSI scores, for instance, are proprietary and only available to those who purchase access to the information. Conversely, the GRI reporting standard is widely accessible and used among companies engaged in sustainability reporting, worldwide.

I used the following criteria to calculate a Sustainability Report score. One point for each metric out of a possible total of five. I assigned partial credit in certain cases where they may have met some of the aspects of a criteria, but not sufficient to earn a full point on this scale. For instance, the definitions of “sustainability report”, “corporate social responsibility report” and “environmental impact report” may cover many of the same metrics, but they are distinct. Further, not all organizations seek to comply with the same set of sustainability standards, either formally through verification, or informally through disclosure. Since GRI is among the most robust and widely used of standards I did include a point for using GRI standards as guidance, even if they did not yet complete the official compliance process. GRI verification and compliance may be achieved over a scale of years, so this helps represent these periodic reports on corporate sustainability efforts as snapshots on a spectrum rather than a toggle switch.

- SustRep_Exists - A Sustainability report exists for this company
- SustRep_Current - The Sustainability Report is current
- SustRep_Primary_Company - The Sustainability Report was done by the IOU at the most grass-roots level, rather than by a parent or holding company
- SustRep_GRI_related - The Sustainability Report uses Global Reporting Initiative standards to guide the reporting process (regardless of whether or not they're in official compliance with the standards)
- SustRep_MA_Included - The company reports having done a Materiality Assessment with their stakeholders (internal, external, or both)

Communicating with stakeholders and shareholders

In order to explore in greater depth whether IOUs are taking shareholder concerns seriously, I evaluated several sets of documents produced by a small subset of those found to have produced high quality CSR reports. Having already evaluated all WECC IOU CSR reports, I now turned my attention to a sample of WECC IOU investor reports, particularly investor meeting presentations during the first quarter. This is often when companies signal decisions and new directions based on the annual reports they would have produced from the fourth quarter, in the previous year. I again use solar as a key focal point and search term in this analysis.

Results

The results of my analysis show the residential solar PV ratio in each utility territory compared with their CSR scores. While this analysis suggests a relationship between solar PV and the quality of CSR reporting, there may be other confounding factors that hold an equal or stronger relationship with the relative quantity of solar PV installations. These are explored in the findings and discussion sections to follow.

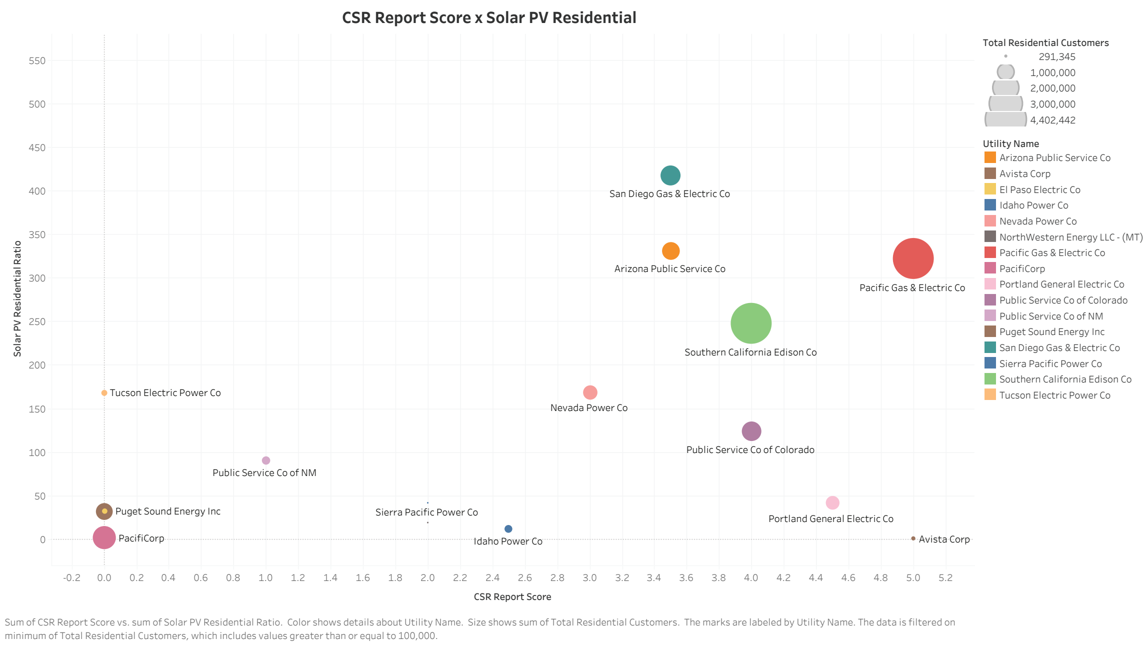


Figure 3.1 Quality of CSR reporting vs. residential solar PV installations

Note that the utilities with the highest CSR scores are diverse in customer size and also in the relative amount of solar in their territories. See the cross-tabulation in Table 3.1 for more details on the results of this analysis.

Cross tabulation

Utility Name	Holding_Co..	Holding Co Ultimate	Operating States	CSR Report Score	Solar PV Total Ratio	Solar PV Residential Ratio	RPS Score	Total Residential Customers
Pacific Gas &..	1	Pacific Gas & Elect..	CA	5	536	322	2	4,402,442
Avista Corp	1	Avista Corp	ID, MT, WA	5	1	1	*	333,346
Portland Gen..	1	Portland General E..	OR	4.5	71	41	2	752,365
Southern Cal..	1	Southern Californi..	CA	4	375	248	2	4,401,781
Public Servic..	2	XCEL Energy	CO	4	217	124	2	1,228,305
San Diego Ga..	2	Sempra	CA	3.5	531	418	2	1,272,052
Arizona Publ..	2	Pinnacle West	AZ	3.5	528	331	2	1,061,814
Nevada Pow..	3	Berkshire Hathaw..	NV	3	212	169	2	796,196
Idaho Power ..	2	IDACORP, Inc.	ID, OR	2.5	16	11	*	440,362
NorthWeste..	2	NorthWestern Cor..	MT, WY	2	28	19	*	291,345
Sierra Pacifi..	2	Berkshire Hathaw..	NV	2	133	41	2	291,401
Public Servic..	2	PNM Resources	NM	1	171	91	2	461,248
El Paso Elect..	1	El Paso Electric Co	NM, TX	0	41	33	2	362,138
PacifiCorp	2	Berkshire Hathaw..	CA, ID, OR, UT, WA, WY, OR	0	3	1	*	1,598,696
Puget Sound ..	2	Puget Energy	WA	0	36	32	2	984,739
Tucson Elect..	3	Fortis Inc.	AZ	0	357	168	2	378,992

CSR Report Score 0–6

CSR Report Score, Solar PV Total Ratio, Solar PV Residential Ratio, RPS Score and Total Residential Customers broken down by Utility Name, Holding_Company_Level, Holding Co Ultimate and Operating States. Color shows CSR Report Score. The data is filtered on minimum of Total Residential Customers, which includes values greater than or equal to 100,000.

Table 3.1 Cross tabulation of quality of CSR reporting vs. residential solar PV installations.

Findings

I derive five major findings from this study:

Finding #1 Marketplace dynamics

Companies that have a high solar ratio score also have high CSR reporting scores, with only one exception. This finding indicates a correlation between high quality CSR reporting and high levels of solar PV adoption within each utility's service territory.

In general, companies that have large customer bases correlate more tightly to this trend. For instance, in California, the size of the utility ranking correlates closely to their CSR reporting score rankings. Thus, the CSR reporting score is a good predictor of adoption when the company has at least 500,000 residential customers. That said, not all companies follow this rule; in other words, there are examples of smaller companies that nonetheless exhibit high CSR reporting scores.

This finding indicates a correlation between high quality CSR reporting and high levels of solar PV adoption within each utility's service territory. Of the n=25 total companies examined, n=16 have sustainability reports (64%). When filtered for companies with at least 100,000 residential customers, these numbers are n=16 total companies, n=12 with having sustainability reports (75%). This trend shows that companies with larger customer bases are somewhat more likely to have sustainability reports.

Finding #2 Government regulation

State-level RPSs are now approaching a stage where they are, practically speaking, no longer a reliable indicator of Solar ratio or DG ratio.

This finding replicates findings from the literature on the subject of RPSs (Carley & Miller, 2012) which shows that while these regulatory policies and incentives were useful in the past, some of them are now sun-setting and others are facing net-metering challenges which could slow down growth in their service territories. Standards, practices, and the simple reality of policies being hobbled or retired without major modification or extension have led to this state of being. SRP and Nevada regulators are examples.

It is very important to note that this does not mean RPSs are worthless or that they have no value. On the contrary – they have had great value in promoting renewable energy technologies in general and solar PV in particular. I will say this again, RPSs are not worthless. They are, however, under attack and have been for quite some time.

The theory for looking at state RPSs also extends to the concept of levers of government. I propose that companies without a diversified parent holding company are more successful at focusing on a narrow set of goals and strategies. Further, companies that perform robust stakeholder engagements reap the benefits of better information and signals in a marketplace of ideas where risk management takes into account more than just shareholder's return-on-investment. I also propose that governance regimes where citizens have more direct power and input on policies can enact policies and administrative rules that better reflect citizen stakeholder values within those communities. Thus, PUCs with constitutional genesis are given greater weight in my scoring than those in states where they have less power. Further, RPSs that are voluntary are given less weight in my rankings.

Finding #3 Materiality Assessments

Of the companies that ranked highest on Solar Ratio scores (4-5), all but one had a materiality assessment (MA). MAs are all about stakeholder engagement and assessing stakeholder values.

Materiality assessments are important for companies to understand the desires and preferences of all their stakeholders, not just their shareholders. They can then assess how closely their existing strategies align with the stated goals of their stakeholders. This indicates a relation or correlation between solar PV adoption and stakeholder engagement, which is what MAs represent. Materiality assessments can also be a useful tool in risk assessment, both internally and externally.

Finding #4 CSR Reporting

Among the companies that were ranked as part of the DJSI, all but one chose not to advertise that fact widely.

This finding matches research indicating that companies seek to avoid perceived hypocrisy in the public eye. (Carlos & Lewis, 2017) This tactic might also explain some companies' reluctance to do a robust materiality assessment that includes external stakeholders because doing so could potentially expose a disconnect between their corporate strategies and their stakeholder's preferences. CEO's need a safe harbor sometimes, as 80% of CEOs who have embarked on a path of sustainability and then failed, also end up being quickly replaced. (Ripken, 2005)

Finding #5 Virtue Signaling

When it comes to increasing the number of solar PV installations in their territories, utilities state that they are complying with their states' PUC regulations concerning distributed generation.

Contrary to findings #1 and #3, this finding does not support the idea of a shift from shareholder to stakeholder values, nor does it suggest that the observed higher levels of solar PV adoption are the result of CSR reporting or the inclusion of an MA. That said, this finding does not undermine those findings, either.

Companies perform virtue signaling through their shareholder investor meetings, integrated resource plans (IRPs), and through official reporting to the U.S. Security and Exchange Commission (SEC). (*Pinnacle West Capital Corp. - Investors - Events & Presentations*, 2021) (*Pinnacle West Capital Corp. - Investors - Reports - SEC Filings*,

2021) (*PG&E Corporation - News & Events - Events & Presentations*, 2021) (*PG&E Corporation - Financials - SEC Filings*, 2021)

While these shareholder meetings can be illuminating, I find that companies are reluctant to signal their actual investments or commitments beyond what regulators require of them when it comes to solar PV. They may actually exceed the levels of solar required of them in RPSs, rules, and regulations, but given their reluctance to publicly state that they will stretch beyond those requirements, especially if doing so creates material impacts on their financial outcomes, it is difficult to find a correlation between solar PV and CSR reporting and practices. For example, in their 2015 shareholder presentations, APS mentions solar quite a bit while PG&G hardly mentions it at all. By contrast, solar plays a big part in both organizations' CSR reports. While PG&E has a better CSR score for their reports, their solar ratios and RPS scores are very close to APS's scores on both those metrics. (see Table 3.1 in the Results section)

Discussion

Among other findings, the data show that those utilities that employed a materiality assessment as part of their CSR reporting also showed a higher level of solar PV adoption within their territories. What explains the correlation between increased solar PV adoption and the presence of a materiality assessment in the CSR reporting among the electric utilities studied?

Stakeholder engagement theory attempts to explain why some forms of CSR reporting can be considered more robust, and that these more robust forms of stakeholder engagement will correlate with more robust outcomes. Using this theory, I suggest that greater rooftop PV adoption can be explained at least in part by the presence of a more robust form of stakeholder engagement, in that the latter contributes to changes in utility practices and perspectives that favor outcomes that have high signaling value among and/or beneficial outcomes for stakeholders.

According to Manetti (Manetti, 2011), there are differences in quality among CSR reporting types. More specifically, a CSR report that employs a materiality assessment (MA) is more likely to produce more robust stakeholder engagement results. In short, this is because conducting the MA leads to a better understanding of materiality through their stakeholders than not doing one. To gain a better understanding of how materiality could help lead to higher solar PV adoption in this case, I first delve into the theoretical model advanced by Freidman and Miles.

We can evaluate the outcomes of stakeholder engagement by using stakeholder theory. For instance, based on the work of Arnstein's "ladder of citizen participation" (Arnstein, 1969), Friedman and Miles developed a theoretical model of stakeholder engagement that represents a spectrum of increasing quality. These stages range from forms of stakeholder engagement that are primarily aimed at manipulating, informing, or placating citizens to forms that are aimed instead at partnering with or delegating power to stakeholders, with the final stage representing actual citizen "control". Each level corresponds to a distinct type of stakeholder engagement, characterized by specific tools and activities, as well as to specific types of outcomes. These stages are listed below, per Friedman and Miles' *Stakeholders: Theory and Practice*: (Friedman & Miles, 2006)

- Stages 1-2: Manipulation and Therapy (marketing)

- Stages 3-5: Informing, Consultation, and Placation (one-way flow of information, or if two-way, then stakeholder views may be discounted or ignored by management anyway)
- Stage 6: Partnership (stakeholders actually involved in process of planning and decision-making)
- Stage 7: Delegated power (representing minority views, stakeholders feel more well represented)
- Stage 8: Citizen control (when citizens obtain an equal or dominant portion of control through decision-making or managerial power)

Relevant to this study is their claim that levels 3-5 of stakeholder engagement that consider materiality of stakeholder views in a robust way result in outcomes that lead to outcomes that better represent what stakeholders desire. This is the progression of thought that connects stakeholder engagement to distributed residential solar PV as a representation of better outcomes. Distributed residential solar PV may represent better outcomes in a more utilitarian way, and only partially better in a substantive social justice way. Yet these outcomes are still better in some ways than either a failure to adopt renewable energy generation or, alternatively, even, approaches that emphasize large, utility-scale and centralized solar PV, wind, or other low-carbon generation. When taken from a strong sustainability perspective, where society and economies only exist within the scope of a broader ecology, then social and economic concerns follow environmental concerns. When viewed from a weak sustainability perspective with economics disconnected from externalities, then centralized or simply no solar PV may seem better than distributed residential solar PV.

By conducting a robust materiality assessment, companies may achieve better stakeholder engagement, the results of which could thus support better sustainability outcomes which are also more well suited to the populations they represent.

Europe has done a relatively better job of requiring robust stakeholder engagement through sustainability reporting than the US. (Van der Lugt et al., 2020) Currently, Delaware is the only state within the US that has a law requiring some form of CSR, and even this is very recent. (*TITLE 6 - CHAPTER 50E. Certification of Adoption of Transparency and Sustainability Standards by Delaware Business Entities*, n.d.) That said, Delaware's Voluntary Sustainability Certification Law is only a small portion of the requirements for a standard certified GRI report. (Zeberkiewicz, 2018)

Stakeholder engagement often looks different than shareholder engagement. The latter is very regulated, while the former is somewhat less formal. As Ripken notes, corporate leaders often use conservative messaging in their communications with shareholders via forward-looking statements. (Ripken, 2005) They may do this to avoid being wrong about the future which could affect investor profits and earnings. I suggest that this is more than simply a due diligence to avoid misleading investors, particularly since "safe harbor" laws were put into place to protect companies from being wrong about the future, just as long as they include sufficient disclaimers in their financial filings and investor communications.

Conclusion

This chapter explores the dynamics of networks of communication and deliberations about renewable energy adoption at the corporate level. This large, organizational perspective is different from the individual and community perspectives of the first two papers but offers many insights into how companies make decisions about adopting solar PV at an institutional level. The disclosures that they make about internally focused and externally focused risk assessment, and their visions of an energy future are quite important to a wide variety of stakeholders beyond shareholders and board members.

Although some study findings are suggestive of a shift from shareholder to stakeholder values, they are not conclusive; moreover, one study finding appears to question such a shift. That said, the study results point to a potentially important correlation between robust stakeholder engagement and relatively higher levels of solar PV adoption. Moreover, these results are not limited to IOUs with a specific size or type of customer base, but apply to a diverse range of IOUs. As stated, the utilities with the highest CSR scores are diverse in customer size and also in the relative amount of solar in their territories. This is important for the motivating research questions because, while investors push IOUs to become more in line with sustainability best practices, and the transformational potential of enacting sustainability reporting practices is significant, stakeholders and regulatory bodies still need ways to determine if IOUs are delivering on desired outcomes. In addition to RPSs and other governance mechanisms and tools, sustainability reporting and technologies such as solar serve as focal points and proxies that point toward a more sustainable path. They are one more tool to help determine if companies are merely virtue signaling, or if they are enacting meaningful change.

A well-functioning governance mechanism in corporations helps them match their corporate strategies and goals with the values of stakeholders. A strategy that includes robust stakeholder engagement and corporate responsibility reporting as a process for dealing with sustainability issues should be more reflective of the broader values of society in general than just the profit motivations of the investors. The very act of performing the process for evaluating sustainability and corporate social responsibility for a particular corporation facilitates a certain kind of rational thinking and broader thinking that can be good not only for society but for business as well.

Overall, with these three studies in this dissertation, I hope to offer both a contribution to the Sustainability literature and Innovation literature as well as a guide for many actors and institutions in these spaces who may wish to gain a better understanding of the dynamics of decision making when it comes to adopting renewable energy writ large and solar PV in particular.

REFERENCES

Adomatis, S., & Hoen, B. (2016). Appraising Into The Sun: Six-State Solar Home Paired-Sale Analysis. *Lawrence Berkeley National Laboratory. Berkeley, CA*. https://emp.lbl.gov/sites/all/files/lbnl-1002778_0.pdf

Arizona ZIP Codes List, Map, Demographics, and Shipping. (n.d.). Retrieved June 25, 2021, from https://www.unitedstateszipcodes.org/az/

Arnstein, S. R. (1969). A Ladder Of Citizen Participation. *Journal of the American Institute of Planners*, *35*(4), 216–224. https://doi.org/10.1080/01944366908977225

Barbose, G. (2021). *U.S. Renewables Portfolio Standards 2021 Status Update: Early Release*.

Baumgartner, R. J., & Ebner, D. (2010). Corporate sustainability strategies: Sustainability profiles and maturity levels. *Sustainable Development*, *18*(2), 76–89. https://doi.org/10.1002/sd.447

Brady, J. (2014, July 15). *Leased Solar Panels Can Cast A Shadow Over A Home's Value: NPR*. http://www.npr.org/2014/07/15/330769382/leased-solar-panels-can-cast-a-shadow-over-a-homes-value

Brown, M. A., Hubbs, J., Xinyi Gu, V., & Cha, M.-K. (2021). Rooftop solar for all: Closing the gap between the technically possible and the achievable. *Energy Research & Social Science*, *80*, 102203. https://doi.org/10.1016/j.erss.2021.102203

Bureau, U. C. (n.d.). *ZIP Code Tabulation Areas (ZCTAs)*. The United States Census Bureau. Retrieved June 25, 2021, from https://www.census.gov/programs-surveys/geography/guidance/geo-areas/zctas.html

California Solar Initiative. (n.d.). Retrieved July 5, 2021, from https://www.cpuc.ca.gov/General.aspx?id=6043

Carley, S., & Miller, C. (2012). Regulatory Stringency and Policy Drivers: A Reassessment of Renewable Portfolio Standards. *Policy Studies Journal*, *40*(4), 730–756. https://doi.org/10.1111/j.1541-0072.2012.00471.x

Carlos, W. C., & Lewis, B. W. (2017). Strategic Silence: Withholding Certification Status as a Hypocrisy Avoidance Tactic. *Administrative Science Quarterly*, 000183921769508. https://doi.org/10.1177/0001839217695089

CSA Methodology | S&P Global. (n.d.). Retrieved March 17, 2021, from https://www.spglobal.com/esg/csa/methodology/

CSI Multifamily Affordable Solar Housing (MASH) Program. (n.d.). Retrieved July 5, 2021, from https://www.cpuc.ca.gov/General.aspx?id=3752

CSI Single-Family Affordable Solar Homes (SASH) Program. (n.d.). Retrieved July 5, 2021, from https://www.cpuc.ca.gov/General.aspx?id=3043

Dastrup, S. R., Graff Zivin, J., Costa, D. L., & Kahn, M. E. (2012). Understanding the Solar Home price premium: Electricity generation and “Green” social status. *European Economic Review*, *56*(5), 961–973. https://doi.org/10.1016/j.euroecorev.2012.02.006

Dharshing, S. (2017). Household dynamics of technology adoption: A spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany.

Energy Research & Social Science, *23*, 113–124. https://doi.org/10.1016/j.erss.2016.10.012

Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy Policy*, *34*(14), 1797–1806. https://doi.org/10.1016/j.enpol.2005.01.001

Friedman, A. L., & Miles, S. (2006). *Stakeholders: Theory and practice*. Oxford University Press on Demand.

Gaur, V., & Lang, C. (2020). Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island. *University of Rhode Island Cooperative Extension*, 46. https://web.uri.edu/coopext/valuing-sitingoptions-for-commercial-scale-solar-energy-in-rhode-island/

Graziano, M., Fiaschetti, M., & Atkinson-Palombo, C. (2019). Peer effects in the adoption of solar energy technologies in the United States: An urban case study. *Energy Research & Social Science*, *48*, 75–84. https://doi.org/10.1016/j.erss.2018.09.002

Graziano, M., & Gillingham, K. (2014). Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment. *Journal of Economic Geography*. https://doi.org/10.1093/jeg/lbu036

GRI Standards English Language. (n.d.). Retrieved March 17, 2021, from https://www.globalreporting.org/how-to-use-the-gri-standards/gri-standards-english-language/

Hoen, B., Adomatis, S., Jackson, T., Graff-Zivin, J., Thayer, M., Klise, G. T., & Wiser, R. (2015). Selling into the Sun: Price Premium Analysis of a Multi-State Dataset of Solar Homes. *Lawrence Berkeley National Laboratory. Berkeley, CA*. https://emp.lbl.gov/sites/all/files/selling-into-the-sun-jan12.pdf

Hoen, B., Rand, J., & Adomatis, S. (2017). *Leasing into the sun: A mixed method analysis of transactions of homes with third party owned solar* (LBNL-1007003). Lawrence Berkeley National Laboratory.

Intellectus Statistics [Online computer software]. (2021). Intellectus Statistics. https://analyze.intellectusstatistics.com/

Kollins, K., Speer, B., & Cory, K. (2010). *Solar PV Project Financing: Regulatory and Legislative Challenges for Third-Party PPA System Owners*. http://www.nrel.gov/docs/fy10osti/46723.pdf

Kurdgelashvili, L., Shih, C.-H., Yang, F., & Garg, M. (2019). An empirical analysis of county-level residential PV adoption in California. *Technological Forecasting and Social Change*, *139*, 321–333. https://doi.org/10.1016/j.techfore.2018.11.021

Machado, C. G., Pinheiro de Lima, E., Gouvea da Costa, S. E., Angelis, J. J., & Mattioda, R. A. (2017). Framing maturity based on sustainable operations management principles. *Operational Excellence towards Sustainable Development Goals through Industry 4.0*, *190*, 3–21. https://doi.org/10.1016/j.ijpe.2017.01.020

Manetti, G. (2011). The quality of stakeholder engagement in sustainability reporting: Empirical evidence and critical points. *Corporate Social-Responsibility and Environmental Management*, *18*(2), 110–122. https://doi.org/10.1002/csr.255

Mundaca, L., & Samahita, M. (2020). What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. *Energy Research & Social Science*, *60*, 101319. https://doi.org/10.1016/j.erss.2019.101319

O'Leary, J. (2017). *ASU Solar Housing Survey*. Zenodo. https://doi.org/10.5281/zenodo.556202

OMB BULLETIN NO. 18-04 Revised Delineations of Metropolitan Statistical Areas, Micropolitan Statistical Areas, and Combined Statistical Areas, and Guidance on Uses of the Delineations of These Areas, (2018). https://www.whitehouse.gov/wp-content/uploads/2018/09/Bulletin-18-04.pdf

O'Shaughnessy, E. (2021). Toward a more productive discourse on rooftop solar and energy justice. *Joule*. https://doi.org/10.1016/j.joule.2021.08.006

PG&E Corporation—Financials—SEC Filings. (2021). https://investor.pgecorp.com/financials/sec-filings/default.aspx

PG&E Corporation—News & Events—Events & Presentations. (2021). https://investor.pgecorp.com/news-events/events-and-presentations/default.aspx

Pinnacle West Capital Corp. - Investors—Events & Presentations. (2021). http://www.pinnaclewest.com/investors/events-and-presentations/default.aspx

Pinnacle West Capital Corp. - Investors—Reports—SEC Filings. (2021). http://www.pinnaclewest.com/investors/reports/sec-filings/default.aspx

Pless, J., Fell, H., & Sigrin, B. (2020). Information Searching in the Residential Solar PV Market. *The Energy Journal*, *41*(4). https://doi.org/10.5547/01956574.41.4.jple

Pretnar, N., & Abajian, A. (2021). *An Aggregate Perspective on the Geo-spatial Distribution of Residential Solar Panels* (SSRN Scholarly Paper ID 3771496). Social Science Research Network. https://doi.org/10.2139/ssrn.3771496

Public Utility Holding Company Act of 1935: 1935-1992. (n.d.). Retrieved May 5, 2021, from https://www.eia.gov/electricity/pdfpages/puhca/index.php

Ripken, S. K. (2005). Predictions, projections, and precautions: Conveying cautionary warnings in corporate forward-looking statements. *University of Illinois Law Review*, *2005*(4), 929–987. https://search.lib.asu.edu/primo-explore/fulldisplay?docid=TN_gale_legal140026394&context=PC&vid=01ASU&search_scope=Everything&tab=default_tab&lang=en_US

Rogers, E. M. (2014). *Diffusion of innovations, 5th edition*. Free Press. http://rbdigital.oneclickdigital.com

Selling or Buying a Home with Solar Panels | SolarCity. (2017). Buying and Selling a Solar Home. http://www.solarcity.com/residential/solar-energy-faqs/buying-selling-solar-homes

Silvius, A. J. G. (2015). *A Maturity Model for Integrating Sustainability in Projects and Project Management*.

Sunter, D. A., Castellanos, S., & Kammen, D. M. (2019). Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nature Sustainability*, *2*(1), 71–76. https://doi.org/10.1038/s41893-018-0204-z

TITLE 6—CHAPTER 50E. Certification of Adoption of Transparency and Sustainability standards by Delaware Business Entities. (n.d.). Retrieved September 2, 2020, from https://delcode.delaware.gov/title6/c050e/index.shtml

Tracking the Sun | Electricity Markets and Policy Group. (n.d.). Retrieved July 3, 2021, from https://emp.lbl.gov/tracking-the-sun/

US Census Bureau. (2021, September 27). *2020 DEC Redistricting Data (PL 94-171) Table H1*. Census.Gov. https://www.census.gov/rdo

U.S. Department of Housing and Urban Development. (2014). *Single Family Housing Policy Handbook 4000.1* (Handbook Handbook 4000-1; p. 298). U.S. Department of Housing and Urban Development. https://portal.hud.gov/hudportal/HUD?src=/program_offices/housing/sfh/handbook_4000-1

U.S. Department of Veterans Affairs. (2008). *Lenders Handbook—VA Pamphlet 26-7—Web Automated Reference Material System* (Handbook VA Pamphlet 26-7; p. Chapters 11 and 12). U.S. Department of Veterans Affairs. https://www.benefits.va.gov/warms/pam26_7.asp

US Energy Information Administration. (2021, October 28). *Form EIA-861M (formerly EIA-826) detailed data*. Form EIA-861M (Formerly EIA-826) Detailed Data. https://www.eia.gov/electricity/data/eia861m/#solarpv

Van der Lugt, C. T., van de Wijs, P. P., & Petrovics, D. (2020). *Carrots & Sticks 2020—Sustainability reporting policy: Global trends in disclosure as the ESG agenda goes mainstream* (Carrots & Sticks, p. 37). Global Reporting Initiative (GRI) and the University of Stellenbosch Business School (USB). https://www.carrotsandsticks.net/media/zirbzabv/carrots-and-sticks-2020-interactive.pdf

Wade, W. (2014, June 24). *Rooftop Solar Leases Scaring Buyers When Homeowners Sell—Bloomberg Business*. Bloomberg.Com. http://www.bloomberg.com/news/articles/2014-06-23/rooftop-solar-leases-scaring-buyers-when-homeowners-sell

Winner, L. (1980). Do artifacts have politics? *Daedalus*, *109*(1), 121–136.

Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001

Zeberkiewicz, J. M. (2018, July 15). Delaware's Voluntary Sustainability Certification Law. *The Harvard Law School Forum on Corporate Governance*. https://corpgov.law.harvard.edu/2018/07/15/delawares-voluntary-sustainability-certification-law/

APPENDIX A

SUPPLEMENTAL GRAPHS AND TABLES

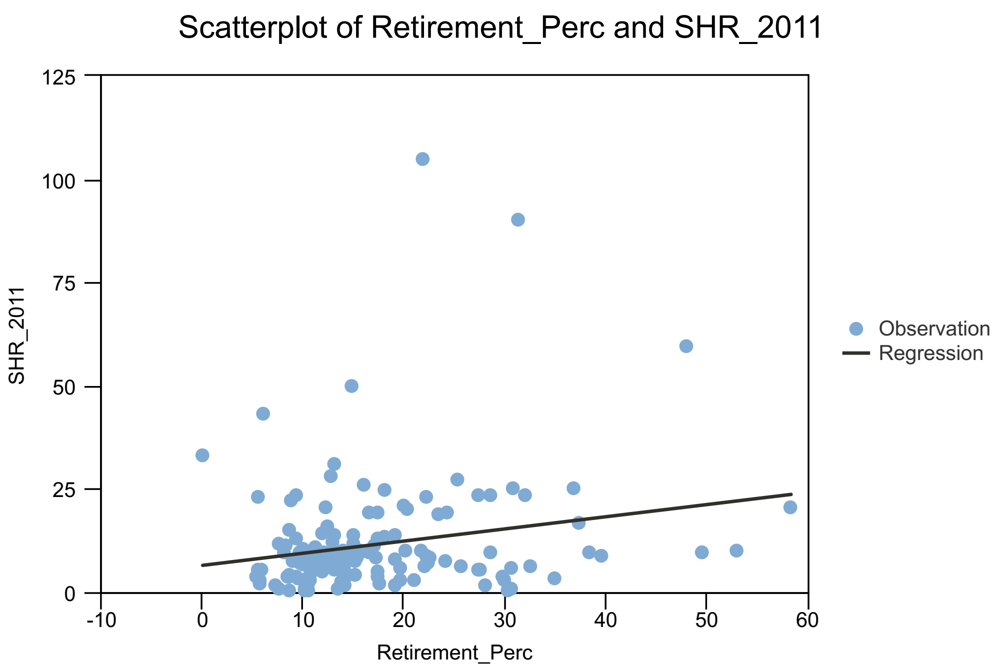


Figure 1.5 2011 Scatterplot of SHR and Retirement percentage

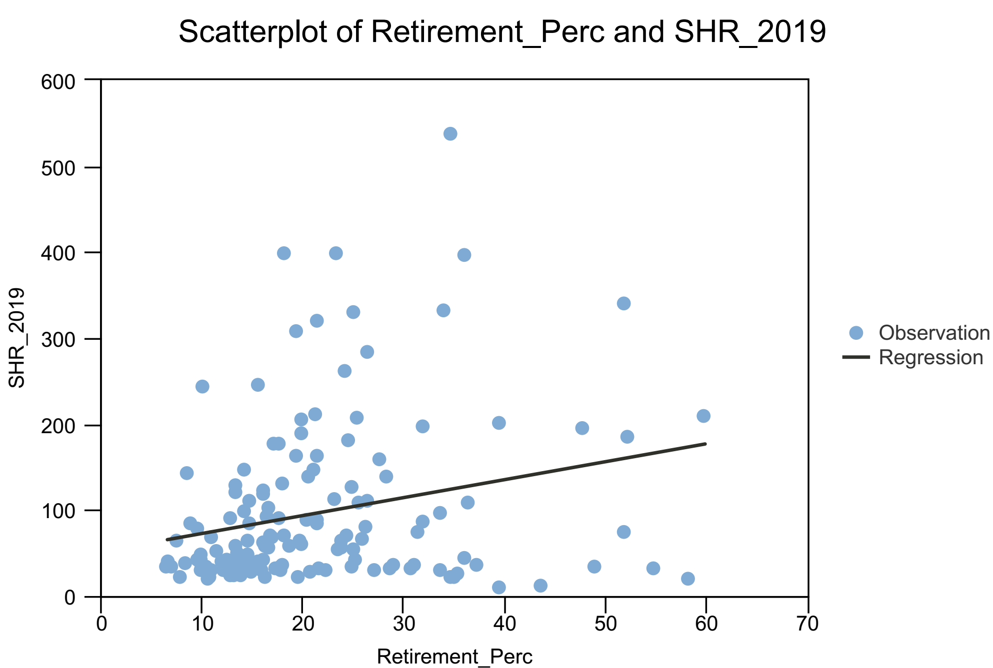


Figure 1.6 2019 Scatterplot of SHR and Retirement percentage

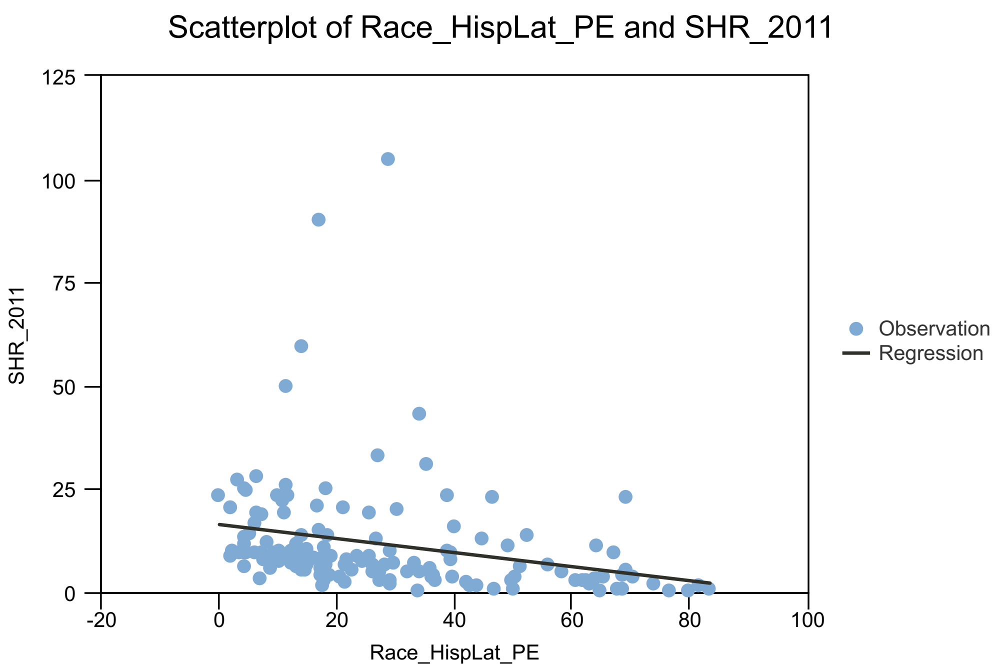


Figure 1.7 2011 Scatterplot of SHR and Race-Ethnicity: Hispanic-Latino

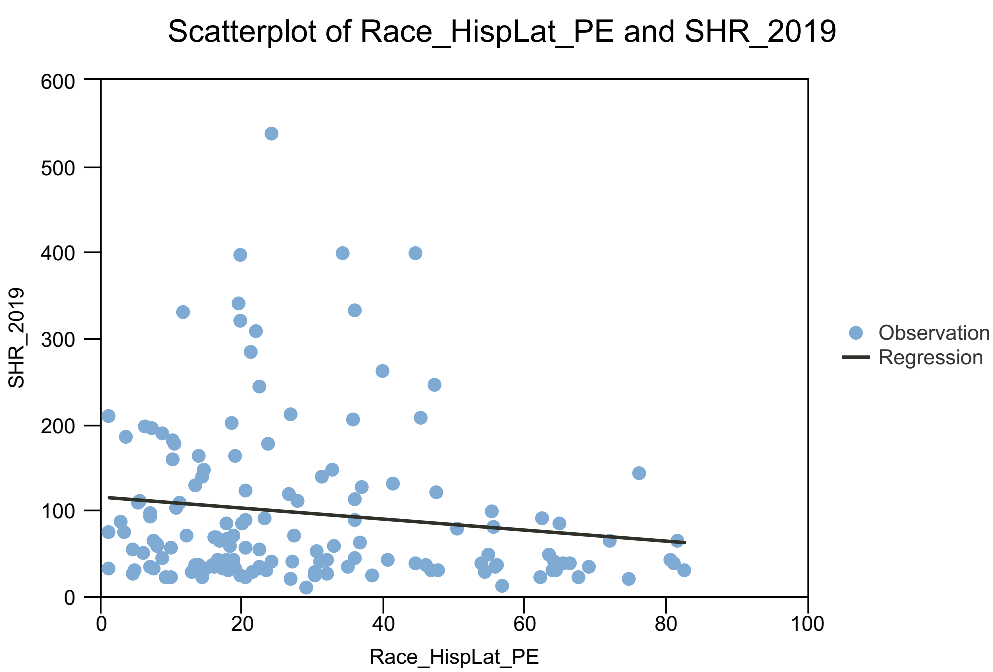
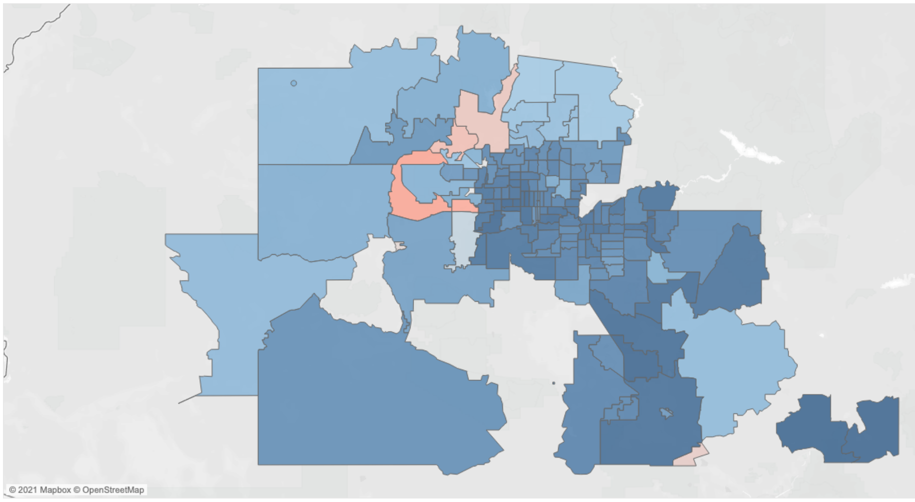


Figure 1.8 2019 Scatterplot of SHR and Race-Ethnicity: Hispanic-Latino

2011 SHR

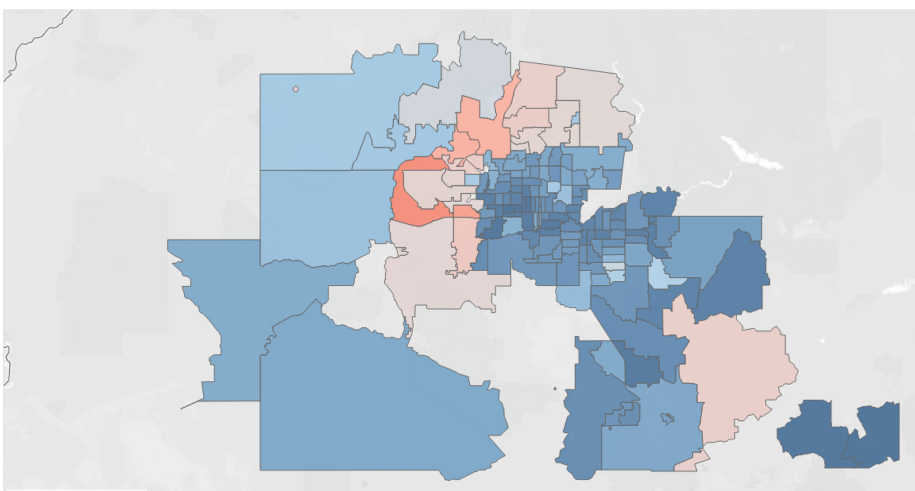


2011 SHR
Average: 11.6
Minimum: 0.4
Maximum: 105.0
Median: 7.9
Standard deviation: 13.9
First quartile: 4.3
Third quartile: 13.0
Skewness: 3.95
Excess Kurtosis: 20.37

SHR 2011
0.4 537.2

Figure 1.9 2011 SHR map of the Phoenix area MSA

2012 SHR



2012 SHR
Average: 18.5
Minimum: 0.9
Maximum: 209.8
Median: 11.4
Standard deviation: 24.1
First quartile: 7.7
Third quartile: 19.3
Skewness: 4.89
Excess Kurtosis: 31.27

SHR 2012
0.4 537.2

Figure 1.10 2012 SHR map of the Phoenix area MSA

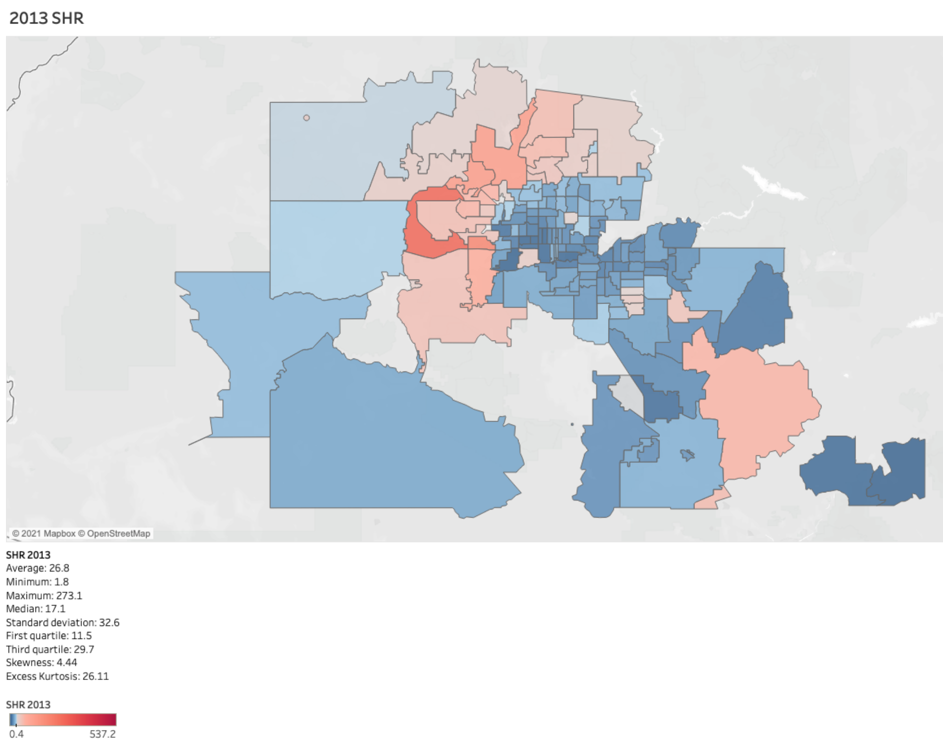


Figure 1.11 2013 SHR map of the Phoenix area MSA

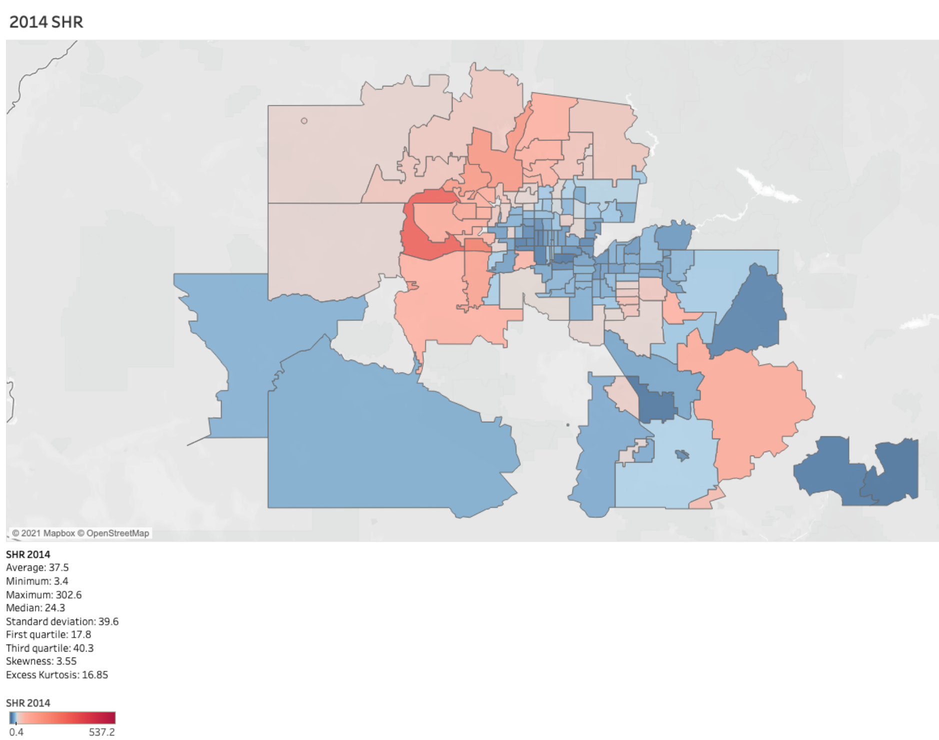


Figure 1.12 2014 SHR map of the Phoenix area MSA

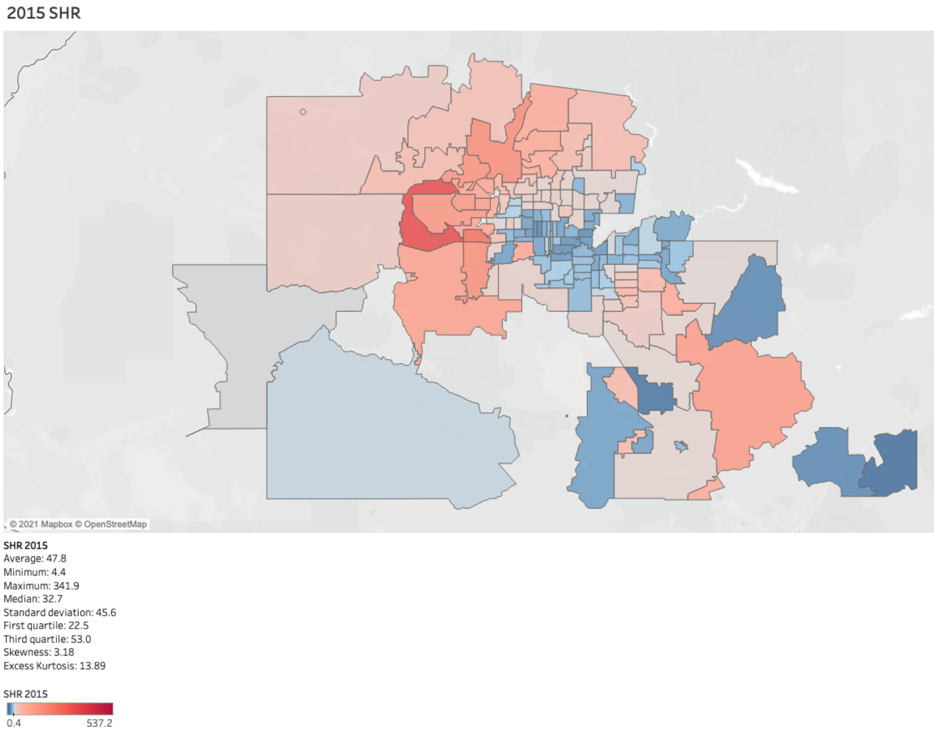


Figure 1.13 2015 SHR map of the Phoenix area MSA

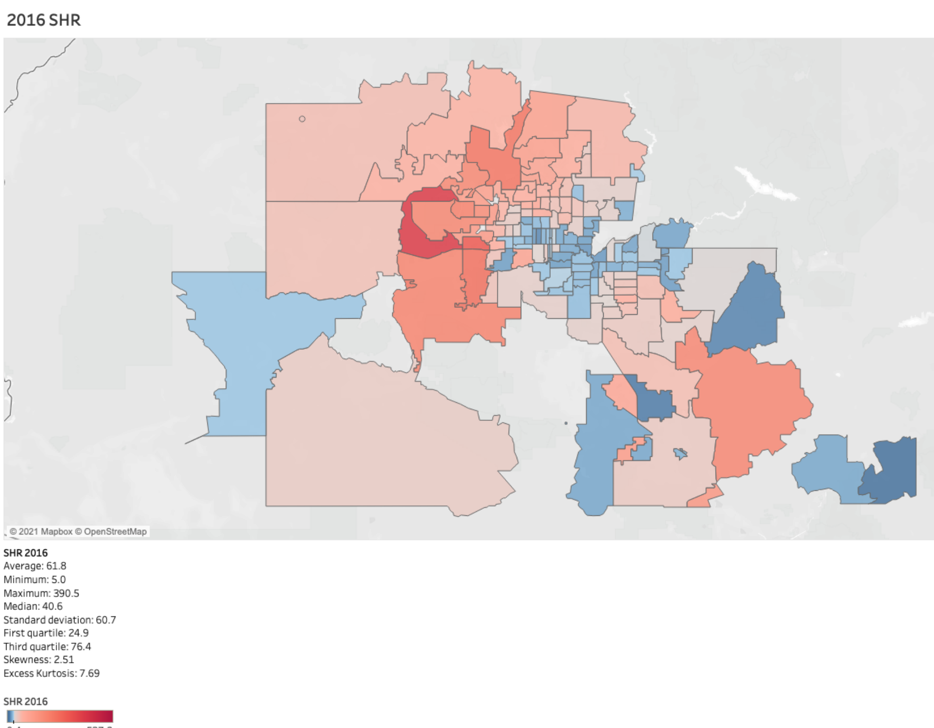


Figure 1.14 2016 SHR map of the Phoenix area MSA

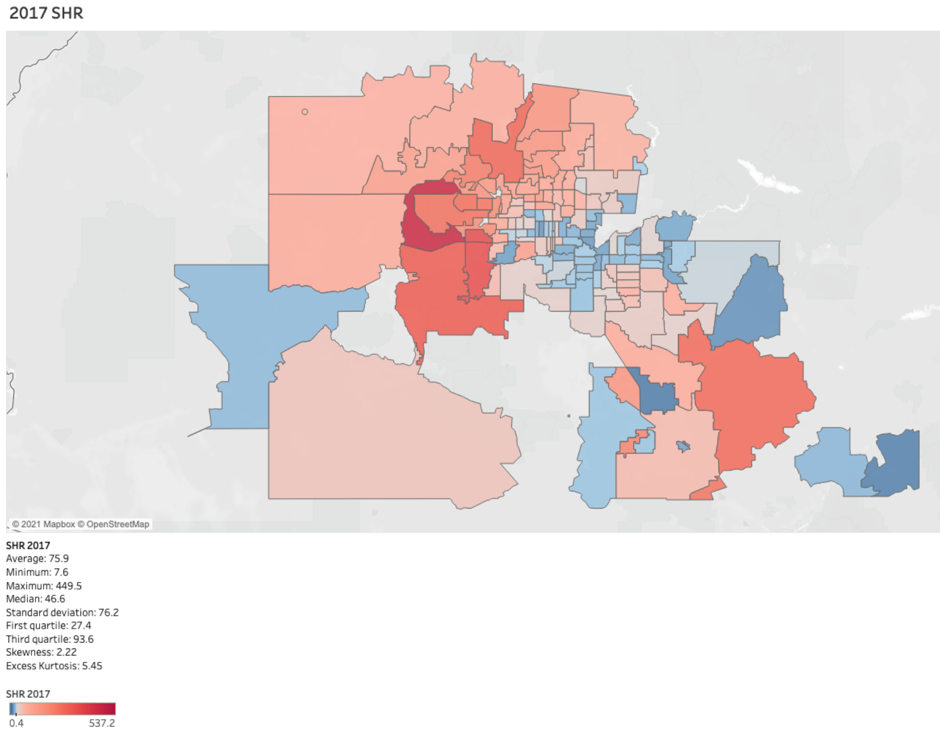


Figure 1.15 2017 SHR map of the Phoenix area MSA

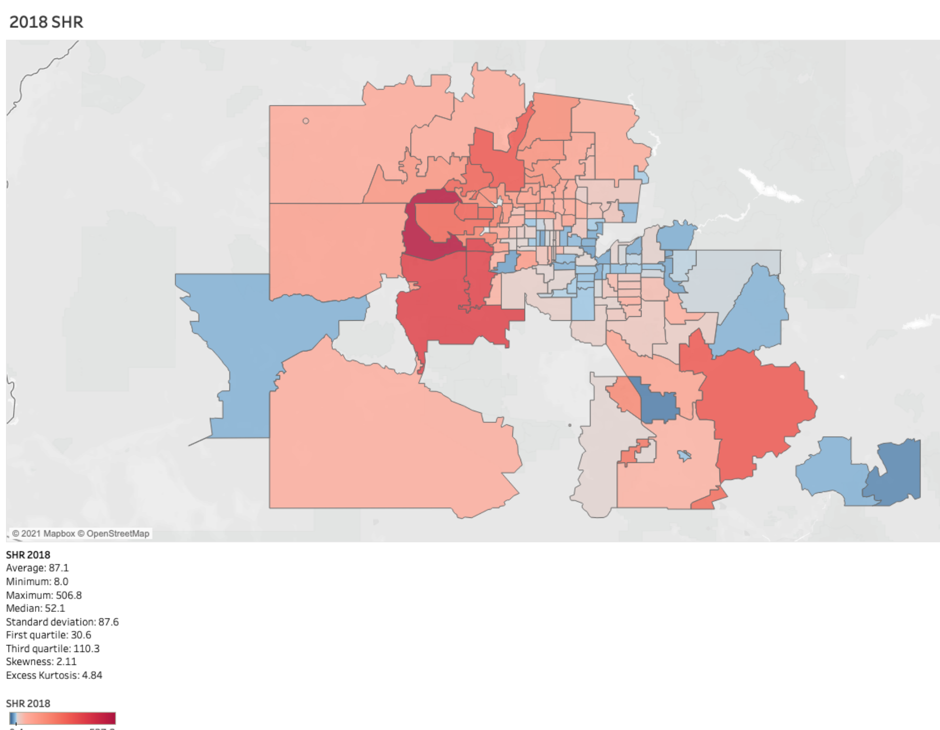


Figure 1.16 2018 SHR map of the Phoenix area MSA

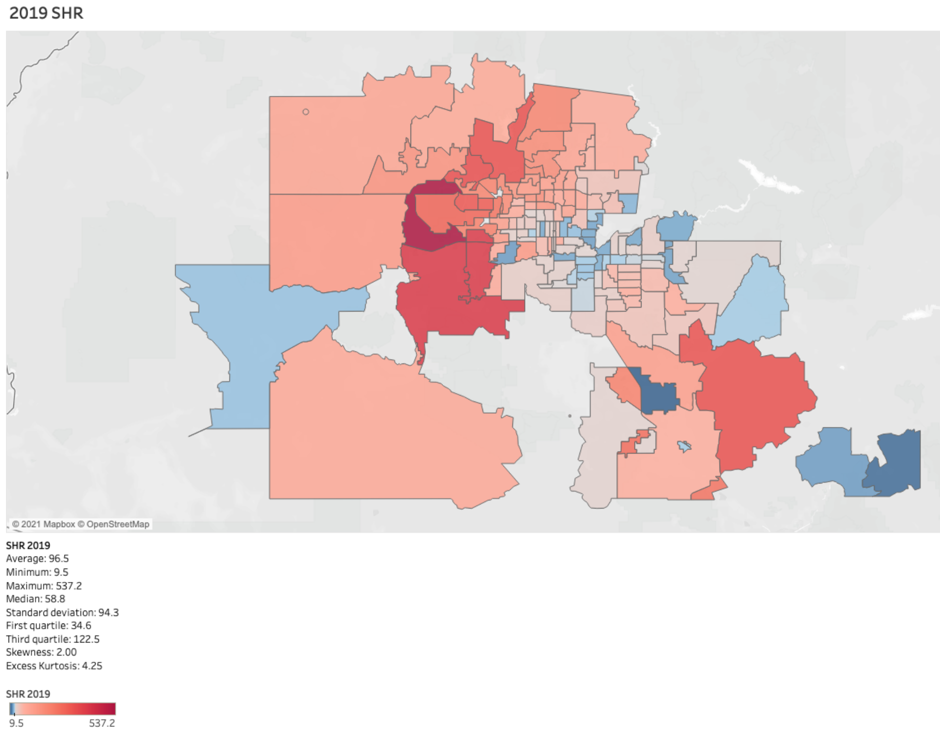


Figure 1.17 2019 SHR map of the Phoenix area MSA

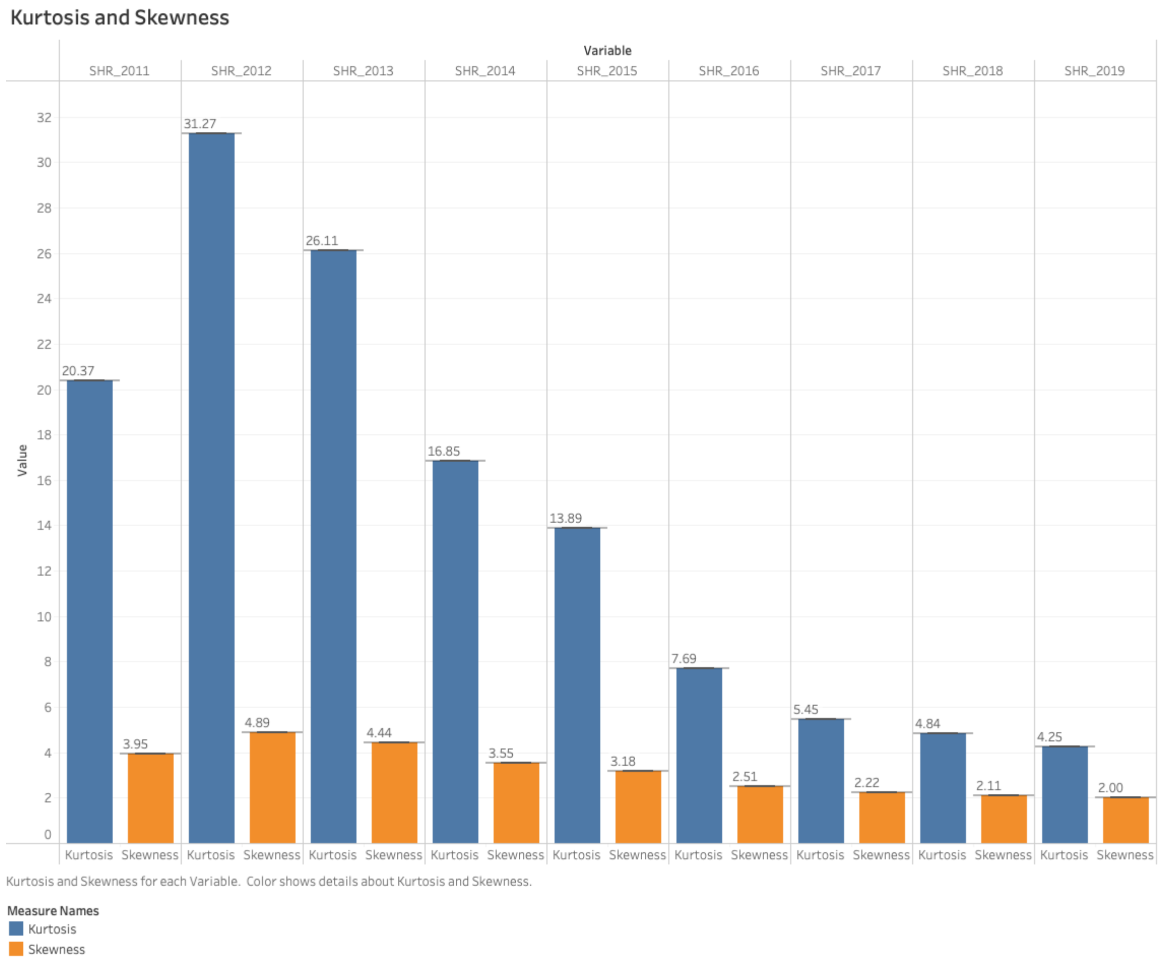


Figure 1.18 Kurtosis and Skewness of SHR distribution from 2011-2019

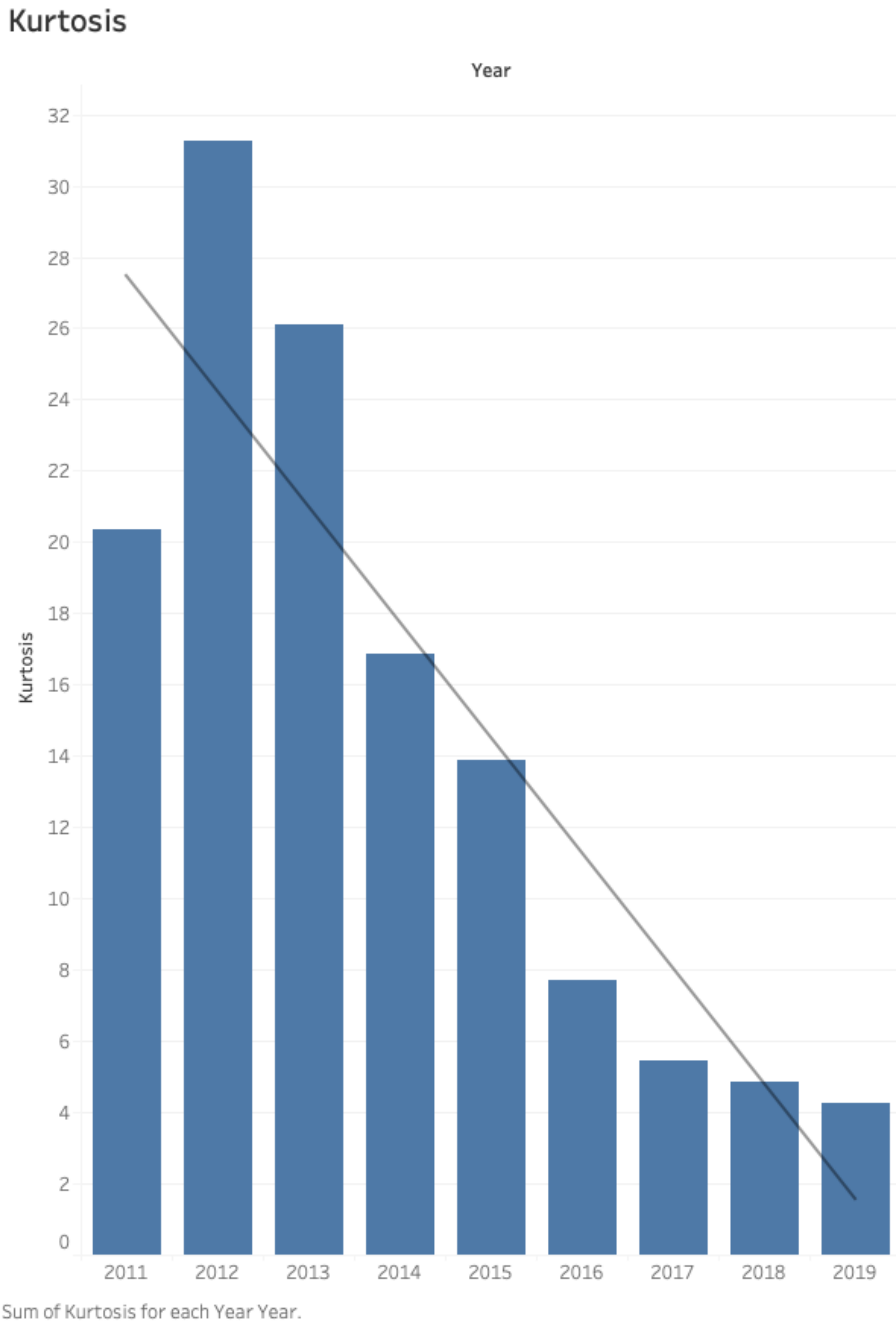


Figure 1.19 Kurtosis and its decline from 2011-2019

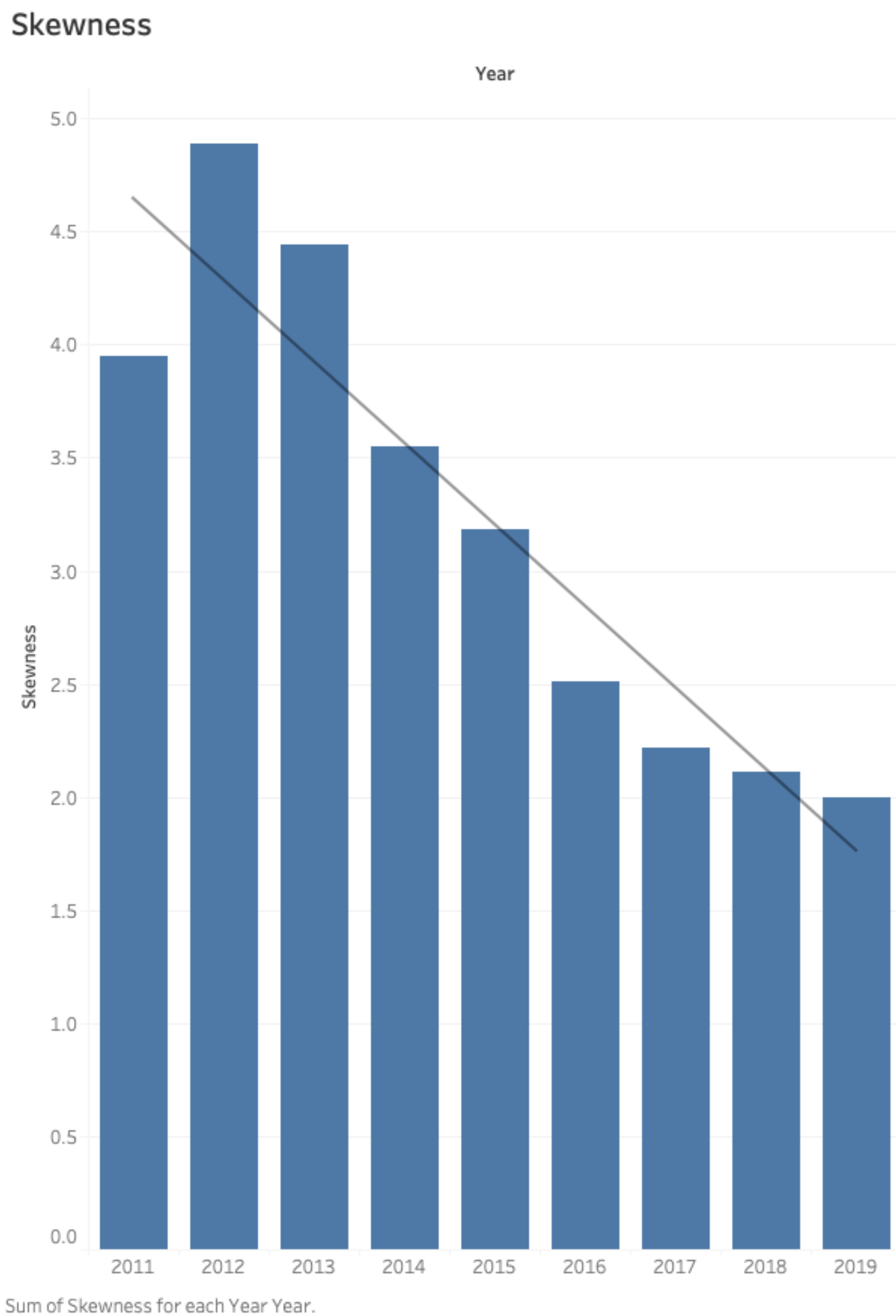


Figure 1.20 Skewness and its decline from 2011-2019

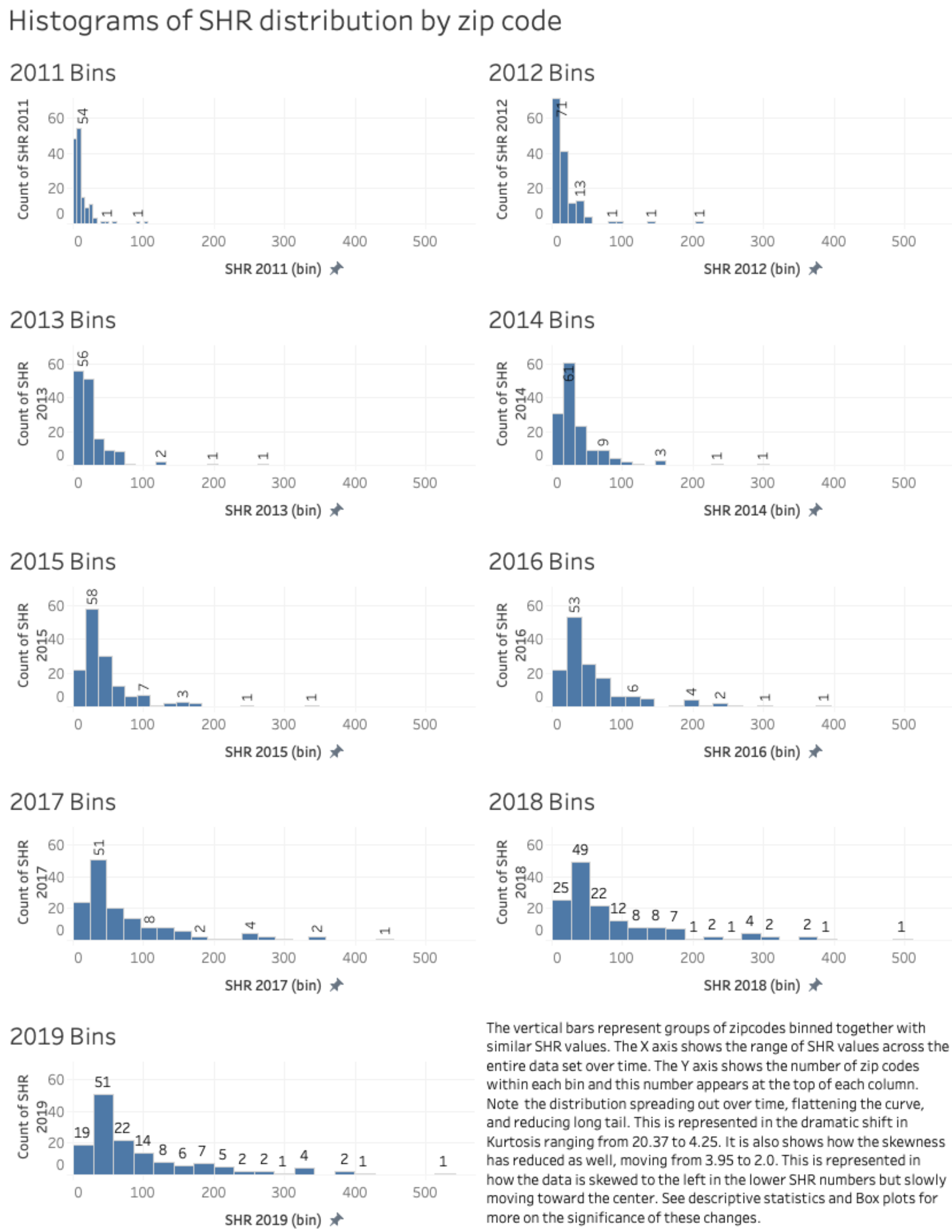


Figure 1.21 Histograms of SHR distribution by zip code from 2011-2019

Residential Solar PV installation data - LBNL	
UniqueID_AZ	Unique ID for every single solar installation in this dataset. Sequential numbers assigned by researcher just for this project.
Installs RT	Count of installations, Year-to-date
Installs YT	Count of installations added that year
TPO RT	Count of Third-party-owned installations, Year-to-date
TPO RT Perc	Third-party-owned installations as a percentage of all installations Year-to-date
TPO YT	Count of Third-party-owned installations added that year
TPO YT Perc	Third-party-owned installations as a percentage of installations added that year
NC RT	Count of New Construction installations, Year-to-date
NC RT Perc	New Construction installations as a percentage of all installations Year-to-date
NC YT	New Construction installations as a percentage of installations added that year
NC YT Perc	New Construction installations as a percentage of installations added that year
SHR	Solar Housing Ratio, calculation = (Installs RT / OOH_count) x 1000 Count of installations Year-to-date divided by owner occupied housing count, then multiplied by 1000
Housing price data - Zillow research site	
ZHVI	ZHVI Single-Family Homes Time Series by Zip Code
Housing DP04 Variables - US Census	
OOH_count	Owner Occupied Homes, total count
OOH_perc	Owner Occupied Homes, total percentage
ROH_count	Rental Homes, total count
ROH_perc	Rental Homes, total percentage
Age and Sex S0101 Variables - US Census	
POPtot	Total Population
AGEmed	Median age
OADR	Old-age dependency ratio
Income S1901 Variables - US Census	
Households total	Total Households
Income Median	Median Income
Income Mean	Mean Income

Less 10K PE	% of Households making Less than $10,000
10-15K PE	% of Households making $10,000 to $14,999
15-25K PE	% of Households making $15,000 to $24,999
25-35K PE	% of Households making $25,000 to $34,999
35-50K PE	% of Households making $35,000 to $49,999
50-75K PE	% of Households making $50,000 to $74,999
75-100K PE	% of Households making $75,000 to $99,999
100-150K PE	% of Households making $100,000 to $149,999
150-200K PE	% of Households making $150,000 to $199,999
200K more PE	% of Households making $200,000 or more
Retirement B19059 Variables - US Census	
Total Households	Total Households
With retirement income	Count of households with retirement income
No retirement income	Count of households with no retirement income
Retirement_Perc	Percentage of households with retirement income
Race and Ethnicity DP05 Variables - US Census	
Total Pop E	Total Population
One Race E	One race
One Race PE	One race %
Two Race plus E	Two or more races
Two Race plus PE	Two or more races %
Race White E	White
Race White PE	White %
Race Black E	Black
Race Black PE	Black %
Race AmIn E	American Indian
Race AmIn PE	American Indian %
Race Asian E	Asian
Race Asian PE	Asian %
Race PacIsl E	Native Hawaiian and Other Pacific Islander
Race PacIsl PE	Native Hawaiian and Other Pacific Islander %
Race Other E	Some other race
Race Other PE	Some other race %
Race HispLat E	Hispanic or Latino (of any race)
Race HispLat PE	Hispanic or Latino (of any race) %
Race NonHispLat E	Not Hispanic or Latino
Race NonHispLat PE	Not Hispanic or Latino %

Table 1.4: Codes for all data used in calculations for chapter 1

	SHR 2011	SHR 2012	SHR 2013	SHR 2014	SHR 2015	SHR 2016	SHR 2017	SHR 2018	SHR 2019
10	0.742	1.879	3.713	7.911	13.11	16.637	18.236	20.091	22.901
20	2.883	4.875	8.493	14.162	18.365	20.821	23.668	26.57	30.438
25	3.602	5.941	10.033	15.954	20.496	23.904	26.364	28.486	32.533
30	4.322	7.872	11.834	18.382	23.03	25.211	27.943	31.22	35.13
40	6.086	9.805	13.972	20.463	26.279	28.652	32.444	36.026	41.15
50	7.471	11.095	16.819	22.971	32	39.385	45.398	51.241	55.474
60	9.014	14.07	19.993	28.412	37.936	46.849	56.967	65.81	71.059
70	10.047	17.074	24.214	35.161	45.999	61.536	76.396	86.645	96.42
75	12.01	18.703	28.87	39.478	51.311	72.495	87.298	104.904	115.996
80	14.269	24.579	34.904	45.727	60.459	80.274	108.235	125.744	139.939
90	23.466	36.154	53.02	76.796	95.415	125.357	152.54	180.929	207.221

Table 1.5: SHR Quantiles for all the years in this study, chapter 1

Variable	**n**	**%**
Q14_Demographics_Gender		
Female	102	36.429
Male	175	62.5
Missing	3	1.071
Q16_Demographics_Education		
Bachelor degree	104	37.143
Graduate degree	92	32.857
Some college but no degree	40	14.286
Trade/technical/vocational training	11	3.929
Associate degree	17	6.071
High school graduate, diploma or equivalent (for example: GED)	12	4.286
Missing	4	1.429
Q17_Demographics_Income_Range		
$100,000 or more	128	45.714
$90,000 â€“ $99,999	24	8.571
$50,000 â€“ $59,999	13	4.643
$20,000 - $29,999	3	1.071
$70,000 â€“ $79,999	25	8.929
$60,000 â€“ $69,999	22	7.857
$40,000 â€“ $49,999	10	3.571
$80,000 â€“ $89,999	9	3.214
$30,000 â€“ $39,999	15	5.357
Less than $20,000	1	0.357
Missing	30	10.714
Q15_Demographics_Race_Ethnicity		
White	239	85.357
Other or multiple race/ethnicity	6	2.143
Prefer not to answer	8	2.857
Hispanic or Latino	8	2.857
Black or African American	6	2.143
American Indian or Alaska Native	1	0.357
Asian	4	1.429
Missing	8	2.857

Table 2.3: Descriptive statistics for gender, education, income, race and ethnicity.

APPENDIX B

SOLAR HOUSING SURVEY METHODOLOGY

Solar Housing Survey Report

Data Assessment and Descriptive Statistics

Intro

The purpose of this study was to examine how rooftop solar PV affected residential real estate transactions in Maricopa County, Arizona. The primary goal was to determine which of three financing arrangements existed at the time the homes were sold. These arrangements included leases with "payments" remaining at the time of sale, "prepaid" solar leases, and "owned" solar PV systems. The hypothesis is that the different kinds of ownership models for solar PV are treated in a measurably different way by the marketplace and this results in different outcomes for those who purchase these homes. Through the questions in the survey we hope to quantitatively and qualitatively measure people's experiences with pre-existing solar PV in the residential real estate market.

Sampling frame

We sampled solar housing real estate sales where the close of escrow occurred between 01 January, 2014 through 01 July, 2015. Surveys were sent out in August and September of 2015. The second round of duplicate mailings served to remind people who had not already responded to the survey from the first round.

We sampled households in single-family residential homes in Maricopa County, Arizona. While some areas of Pinal county do fall within the realm of the Phoenix-Mesa-Scottsdale metropolitan statistical area (MSA), as defined by the US Office of

Management and Budget, Maricopa County is definitely the “central county” and Pinal would be considered an “outlying county”. Further, the number of potential respondents in the MSA boundaries that overlapped Pinal county was very small, yet more difficult to capture and compare without using geospatial software or datasets to constrain the parameters to MSA boundaries.

The homes sampled already had solar PV installed at the time of sale. Solar hot water heaters did not qualify. Respondents must have identified themselves as the current homeowner at the time of the survey. While it might be possible for the mailed survey to be somehow forwarded to a landlord of a rented property, that landlord might not have a keen sense of how the solar has performed over time, nor a close interaction with the solar PV. However, if the solar PV element was a consideration in their purchase of the property, then we would want to hear about that as well. For instance, some landlords make utilities included in their rental agreement, thus might glean some profit by charging a flat monthly electricity fee to their tenants, yet paying less with a solar PV ownership or lease agreement on the property that they own. Some of the homes sampled had only solar hot water heaters but no solar PV. These respondents were excluded from the sample because we were only using solar PV as a technological focal point. Solar hot water heating is a very different technology and includes a very different set of interactions between actors and systems.

Instruments and Measures

Protocols for the Survey

This survey was distributed via US mail. The envelope contained three items. 1) Cover letter. 2) Double-sided survey questionnaire. 3) Metered business return envelope. No postage was necessary for respondents.

The questions are listed below, in the order in which they were presented to the respondents. The naming format for these questions (Q1…) was not sequential due to difficulties with the Qualtrics interface but were retained as identifiers anyway in order to maintain consistency between digital and paper responses. These "Q1" indicators were not printed on the survey. The paper version and the online version used the same ordering of questions. We also used skip-check logic that automatically skipped questions for online respondents if they did not apply to them based on their previous answers.

See cover letter and Questionnaire documents for exact layout of questionnaire.

Survey Questions listed below:

Q1 - Please enter the 4-digit Secure ID code. (Located in the upper right hand corner of the survey you received)

fill in the blank

Q2 - Do you currently own the home at this address?

a) Yes

b) No

Q25 - What kind of financing did you use to purchase this home?

a) Conventional

b) FHA

c) VA

d) Cash

e) Other

Q4 - What is the size of your solar PV system? (in kW)

fill in the blank

Q5 - Was the solar PV system leased or owned outright by the previous homeowner?

a) Leased solar

b) Owned solar

Q6 - If the solar PV system was leased, did you take over payments, or was the lease prepaid by the seller of the home?

a) Took over payments on the lease

b) Lease was pre-paid

c) N/A - system is owned

Q7 - If you took over payments on the solar lease, then how much was the monthly payment? (in $USD)

fill in the blank

Q8 - What is the name of the solar company who installed or owns the solar PV on your roof?

fill in the blank

Q9 - If the solar PV system was leased with outstanding payments, was the seller required

to pre-pay the lease before the sale of the home could be completed?

a) Yes, this was a stipulation

b) No, this was not a stipulation

c) I don't know

Q10 - Think back to before you purchased this home. When you thought about solar PV, how did the following factors influence your decision on whether or not to purchase this property?

This was a matrix of ten questions. The questions were on the Y axis and a modified Likert scale on the X axis.

The five Likert scale options included:

Very negative, Somewhat negative, Neutral, Somewhat positive, Very positive

The ten questions are listed below:

Q10_1 Good for the environment

Q10_2 Concerned about climate change

Q10_3 Cleaner energy

Q10_4 Lower electricity bills

Q10_5 Earn extra money from net-metering

Q10_6 Planning to rent the property

Q10_7 Someone I know had solar

Q10_8 Maintenance and repair costs

Q10_9 Adds value to the home

Q10_10 Would like to go off-grid

Q18 - How familiar are you with the idea of installing batteries in your home to store solar energy for later use? (This is often called "Solar Plus Batteries")

a) Very familiar

b) Somewhat familiar

c) A little familiar

d) Vaguely familiar

e) Never heard of it

Q19 - If you were to purchase home batteries for energy storage, how would you most likely use the batteries? (Rank from 1 to 3, with 1 = most likely, and 3 = least likely)

___ Backup (to provide energy in case of blackout)

___ Cycling energy on and off the grid (storing energy from your solar panels or the grid when it's cheapest, then

using it later when energy costs are more expensive)

___ To go off-grid (coupled with solar or other sources of electricity generation)

Q26 - In your current home, if such batteries had been installed in addition to solar PV, how would the batteries have influenced your decision to purchase the house?

a) Less likely to buy

b) No influence

c) More likely to buy

Q20 - How likely are you to install a home battery for energy storage in your current home?

a) Very Unlikely b) Unlikely c) Undecided d) Likely e) Very Likely

Q14 - What is your gender?

Male, Female

Q13 - What is your age?

fill in the blank

Q17 - What is your combined annual household income? This includes all residents, regardless of whether they are related.

__ Less than $20,000 __ $20,000 – $29,999 __ $30,000 – $39,999 __ $40,000 – $49,999

__ $50,000 – $59,999

__ $60,000 – $69,999 __ $70,000 – $79,999 __ $80,000 – $89,999 __ $90,000 – $99,999

__ $100,000 or more

Q15 - Which of these best describes your race/ethnicity?

___ American Indian or Alaska Native

___ Asian

___ Black or African American

___ Hispanic or Latino

___ Native Hawaiian or other Pacific Islander

___ White

___ Other or multiple race/ethnicity

___ Prefer not to answer

Q16 - What is the highest level of school you have completed or the highest degree you have received?

___ Grade school

___ Trade/technical/vocational training

___ Some high school, no diploma

___ High school graduate, diploma or equivalent (eg: GED)

___ Some college but no degree

___ Associate degree

___ Bachelor degree

___ Graduate degree

Q11 - Has the solar PV arrangement lived up to your expectations before purchasing this home? Why or why not?

fill in the blank

Q12 - Please tell us anything else you would like to share about your experience purchasing a solar home.

fill in the blank

Measures:

See cover letter and Questionnaire documents for exact language of survey fixed responses.

Survey Question descriptions:

Q1 - Unique ID used to track respondents across databases while maintaining anonymity.

Q2 - Establishes ownership of home. If yes, response was included. If no, then response was automatically excluded since the recruitment cover letter states that only the homeowner may participate in this survey. All 280 responses were from homeowners. Non-compliant responses for this key question are not included in this data set.

Q25 - Key question identifies financing model that respondent used to purchase home.

Q4 - Establishes the size of the solar PV system for comparison.

Q5 - Key question establishes basic financial model for solar PV system.

Q6 - Establishes whether respondent inherited payments from previous owner or if the lease was already paid off before final sale of the home.

Q7 - Monthly lease payment.

Q8 - Identifies solar installer.

Q9 - Key question establishes whether seller was required to pay off solar lease before home could be sold.

Q10 - Question introduction acts as a primer for memory and context, framing the subject and focusing on the thought process or heuristics that they used when thinking about solar PV on this home and how it might have impacted their decision to purchase the home.

This is a matrix of ten questions. The questions were on the Y axis and a modified Likert scale on the X axis.

The five Likert scale options include:

Very negative, Somewhat negative, Neutral, Somewhat positive, Very positive

The ten questions are classified below: (see questionnaire document for full text)

Q10_1 Environmental - global and conceptual

Q10_2 Environmental - global and conceptual

Q10_3 Environmental - local implication

Q10_4 Financial

Q10_5 Financial

Q10_6 Financial

Q10_7 Social networking interactions

Q10_8 Financial

Q10_9 Financial

Q10_10 Usage preferences, different from grid-tied solar. Sets up thinking for following questions on solar storage.

Q18 - Measures familiarity with solar storage technology.

Q19 - Measures preferences for different types of usage for solar batteries.

Q26 - Measures potential influence of solar batteries on home-buying decisions.

Note: This survey was performed in the year 2015, at a time when solar battery storage was emerging in mass media, but still a fairly new concept to most people. It was also a time just before the now-emerging trend of reducing or eliminating net-metering policies in Arizona and nation-wide.

Q20 - Measures potential influence of preferences on choice of whether to purchase solar storage technologies in the future.

Q14 - Demographics - gender

Q13 - Demographics - age

Q17 - Demographics - income

Q15 - Demographics - race/ethnicity

Q15_TEXT_Demographics_Race_Ethnicity

This is a field into which people who indicated “other” had the option to enter multiple races or ethnicities. They were recorded here.

Q16 - Demographics - education

Q11 - Open essay question - measures expectations vs perceived outcomes

Q12 - Open essay question - asks for any information that was not already represented in previous questions but that respondents felt were still important to them in their solar-home buying experience.

Note: The responses to Q11 and Q12 varied widely. While these questions did serve their intended purpose, respondents also included a great deal of comments and information related to things like solar PV markets, environmental preferences, social and policy preferences, among other topics.

Data Description:

This survey is important for real estate evaluations because it seeks to create a set of empirical observations about many individual experiences that may not be fully or accurately captured through media reports or inter-personal storytelling. For example, one of the aspects not captured by other pre-existing data sets is the distinction between paid-off solar lease arrangements at the time of sale and. leases that still had payments remaining. The public narrative treated all leases the same for the purposes of real estate sales (aka: "leased solar vs. owned solar") but the sub-category of data within leases actually suggests very different outcomes. Potential homebuyers, realtors, assessors, utilities, and policy makers could all benefit from this information.

Data collection and data entry:

We included a short URL in the cover letter that respondents could enter into their web browser to fill out the survey via our Qualtrics portal. It was mobile friendly. Only a handful of respondents took advantage of this method, even though it also included a QR code that people could access with their mobile devices. The vast majority of respondents chose to return their responses via the paper survey. We then entered this raw information into the Qualtrics web portal manually. Once imported into one database, we performed quality-control which included checking the spelling of solar company names, translation of text into numbers for reported kW size, excluding respondents with solar hot water heaters only, and duplicate responses. The latter two measures accounted for those excluded from the survey.

Notes on quality assurance:

Q19 - Solar storage rankings

One of the solar storage questions was supposed to be a ranked number question. People often answered this question improperly, in part due to the translation from digital to paper. The digital version had logic fail-safes to make sure people answered correctly while the paper version did not. Instead of ranking all three options together with a unique number from 1-3 as instructed, they used it more like a Likert scale and ranked each option individually from 1-3. This means that, while still somewhat useful to get a general sense of their preferences, this question (Q19) is neither consistently quantifiable no statistically reliable, due to the high number of non-standard responses.

Q4 - What is the size of your solar PV system? (in kW)

This question had a lot of quality control applied to it. Respondents often gave answers in what appeared to be watts (W), not kilowatts (kW). Sometimes they indicated that they weren't sure or gave answers that had to do with some other calculation instead. For those that appeared to simply answer in W instead of kW, we checked the size of the home and panels using Google earth. Where the size of the home and its installed panels appeared to be logical and reasonable, we made the adjustment to comply with kW readings.

Q8: Solar Installer

When people indicated their solar installer, sometimes the information was incomplete, incorrectly entered, or simply blank. For the records where we did have responses, we went onto Google to search for each one in order to verify the following information about each installer: a) Correct spelling of company name; b) Solar Installer actually existed and operated within Arizona. This was important because some installer names are quite similar, sometimes only a few characters different. By accurately listing the installers, we may then be able to calculate which companies did the most installations in a particular area. This could then be compared to other demographic data for analysis.

File Architecture:

This data set is in a flat file saved in .csv format. It is named: "SH_Survey_Data". The vast majority of the data was collected via paper surveys and input into the online

Qualtrics survey portal. It was then exported as .csv files and imported in batches into a Filemaker Pro database for easy viewing and analysis. Once the data was input, organized, anonymized (eg., removing personal information such as name and phone number or other contact information that respondents provided in the survey, even though this information was not requested) it was exported again to .csv format.

Variable Description:

Solar financing

The primary variables of this study have to do with ownership of the solar panels (Q5) and financing models at the time of home sale (Q6). For the two types of solar ownership respondents indicated: 151 “leased” solar arrangements and 128 “owned” solar arrangements. Of the leased solar, 95 of respondents took over payments on the lease, while 54 of the leases were pre-paid before completion of the home sale. These prepaid leases represent perhaps the most important variable in this study, as this data had not been previously captured and analyzed in this way. Another important variable is whether or not a pre-paid lease was a stipulation before the sale of the home could occur (Q9). Of the sales involving solar leases, prepaid leases were required in 13, while 85 of respondents indicated it was not a stipulation and 39 said they did not know if it was a stipulation or not.

Home financing

The third most important variable for analysis here is the question asking what kind of financing the respondents used to purchase their homes (Q25). These financing models each have different requirements and restrictions as to how or even whether real estate appraisers may value solar when determining a fair market value for the home at the time of sale. The responses for the different types of loans are as follows: 137 Conventional, 33 FHA, 32 VA, 74 Cash, 4 Other.

Demographics

The demographic questions ask about the respondent's gender (Q14), age (Q13), household income (Q17), race/ethnicity (Q15), and education (Q16). There were 175 Male and 102 Female respondents. The mean average age of these respondents was 54 years old. The greatest number of responses for income (128 responses) showed that these households made over $100,000 of annual income. The vast majority (239) self-identified as being white. As for education levels, 213 respondents reported having an associate degree or higher.

Variables for Organization and analysis:

new_primary_key

This is the primary key through which this data may be related to other data sets. It replaces the Q1 Unique ID and is also populated with a random number set.

Misc. Comments

Comments about nonstandard responses or why respondent was omitted. For instance, several respondents had solar hot water heaters only, not solar PV. This was recorded in this field and those records were excluded from this data set. In other examples, people wrote comments or expanded on answers in the margins of the survey. This was made note of in this field.

Zip_code

This is the zip code in which the home is located.

Q17 Income Range Holder

This is a quantitative field that represents the textual range which people chose. For instance, "<$20,000" = 10 in this numbered field. "$20,000-$30,000" = 20. "$30,000-$40,000" = 30, etc… It exists only for simplicity in being able to easily search for and quantify the results for this variable, since the respondents were offered a range rather than asked to indicate an exact amount.

Q15_TEXT_Demographics_Race_Ethnicity

The people who indicated "other" for race or ethnicity had the option to enter their multiple races or ethnicities here in this field.