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An Exploration of Property-Value Impacts Near Utility-Scale Solar Installations

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Abstract

Nationwide, electric utilities increasingly rely on solar installations as part of their energy portfolio. This trend begs the question of how they affect nearby home values. Understanding whether these installations are amenities or disamenities and the scale thereof will help policymakers, solar developers, and local utilities to site and build solar installations with minimal disruption to nearby communities. This paper investigates where large solar installations are located, the housing and income characteristics of the surrounding areas, and if the installations affect nearby residential property values. We approach these questions using geospatial analysis and a survey of residential property assessors. Geospatial analysis examines both housing density and median income surrounding these facilities, while the survey gauges local assessors' opinions of the impacts of these installations on property values. Property values can be a useful proxy for various non-market goods like scenic value, tax benefits, and of particular interest here, both positive and negative perceptions of utility-scale solar facilities. Our results show that while a majority of survey respondents estimated a value impact of zero, some estimated a negative impact associated with close distances between the home and the facility, and larger facility size. Regardless of these perceptions, geospatial analysis shows that relatively few homes are likely to be impacted. Though only one component of a larger analysis, these property value impacts are likely to be of growing interest as more solar facilities are built. This exploration of impacts will help inform solar developers, public officials, home assessors, and homeowners about the effects and implications of solar energy infrastructure.

Introduction

The installation of utility-scale solar facilities continues at a rapid pace across the United States, with over ten gigawatts of new photovoltaic (PV) capacity installed in 2016 alone (Bollinger et al., 2017: p. 1; Perea et al., 2016). These utility-scale PV installations, often informally called solar farms (Fehrenbacher, 2016; New York State PV Trainers Network, 2017), are defined here to include installations one megawatt (MW_{AC}) and larger. Like other power plants, these utility-scale solar installations have the potential to impact nearby home values. The potential adverse impact on home prices due to the installation of solar utilities is relevant to solar developers, public officials, home appraisers, and homeowners, yet no peer-reviewed literature has directly addressed the subject to date.

The primary research question is: Do utility-scale solar PV installations impact the value of nearby homes? This study contributes to the existing literature on amenities and disamenities by extending the research to utility-scale solar PV installations. Amenities are considered to be features that increase the value of a home, while disamenities have the opposite effect. The information in this study tackles relevant issues for solar stakeholders and identifies questions for future research.

Background and Literature Review

Residential housing literature covers a broad range of amenities and disamenities, including open-space and water views (Anderson & West, 2006; Bond et al., 2002), as well as landfills, coal-fired power plants, shale gas production facilities, oil and sour gas facilities, and transmission lines (Anderson et al., 2007; Des Rosiers, 2002; Case et al., 2006; Muehlenbachs et al., 2014; Davis, 2008; Locke, 2012), respectively. Research on High Voltage Transmission Lines (HVTLs), for example, has found adverse effects on proximate home values to be present in some analyses, while not in others, and, in general to be sensitive to micro-siting differences (Anderson et al., 2007; Des Rosiers, 2002). Alternatively, research on power plants and natural gas facilities has found that increasing proximity to the disamenity correlates to a greater change in property values (Davis, 2008; Boxall, 2005).

In the case of utility-scale wind turbines, much of the available research in the U.S. has not found consistent or compelling evidence of sales price impacts on homes (Hoen et al., 2015; Hoen & Atkinson-Palombo, 2016; Lang & Opaluch, 2013). In fact some studies have documented wind turbines' connection to increased property tax revenues to local school districts (and local taxing entities), which might be connected to increased property values by extension (Loomis & Aldeman, 2011). Additional benefits of utility-scale wind can include job growth, supply industry growth, landowner profits, and road improvement, most of which are an effect of increased tax revenue from the large installations (Loomis et al., 2016). Recent survey results suggest that U.S. residents living near wind facilities prefer living next to a wind turbine over more conventional energy infrastructure, such as coal, nuclear and natural gas (Hoen et al., 2018). Respondents in the same survey who lived within a half a mile of a wind project expressed similar preferences between living next to a wind (37 percent) or a solar facility (24 percent), with roughly a third having no opinion, but these differences were not statistically significant. This, therefore, suggests that disamenity research on wind's effects on property values, a proxy for local preferences, might provide a reasonable basis for comparison to utility-scale solar facilities.

To the best of the authors' knowledge, no existing peer-reviewed research provides quantitative evidence of property value impacts associated with utility-scale solar facilities, but existing studies address related areas. Previous research on residential PV installations, for example, has indicated that buyers place a premium on homes with PV systems (Hoen et al., 2017). In addition, available literature has explored public opinions surrounding utility-scale solar installations and perceived property value impacts. A survey by Carlisle et al. found that around 80 percent of U.S. survey respondents support the development of large-scale solar facilities both in the U.S. generally, and within their own county (2015). However, this survey also indicated that 70 percent of respondents believe these installations will decrease property values. A public opinion survey on solar facilities by the Idaho National Laboratory found that 43 percent of respondents in the southwest United States believed that a view of a large-scale solar facility would decrease the value of their home, while 23 percent believed it would increase the value (Idaho National Laboratory, 2013). In the same survey, one fifth of respondents indicated that a buffer of less than a mile would be acceptable between utility-scale solar facilities and residential areas (21 percent), while the remainder believed the buffer should be between one and five miles (26 percent), six and ten miles (16 percent), more than ten miles (21 percent), or were unsure or had no preference (16 percent). Notably, respondents in the southwest sample were more open to proximity to solar installations within one mile of a residential area (26 percent) than was the national sample. Finally, select appraiser research conducted in North Carolina has found that utility-scale solar facilities have no impact on property values (Kirkland, 2006).

In addition to the above research, various media outlets provide evidence of a perceived impact on home prices by homeowners. News articles from California, North Carolina, and Tennessee, for example, identify communities that expressed displeasure over solar installations proposed or constructed near their homes (Lunetta, 2017; McShane, 2014; West, 2015). Online forums also indicate concern by homeowners about the potential impact of a solar farm on home values (Zillow, 2017; Realtor.com, 2011; HackettstownLiFE, 2011). Some common concerns over proximity to solar farms include changes in property values due to the solar installation's appearance, safety or health concerns, or changes in the environment, such as water run-off or displaced wildlife (McShane, 2014; HackettstownLiFE, 2011; West, 2015; Appraisers Forum, 2015). Other homeowners expressed no concern about living near a solar facility, or even preferred solar farms to alternative uses like animal agriculture, wind farms, industrial uses, or housing development (Zillow, 2017; HackettstownLiFE, 2011). Online forums also indicate that appraisers have varying opinions about whether solar installations may constitute a disamenity (Appraisers Forum, 2015).

Building upon the available amenity, disamenity, and public opinion literature, this study explores the impact of utility-scale solar installations on home values using two complementary analytical approaches: a geospatial solar-siting analysis and a survey of property assessors. First, the solar-siting analysis examines both housing density and median income surrounding these solar facilities. This will provide context on the scope of potential impacts due to proximity to solar, by identifying the number of homes that may be affected and the characteristics of those residents. Next, a survey of residential property assessors was conducted to evaluate the scale and direction of those impacts, if any. This research seeks to understand both the characteristics of utility-scale solar installations as they relate to neighboring homes, and any potential impact on home prices due to proximity to a solar installation. The remainder of the paper outlines the data, methodology, and results of each analytical approach. It then identifies limitations and suggestions for further research, and concludes with recommendations for policymakers and other stakeholders.

Solar-Siting Analysis

The solar-siting analysis assesses the scope and equity distribution of utility-scale solar's potential impact on nearby property values. It does so by considering the number of homes that may be affected by proximity to solar. To do this, we mapped the locations for utility-scale solar facilities in ArcGIS 10.5, and combined it with housing census and median income data. The median income data was compared to the national average to determine if the siting of utility-scale solar raises any equity concerns.

Data

The primary data for this analysis is 956 unique solar sites completed in 2016 or earlier with confirmed latitude and longitude coordinates. This list was developed using data from the U.S. Energy Information Administration's (EIA) Form 860 and proprietary data from Lawrence Berkeley National Lab (LBNL), containing a total of 1,805 solar installations. Many utility-scale solar sites were included in both datasets, but sometimes differed in coordinates or total capacity due to aggregation. To ensure the accuracy of the latitude and longitude coordinates for these sites, the research team reviewed satellite images of each site. Installations were excluded if the provided coordinates were not directly on top of solar panels in satellite imagery. Where the EIA and LBNL sources reported different coordinates, the coordinates that more accurately aligned with the center of the array were used. Finally, entries in the EIA's database with a shared plant code ID were combined into a single facility with their summed nameplate capacity.

Ultimately we used 956 out of 1,805 installations that had been cleaned and compiled from the EIA and LBNL sources in this mapping analysis. In general, this sample of facilities used in the analysis has a similar distribution of nameplate capacity to the 1,805 installation sites. The average nameplate capacity of the full sample (1,805 installations) and the selection used in our analysis (956 installations) were not statistically significantly different (p-value = 0.5). For a complete comparison of the analyzed and total solar installation descriptive statistics, see **Appendix C.1.** The location of the facilities is also similarly distributed, with California hosting the most facilities, followed by North Carolina, in both sets. Thus, these 956 sites are representative of the total 1,805 installations from the EIA and LBNL sources. **Figures C.2 and C.3** in the appendix present histograms of total nameplate capacity for the two groups. The minimum, median, average, and maximum capacity of these 956 installations is $0.4MW_{AC}$, $4MW_{AC}$, $12MW_{AC}$, and $314MW_{AC}$, respectively.[1] These installations were then broken into categories based on capacity: 1-4.99MW, 5-9.99MW, 10-19.99MW, 20-49.99MW, 50-99.99MW, and 100+ MW.

[1] While we define utility-scale solar as facilities 1MW and higher, three sites under 1MW were included in the underlying EIA database. These were included in our dataset as well.

These GIS data are merged with data on housing density and median household income estimates throughout the United States. We used data on housing population density and median household income from the American Community Survey's 5-Year estimates of unweighted sample housing units and median household income by census block group. We joined estimated housing units and median household income per block group to TIGER/Line Shapefiles provided by the U.S. Census Bureau and displayed them as a density across the United States.

Methodology

To begin this analysis, the latitude and longitude coordinates for the verified operating solar facilities were plotted in ArcGIS. Starting from the coordinates of the solar facility, radii of 100 feet up to three miles were used to create select areas, or buffers, around the solar facilities. To account for the area of the solar facility itself, where no home could possibly exist, a circular area originating from the center of the facility was created, which we call here a "pseudo-polygon" (See **Figure A.1**). These pseudo-polygons were calculated by estimating the average area of utility-scale solar installations (the team assumed an average of 6 acres/MW), and then calculating the radius needed to equal the estimated area required. Pseudo-polygons were created for the following categories: 1MW = 1-4.99MW (6 acre circle); 5MW = 5-9.99MW (30 acres), 10MW = 10-19.99MW (60 acres); 20MW = 20-49.99MW (120 acres); 50MW = 50-99.99MW (300 acres); and 100MW = 100MW+ (600 acres) facilities. For the complete pseudo-polygon calculations, see **Appendix C.4**. Outside the pseudo-polygon, buffer zones of 100 feet, 500 feet, 1,000 feet, one half mile, one mile, and three miles were then used to estimate distances from the facilities. For a full extent of the buffer zones, see **Appendix C.5**. Estimates of the number of homes that exist within each zone were calculated, using the proportion of the block groups which overlapped with the distance radii. The number of homes within each distance radii were summed, by combining the buffer zones with aggregate housing data block group polygons. In some cases, those polygons did not fall completely within the buffer zones. In that case, housing units were estimated by comparing the area of the block group to the area intersecting the buffer zone, and proportioning the total housing units for the block group accordingly.

Albuquerque Solar Energy Center
Distance Radii and Pseudo-Polygon

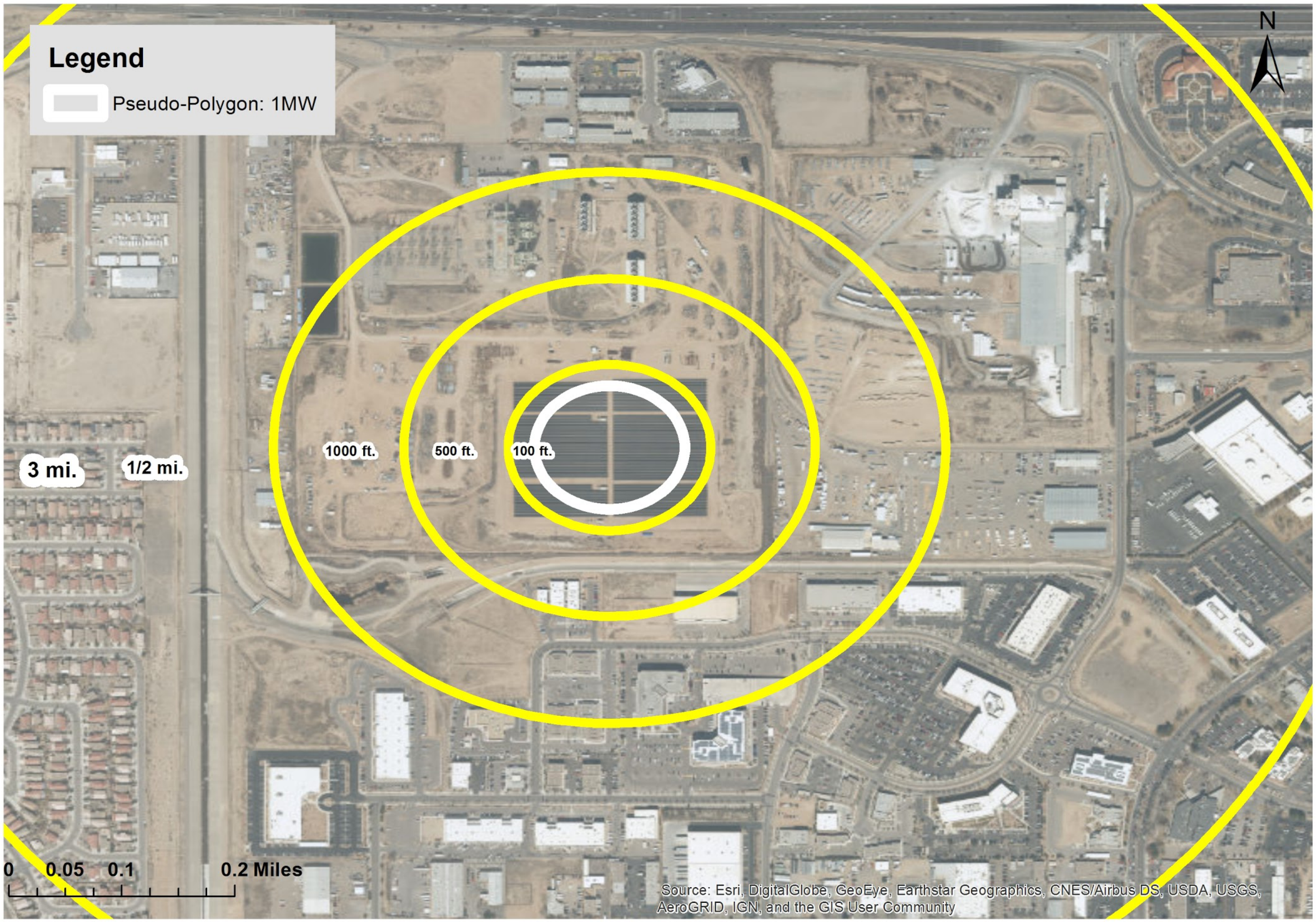


Figure A.1: *A satellite image of a pseudo-polygon (white) and the buffers (yellow) beginning at 100ft out to ½ mile are shown above. The pseudo-polygon buffers the area of the facility to account for the area where no homes can exist. As presented above, the pseudo-polygon does not encompass the entire facility, making the polygons a conservative estimate of the true facility size.*

The next analysis with ArcGIS sought to compare the median household income of residents living near utility-scale solar installations to that of the national average. Given the rapid growth of utility-scale solar within the past decade, the income of residents living nearby utility-scale solar utilities serves as an important indicator of equity in the siting of those facilities. This may be due, in part, to lower land prices. If solar were to be determined a disamenity, disproportionate build-out of utility-scale solar in lower-income communities could raise concerns about equity. In contrast, if proximity to solar is found to be an amenity, presence near lower income communities could increase home values. To determine whether or not utility-scale solar is located in communities which earn less than the national median income, we compared 2015 median income figures by block group within three miles of utility-scale solar installations to the national median income in the same year.

As above, 2015 U.S. median household income by block group data from the IPUMS NHGIS Database was joined with 2015 Block Group TIGER/Line shapefiles in ArcGIS. Of the median income data, approximately 6,484 of the 217,203 block groups (about 3 percent) did not report median incomes. As with housing density, most distance radii capture multiple block groups with differing reported median incomes. To estimate the median income at every distance, each distance radius was broken down by its percent of block groups. The median income of each weighted block group was then totaled to find a unique median income for every distance radius. In ArcGIS, this was accomplished using the same installation data and pseudo-polygons as above, and by intersecting these datasets with block group median income. A weighted sum of median income surrounding each facility at every buffer distance was calculated by determining the area of the block group intersected in proportion to the rest of the buffer area. The proportion of the block group area was then multiplied by its median income. Finally, the median income for the total area of the buffer was summed using the facility ID.

Results

Our analysis indicates that the greatest total number of estimated homes in proximity to solar installations is within three miles (cumulatively) of 1MW facilities (534,725 homes), while the smallest number of estimated homes is within 100 feet of 100MW facilities (ten homes). Heat maps of housing population with utility-scale solar installation locations both nationwide and California alone are presented in **Appendices C.6** and **C.7**. An estimate of the total number of homes within three miles of the 956 solar facilities used in our analysis is presented in **Table A.1** (for an extrapolation of the total number of homes within three miles of all 1,805 facilities, see **Appendix C.7**). These findings are consistent with the authors' expectations that more homes will be located near smaller facilities, where areas of higher population densities can only permit small facilities, and accordingly that the largest facilities will be located in rural regions. Not surprisingly, the total number of homes increases as distance from the facility, and therefore land area, increases. Further, an estimate of the average number of homes residing within the various distance radii of the capacity range of solar facilities is shown in **Table A.2**. These findings show similar trends: more homes will be found further from facilities and near smaller facilities. An average of 22 homes are located within three miles of a 1MW facility, while less than one home will be located within 100 feet of a 100MW facility, on average. Finally, a stacked bar of new utility-scale solar installations by year online and capacity size is presented in **Chart A.1**. This suggests that while the total number of all facilities is rapidly increasing, the largest facilities, 50MW and 100MW+ appear to be increasing the most rapidly.

Table A.1: *The table below provides a count of the total number of homes in the U.S. located within certain distances of utility-scale solar. As indicated below, housing estimates increase as the utility-scale solar installations decreases in MW capacity and distance from the facility increases.*

Table A.1
Total Number of Homes Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

Distance from Installation	Facility Size					
	1 - 4.99MW	**5 - 9.99MW**	**10 - 19.99MW**	**20 - 49.99MW**	**50 - 99.99MW**	**100MW**
	n = 521	n = 230	n = 83	n = 72	n = 23	n = 27
100 feet	184	129	42	41	14	10
500 feet	821	313	90	69	20	13
1000 feet	2,341	664	195	115	30	17
1/2 mile	14,146	2,747	942	438	77	34
1 mile	58,497	9,675	3,349	1,407	204	72
3 miles	534,725	87,597	27,983	10,970	1,890	419

Note: These housing counts are inlcusive of estimated homes near 956 utility-scale solar installations with verified coordinates. It does not represent a count housing near all known utility-scale solar installations in the United States.

Sources: U.S. Census Bureau 2012-2016 American Community Survey 5-Year Estimates, Unweighted Sample Housing Units. Solar installation coordinates based on EIA's Form 860 2016 Early Release and Lawrence Berkeley National Lab's proprietary Solar Installation data.

Table A.2: *The table below provides a count of the average number of homes within a certain distances of individual utility-scale solar installations. The actual number of homes will vary by facility, but this table may serve as a useful tool for estimating the number of homes impacted by utility-scale solar*

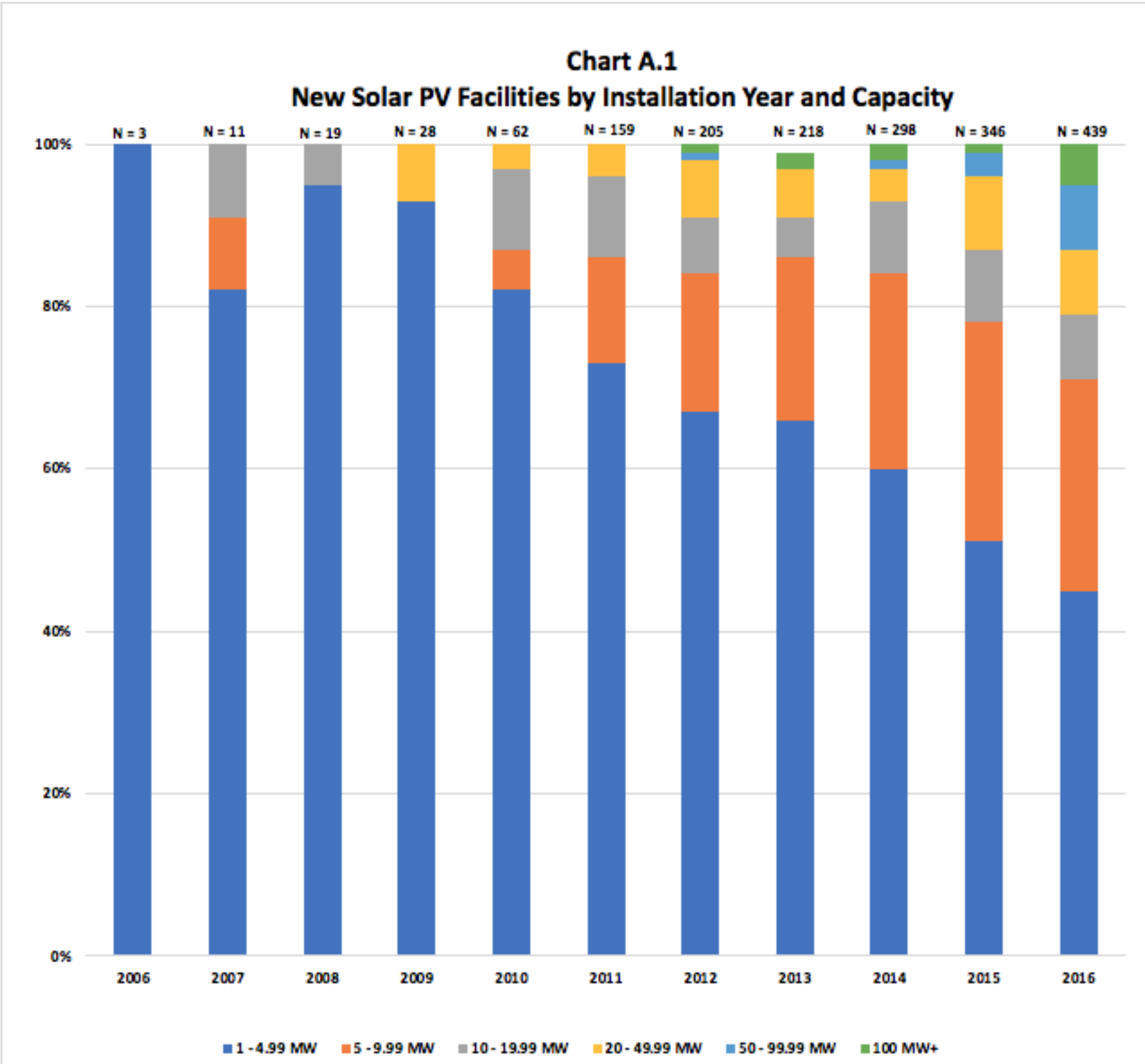
Table A.2
Average Number of Homes Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

Distance from Installation	Facility Size					
	1 - 4.99MW	**5 - 9.99MW**	**10 - 19.99MW**	**20 - 49.99MW**	**50 - 99.99MW**	**100MW+**
	n = 521	n = 230	n = 83	n = 72	n = 23	n = 27
100 feet	0.30	0.48	0.41	0.46	0.53	0.26
500 feet	0.98	0.97	0.76	0.73	0.68	0.27
1000 feet	2.23	1.72	1.45	0.94	0.91	0.34
1/2 mile	6.86	4.89	4.88	2.05	1.96	0.57
1 mile	13.25	9.64	10.24	3.53	4.00	1.11
3 miles	21.57	21.67	23.84	12.89	12.27	2.22

Note: These average housing counts are based on estimated homes near 956 utility-scale solar installations with verified coordinates only. They do not include all known utility-scale solar installations in the United States.

Sources: U.S. Census Bureau 2012-2016 American Community Survey 5-Year Estimates, Unweighted Sample Housing Units. Solar installation coordinates based on EIA's Form 860 2016 Early Release and Lawrence Berkeley National Lab's proprietary Solar Installation data.

Chart A.1: The chart below provides a count of utility-scale solar shown by capacity and year online, shown as a percentage. While 1MW are steadily increasing, larger utility-scale solar installations appear to be gaining prominence.

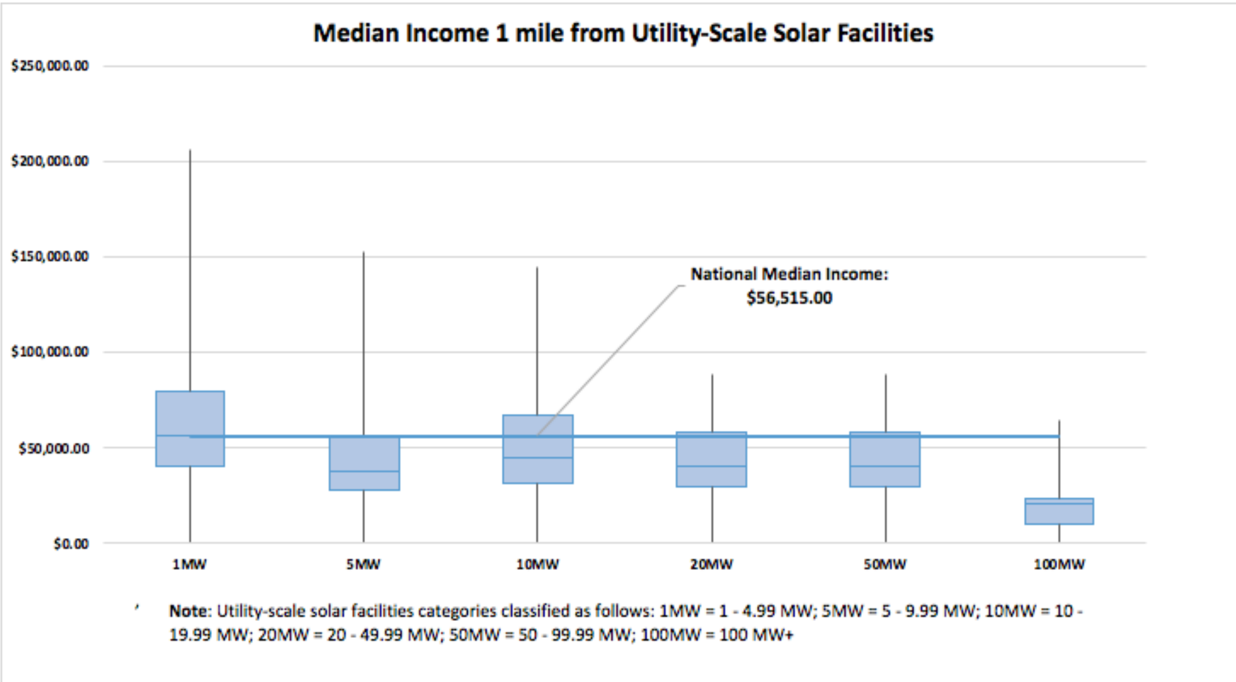


These housing density estimates inform the survey analysis discussed below by estimating the magnitude of property value impacts, if present. These total housing estimates are conservative as they only consider the 956 confirmed utility-scale solar sites, rather than all known solar sites in the United States. While an extrapolation is made in the appendix (**C.8**), the estimates are less certain. Further analysis should be expanded to all utility-scale solar sites in the U.S. with corrected coordinates, and continued analysis that stretches beyond 2015-2016 will be critical given the rapid growth of utility-scale solar. In regards to the average housing density estimates, they follow the trend that fewer homes will be expected at increasing facility sizes and decreasing distance from a facility. This housing data can be used to estimate the number of transactions that occur within these buffer zones. Transaction estimates can be adjusted based on region and current market trends.

This analysis also considered median household incomes surrounding solar installations. The estimates of 2015 median income by block group is displayed below as a box plot with a horizontal line indicating the national median household income for that year ($56,515) (See **Chart A.2**). The highest median income was located within three miles of 1MW facilities ($59,579), while the lowest median income was located within one mile of 50MW facilities ($34,223). Most notable were the consistencies of the median income near 1MW facilities with that of the national average; and that the interquartile ranges for 100MW facilities are lower than the interquartile ranges of 50MW facilities, at all distances. These findings highlight that larger facilities tend to be sited in areas with lower incomes. However, because only 27 100MW facilities were included in this analysis – in contrast to the 521 1MW facilities – the fewer observations will make the median income reported near the 27 100MW facilities more impactful to the analysis. Overall, less variability in median income of nearby residents was observed with increasing distance from a facility. Residents living within 100 feet to three miles of a 1MW utility-scale solar facility maintained relatively similar incomes ranging from approximately $57,000 to $59,000.

While not definitive, these findings raise preliminary concerns regarding equity in the locating of utility-scale solar. Our analyses suggest that the largest utility-scale solar facilities are most likely to be located in areas where residents earn lower incomes than the national average. This is consistent with the expectation that the largest facilities would require hundreds of acres of land, which will more likely be located in rural areas. Issues with unreported median incomes by some block groups influenced the calculations performed. An estimated median income of $58.89 within one mile of a 50MW facility was calculated here, but is unlikely. These low estimates are the result of unreported median income data in some block groups. While the null values were not included in the analysis, the values nevertheless affected the weighted sum calculations. Despite unreported median incomes, examination of the interquartile ranges provide valuable insight on the economic status of residents living near utility-scale solar. With the rapid expansion of utility-scale solar, our research suggests that property value impacts, whether positive, neutral or negative, could disproportionately affect homeowner's with lower incomes.

Chart A.2: *These box plots display reported median income of all residents living within one mile of utility-scale solar installations. The horizontal line displays the national median income. In general the interquartile ranges of reported median income appear to decline as installation size increases. Extreme minimums are the result of unreported income by block groups, as noted above. For a complete overview of median income, see* ***Appendix C.***



Survey of Home Assessors

Data

In addition to evaluating the scope of potential property value impacts, this research sought to quantify the scale and direction of those impacts. We distributed an online survey to public sector property assessors in 430 unique counties identified by the EIA Form 860 data as having at least one utility-scale solar PV installation. The aim of this survey was to collect opinions as to the effects of utility-scale solar PV installations on property values. Survey questions sought to evaluate, a) whether assessors believe there is an impact on home prices from utility-scale solar installations, b) the scale and direction of those impacts, and c) the sources of those impacts. Assessors, appraisers and real estate agents were all considered as possible targets for this survey research. We ultimately selected assessors, or appraisers hired by the public sector (herein referred to jointly as “assessors”), because of their work as public servants responsible for providing assessments of property values, in accordance with professional standards.

The survey asked respondents to provide several control variables, including their state and county, years of professional experience, and whether their manual provides instructions regarding utility-scale solar PV installations. They were also asked to provide their opinion of solar energy in the United States, using a 7-point Likert scale. For a full copy of the survey, see **Appendix D.1**.

To address our research questions regarding possible property value impacts, respondents were asked to estimate the impact on residential property values of three sizes of solar PV installations – 1.5MW, 20MW and 102MW – at distances ranging from 100 feet to three miles from the nearest home. These questions took the form of sliders with a range of negative 50 percent to positive 50 percent. A satellite image indicating the approximate size of each installation was also provided as a visual aid. In preparing these questions, we hoped to capture actual adjustments made by assessors in their professional practice, but allowed for perceptions of potential impacts for those assessors that have not made such adjustments. Additionally, the respondents were asked to indicate on a 5-point Likert scale whether various features of solar installations, such as their size, height, and presence of a fence or other visual barriers, would have a positive or negative impact on property values.

This survey was determined by the University of Texas at Austin IRB to be exempt from review.[2] The survey was distributed via email to approximately 400 email addresses obtained via publicly available websites. In addition, 53 counties with high numbers of installations, high total PV solar capacity, and/or older installations were identified as high priority survey targets, and were selected for phone follow-up to request their county's participation. Phone follow-ups occurred over two weeks and not all counties were reached. This follow-up procedure motivated an additional eight responses.

[2] IRB Study Number 2017-12-0067 was determined to be exempt for the qualifying period 03/20/2018 to 03/19/2021.

Survey Results

Of the approximately 400 assessors contacted via email, 37 consented to participate in the survey (a 10 percent response rate, approximately). Survey respondents were geographically dispersed across the United States, and represented 23 states of the 42 known to have utility-scale solar facilities, according to the EIA Form 860. North Carolina provided the most respondents (8), followed by Florida (3), Massachusetts (2), Connecticut (2) and Utah (2). All other states represented had one respondent. Notably, no responses were recorded from California, despite efforts to contact 13 California counties by phone. Below, **Figure B.1** provides a map of responses by state. For a more detailed breakdown of response rates by state and question, see **Appendix D.2**.

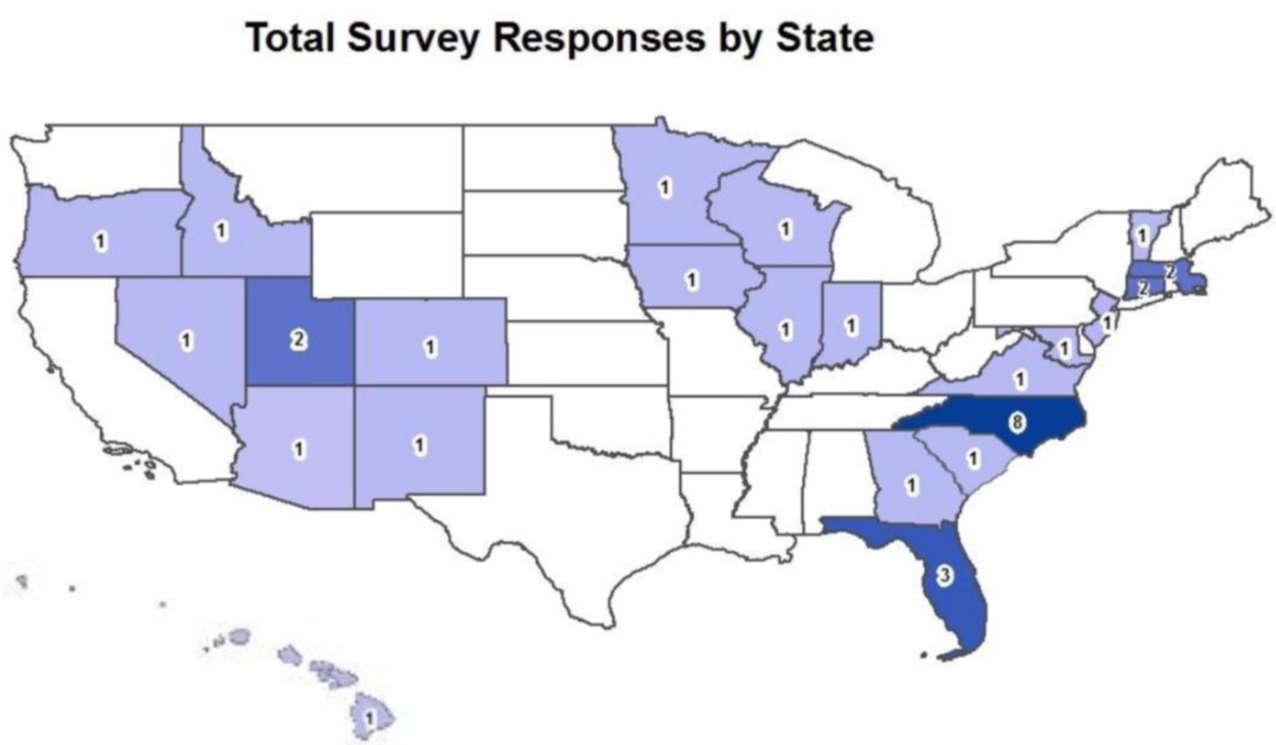
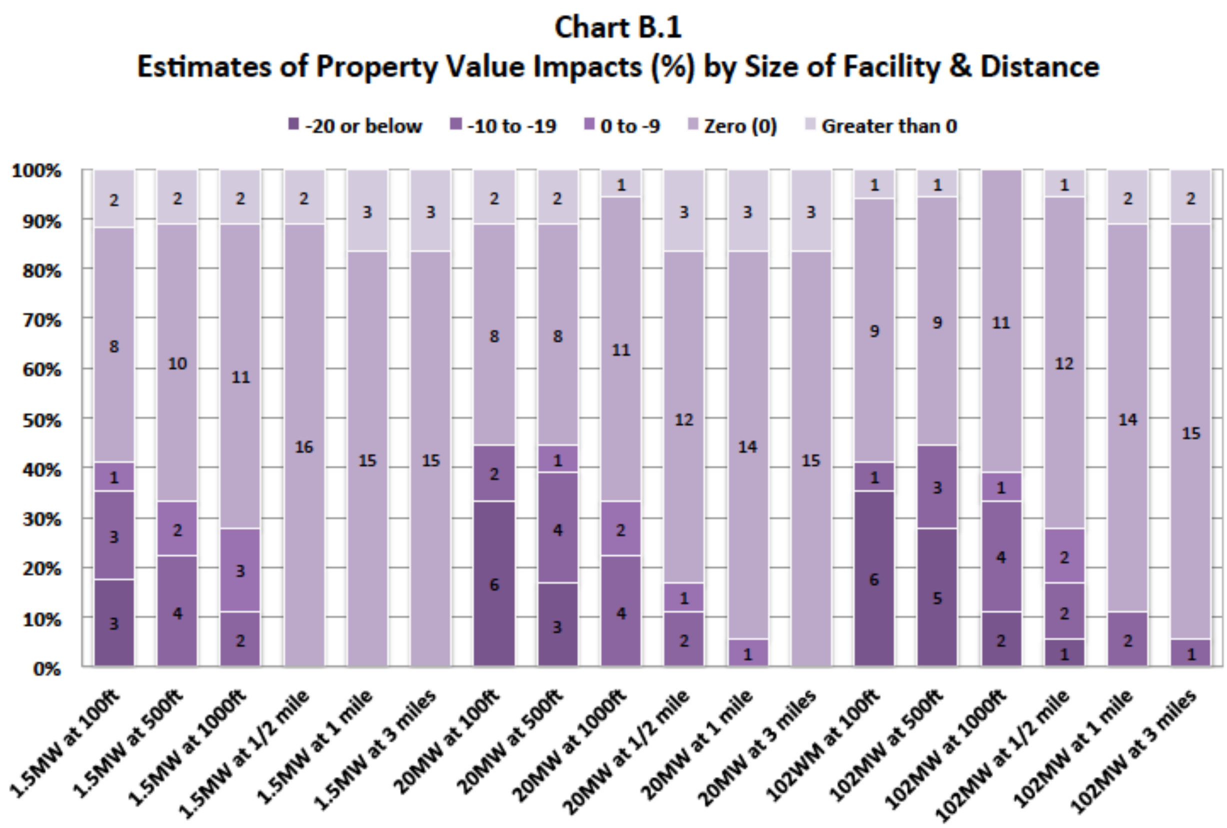


Figure B.1: *A map with the county of respondents by state is shown above.*

The number of responses varied per question, from a low of 18 to a high of 36, with more respondents providing information for control variables than for research questions surrounding estimates of property value impacts. Of the respondents that elected to participate, all were current assessors with between two years and over 40 years of assessment experience, and a mean of 21 years. The majority of respondents have completed a residential home assessment within the last two years (77 percent). Almost all respondents have completed a residential home assessment since a solar facility came online in their county (91 percent). About half of respondents that provided an answer indicated they had assessed a home near a utility-scale solar installation (45 percent), while the remainder had not (55 percent). Only one respondent (5 percent) had actually adjusted the value of a home based on the presence of a solar installation, while 21 (95 percent) had not, with the remainder declining to answer. Finally, on a 5-point Likert scale, all respondents indicated having either a neutral, positive, or extremely positive opinion of solar.

To estimate the scale and direction of property value impacts from solar installations, if any, respondents were asked to estimate this impact in percentage terms at varying distances from three sizes of solar facilities: 1.5MW, 20MW and 102MW. A summary of these responses can be seen in **Chart B.1** below. Additional descriptive statistics of the results can be seen in **Appendices D.3 - D.5**.

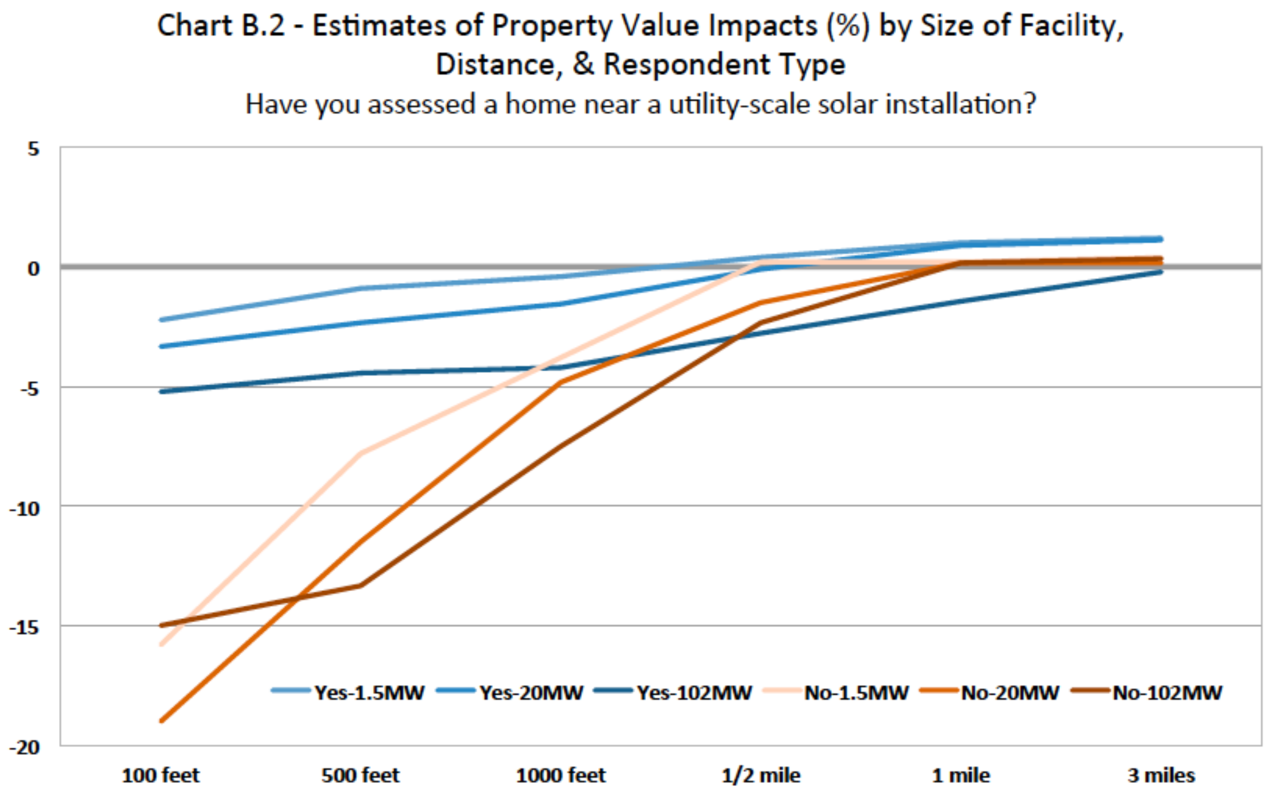
Chart B.1: *The below chart shows the estimates of home value impacts for all respondents, broken down by share of responses in various groups, at each distance for the three facility sizes.*



Estimated property value impacts at all distances and all facility sizes had a median and mode of zero percent. The majority of responses suggested either no impact (66 percent of all estimates) on home prices, or a positive impact (11 percent of all estimates), as a result of proximity to solar installations. However, some respondents did estimate a negative impact on home prices associated with solar installations. When averaging estimates across all respondents, the estimated impact was negative up to 1,000 feet, one half mile and one mile for 1.5MW, 20MW and 102MW facilities, respectively. The averages suggest that respondents estimate that greater proximity to utility-scale solar installations is linked to a more negative property value impact, and that those impacts would be larger as the size of the solar installation increases. In discussing the averages, however, it is worthy of note that highly negative estimates from a few respondents appeared to be pulling the average away from the median. For a discussion of property value impacts in dollars, see **Appendix D.7**.

Survey respondents were also asked to indicate whether they have assessed a home near a utility-scale solar installation. When comparing results of the estimated property value impacts of those that have assessed homes near solar installations to those that haven't, the data suggest that those with experience assessing near these installations are more conservative in their estimates of impact. The average estimated impact at each facility size, distance, and by assessor group is shown in **Chart B.2**. On average, respondents that have assessed near solar installations (n = 10) estimated that home value would decline by 3 percent, on average, when within 100 feet of a 20MW installation. Respondents that have not assessed near solar installations (n = 6), by contrast, estimated a 19 percent drop, on average, for the same facility size and distance. These differences were statistically significant at 100 feet and 500 feet, for 1.5MW and 20MW facilities, respectively, at the 5 percent significance level. While the responses of these two groups are different at closer proximities, they appear to converge at around one half mile.

Chart B.2: *The below chart shows the average estimate of home value impacts for two groups of respondents - those that have assessed a home near a utility-scale solar installation ("Yes") and those that have not ("No"). It shows the average of responses for each group for each distance and facility size.*



Facility size, distance, and an assessor's experience assessing near a solar installation all appear to influence estimates of impact provided by the respondent. A linear regression with clustered standard errors by respondent was used to evaluate the scale and significance of those effects. Results from this regression are shown below in **Table B.1**. The results indicate that distance does impact estimates, with greater distance between the home and the installation being associated with less negative estimates (0.04 percent per 100 feet). The results also suggest that experience assessing near a solar installation is associated with a much less negative estimate of impact (4.2 percent). Finally, the results suggest that an increase in the installation's size is associated with a more negative estimate (-0.02 percent per MW), although this result is not significant at the 10 percent level. Overall, this model has an R^2 value of 0.16, indicating relatively low explanatory power.

Table B.1: *The below table provides results from a regression model with estimates of property value impact, in percentage terms, due to proximity to solar installations as the dependent variable, and facility size (in MW), distance (in 100 feet), and a dummy variable for whether the respondent has assessed a home near a utility-scale solar installation in the past as independent variables.*

Table B.1
Regression of Estimated PV Impact (%) against Size, Distance, and Prior Assessment Near Solar

Variable	Coefficient (St. Error)	p-value
Facility Size (MW)	-0.022 (0.013)	0.121
Distance (in 100 ft)	0.042 ** (0.015)	0.014
Prior Assessment Near Solar	4.200 * (2.335)	0.092
Constant	-6.420 ** (2.356)	0.016
R^2	0.164	
No. of Observations	268	

Note: ** significant at the 5% level
* significant at the 10% level

Further, to control for the explanatory power of individual respondent's own opinions underlying their estimates of impact, we add fixed effects for each respondent to the model, removing the flag for prior assessment experience. The resulting model has an R^2 of 0.44. The coefficients on size (-0.02 percent per MW) and distance (0.04 percent per 100 feet) show little change, while size has become significant at the 10 percent level. Results for this regression are shown in **Table B.2** below.

Table B.2: *The below table provides results from a regression model with estimates of property value impact, in percentage terms, due to proximity to solar installations as the dependent variable, and facility size (in MW), distance (in 100 feet), and fixed effects for each respondent as independent variables.*

Table B.2
Regression of Estimated PV Impact (%) against Size, Distance, and Respondent ID

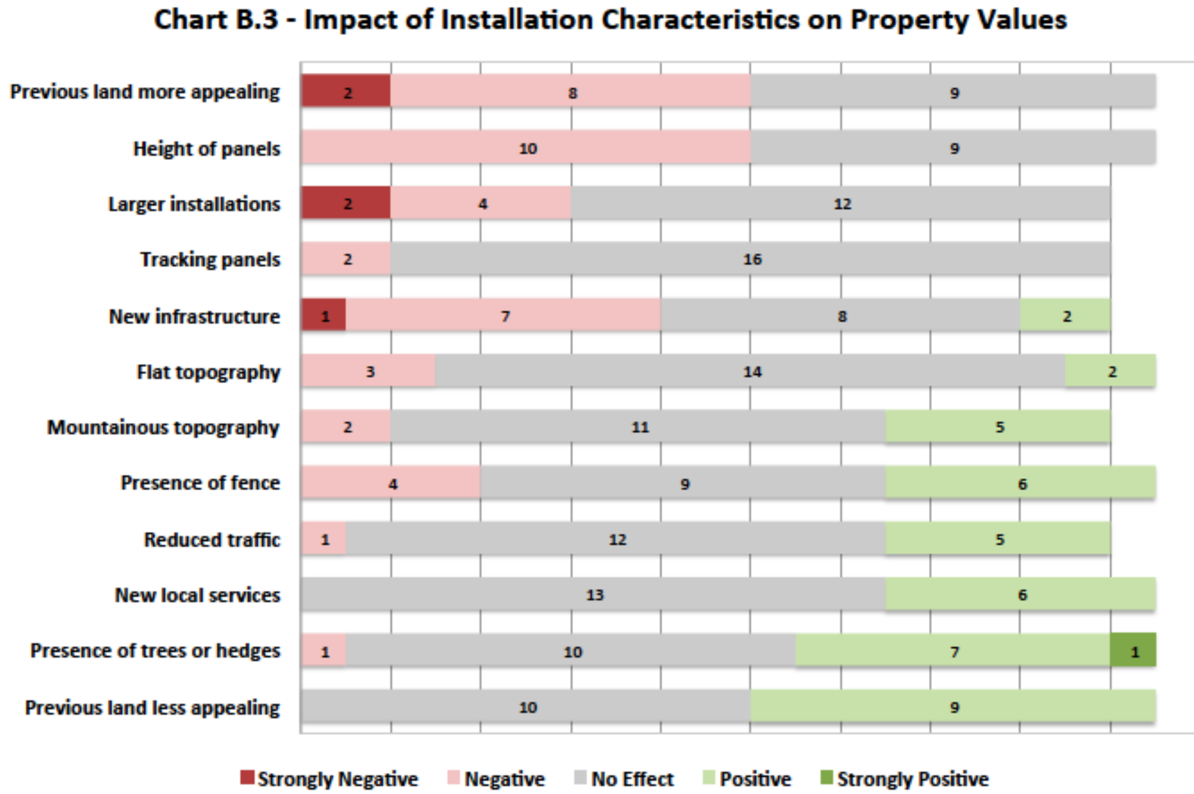
Variable	Coefficient (St. Error)	p-value	Prior Assessment
Facility Size (MW)	-0.022 * (0.011)	0.070	
Distance (in 100 ft)	0.043 *** (0.014)	0.005	
Respondent 2	7.500 *** (0.000)	0.000	Y
Respondent 3	7.500 *** (0.000)	0.000	Y
Respondent 4	7.500 *** (0.000)	0.000	--
Respondent 5	7.500 *** (0.000)	0.000	Y
Respondent 6	6.269 *** (0.523)	0.000	Y
Respondent 7	7.500 *** (0.000)	0.000	N
Respondent 8	-3.730 *** (0.227)	0.000	N
Respondent 9	0.000 (0.000)	0.387	N
Respondent 10	7.500 *** (0.000)	0.000	Y
Respondent 11	2.667 *** (0.000)	0.000	Y
Respondent 12	8.722 *** (0.000)	0.000	Y
Respondent 13	9.167 *** (0.000)	0.000	Y

Respondent 14	7.500 *** (0.000)	0.000	Y
Respondent 15	-3.330 *** (0.000)	0.000	–
Respondent 16	4.722 *** (0.000)	0.000	–
Respondent 17	-2.778 *** (0.000)	0.000	Y
Respondent 18	8.444 *** (0.000)	0.000	N
Respondent 19	-2.684 *** (0.065)	0.000	N
Constant	-8.422 *** (0.513)	0.000	
R^2	0.439		
No. of Observations	322		

Note: *** significant at the 1% level
** significant at the 5% level
* significant at the 10% level

In addition to estimates of impact, this survey aimed to identify which features of utility-scale installations, if any, might influence whether the facility is an amenity or disamenity. Respondents were asked to indicate on a 5-point Likert scale whether 12 distinct features of a solar installation would have a positive or negative impact on nearby residential property values. For full results, see **Chart B.3.** In general, the installation of a solar facility on land that was previously more appealing is opined to have a negative impact. By contrast, the installation of solar on land that had an unappealing use previously is believed to have a positive property value impact. Other features associated with negative property value impacts included higher panels, larger installations, and new infrastructure, such as power lines. The presence of trees or hedges around the array, the introduction of new local services, and reduced traffic flow were considered to have positive property value impacts. Noteworthy, however, is that the majority of respondents indicated that any given feature had no impact on property values, suggesting the features of the installation itself will not impact whether it is an amenity or disamenity.

Chart B.3: *The below bar chart shows the count of responses of each type about the impact of each characteristic of solar installations on property values. Responses ranged from "Strongly Negative" to "Strongly Positive".*



Other noteworthy observations can be drawn from the survey data. Respondents were asked to indicate if they have adjusted a home's value due to proximity to a solar installation. Only one respondent out of 18 that had assessed homes near solar facilities, indicated they had made such an adjustment. This respondent estimated a negative impact of 10 percent, 15 percent, and 25 percent for homes within 100 feet of a 1.5MW, 20MW and 102MW installation, respectively. Meanwhile, only two respondents indicated that their professional manual or other training materials provide instructions regarding residential assessments near utility-scale solar installations. These respondents were located in North Carolina and Wisconsin, states with a very large number of utility-scale solar installations and very few, respectively. Of those two, only the respondent from North Carolina provided estimates of value impacts, estimating zero percent impact across all three facility sizes at all distances.

While the survey results suggest there could be negative residential property value impacts at some proximity to solar installations, the results of the geospatial analysis suggest these impacts are unlikely to be felt by many homeowners. Estimated negative impacts from proximity to solar installations were greatest at 100 feet from the installation. However, the results of the solar-siting analysis suggest that there is less than one home, on average, within 100 feet of a utility-scale solar installation. Within half a mile of solar installations – a distance at which the average estimated impact was negative for all facility sizes – there are only seven homes near a 1MW installation, on average, and even fewer as the size of the installation increases. At the highest estimated housing density, there are 22 homes, on average, within three miles of a 1MW solar installation. However, at this distance survey respondents estimated a positive property value impact of 0.8 percent, on average.

Discussion

The results of our solar-siting analysis and survey provide some information on which to begin to estimate potential property value impacts due to proximity to solar installations. Survey responses were mixed; estimates were zero or positive for most responses, but were negative at some distances on average. Our regression models suggested that estimates were more negative at closer proximity to the installation, with greater installation size, and when provided by assessors that had not previously assessed a home near a utility-scale solar facility. In reviewing the survey results, the role of an assessor's experience working near solar facilities is worthy of note. Assessors with experience assessing near solar installations perceived considerably smaller impacts than those without such experience. In addition, the majority of assessors with experience assessing homes near solar installations did not adjust property values based on that proximity. We cannot determine from the survey whether this is because the assessors see no evidence of value impacts, or because they lack professional instructions on how make such adjustments. Even where respondents estimated negative impacts, these were typically at close proximity to the facilities. At these proximities, our solar-siting analysis suggested the number of homes likely to be impacted would be low.

The research team faced several challenges when cleaning and collecting the data for our analysis. For the solar-siting analysis, determining the accuracy of installation coordinates via satellite imagery was subject to human error. In addition, the missing block group data for median income estimates led to lower estimates than are feasible in some regions. For the survey, the geographic distribution of respondents was not representative of the distribution of solar facilities across the United States. In particular, there were no responses from California which is home to the largest number of utility-scale solar facilities. In addition, due to our small sample size, we were unable to conduct many statistical tests to test relationships in our data. These low sample sizes also led responses from a few respondents to shift the mean far from the median values. Finally, some respondents expressed hesitation in completing the survey given the lack of statistical evidence to support any estimates of property value impacts. This was difficult to address given our goal of establishing such evidence. In addition, some assessors were not aware of installations in their county, despite EIA installation data demonstrating otherwise.

Despite these challenges, the survey illuminated the opinions of assessors nationwide regarding large solar projects. Multiple assessors noted in the survey that installations in their counties are located in rural areas. These isolated settings led one respondent assessor to indicate they, "have seen no impact on real estate (home) values." Multiple respondents also noted that there is insufficient data to answer the survey questions, either due to a lack of statistical evidence or because there was only one installation in their area for reference. Our data show a discrepancy between the actual number of installations in a given county and the number perceived to be there by the assessor, which suggests that assessors may be unaware of installations within their own counties. It also indicates a lack of responsiveness to the presence of installations in such a case. One respondent cited "reasonable setback/buffers and screening" as neutralizing any potential property value impacts. Finally, another respondent introduced the importance of homeowner perception, in that "the initial fears of homeowners are the worst, being clear and upfront about how scale, potential reflection and appearance are important." Overall, we see that the assessors surveyed often see no impact due to rurality or do not feel they can make a judgment due to lack of data or evidence.

In the future, several modifications could be made to improve upon this research. In the geospatial analysis, coordinate accuracy was reviewed via satellite imagery. However, rather than excluding inaccurate coordinates, future research could improve upon this by correcting those coordinates. While our geospatial analysis relied on pseudo-polygons to estimate the surface area of facilities, generating polygon shapefiles for every site would provide more accurate estimates of housing density and median income surrounding those facilities. In addition, while the pseudo-polygons provide a significant improvement upon housing and income estimates, they were limited by the use of buckets for the size of the facilities. These polygons were based on estimates of the sizes of 1MW, 5MW, 10MW, 20MW, 50MW, and 100MW facilities only, and therefore do not estimate the exact area of each individual facility based on its capacity. As a result, these pseudo-polygons are conservative estimates of the facility's total area. There are also multiple options for continued survey research on this topic. A contingent valuation (Type III) survey could ask respondents to comment on the property values of two homes that are identical except for proximity to a utility-scale solar installation. Alternatively, a survey tool like the one used in this research could gauge perceptions of realtors or homeowners and ask about willingness to pay as a proxy for property values.

In addition to the analyses conducted here, future analyses could be improved by focusing on solar sites that are both of an appropriate size to potentially impact home values, and near a sufficient number of properties. In addition, current housing estimates could estimate the number of home transactions occurring near utility-scale solar installations. The number of homes transactions needed to generate sufficient statistical power and effect size for a hedonic regression model, for example, can inform future disamenity research. To better incorporate the effect of visual disturbance, future studies could also incorporate ArcGIS Viewshed analysis, elevation contours, or dummy variables for visibility. This study did not differentiate between ground-mounted and rooftop installations, although the vast majority of the analyzed plants are assumed to be ground-mounted. Future research could make this distinction and remove rooftop installations from the dataset. In addition, multiple assessors indicated that the installations in their counties were rural and not proximate to residential properties. Subsequent studies could pivot by investigating effects on land values, rather than home values, to account for rurality. Finally, to shift from perceived to actual property value impacts, future research can conduct analyses on home sales data to collect empirical evidence of actual property value impacts.

Conclusion

This study has investigated utility-scale solar facilities as a potential amenity or disamenity. To do so, it aimed to understand both the scope of homes potentially impacted by proximity to solar installations, and the scale and direction of those impacts, if any. The results of the solar-siting analysis indicate that very few homes, on average, are located around these utility-scale solar installations. On average, we estimate 0.53 homes or fewer are located within 100 feet of the solar installations analyzed in this research. Within three miles, we estimate only 23.84 homes surrounded 10MW facilities, on average. These results suggest the number of homes that could potentially be impacted by the presence of utility-scale solar installations are relatively few. However, as the cumulative numbers of solar installations continues to grow, the number of homes potentially impacted also grows. This is particularly true if installations are located in more dense, urban areas. In addition, the solar-siting analysis suggests that median income surrounding large solar installations may be lower than those surrounding smaller installations. Given the authors' expectations that smaller solar facilities are more likely to be located in urban areas, which typically have higher median incomes, this is not unexpected. However, it brings in questions surrounding the equity of potential property value impacts due to proximity to installations, on the basis of income level.

Results from our survey of residential home assessors show that the majority of respondents believe that proximity to a solar installation has either no impact or a positive impact on home values. However, variation in responses by size of the facility, distance from the home, and the assessor's experience assessing near such an installation previously, all impacted those estimates. Regression analyses suggest that closer proximity to an installation is associated with more negative estimates of property value impacts, as is larger installation size. Prior experience assessing near a solar installation, by contrast, was associated with more conservative estimates of impact. Meanwhile, the median and mode of all estimates of impact was zero, suggesting negative estimates from a few respondents were pulling down the mean. Additionally, the survey results indicate that respondents believe some features of solar installations may be associated with positive impacts. These include a location on land that previously had an unappealing use, or the presence of trees or other visual barriers around the array. Meanwhile, features such as being located on land that previously had an appealing use and higher installations are expected to have a negative impact, according to the respondents.

The results of this research may be of interest to solar developers, public officials, home assessors, and homeowners. In particular, solar developers should be conscientious of potential impacts on property values from their selection of a solar site and potential pushback they may face from homeowners in the process. Public officials are often tasked with approving the proposed locations of new solar installations, and, therefore, would be interested to know about the benefits or adverse consequences of those decisions. Public assessors, meanwhile, are tasked with assessing the value of homes including those located near solar facilities. The results of our survey indicate that very few assessors currently receive any instructions in their professional manual or other training materials surrounding assessments near solar installations. Finally, homeowners have an interest in the value of their home as an asset, and may be inclined to resist any modifications to nearby land use that could hurt their home's value.

This research suggests several policy interventions may be appropriate as additional research is conducted around impacts from solar installations. First, regulations around an installation's appearance and land use may help minimize impacts on property values. For example, incorporating vegetation to block the visibility of solar panels, keeping panels low to the ground, or using land with a previously unappealing use, such as an animal feedlot, may prove helpful. Second, engaging the public in the design process for these installations may help allay homeowner concerns. Third, a consideration of housing density by distance around the proposed facility should help identify the scope of potential impact for any particular facility, with the expectation that greater distance between the facility and the home is likely to see fewer impacts, if any. Finally, the results of our survey suggest a need to provide consistent and thorough instructions to property assessors on when and how to incorporate these installations into their assessment practice. Given the interest of various stakeholders, we expect continued research to better understand whether utility-scale solar causes negative price impacts to be a valuable addition to current amenity and disamenity literature.

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Appendices

Appendix C.1 - Descriptive Statistics of Analyzed & Actual Utility-Scale Solar Installations

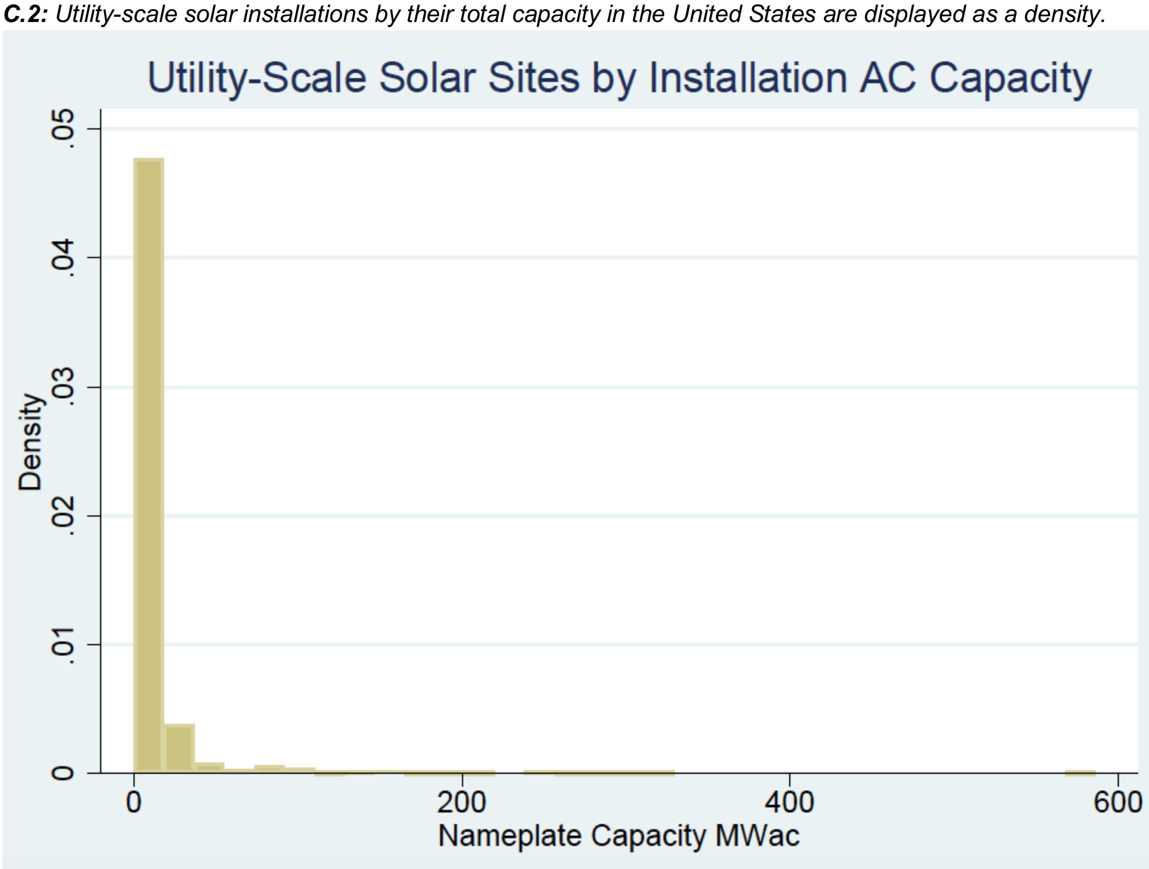
C.1: The table below provides a comparison of the sites used in the analysis (row 1) and the complete number of utility-scale solar (row 2).

Appendix C.1
Descrpitive Statistics of Analyzed and Total Utility-Scale Solar Installations

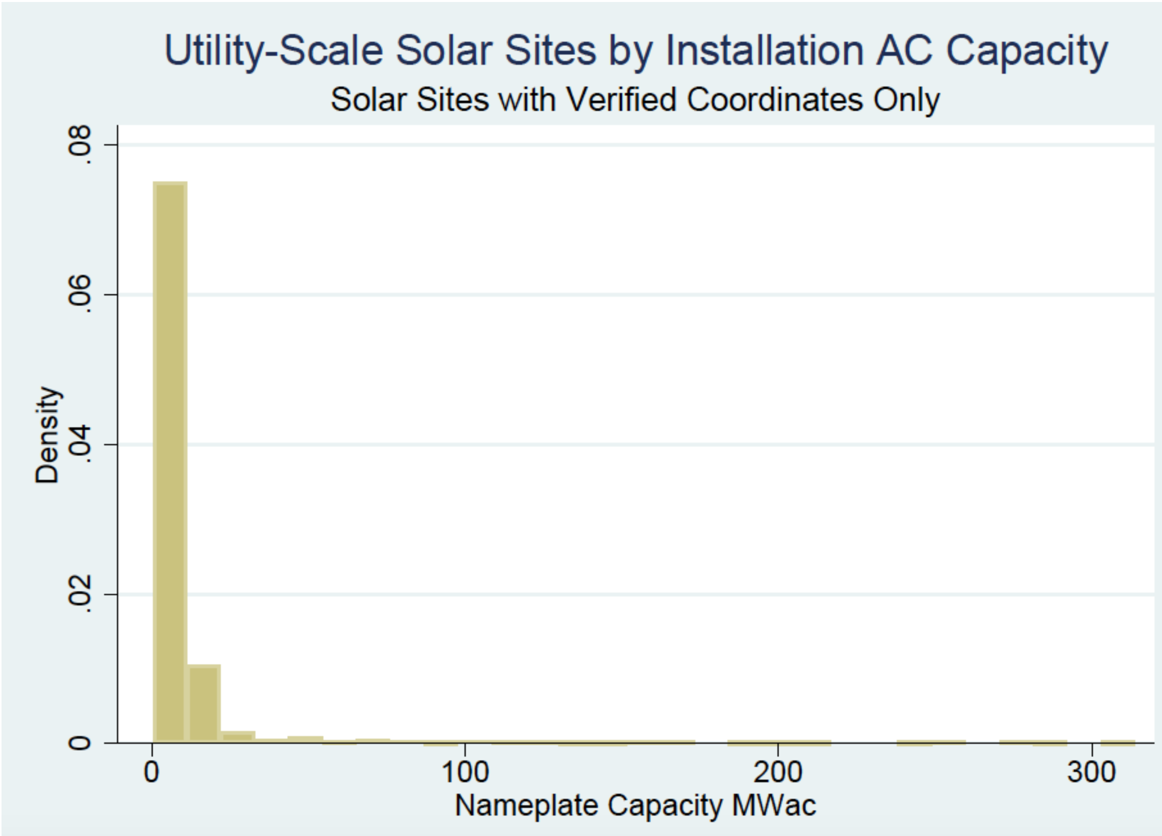
Mean	Standard Deviation	Min	25th Percentile	Median	75th Percentile	Max	n
11.3	32.7	0.1	1.6	3.2	5.5	585.9	1805
12.2	32.6	0.4	1.7	4.0	7.0	313.7	956

Appendices C.2 & C.3 - Histograms of Installation Capacity

C.2: *Utility-scale solar installations by their total capacity in the United States are displayed as a density.*



C.3: *Utility-scale solar facilities by capacity used in this analysis are displayed as a density. Comparison of the two charts shows that this research contained a greater proportion of low capacity facilities.*



Appendix C.4 - Pseudo-Polygon Calculations

C.4: *The table below shows the calculations used to create the pseudo-polygons. The team estimated approximately*

Appendix C.4
Pseudo-Polygon Calculations

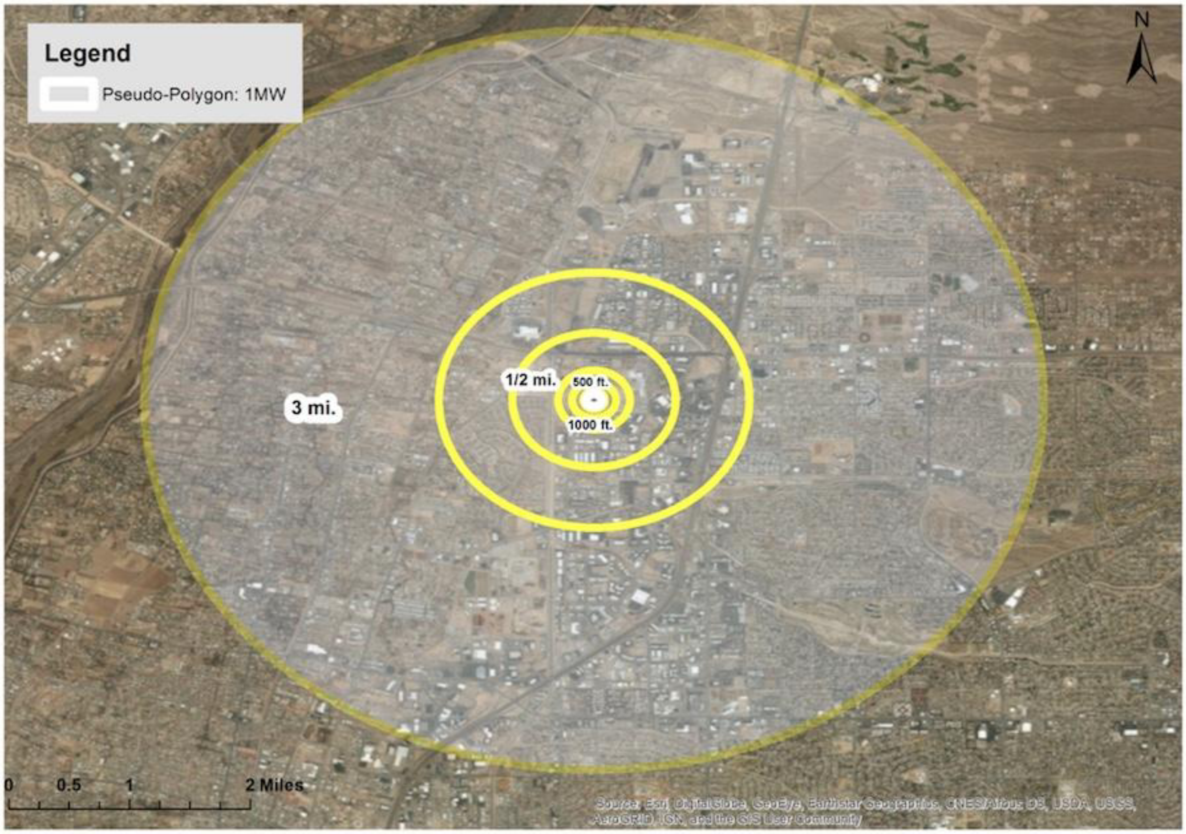
Facility Size (MW)	Area (Acre)	Radius (Acre)	Area (sq. ft.)	Radius (ft.)
1	6	1.382	261,360	288.4253
5	30	3.090	1,306,800	644.9385
10	60	4.370	2,613,600	912.0808
20	120	6.180	5,227,200	1,289.88
50	300	9.772	13,068,000	2,039.47
100	600	13.820	26,136,000	2,884.25

Note: *Team assumed 6 acres/MW to estimate the average facility area*

6 acres/MW, which was evidently conservative.

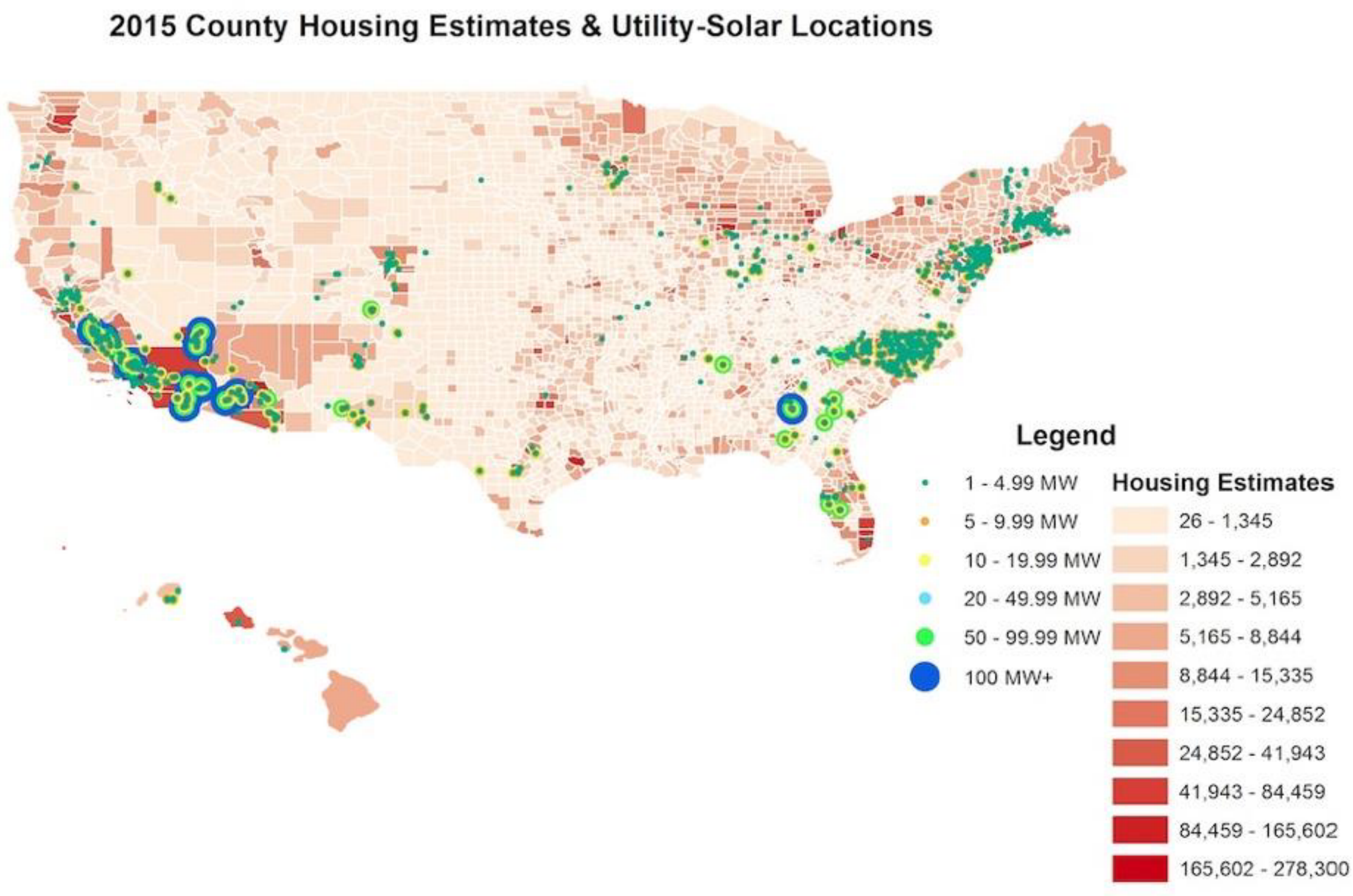
Appendix C.5 - Full Extent of Buffer Zones

Albuquerque Solar Energy Center
Distance Radii and Pseudo-Polygon: Full Extent



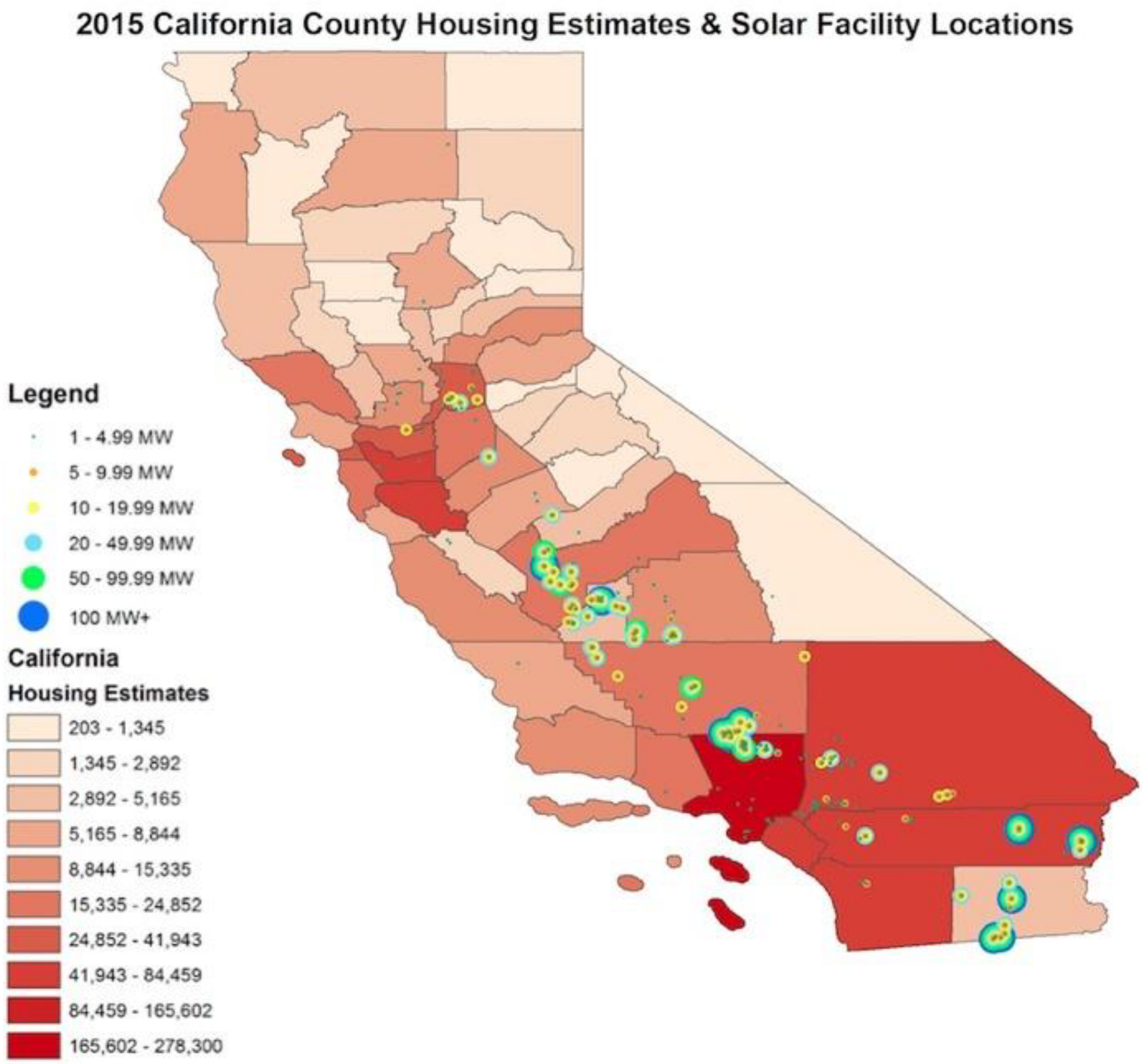
C.5: *A satellite image of the buffers (in yellow) beginning at 100ft (shown at 500ft) out to three miles are shown above. Total and average estimates of homes are made within these buffer zones and select distances.*

Appendix C.6 - Map of Housing Density Near Select Solar Sites in the U.S.



C.6: *A heat map of 2015 population in the United States with the location of utility-solar installations displayed by county. Population data was aggregated at the county level to display U.S. housing density. While block groups provide the most specific data on the location of housing populations, the are often too small to display on a nationwide map.*

Appendix C.7 - Map of Housing Density Near Select Solar Sites in California



C.7: *California housing density with utility-scale solar installations. A heat map of 2015 county population in California underscores that California is a region of high-interest to utility-scale solar research. The state is both populous and contains the most and largest utility-scale solar in the country.*

Appendix C.8 - Total Number of Homes Near Utility-Scale Solar Installations, Extrapolated to 1,805 Installations

C.8: *The table below provides a count of the total number of homes within certain distances of utility-scale solar installations. The following estimates were extrapolated to 1,805 installations using the estimates made with the 956 confirmed utility-scale solar installations.*

Appendix C.8
Extrapolated Total Number of Homes Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

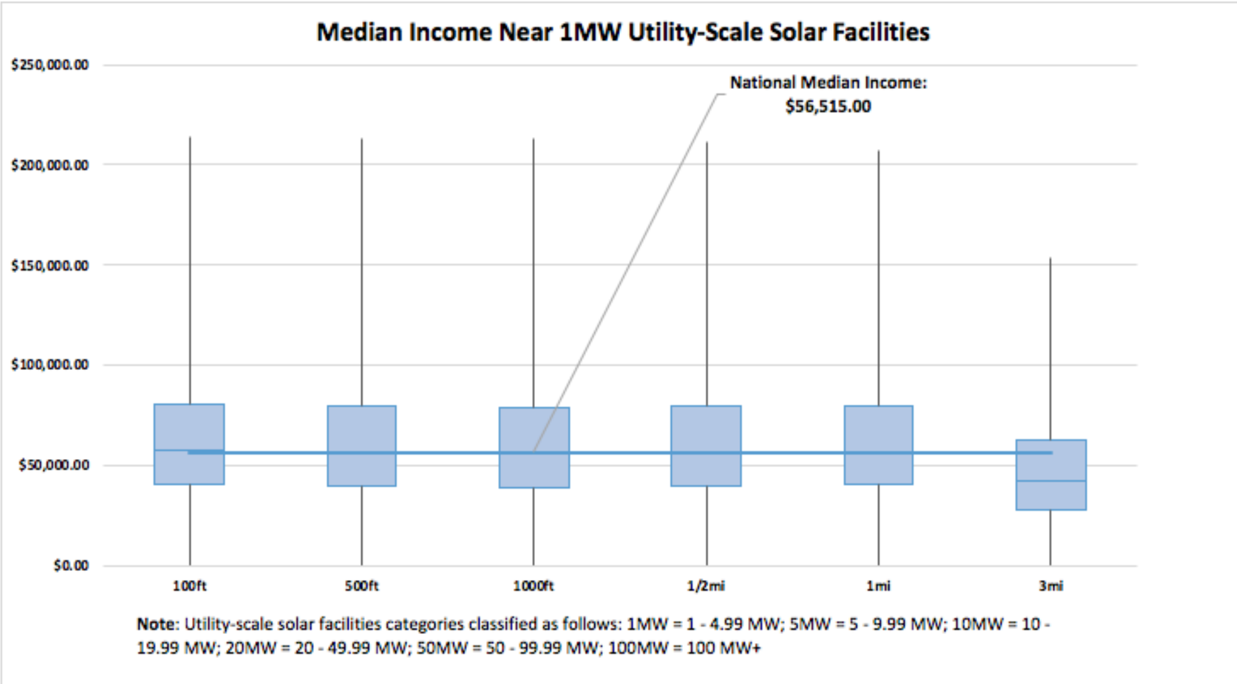
	Facility Size					
Distance from Installation	1 - 4.99MW	5 - 9.99MW	10 - 19.99MW	20 - 49.99MW	50 - 99.99MW	100 MW+
100 feet	348	244	79	77	27	19
500 feet	1,550	592	170	131	39	25
1000 feet	4,421	1,253	368	217	57	32
1/2 mile	26,709	5,187	1,778	828	145	63
1 mile	110,446	18,267	6,324	2,656	385	137
3 miles	1,009,601	165,389	52,834	20,711	3,568	792

Note: These housing counts are inlcusive of estimated homes near 956 utility-scale solar installations with verified coordinates, extrapolated to 1,805 existing solar installations

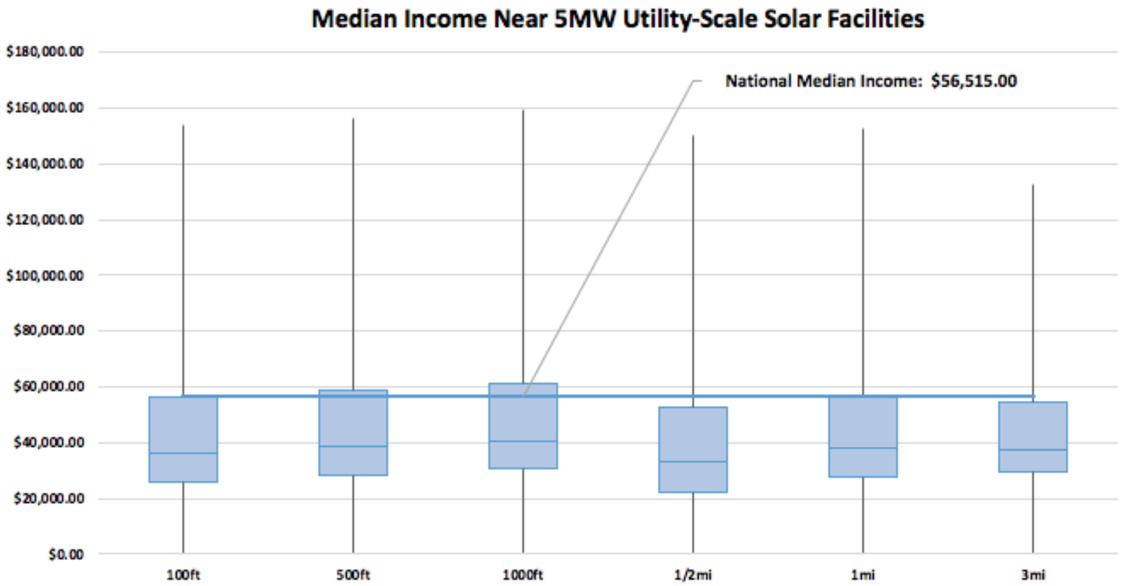
Sources: U.S. Census Bureau 2012-2016 American Community Survey 5-Year Estimates, Unweighted Sample Housing Units. Solar installation coordinates based on EIA's Form 860 2016 Early Release and Lawrence Berkeley National Lab's proprietary Solar Installation data.

Appendices C.9 - C.19 - Boxplots of Median Income by Installation Size

C.9: *Median income near all 1MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income corresponds with the median income near 1MW facilities relatively well. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*

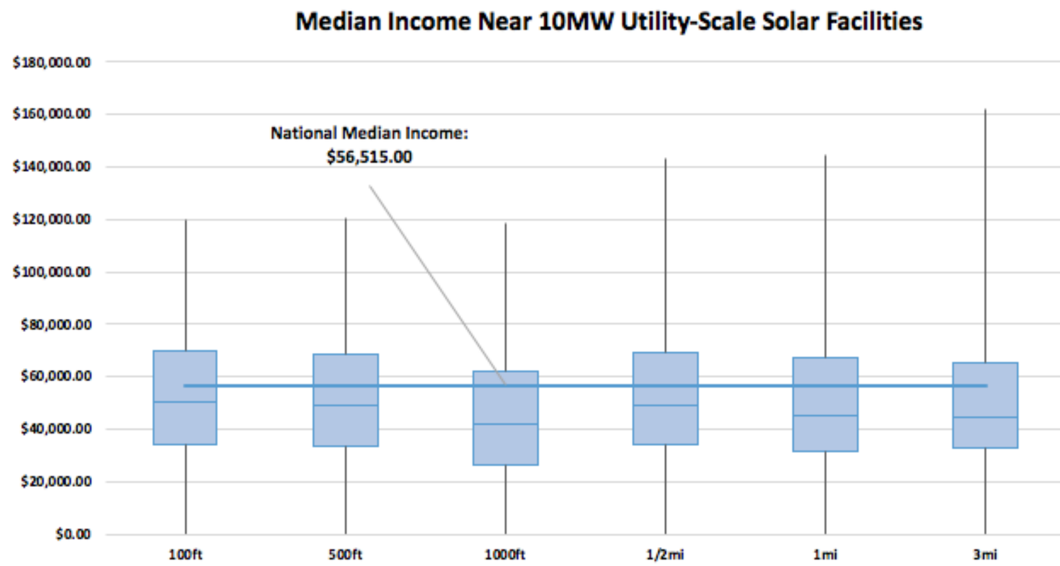


C.10: *Median income near all 5MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be higher than that of residents who live in proximity to 5MW utility-scale solar facilities. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



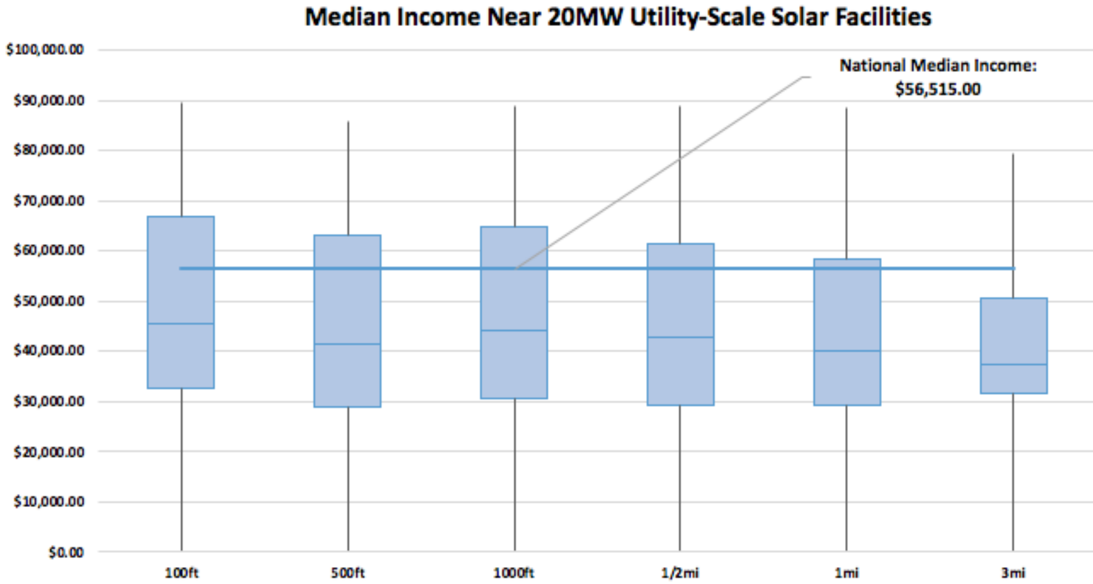
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.11: *Median income near all 10MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be higher than that of residents who live in proximity to 10MW utility-scale solar facilities. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



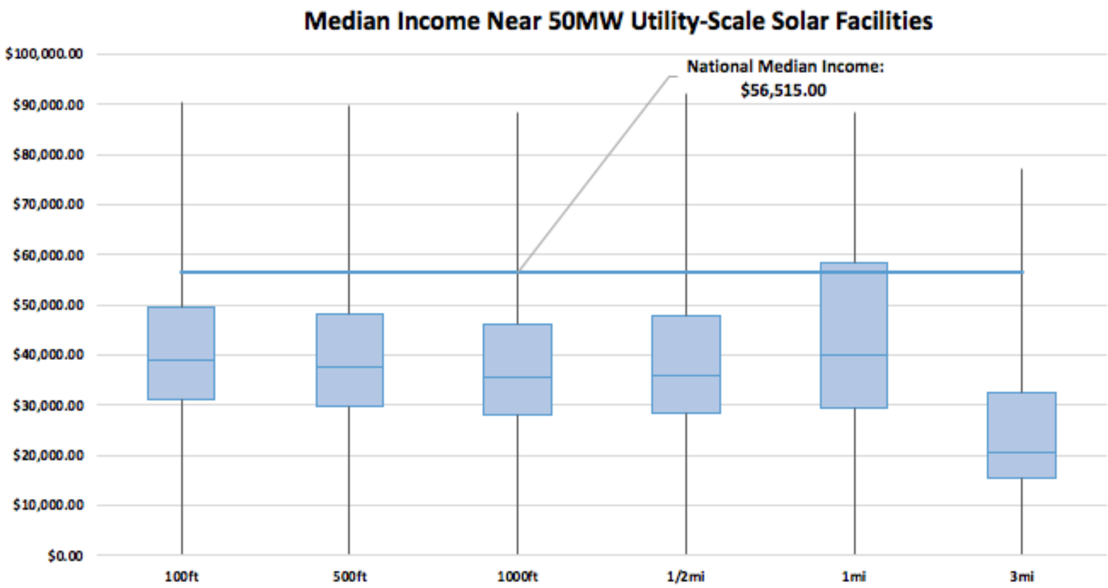
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.12: *Median income near all 20MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be higher than that of residents who live in proximity to 20MW utility-scale solar facilities. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



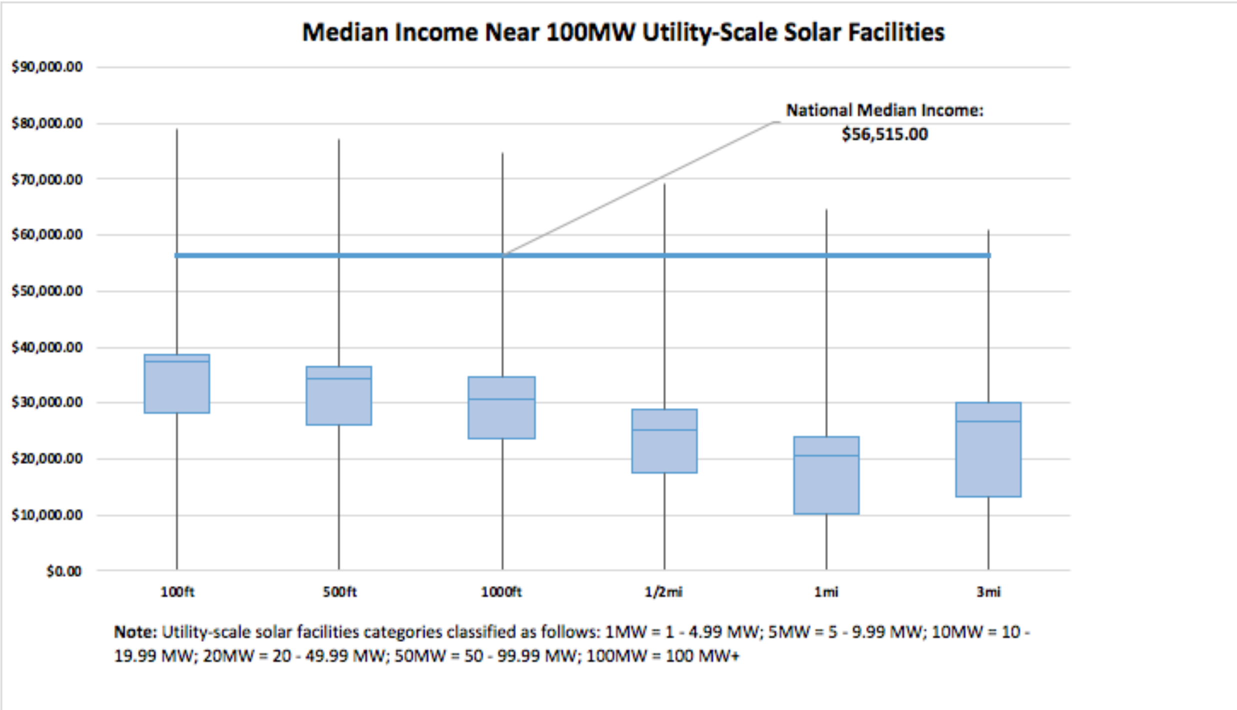
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.13: *Median income near all 50MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be higher than that of residents who live in proximity to 50MW utility-scale solar facilities. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*

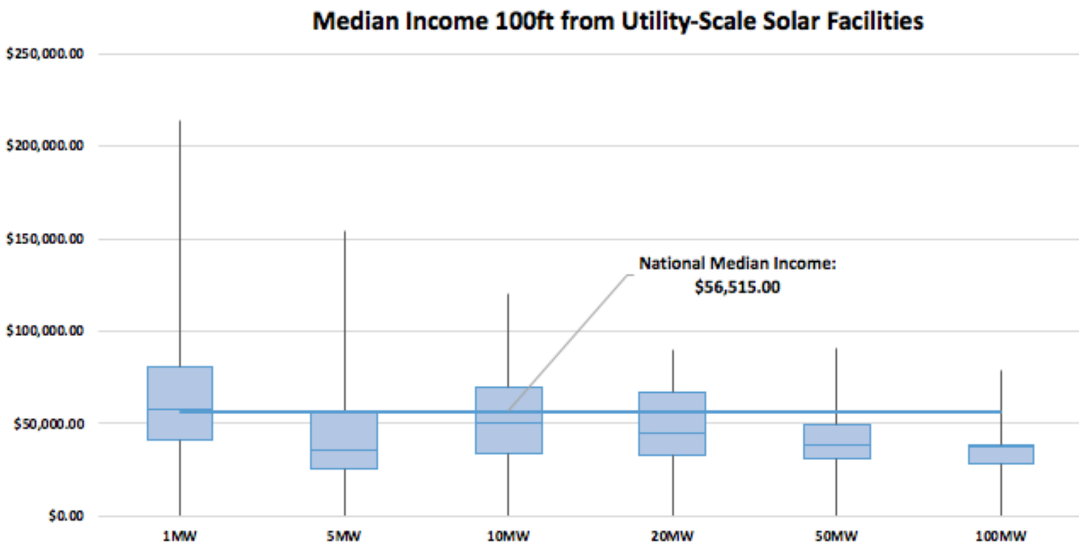


Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.14: *Median income near all 100MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be much higher than that of residents who live in proximity to 100MW utility-scale solar facilities. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*

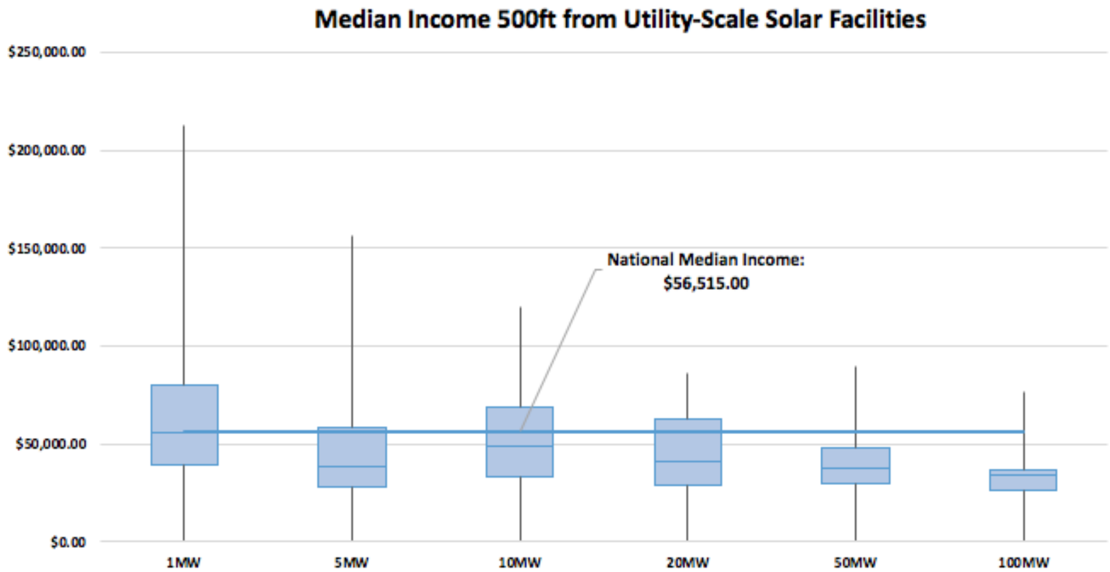


C.15: *Median income 100ft from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



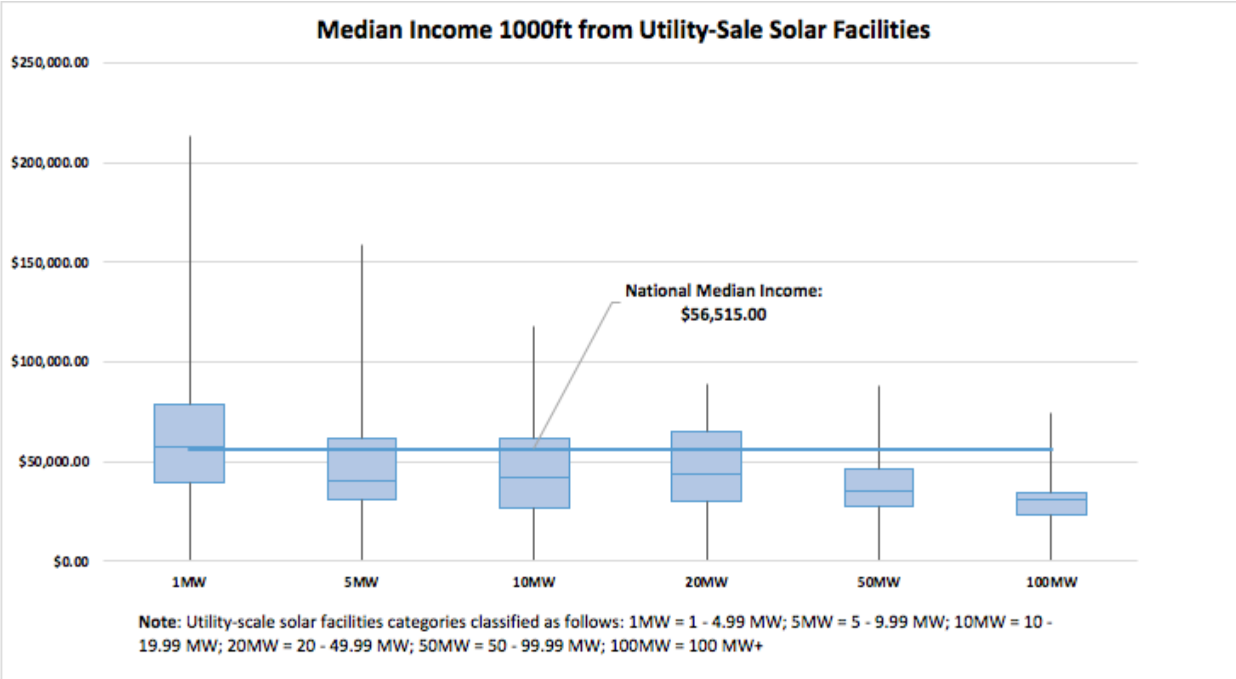
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW +

C.16: *Median income 500ft from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*

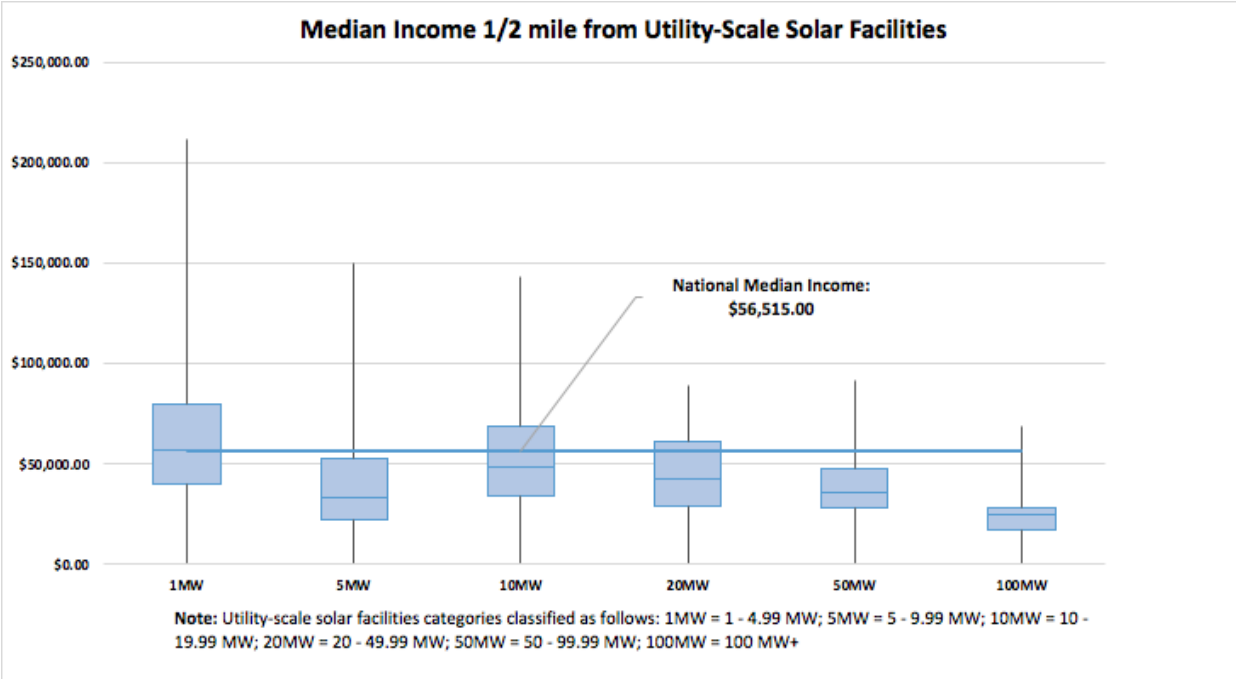


Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

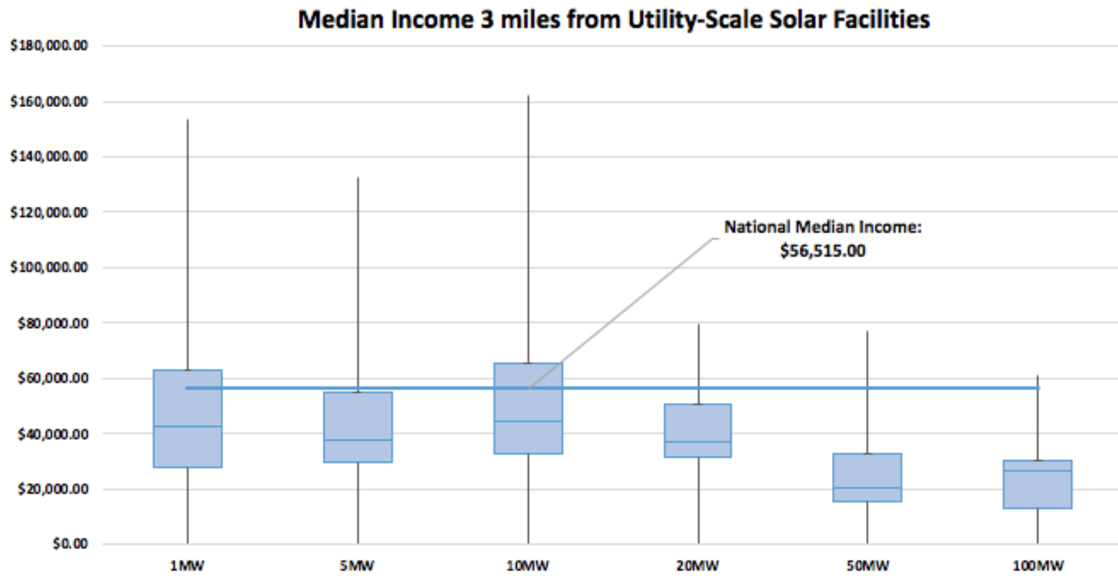
C.17: *Median income 1,000ft from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



C.18: *Median income half a mile from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



C.19: *Median income three miles from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. Extreme minimums were caused by unreported median income by about 3 percent of block groups, which affected the weighted sum calculations.*



Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5 MW = 5 - 9.99 MW; 10MW = 10 - 19.99; 20MW = 20 - 49.99 MW; 50 MW = 50 - 99.99 MW; 100MW = 100 MW+

Appendix C.20 - Median Income Near Solar Facilities

C.20: *The table below provides estimates of median income by facility size and distance from a solar facility.*

Appendix C.20
Median Income Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

Facility Type & Distance	Median Income				
	Min	1st Quartile	Median	3rd Quartile	Max
1 MW					
100 ft	$ 36	$ 41,047	$ 57,729	$ 80,801	$ 213,688
500 ft	$ 860	$ 40,622	$ 57,109	$ 80,608	$ 213,688
1000 ft	$ 355	$ 39,778	$ 57,600	$ 79,467	$ 213,688
1/2 mile	$ 27	$ 40,299	$ 57,296	$ 79,983	$ 211,761
1 mile	$ 128	$ 40,949	$ 56,887	$ 79,848	$ 206,895
3 miles	$ 17,139	$ 44,831	$ 59,579	$ 80,339	$ 170,451
5 MW					
100 ft	$ 6,114	$ 31,901	$ 42,188	$ 62,289	$ 159,833
500 ft	$ 3,531	$ 31,882	$ 42,120	$ 62,289	$ 159,833
1000 ft	$ 767	$ 31,572	$ 41,548	$ 62,111	$ 159,833
1/2 mile	$ 9,479	$ 31,810	$ 42,770	$ 62,089	$ 159,783
1 mile	$ 4,621	$ 32,490	$ 42,563	$ 61,549	$ 157,272
3 miles	$ 5,400	$ 35,226	$ 43,080	$ 60,130	$ 138,211
10 MW					
100 ft	$ 2,162	$ 36,467	$ 52,234	$ 72,143	$ 122,061
500 ft	$ 3,229	$ 36,467	$ 52,159	$ 71,828	$ 123,411
1000 ft	$ 9,984	$ 36,467	$ 51,856	$ 71,828	$ 128,343
1/2 mile	$ 1,998	$ 36,402	$ 50,788	$ 71,157	$ 145,389
1 mile	$ 4,135	$ 35,730	$ 49,397	$ 71,564	$ 148,741
3 miles	$ 3,548	$ 36,121	$ 47,984	$ 69,120	$ 165,564
20 MW					
100 ft	$ 517	$ 33,335	$ 45,888	$ 67,378	$ 90,134
500 ft	$ 4,347	$ 33,416	$ 45,860	$ 67,378	$ 90,134
1000 ft	$ 1,274	$ 31,882	$ 45,500	$ 66,006	$ 90,134
1/2 mile	$ 1,130	$ 30,424	$ 43,882	$ 62,489	$ 90,025
1 mile	$ 1,046	$ 30,482	$ 41,179	$ 59,530	$ 89,594
3 miles	$ 3,835	$ 35,420	$ 41,090	$ 54,269	$ 83,252
50 MW					
100 ft	$ 40	$ 31,338	$ 38,929	$ 49,581	$ 90,505
500 ft	$ 1,425	$ 31,305	$ 38,929	$ 49,581	$ 91,194
1000 ft	$ 3,333	$ 31,277	$ 38,929	$ 49,581	$ 91,907
1/2 mile	$ 1,156	$ 29,679	$ 37,009	$ 49,076	$ 93,230
1 mile	$ 59	$ 28,622	$ 34,223	$ 48,405	$ 94,386
3 miles	$ 13,508	$ 29,061	$ 34,270	$ 46,109	$ 90,734
100 MW					
100 ft	$ 1,344	$ 29,444	$ 38,834	$ 39,889	$ 80,383
500 ft	$ 3,312	$ 29,444	$ 37,725	$ 39,870	$ 80,383
1000 ft	$ 5,632	$ 29,444	$ 36,467	$ 40,249	$ 80,383
1/2 mile	$ 11,146	$ 28,649	$ 36,467	$ 39,870	$ 80,383
1 mile	$ 15,869	$ 26,115	$ 36,467	$ 39,870	$ 80,383
3 miles	$ 9,767	$ 22,936	$ 36,467	$ 39,870	$ 70,747

Note: These estimates are based on the median income in areas surrounding 956 utility-scale solar installations with verified coordinates. It does include all known utility-scale solar installations in the United States.

Sources: IPUMS National Historical Geographic Information System: Version 12.0. 2015 American Community Survey: 5-Year Data [2011-2015, Block Groups & Larger Areas], Minneapolis: University of Minnesota. 2017.
Solar installation coordinates based on EIA's Form 860 2016 Early Release and Lawrence Berkeley National Lab's proprietary Solar Installation data.

Appendix D.1: Survey Instrument

University of Texas - Lawrence Berkeley National Lab Solar Installations and Property Values Study

Hello and thank you for taking the time to participate in our survey on property values near solar installations. Below is a consent form with information about our study. We appreciate your feedback.

Identification of Investigator and Purpose of Study

Thank you for participating in this research study, entitled "Property-Value Impacts Near Utility-Scale Solar Installations." The study is being conducted by Dr. Varun Rai, Leila Al-Hamoodah, Eugenie Schieve, and Kavita Koppa at the LBJ School of Public Affairs of The University of Texas at Austin, PO Box Y, Austin, TX, 78713. You can reach the team via email at varun.rai@mail.utexas.edu.

The purpose of this research study is to examine the effects of utility-scale solar installations on residential property values. Your participation in the study will contribute to a better understanding of how these effects, if they exist, are incorporated into property value assessment. You are free to contact the research team at the above email address to discuss the study. You must be at least 18 years old to participate.

If you agree to participate:

- You will complete a survey about if and how utility-scale solar installations affect property values.
- The survey will take approximately 10 to 15 minutes of your time.
- You will not be compensated for your participation.

Risks/Benefits/Confidentiality of Data
There are no known risks to participation in this survey. There will be no costs to you for participating, nor will you be compensated. Your email address will be kept during the data collection phase for tracking purposes, and to share final results with you if you indicate you want them. A limited number of research team members will have access to the data during data collection and analysis. Personally identifying information, including email address, will be stripped from the final dataset. Email addresses will not be shared.

Participation or Withdrawal
Your participation in this survey is voluntary. You may decline to answer any question and you have the right to withdraw from participation at any time. Withdrawal will not affect your relationship with The University of Texas in any way. If you do not want to participate you may close your browser window at any time to exit the survey. If you do not want to receive any more reminders about the survey, please click the opt-out link in the invitation email you received.

Contacts
If you have any questions about the study or need to update your email address, send an email to varun.rai@mail.utexas.edu. This study has been reviewed by The University of Texas at Austin Institutional Review Board and the study number is [STUDY NUMBER].

Your Rights as a Research Participant
If you have questions about your rights or are dissatisfied at any time with any part of this study, you can contact, anonymously if you wish, the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

This page serves as your formal consent to participate in this study. Please print a copy of this page for your records. If you agree to participate in this study, click indicate your consent below.

Please indicate your consent to participate in this survey.

◯ **I consent** to participate in this survey

◯ I **do not** consent to participate in this survey

Thank you for taking the time to complete this survey. This survey is intended for individuals who are currently or were recently employed as a home assessor or home appraiser in the United States for the public sector. We recommend completing this survey on a laptop or desktop computer, rather than on a phone or tablet.

While completing this survey, please consider the following definitions as used in this survey:

1. **Utility-scale solar installations** include any ground-mounted photovoltaic (PV) solar arrays that sell electricity to a utility rather than providing electricity for residential use. These installations can be of any size but utility-scale are typically considered to be at least 1 megawatt (MW), which may cover between 5 and 9 acres of land per MW. See the images below for examples of utility-scale solar installations.
2. **Assessment** refers to the process of assessing or appraising the value of a home for the public sector.
3. **Assessment value or appraisal value** refers to the monetary value public assessors or public appraisers estimate for a home. For the purposes of this survey, assessment value and appraisal value may be referred to simply as "value". Impacts on home prices refer to monetary impacts (i.e. a change in the value of the home).

If you have any questions while completing the survey, please contact varun.rai@mail.utexas.edu. Thank you for your time.

Examples of utility-scale solar installations in the United States.

We would like to know more about the role in which you assess homes. Which of the following best describes you?

- ◯ I am **currently** an assessor or appraiser for the public sector (i.e. I am employed by a county or town to perform assessments)
- ◯ I was **formerly** an assessor or appraiser for the public sector
- ◯ I have **never** been an assessor or appraiser for the public sector
- ◯ I prefer not to answer

How many years of experience do you or did you have in assessing for the public sector? *Please indicate the number of years only in your response. For example, please indicate "9" rather than "nine" or "9 years."*

____

What was the approximate date of the most recent residential assessment you completed?

Year 2015

Month ✓

January
February
March
April
May
June
July
August
September
October
November
December

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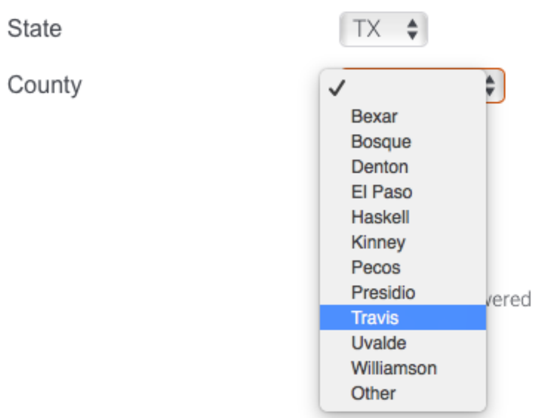
In which state and county (or county equivalent) are/were you most recently employed as an assessor or appraiser for the public sector?



Because you selected "other", please indicate the county (or county equivalent) you are or were most recently employed as an assessor or appraiser for the public sector?

____

To the best of your knowledge, approximately how many utility-scale solar installations are currently operating in the county (or county equivalent) where you are/were most recently employed as an assessor for the public sector?
Please indicate the number of installations only in your response. For example, please indicate "5" rather than "five" or "about five."

____

Does your professional manual or do your professional training materials provide instructions regarding assessing home values that are located near a utility-scale solar installation?

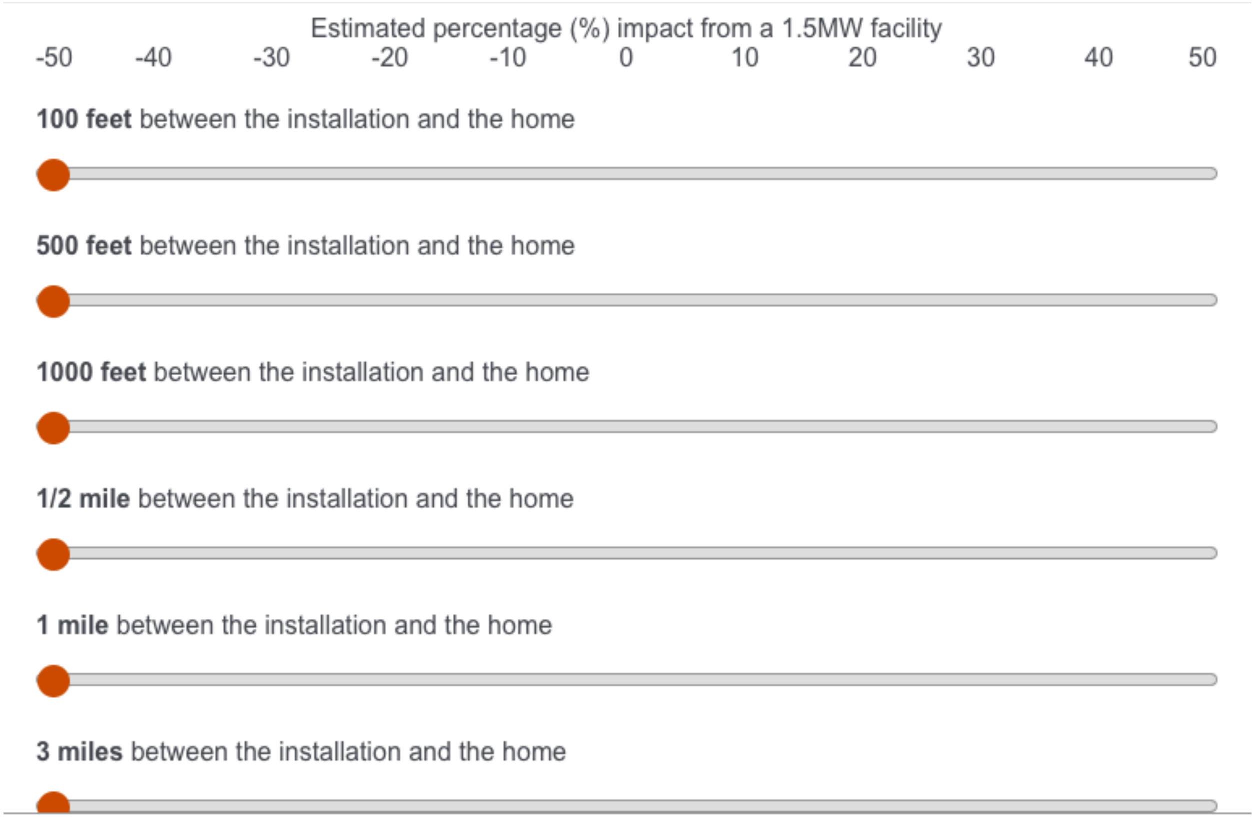
- ○ Yes
- ○ No
- ○ I don't know
- ○ I don't have a manual or other professional materials
- ○ I prefer not to answer

Part I: 1.5MW Facilities

Please use the sliders below to estimate if and how the presence of a **1.5MW** utility-scale solar installation would impact a nearby home's assessment value **in percentage terms**. Please do so at the varying distances between the home and the nearest solar panel.

1.5MW utility-scale solar installations may cover between 7.5 to 13.5 acres. For an example of a 1.5MW solar installation, please refer to the image below.

- Please indicate a value of **0** if the value of the home would not be impacted in any way by the presence of a 1.5MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **greater than 0** if the value of the home would increase by the presence of a 1.5MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **less than 0** if the value of the home would decrease by the presence of a 1.5MW solar installation at a given distance, in percent terms.


Estimated percentage (%) impact from a 1.5MW facility

-50 -40 -30 -20 -10 0 10 20 30 40 50

100 feet between the installation and the home

500 feet between the installation and the home

1000 feet between the installation and the home

1/2 mile between the installation and the home

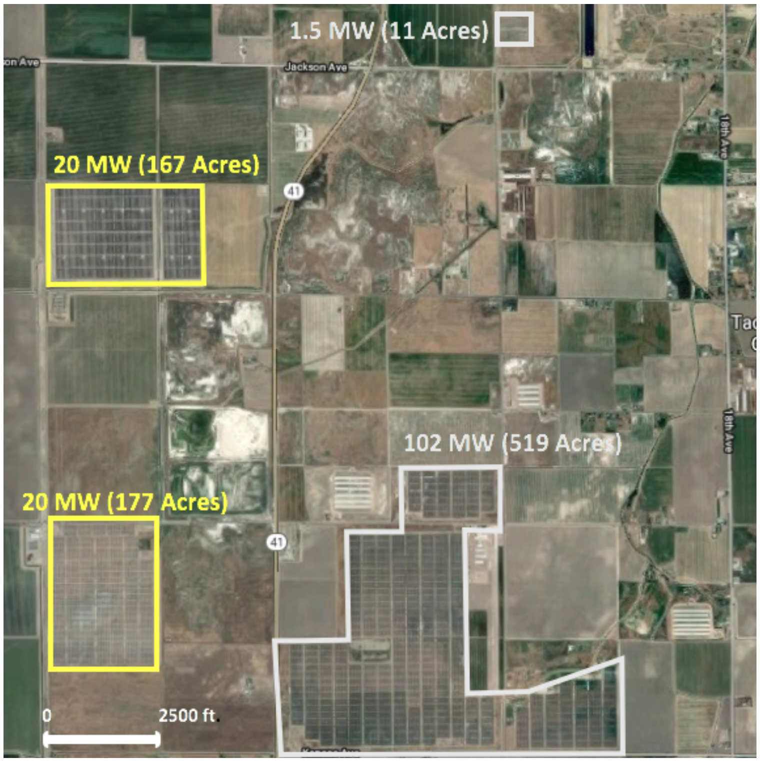
1 mile between the installation and the home

3 miles between the installation and the home

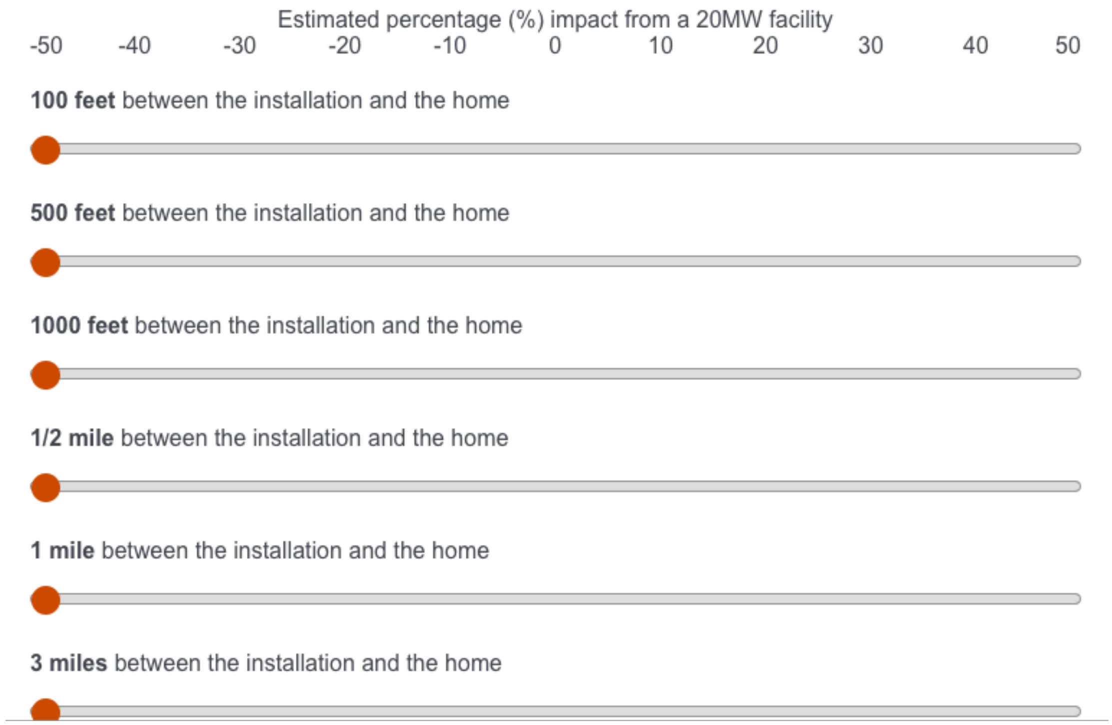
<u>Part II: 20MW Facilities</u>

Please use the sliders below to estimate if and how the presence of a utility-scale solar installation of 20MW would impact a nearby home's assessment value in percentage terms. Please do so at the varying distances between the home and the nearest solar panel.

Utility-scale solar installations of 20MW may cover 100 to 180 acres. For an example of a solar installation of 20MW, please refer to the image below.



- Please indicate a value of **0** if the value of the home would not be impacted in any way by the presence of a 20MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **greater than 0** if the value of the home would increase by the presence of a 20MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **less than 0** if the value of the home would decrease by the presence of a 20MW solar installation at a given distance, in percent terms.


Estimated percentage (%) impact from a 20MW facility
-50 -40 -30 -20 -10 0 10 20 30 40 50

100 feet between the installation and the home

500 feet between the installation and the home

1000 feet between the installation and the home

1/2 mile between the installation and the home

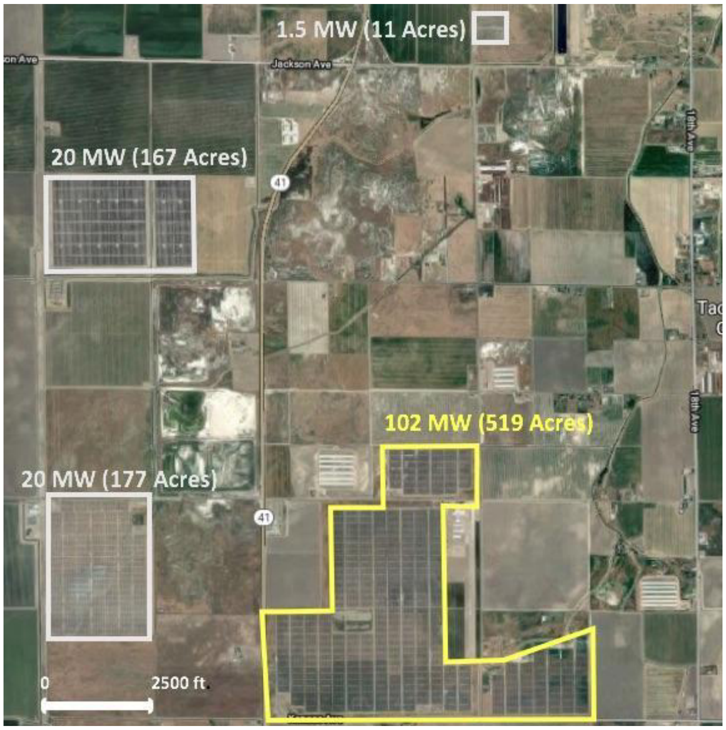
1 mile between the installation and the home

3 miles between the installation and the home

Part III: 102MW Facilities

Please use the sliders below to estimate if and how the presence of a **102MW** utility-scale solar installation would impact a nearby home's assessment value in percentage terms. Please do so at the varying distances between the home and the nearest solar panel.

Utility-scale solar installations 102MW may cover 510 to 918 acres. For an example of a 102MW solar installation, please refer to the image below.



- Please indicate a value of **0** if the value of the home would not be impacted in any way by the presence of a 102MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **greater than 0** if the value of the home would increase by the presence of a 102MW solar installation at a given distance, in percent terms.
- Please indicate the corresponding value **less than 0** if the value of the home would decrease by the presence of a 102MW solar installation at a given distance, in percent terms.

Estimated percentage (%) impact from a 102MW facility

-50 -40 -30 -20 -10 0 10 20 30 40 50

100 feet between the installation and the home

500 feet between the installation and the home

1000 feet between the installation and the home

1/2 mile between the installation and the home

1 mile between the installation and the home

3 miles between the installation and the home

Do you have any other comments on the value impacts from proximity to utility-scale solar installations?

____

Please indicate whether the following features or aspects of a utility-scale installation would have a positive or negative impact on nearby residential property values:

	Strongly negative	Negative	No effect	Positive	Strongly positive
Panels that move to track the sun's position	○	○	○	○	○
Increase in the installation's size	○	○	○	○	○
Increase in the height of the panels from the ground	○	○	○	○	○
Presence of visual barriers around the solar array (e.g. trees, hedges, fence, etc.)	○	○	○	○	○
Mountainous topography surrounding the installation	○	○	○	○	○
Flat topography surrounding the installation	○	○	○	○	○
New infrastructure associated with the installation (e.g. power lines)	○	○	○	○	○

Have you assessed a home near a utility-scale solar installation?

○ Yes

○ No

○ Other (please explain) ______________________________

○ I prefer not to answer

Have you adjusted for the value of a home based on the presence of a utility-scale solar installation in the past?

- ◯ Yes
- ◯ No
- ◯ Other (please explain) ______________________________
- ◯ I prefer not to answer

Do you have any comments on your experience assessing homes near utility-scale solar installations that you would like to share?

____

In general, what is your opinion of solar energy in the U.S.?

- ◯ Extremely positive
- ◯ Somewhat positive
- ◯ Neither positive nor negative
- ◯ Somewhat negative
- ◯ Extremely negative
- ◯ I prefer not to answer

Is there anything in this survey that we should clarify or that you would like to comment on? *This will help us refine our survey to ensure it is as clear as possible.*

____

Would you like to be informed via email of the results of this research upon study completion?

○ Yes

○ No

May we follow up with you via email if we need to clarify your survey responses?

○ Yes

○ No

What is your email address?
Your email address will not be shared and will be used for survey validation and related communication purposes only.

____

Are you ready to submit?
If you are done with the survey, please click the forward button below. If not, please use the back button at the bottom of the screen to return to your previous answers.

Appendix D.2 - Responses by Geographic Region and Question

Appendix D.2: *The above table indicates where respondents come from for each question, as well as the number of respondents per question.*

Respondents by Geographic Region

State	Years of Experience n = 36	Last Assess. Date n = 35	Perceived Install. Count n = 33	Solar PV in Prof. Manual n = 34	Estimates of PV Impacts (%) n = 18	Impact of Solar Features n = 19	Near Assessed Near Solar? n = 22	Adjusted Near Solar? n = 22	Opinion of Solar n = 23
AZ	X	X	--	--	--	--	--	--	--
CO	X	X	X	X	--	--	--	--	--
CT	X	X	X	X	X	X	X	X	X
FL	X	X	X	X	X	X	X	X	X
GA	X	X	X	X	X	--	--	--	--
HI	X	--	X	X	X	X	X	X	X
IA	X	X	X	X	X	X	X	X	X
ID	X	X	X	X	--	--	--	--	--
IL	X	X	X	X	--	--	--	--	--
IN	X	X	X	X	X	X	X	X	X
MA	X	X	X	X	X	X	X	X	X
MD	X	X	X	X	--	--	X	--	X
MN	X	X	X	X	X	X	X	X	X
NC	X	X	X	X	X	X	X	X	X
NJ	X	X	X	X	X	X	X	X	X
NM	X	X	X	X	--	X	X	X	X
NV	X	X	X	X	--	--	--	--	--
OR	X	X	X	X	--	--	X	X	--
SC	X	X	X	X	--	X	X	X	X
UT	X	X	X	X	X	X	X	X	X
VA	X	X	X	X	X	X	X	X	X
VT	X	X	X	X	--	--	--	--	--
WI	X	X	X	X	--	--	X	X	X

Appendix D.3 - Descriptive Statistics for Estimates of Property Value Impacts (%)

Table B.1: *The below table contains descriptive statistics on all respondents' estimates of home value impacts due to proximity to solar installation. These impacts were estimated at several distances between the home and the installation, and for three facility sizes. The table also includes p-values from t-tests measuring whether the mean of responses was statistically different than zero.*

Estimates of Impact on Property Values from Solar Installations by Size and Distance (%)

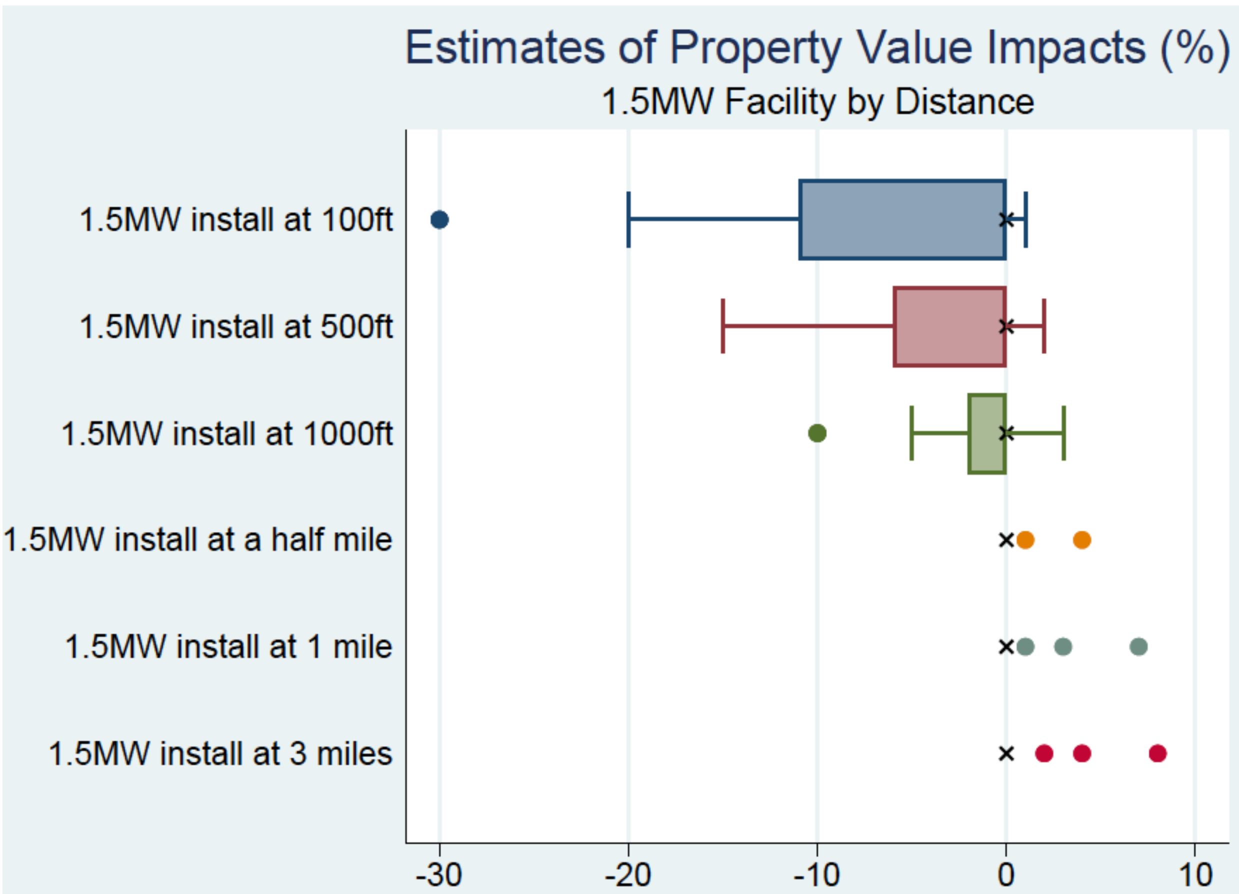
	Mean	Standard Deviation	Min	10th Percentile	Median	90th Percentile	Max	t-test p-value	n
1.5 Megawatts									
100 feet	-7.0	10.7	-30	-30	0	1	1	0.016 **	17
500 feet	-3.2	5.6	-15	-15	0	1	2	0.025 **	18
1000 feet	-1.6	3.6	-10	-10	0	1	3	0.084 *	18
1/2 mile	0.3	1.0	0	0	0	1	4	0.236	18
1 mile	0.6	1.8	0	0	0	3	7	0.158	18
3 miles	0.8	2.1	0	0	0	4	8	0.130	18
20 Megawatts									
100 feet	-10.2	13.9	-40	-30	0	1	5	0.006 **	18
500 feet	-6.4	8.8	-20	-20	0	1	5	0.007 **	18
1000 feet	-3.2	5.5	-15	-15	0	0	1	0.023 **	18
1/2 mile	-1.1	3.5	-10	-10	0	1	3	0.201	18
1 mile	0.2	2.0	-5	0	0	2	6	0.636	18
3 miles	0.6	1.9	0	0	0	2	8	0.193	18
102 Megawatts									
100 feet	-9.8	14.1	-32	-30	0	0	10	0.011 **	17
500 feet	-8.3	11.8	-30	-25	0	0	10	0.008 **	18
1000 feet	-5.7	8.3	-25	-20	0	0	0	0.010 **	18
1/2 mile	-2.7	5.5	-20	-10	0	0	1	0.052 *	18
1 mile	-1.2	4.2	-15	-10	0	1	2	0.236	18
3 miles	0.0	3.1	-10	0	0	2	8	1.000	18

Notes: t-tests test the mean against the null hypothesis of zero
** significant at the 5% level, * significant at the 10% level

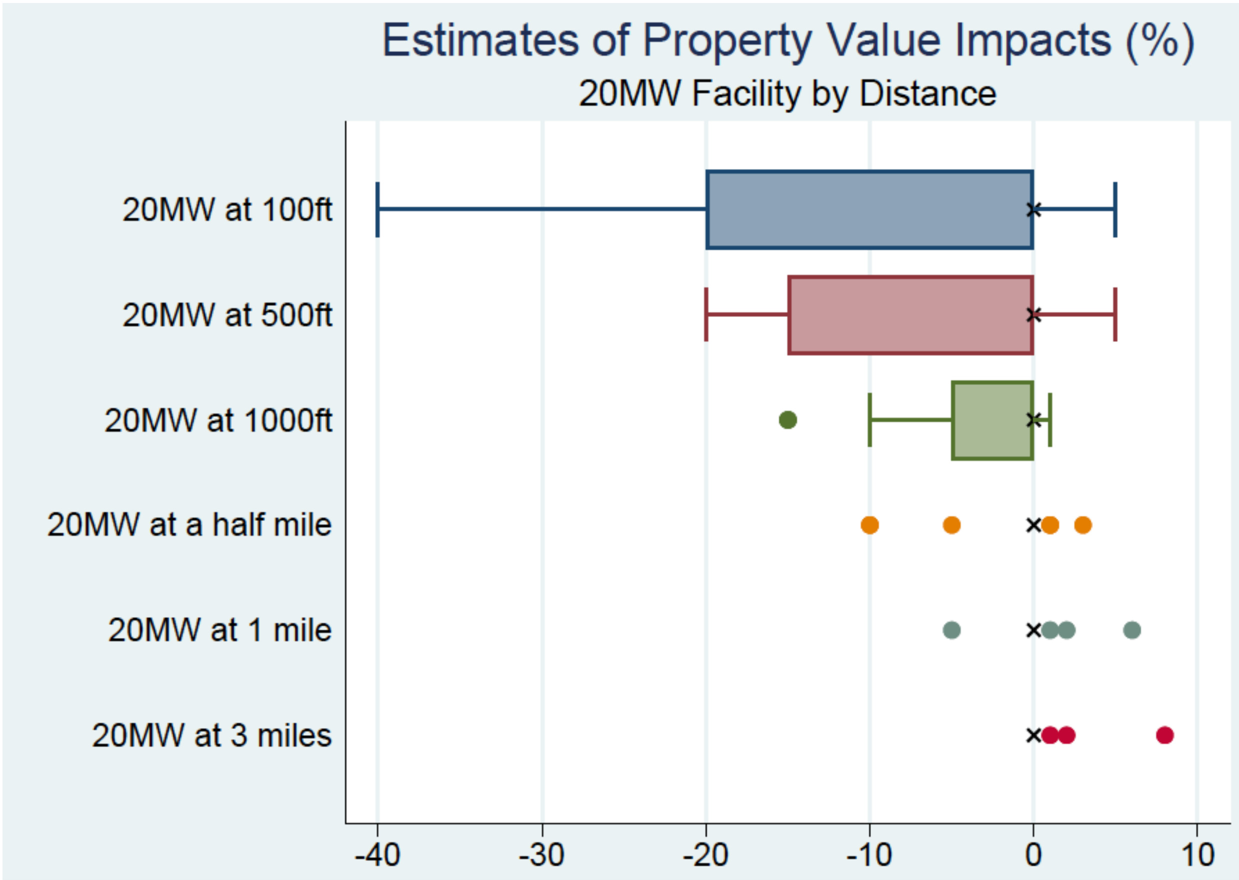
Appendices D.4 - D.6 - Estimates of Property Value Impacts in Boxplots

The following boxplots provide additional information on the variation in survey responses for estimates of property value impacts by facility size and distance.

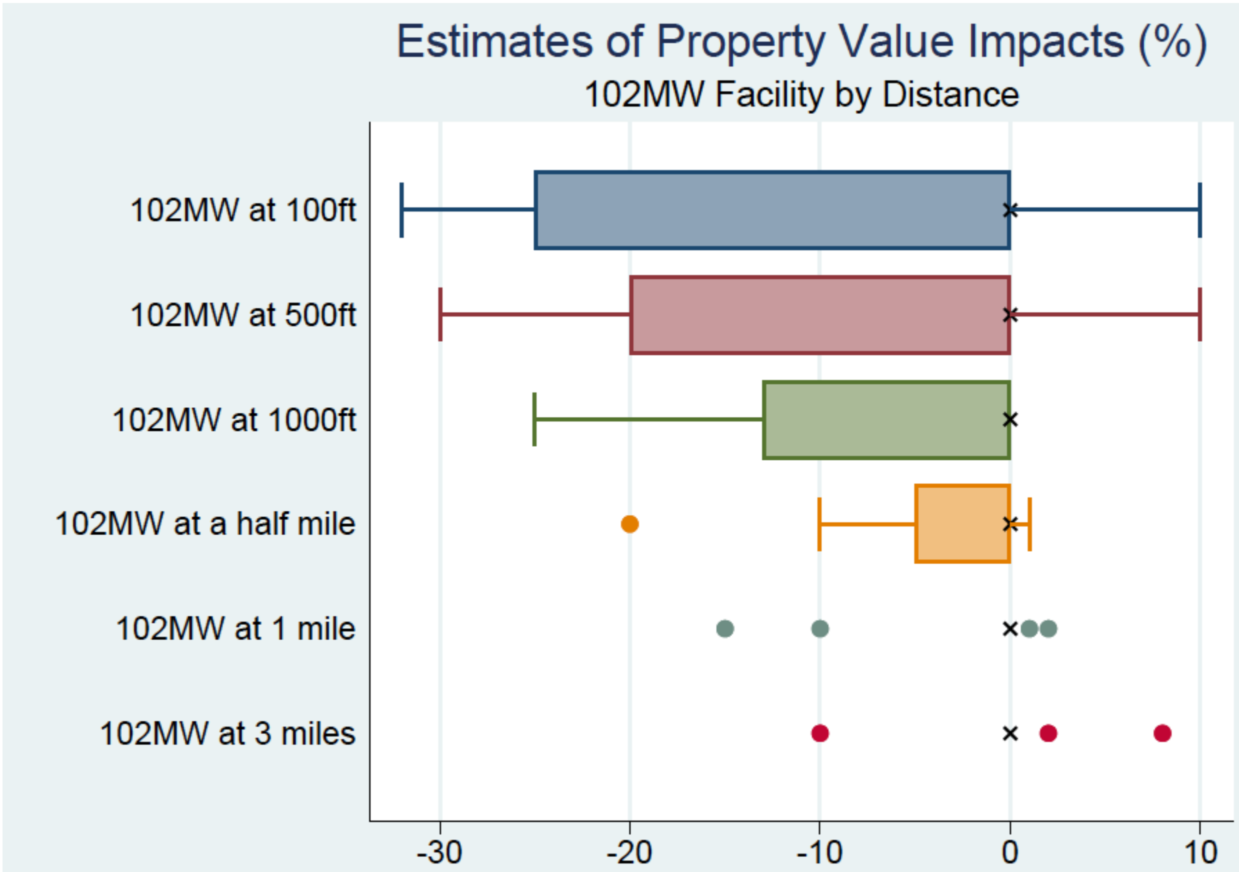
Appendix D.4: *The below boxplots indicate the range of estimates from survey respondents for property value impacts near a 1.5MW facility. The median is indicated with an "X".*



Appendix D.5: *The below boxplots indicate the range of estimates from survey respondents for property value impacts near a 20MW facility. The median is indicated with an "X".*



Appendix D.6: *The below boxplots indicate the range of estimates from survey respondents for property value impacts near a 102MW facility. The median is indicated with an "X".*



Appendix D.7 - Estimating Property Value Impacts in Dollar Terms ($)

To estimate property value impacts in dollar terms, we pulled county-level median home value from the U.S. Census Bureau's 2016 American Community Survey. The below table converts the estimates of property value impacts provided by survey respondents into dollars, based on the median home value in each respondent's county. If this impact were the true impact and the home values were the same for the whole county, then the results suggest that being located 100 feet from a 20MW solar installation would be associated with a $26,252 decline in home value, on average. By contrast, living three miles from a 1.5MW installation would be associated with an average $1,098 gain in value. Of course, variations in median home values and effect sizes across the United States could lead to significant differences by region.

Table: *The below table provides descriptive statistics on the estimate of home value impact translated into dollars. The dollar impacts are estimated by multiplying each respondent's estimate of impact (%) with the median home price in their county.*

Estimates of Property Values Impacts($) by Size and Distance

	Median	Mean	Min	Max	St. Dev.	n
1.5 Megawatts						
100 feet	$0	-$18,874	-$98,760	$1,613	$31,621	17
500 feet	$0	-$9,926	-$74,070	$3,226	$19,841	18
1000 feet	$0	-$5,787	-$49,380	$4,839	$13,427	18
1/2 mile	$0	$411	$0	$6,452	$1,524	18
1 mile	$0	$877	$0	$9,989	$2,547	18
3 miles	$0	$1,098	$0	$11,416	$3,008	18
20 Megawatts						
100 feet	$0	-$26,252	-$119,400	$6,330	$40,673	18
500 feet	$0	-$17,230	-$76,600	$6,330	$27,051	18
1000 feet	$0	-$9,842	-$59,700	$951	$18,367	18
1/2 mile	$0	-$3,475	-$39,800	$4,281	$10,398	18
1 mile	$0	-$398	-$19,900	$8,562	$5,301	18
3 miles	$0	$866	$0	$11,416	$2,745	18
102 Megawatts						
100 feet	$0	-$24,136	-$119,400	$12,660	$38,859	17
500 feet	$0	-$20,998	-$79,600	$12,660	$31,354	18
1000 feet	$0	-$14,961	-$61,950	$0	$23,540	18
1/2 mile	$0	-$6,971	-$49,560	$951	$14,704	18
1 mile	$0	-$4,065	-$39,800	$2,854	$12,549	18
3 miles	$0	-$637	-$24,780	$11,416	$6,601	18