1. Regarding the local, state, and federal permitting requirements, including those required by the U.S. Corps of Engineers, for impacts to water bodies, provide additional information regarding these permitting requirements and the steps that will be taken by Horseshoe Bend to comply with these requirements.

RESPONSE: Please refer to a letter from Copperhead Environmental with information, attached as Exhibit 1.

WITNESS: Marty Marchaterre, Senior Environmental Planner, Copperhead Environmental

COPPERHEAD
ENVIRONMENTAL CONSULTING

Carson Harkrader
Horseshoe Bend Solar, LLC
C/O Carolina Solar Energy
400 W. Main Street, Suite 503
Durham, North Carolina, 27701

11 May 2021

RE: Response to Siting Board Staff's Post-Hearing Request for Information to Horseshoe Bend Solar, LLC Concerning Permitting Requirements Related to Water Bodies

Ms. Harkrader,

The Siting Board Staff's Post-Hearing Request for Information for the Horseshoe Bend Solar, LLC Project ("Project") included the following request:

> Regarding the local, state, and federal permitting requirements, including those required by the U.S. Corps of Engineers, for impacts to water bodies, provide additional information regarding these permitting requirements and the steps that will be taken by Horseshoe Bend to comply with these requirements.

A discussion of potential regulation and permitting requirements of utility scale solar impacts to water bodies is addressed below. Permit applications will follow to the appropriate regulatory body as described below, as the project prepares for construction.

Permits Regarding Impacts to Wetlands, Waters of the United States, and Stormwater

A. Stormwater Discharges Associated with Construction Activity

Regulatory Agency: Kentucky Energy & Environment Cabinet – Department for Environmental Protection – Division of Water

Wetlands, ponds, and streams are present within the Project Site. During construction activities, stormwater erosion and sedimentation may affect these onsite surface water features. Horseshoe Bend expects the Project to result in the discharge of stormwater during construction. Horseshoe Bend intends to comply with the Kentucky Division of Water's (KDOW's) Construction Storm Water Discharge General Permit for those construction activities that disturb one acre or more. Horseshoe Bend will submit a Notice of Intent to KDOW at least seven days prior to the commencement of construction and KDOW will review the notice of intent and provide notification of authorization to discharge. When construction is completed, Horseshoe Bend will provide a notice of termination.

To manage stormwater, use of Best Management Practices, including silt fences, on-site temporary sediment basins, sediment traps, and/or buffer zones (e.g., 25 feet) surrounding jurisdictional streams and wetlands would be implemented. A site-specific stormwater pollution prevention plan ("SWPPP") would be prepared and a copy kept available on site. These stormwater BMPs would minimize sediment from entering Waters of the Commonwealth and sediment migration off site during construction, prior to achievement of final vegetative stabilization.

B. Wetlands and Waters of the United States

Federal Regulatory Agency: United States Army Corps of Engineers – Louisville District

Horseshoe Bend contracted with Copperhead Environmental Consulting, Inc., an environmental engineering company based in Garrard County, KY, to perform an on-site wetlands and stream delineation and to submit an Approved Jurisdictional Determination ("AJD") application to the US Army Corps of Engineers – Louisville District ("USACE"). The AJD has been obtained from the USACE. The AJD process determined which aquatic features are considered federally jurisdictional under the Clean Water Act ("CWA"). Waters of the United States are defined as jurisdictional wetlands and streams. If the Project will discharge or fill into jurisdictional waters, a Section 404 of the CWA permit will be needed from the USACE.

The type of USACE permit required will depend on amount (e.g., acres or linear feet) or type of work (e.g., linear transportation crossing, to jurisdictional wetlands and/or Waters of the US). If the proposed activity has minimal impacts, it may be authorized under a Nationwide Permit ("NWP"). The NWP program was reissued and modified on January 13, 2021 (86 Fed. Reg. 2744). Three NWPs may be used by solar projects: NWP 14 Linear Transportation Projects, NWP 51 Land-based Renewable Energy Generation Facilities, and NWP 57 Electric Utility Line and Telecommunications Activities. If Project impacts exceed threshold requirements of the NWPs, an Individual Permit may be necessary. If jurisdictional waters will be affected by the Project, Horseshoe Bend will obtain a Section 404 permit from the USACE.

Kentucky Regulatory Agency: Kentucky Energy & Environment Cabinet – Department for Environmental Protection – Division of Water Division of Water

Depending on Project impacts and type of Section 404 permit necessary (discussed above), a Section 401 Water Quality Certification may be needed.

If appropriate, Horseshoe Bend will obtain a Section 401 Water Quality Certification and submit an Application for Permit to Construct Across or Along a Stream and/or Water Quality Certification to the KDOW. KDOW reviews projects jointly for potential impacts to water and floodplains (see below for additional discussion of floodplain requirements). Projects proposing to minimally affect Waters of the Commonwealth may be authorized under General Certifications of USACE Nationwide Permits. General Certifications may include impact thresholds and specific conditions for the proposed activity. If the proposed activity qualifies for coverage under a Nationwide Permit and the corresponding General Certification, an applicant does not need any permit or approval from KDOW. An applicant can request a letter from KDOW that the project meets the requirements of an NWP. An Individual Water Quality Certification is required if the activity does not qualify for General Certification.

C. Floodplains

Kentucky Regulatory Agency: Kentucky Energy & Environment Cabinet – Department for Environmental Protection – Division of Water Division of Water

Kentucky Revised Statues, KRS 151.250, state that a person shall not construct across, along, or adjacent to a stream or in the floodway of a stream, unless a permit from the DKOW is issued as established in Kentucky Administrative Regulations, 401 KAR 4:060, Section 2. The KDOW has two types of permits that it issues for floodplain development: 1) General Permit, or 2) Individual Permit. These floodplain requirements only apply to areas within a 100-year floodplain. Only a 5.47-acre section of an intermittent tributary of Greasy Creek is within a 100-year floodplain and will need a floodplain permit if affected.

As established in KRS 151.250 and 401 KAR 4:050, KDOW may allow development along or adjacent to streams without requiring a permit if the actions or proposed actions are of such nature or location as the development will not change the Base Flood Elevation, and is of such nature or action as to have minimal potential for damage or flooding impacts beyond the local area of the action. The General Permit does not require the submission of an application for review by KDOW because the eligible activities are already approved with conditions listed on the permit. Additionally, there is no Public Notice requirement for the permittee as the General Permit has already been noticed by KDOW. Any proposed developments that do not meet the General Permit's eligibility requirements, or that have the potential to change the Base Flood Elevation, are required to obtain a KDOW Individual Permit. Under 401 KAR 4:060, if an individual floodplain permit is required, an application will be completed by Horseshoe Bend and submitted to KDOW for review. An Individual Permit also requires that a public notice is given as part of the stream construction permit application process. If Horseshoe Bend will affect any part of the 5.47-acres within the 100-year floodplain, it will coordinate with KDOW and obtain a floodplain permit as required.

Local Regulatory Agency: Green County Emergency Management

If a 100-year floodplain would be affected, Horseshoe Bend also will obtain a local floodplain permit from Green County. Green County participates in the National Flood Insurance Program and Horseshoe Bend will coordinate with the County to determine if there would be any floodplain restrictions during the building permit application process.

D, Wild and Scenic Rivers, Outstanding State Resource Waters, or other Special Use Waters

The National Wild and Scenic Rivers Act defines rivers as deserving of legal protection because they are free-flowing and possess "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values" or outstandingly remarkable values (ORVs) (16 U.S.C. 1271 et seq.). No waterways in or adjacent to the Project are designated wild and scenic rivers. Similarly, no waterways in or adjacent to the Project Area are designated as Outstanding State Resource Waters or other Special Use Waters as defined by the Kentucky Division of Water. Therefore, no federal or state permitting, regulations, or requirements would be triggered for the Project due to these types of designated waters.

E. Local Permits

No local ordinances or requirements exist related to water body impacts in Green County.

If you have any questions or need clarifications, please contact me.

Sincerely,

Marty Marchaterre

Marty Marchaterre
Senior Environmental Planner
(859) 684-9387
mmarchaterre@copperheadconsulting.com

2. Provide a copy of the property value impact studies performed by the University of Texas at Austin (2018) and the University of Rhode Island (2020) as relied by Kirkland Appraisals in Horseshoe Bend's response to the Wells Engineering Final Report.

RESPONSE: The requested studies are attached as Exhibits 2 & 3.

WITNESS: Rich Kirkland, MAI

Policy Research Project (PRP), LBJ School of Public Affairs,
The University of Texas at Austin, May 2018.

Project Director:
Dr. Varun Rai

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

Leila Al-Hamoodah, Kavita Koppa, Eugenie Schieve, D. Cale Reeves, Ben Hoen, Joachim Seel and Varun Rai

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.

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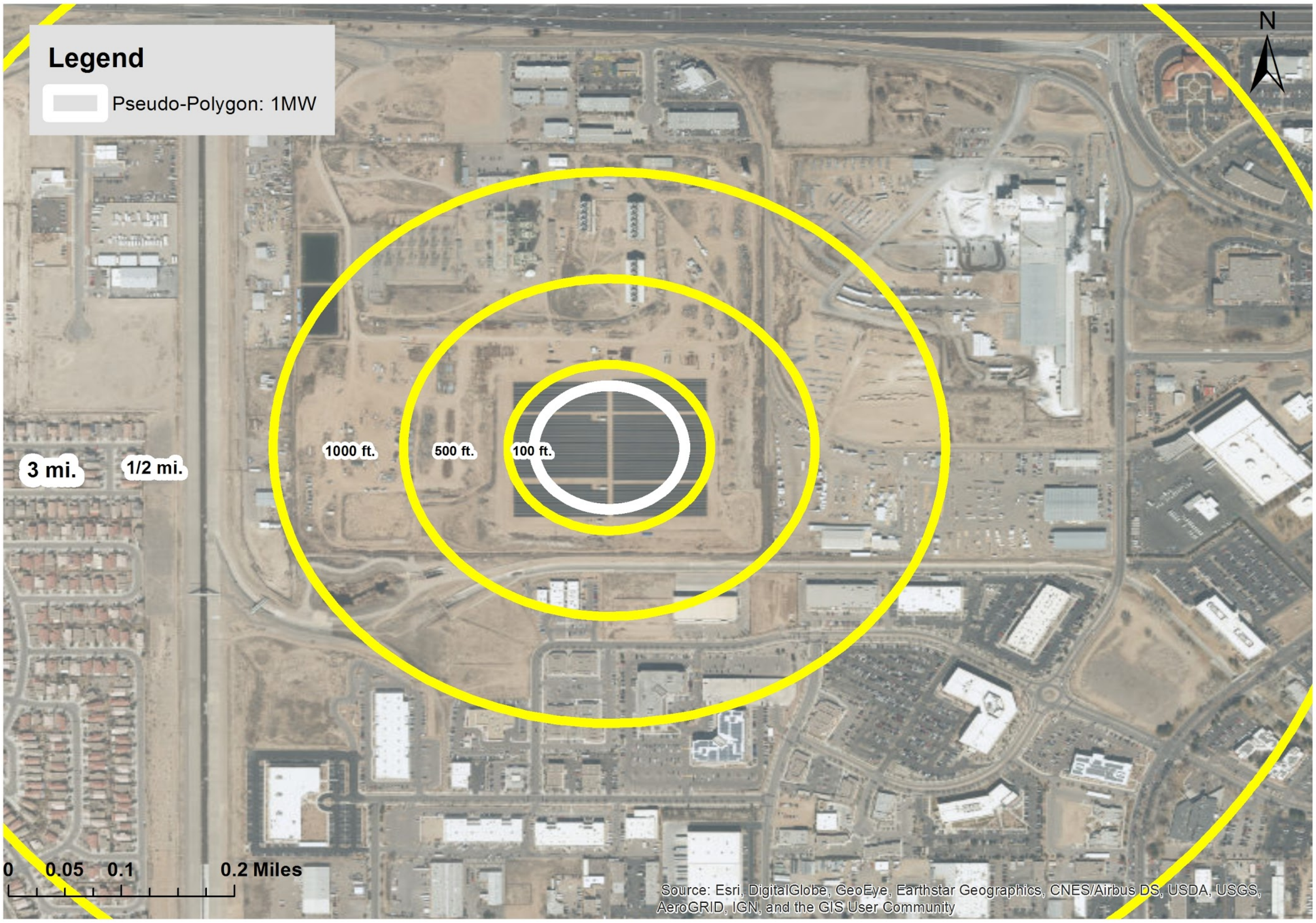
[1] While we define utility-scale solar as facilities 1MW and higher, three sites under 1MW were included in the underlying EIA database. These were included in our dataset as well.

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



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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.*

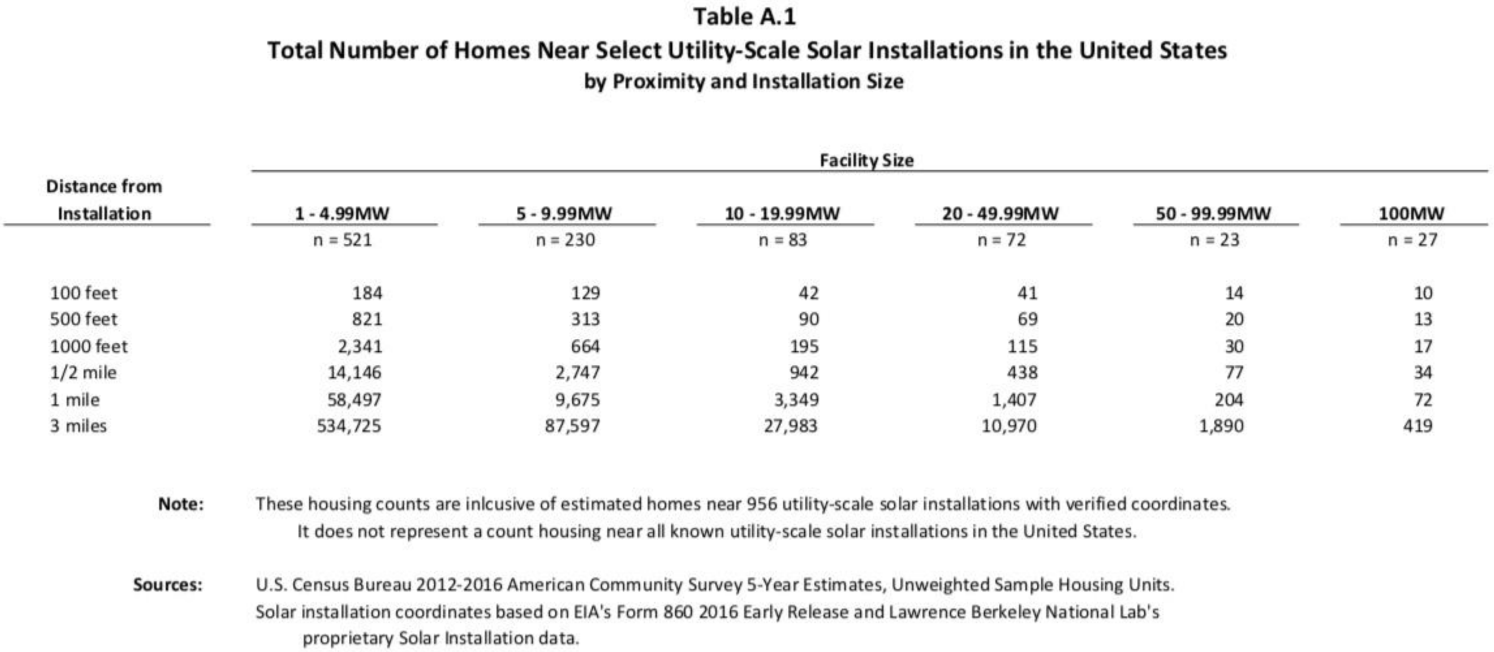


Table A.1
Total Number of Homes Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

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*

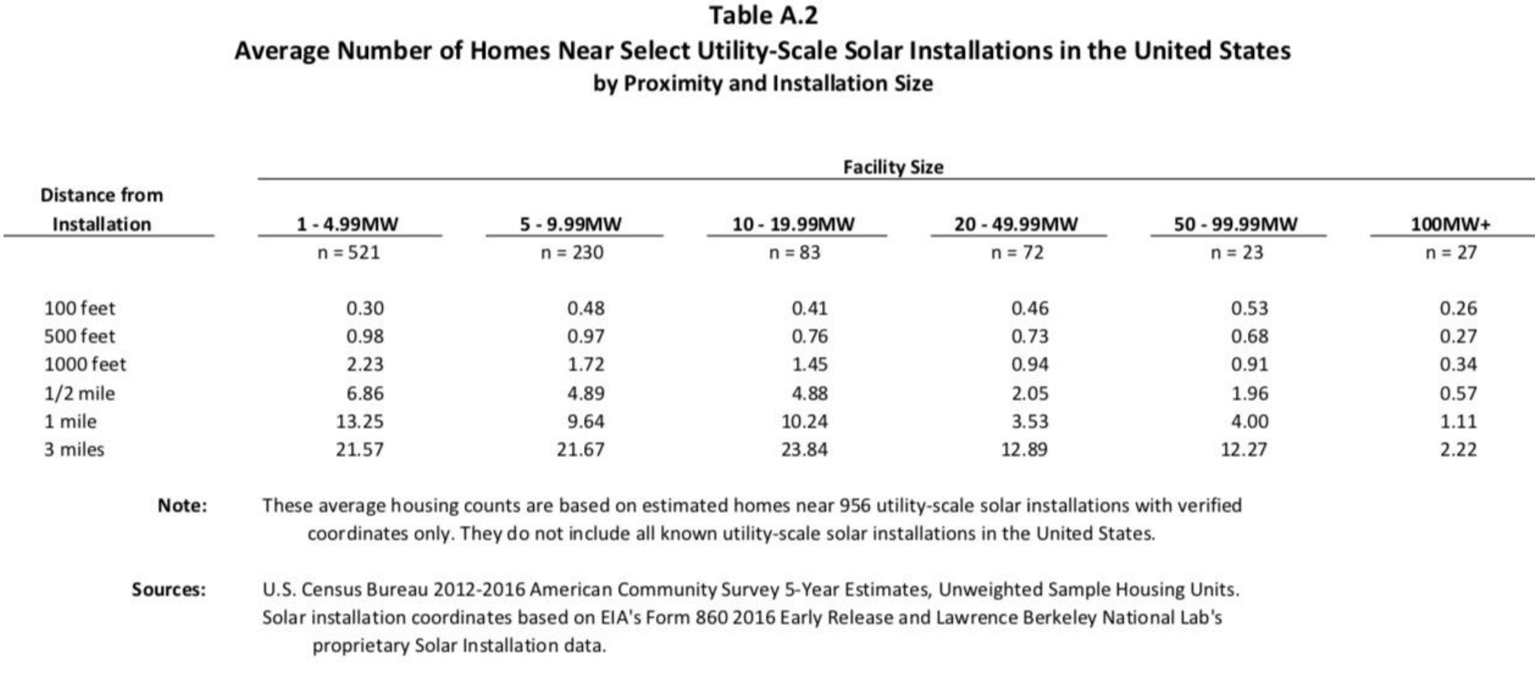


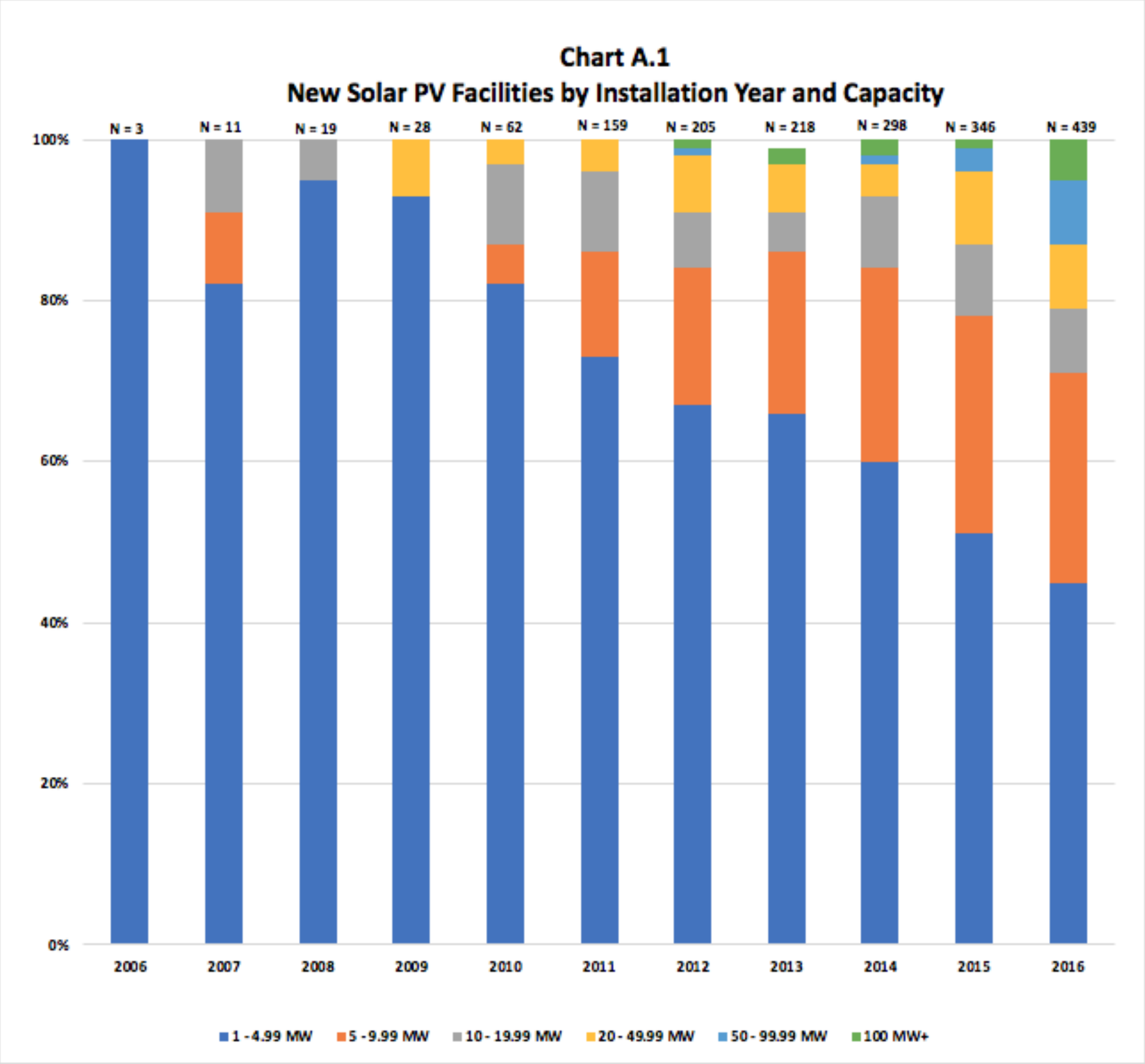
Table A.2
Average Number of Homes Near Select Utility-Scale Solar Installations in the United States
by Proximity and Installation Size

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.

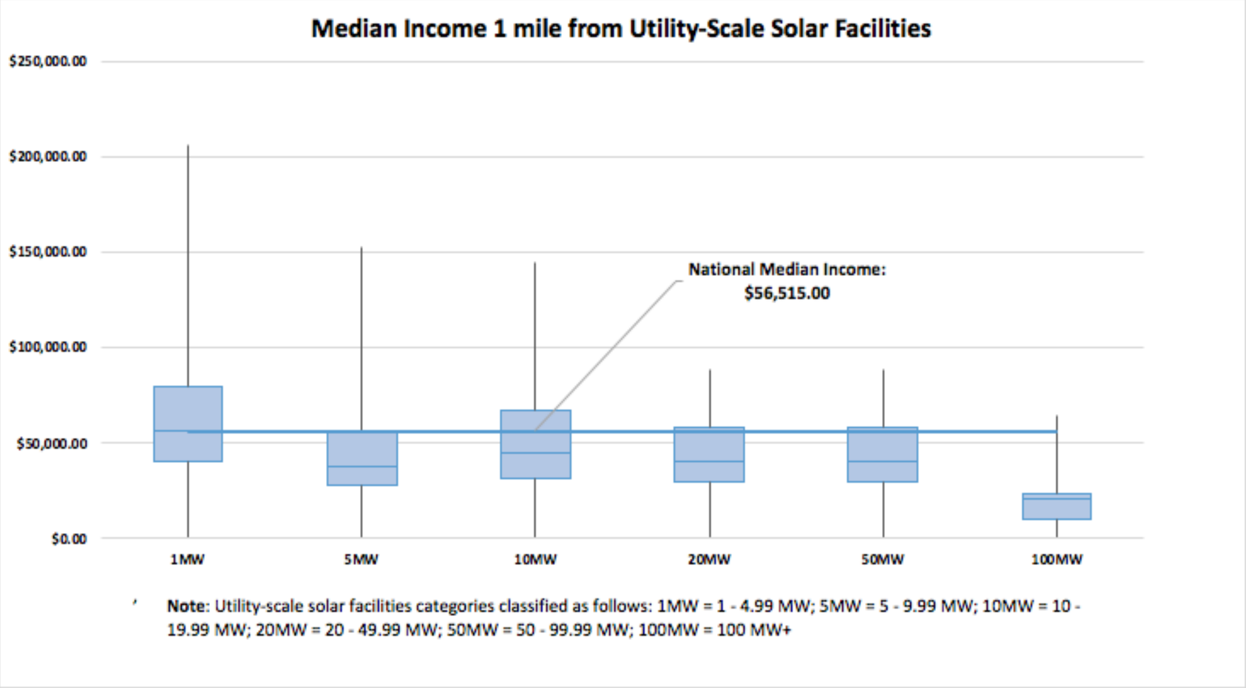


These housing density estimates inform the survey analysis discussed below by estimating the magnitude of property value impacts, if present. These total housing estimates are conservative as they only consider the 956 confirmed utility-scale solar sites, rather than all known solar sites in the United 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.***



Median Income 1 mile from Utility-Scale Solar Facilities

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+

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.

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[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**.

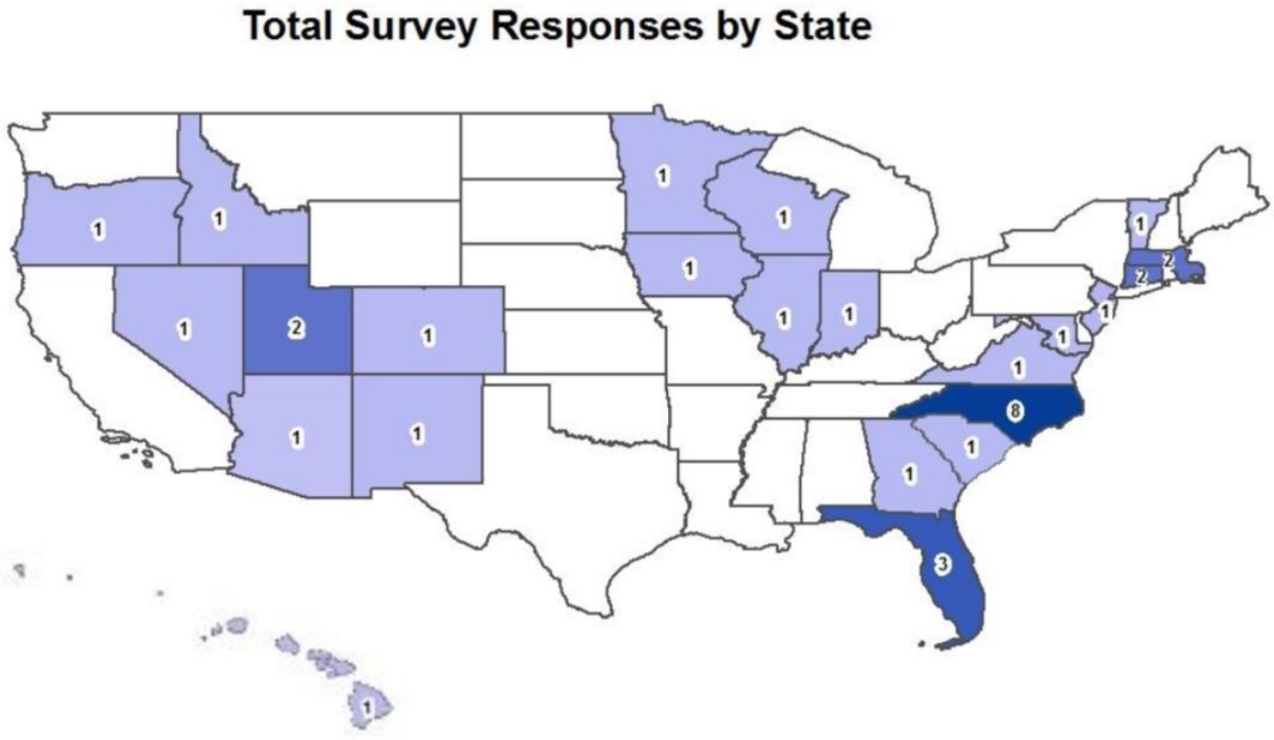
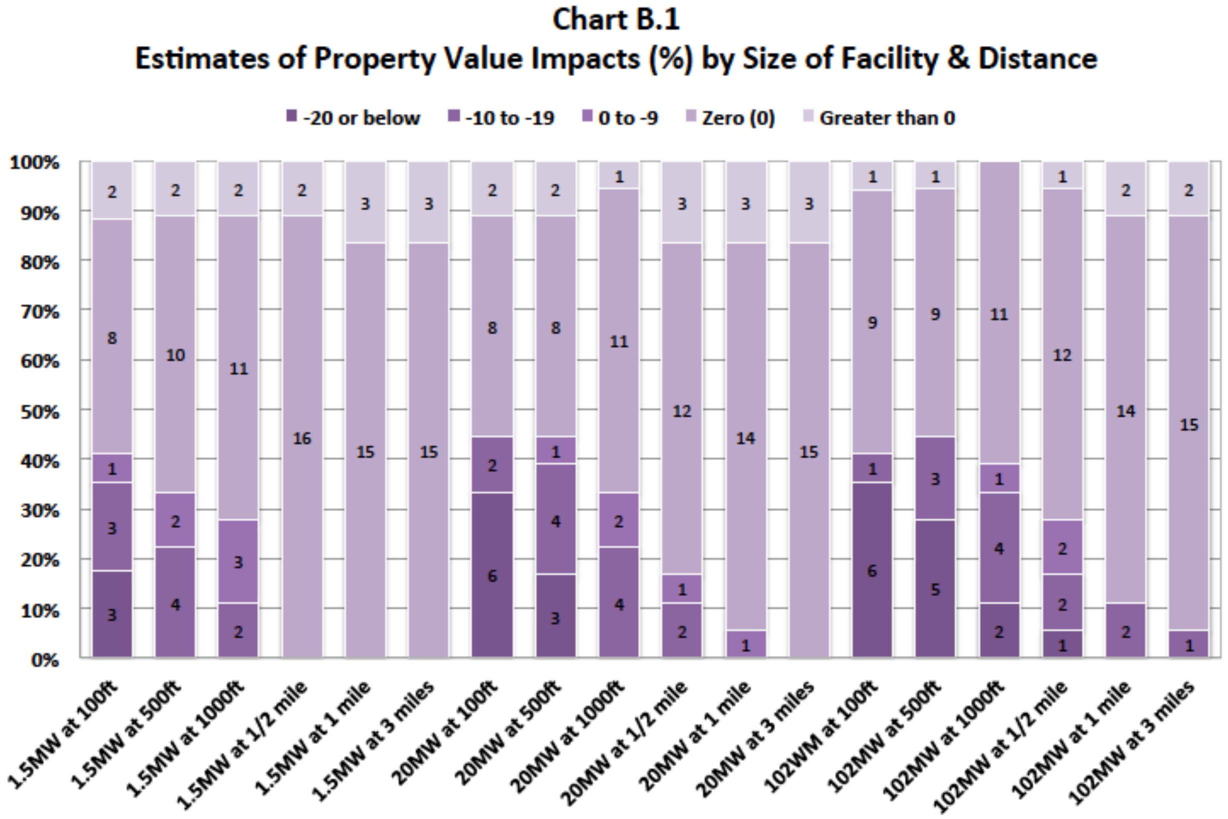


Figure B.1: *A map with the county of respondents by state is shown above.*

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**.

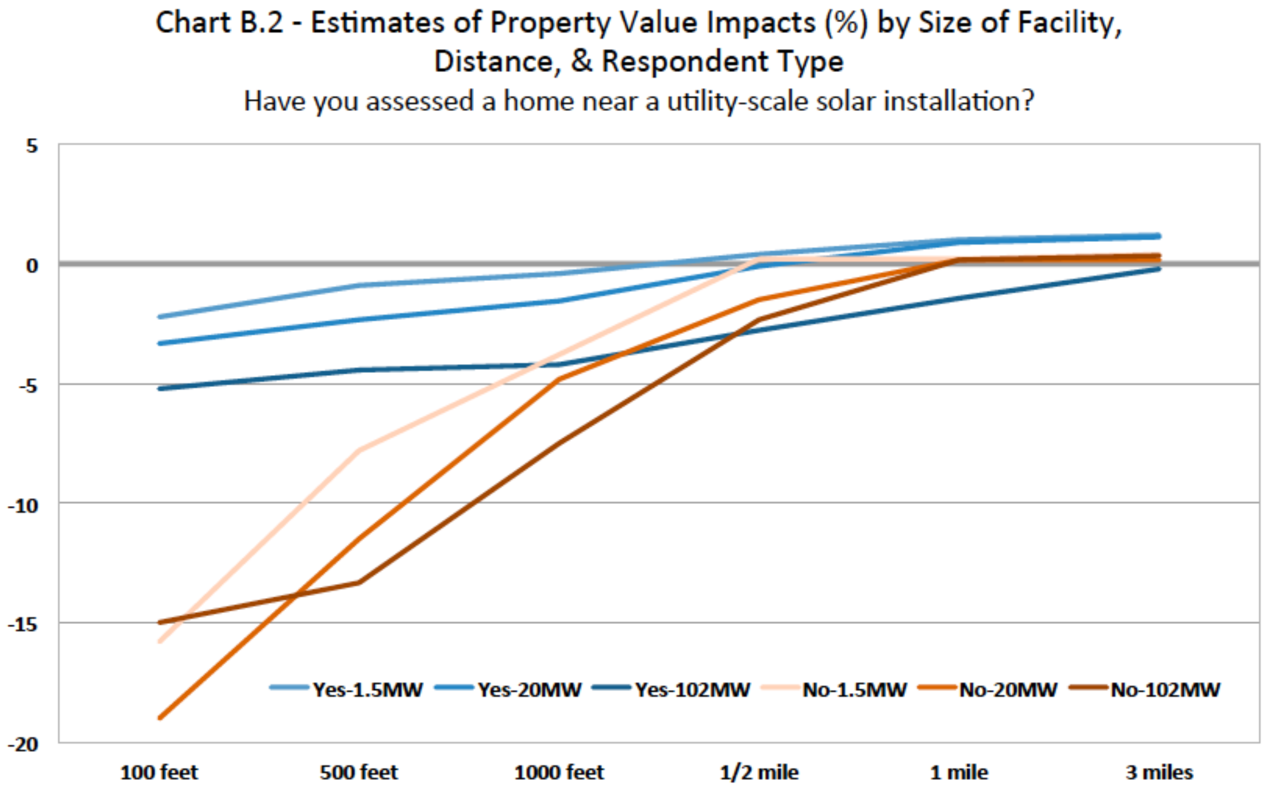
Chart B.1: *The below chart shows the estimates of home value impacts for all respondents, broken down by share of responses in various groups, at each distance for the three facility sizes.*



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.*

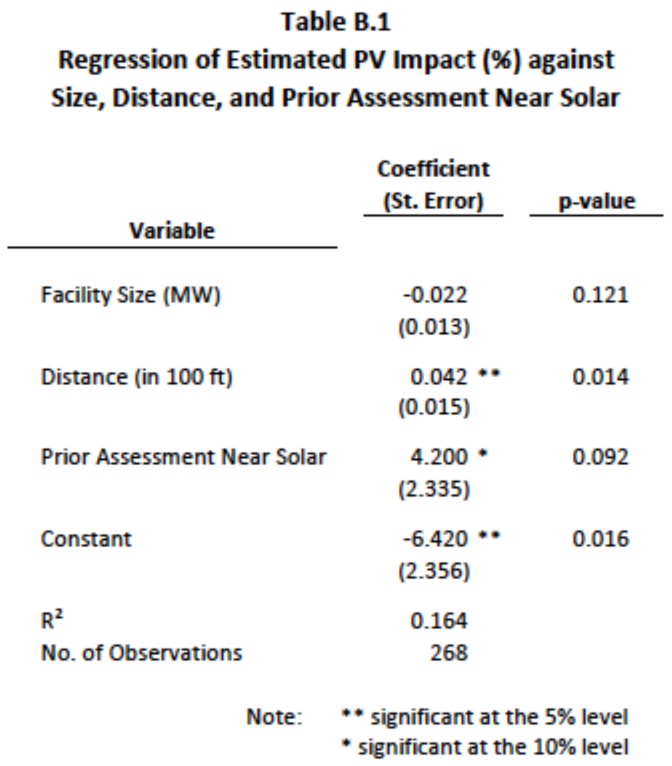


Table B.1
Regression of Estimated PV Impact (%) against Size, Distance, and Prior Assessment Near Solar

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.*

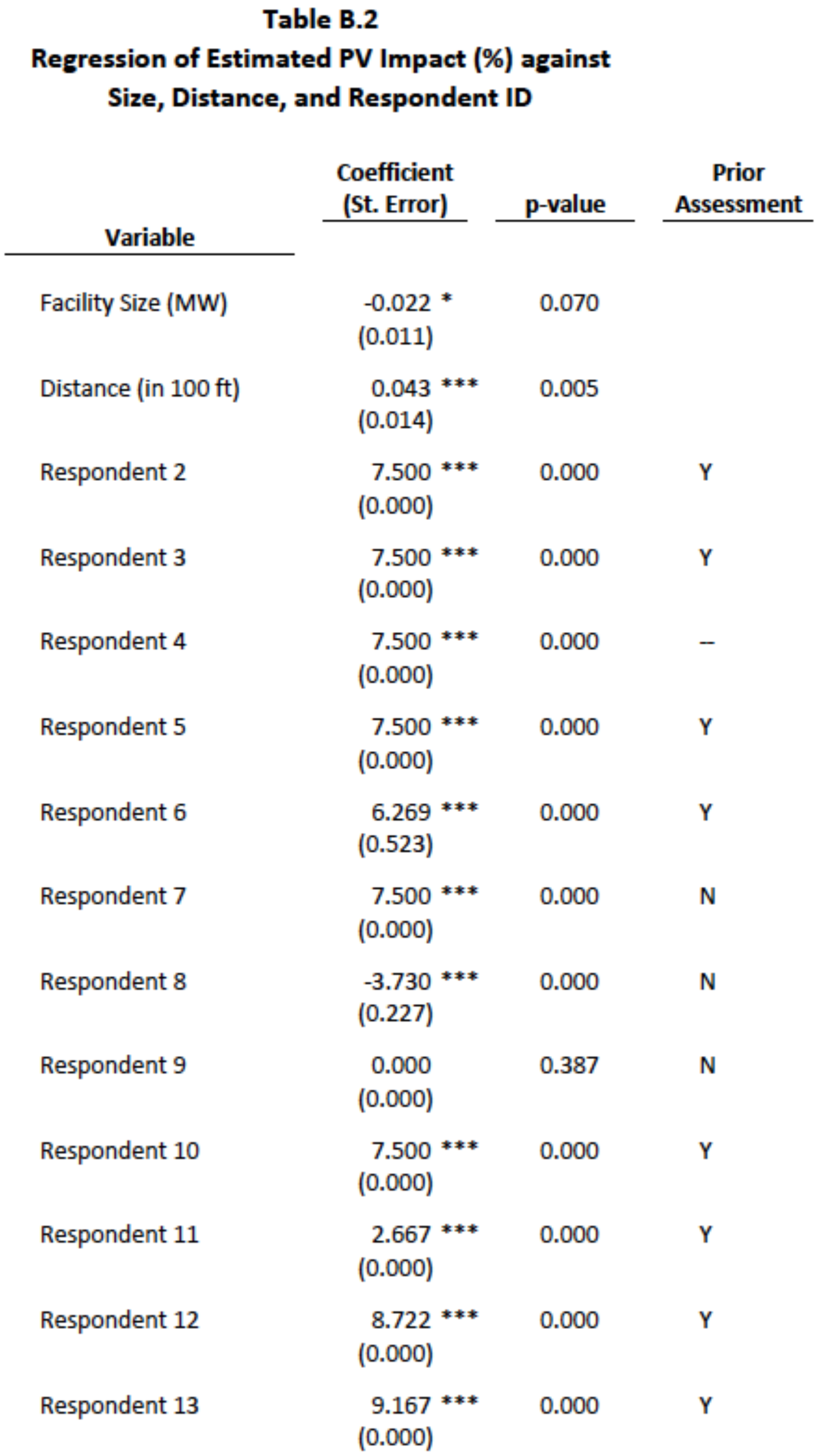


Table B.2
Regression of Estimated PV Impact (%) against Size, Distance, and Respondent ID

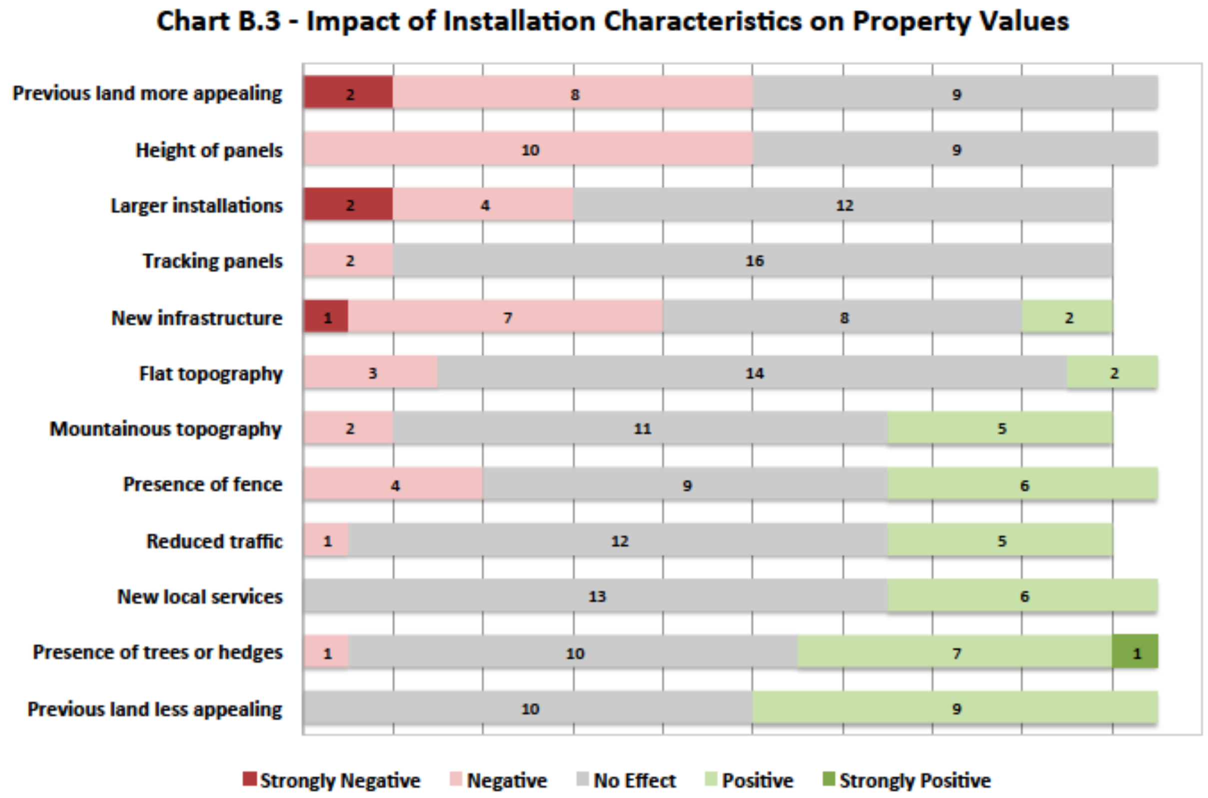
Variable	Coefficient (St. Error)	p-value	Prior Assessment
Facility Size (MW)	-0.022 * (0.011)	0.070	
Distance (in 100 ft)	0.043 *** (0.014)	0.005	
Respondent 2	7.500 *** (0.000)	0.000	Y
Respondent 3	7.500 *** (0.000)	0.000	Y
Respondent 4	7.500 *** (0.000)	0.000	–
Respondent 5	7.500 *** (0.000)	0.000	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	Y
	(0.000)		
Respondent 15	-3.330 ***	0.000	–
	(0.000)		
Respondent 16	4.722 ***	0.000	–
	(0.000)		
Respondent 17	-2.778 ***	0.000	Y
	(0.000)		
Respondent 18	8.444 ***	0.000	N
	(0.000)		
Respondent 19	-2.684 ***	0.000	N
	(0.065)		
Constant	-8.422 ***	0.000	
	(0.513)		
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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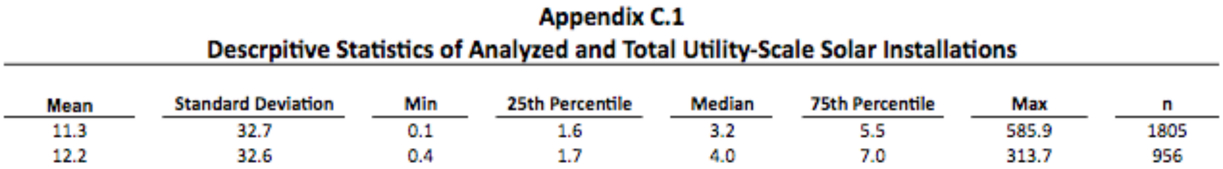
Appendices

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).

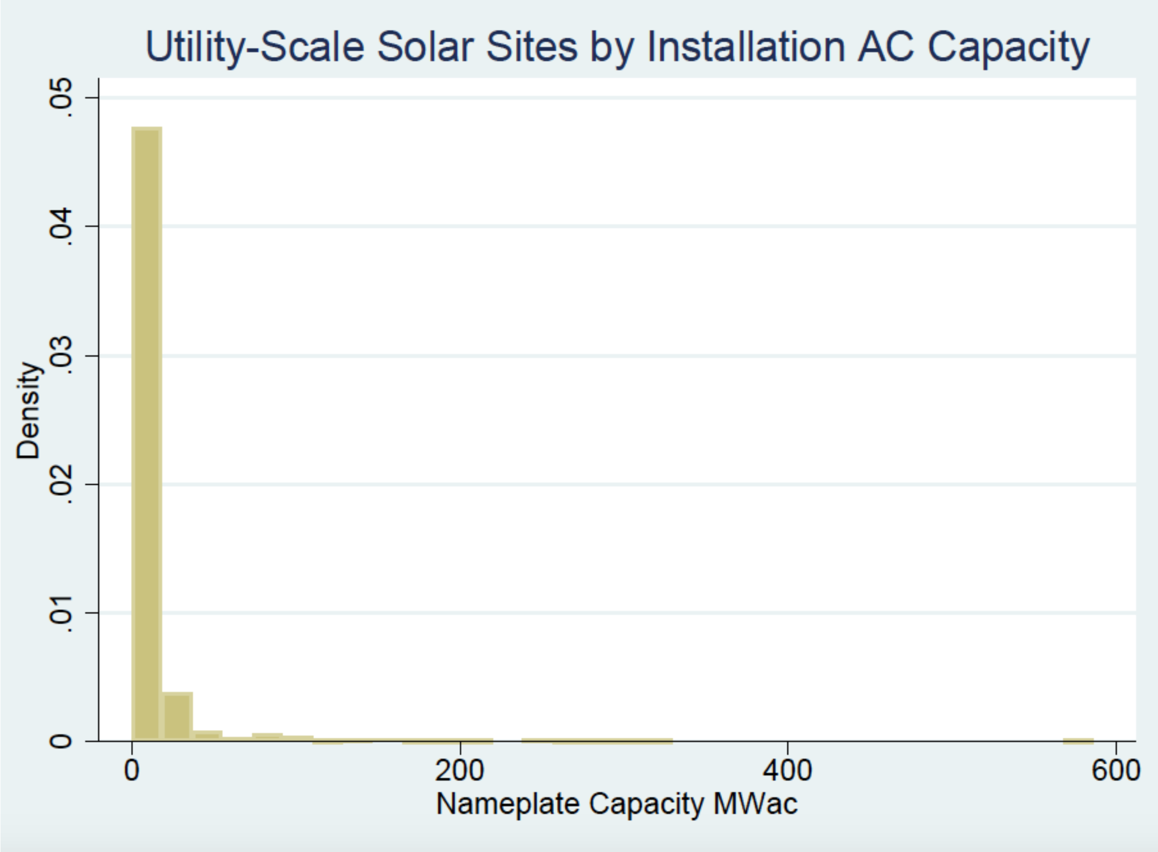


Appendix C.1
Descrpitive Statistics of Analyzed and Total Utility-Scale Solar Installations

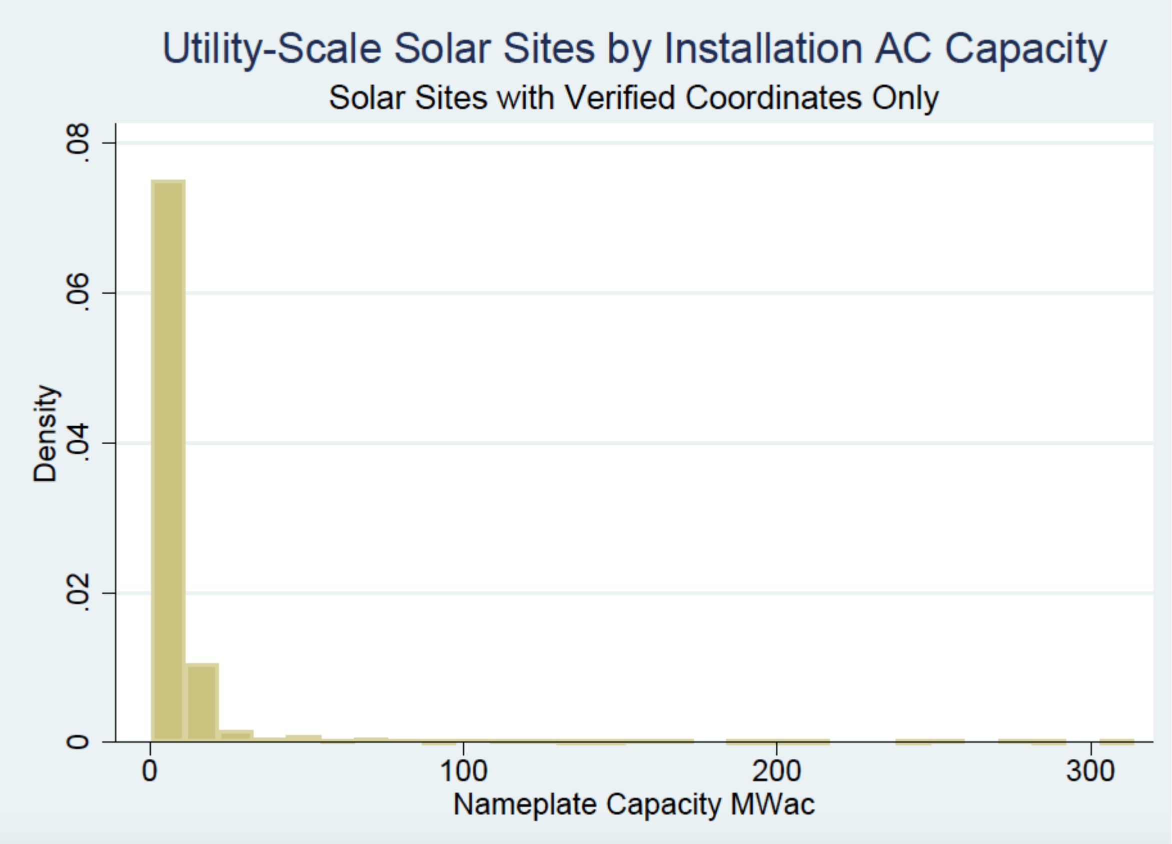
Mean	Standard Deviation	Min	25th Percentile	Median	75th Percentile	Max	n
11.3	32.7	0.1	1.6	3.2	5.5	585.9	1805
12.2	32.6	0.4	1.7	4.0	7.0	313.7	956

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.*

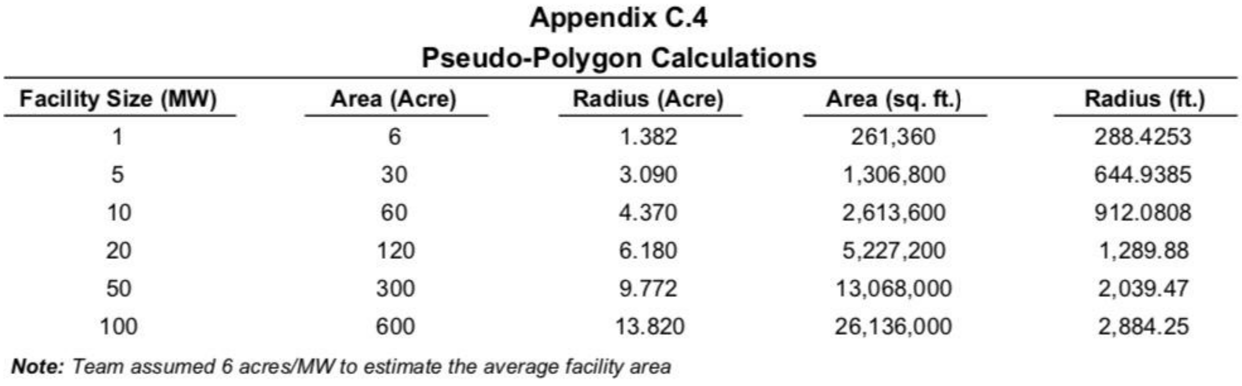


C.3: *Utility-scale solar facilities by capacity used in this analysis are displayed as a density. Comparison of the two charts shows that this research contained a greater proportion of low capacity facilities.*



Appendix C.4 - Pseudo-Polygon Calculations

C.4: *The table below shows the calculations used to create the pseudo-polygons. The team estimated approximately 6 acres/MW, which was evidently conservative.*

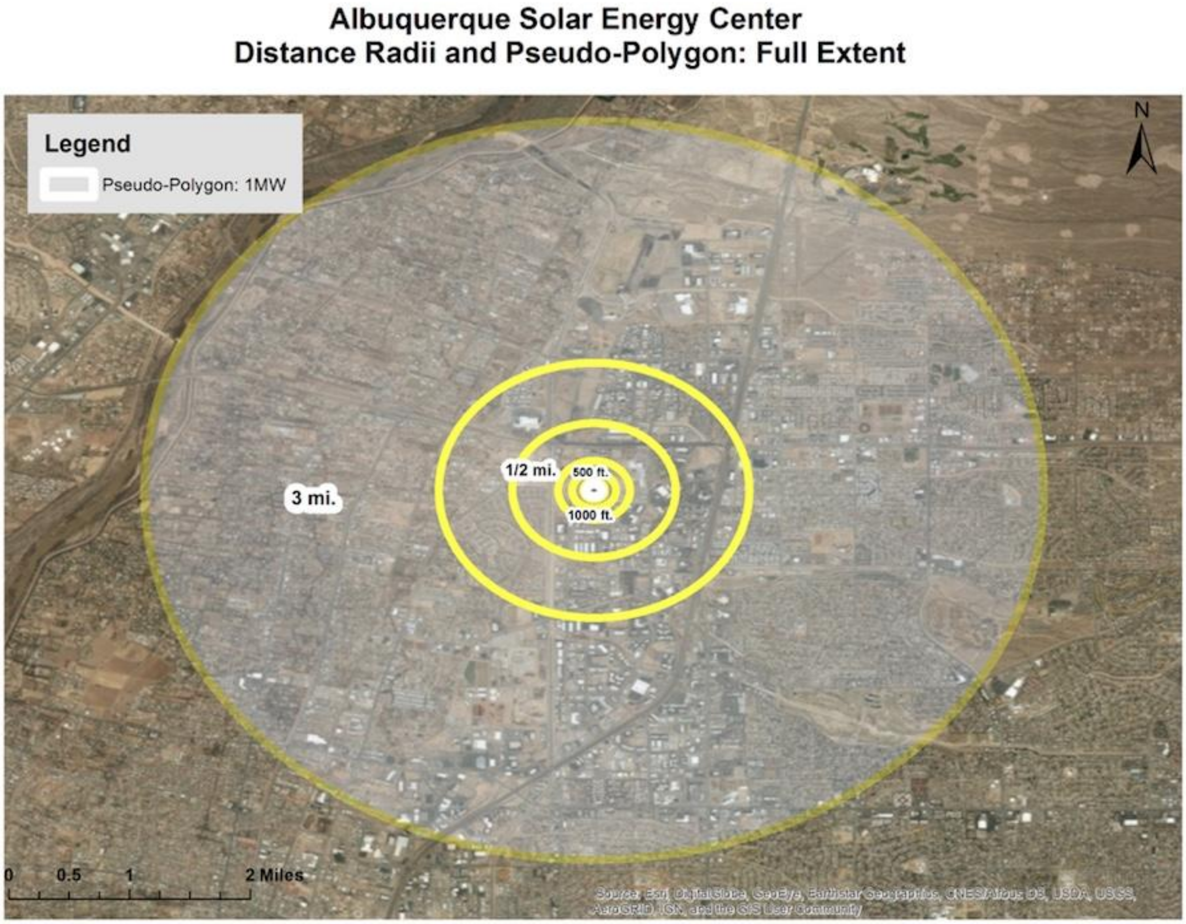


Appendix C.4
Pseudo-Polygon Calculations

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

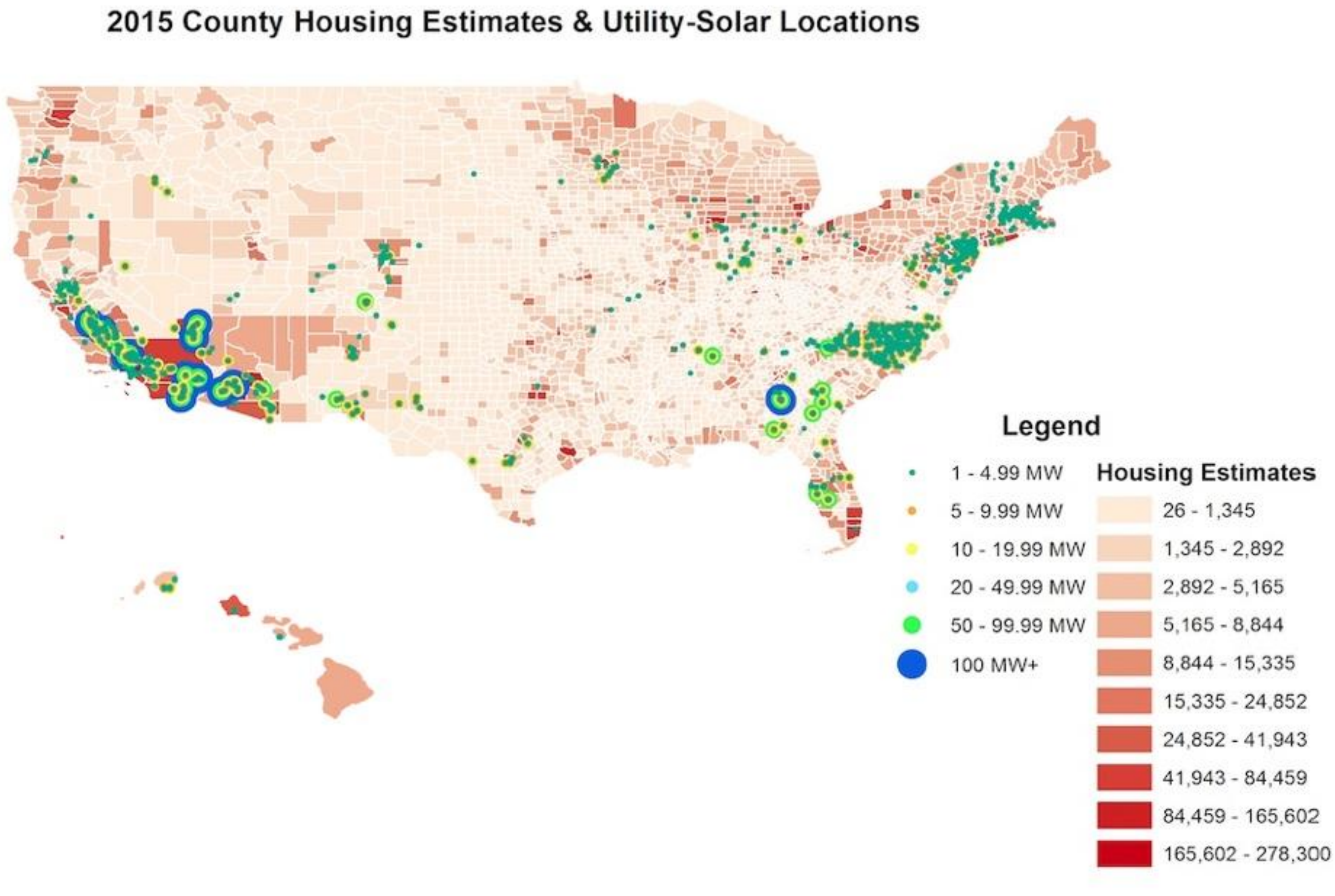
Note: *Team assumed 6 acres/MW to estimate the average facility area*

Appendix C.5 - Full Extent of Buffer Zones



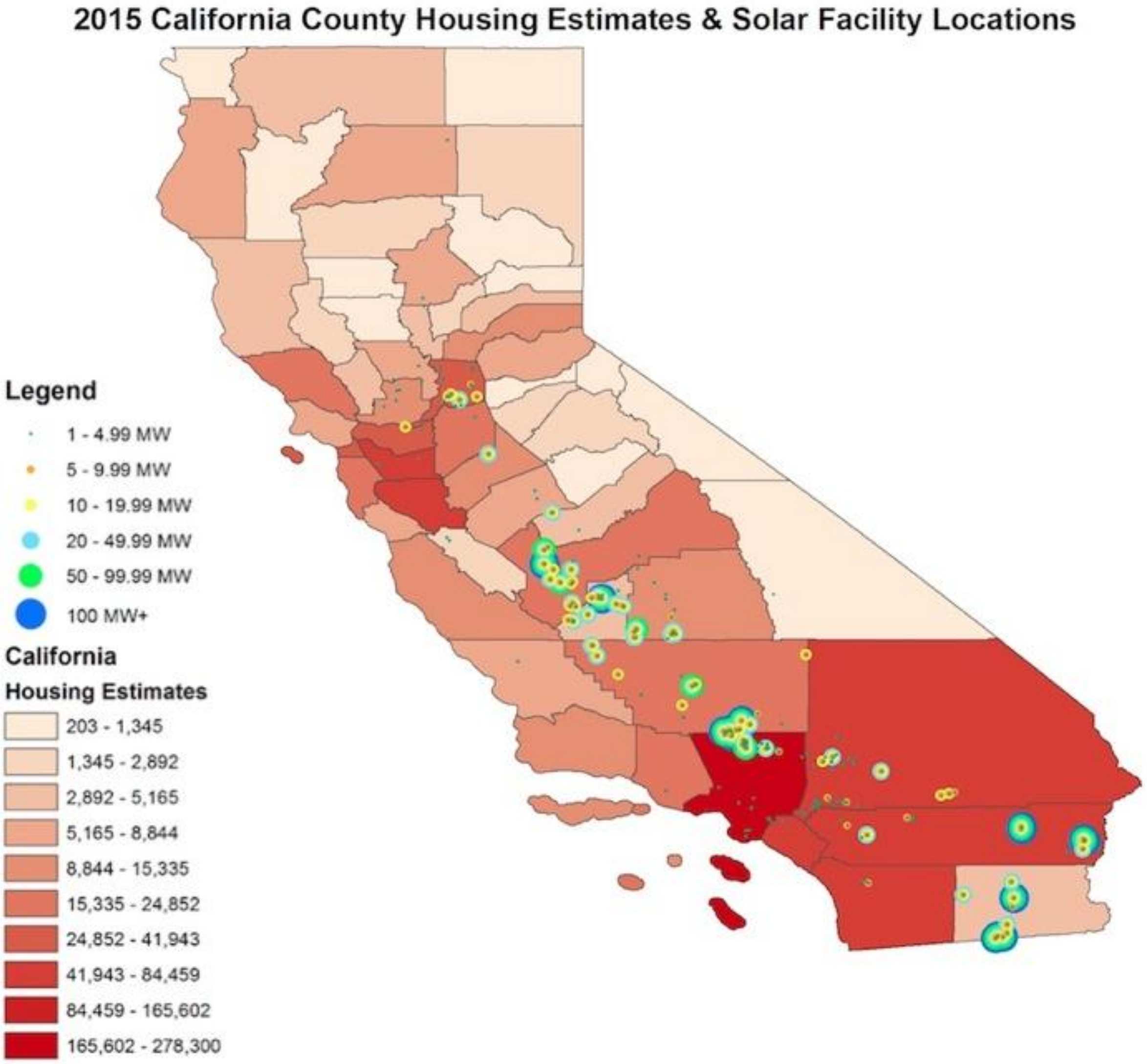
C.5: *A satellite image of the buffers (in yellow) beginning at 100ft (shown at 500ft) out to three miles are shown above. Total and average estimates of homes are made within these buffer zones and select distances.*

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.*

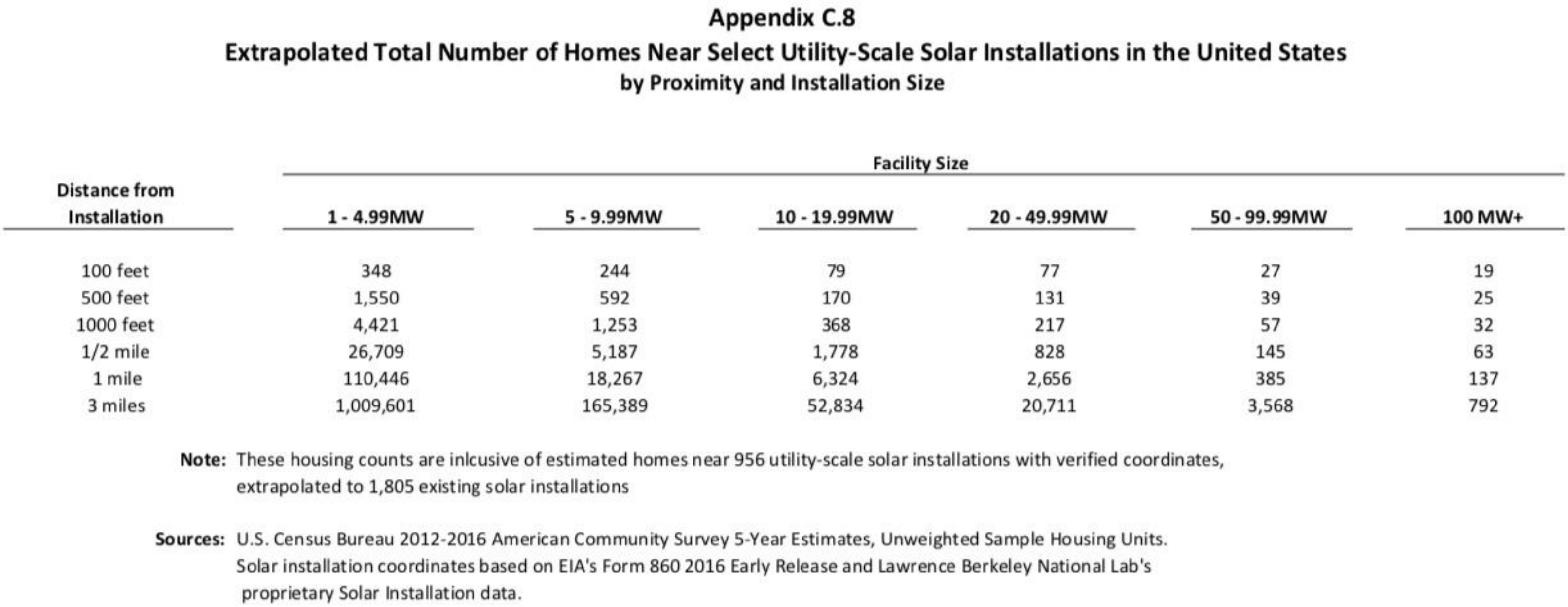
Appendix C.7 - Map of Housing Density Near Select Solar Sites in California



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

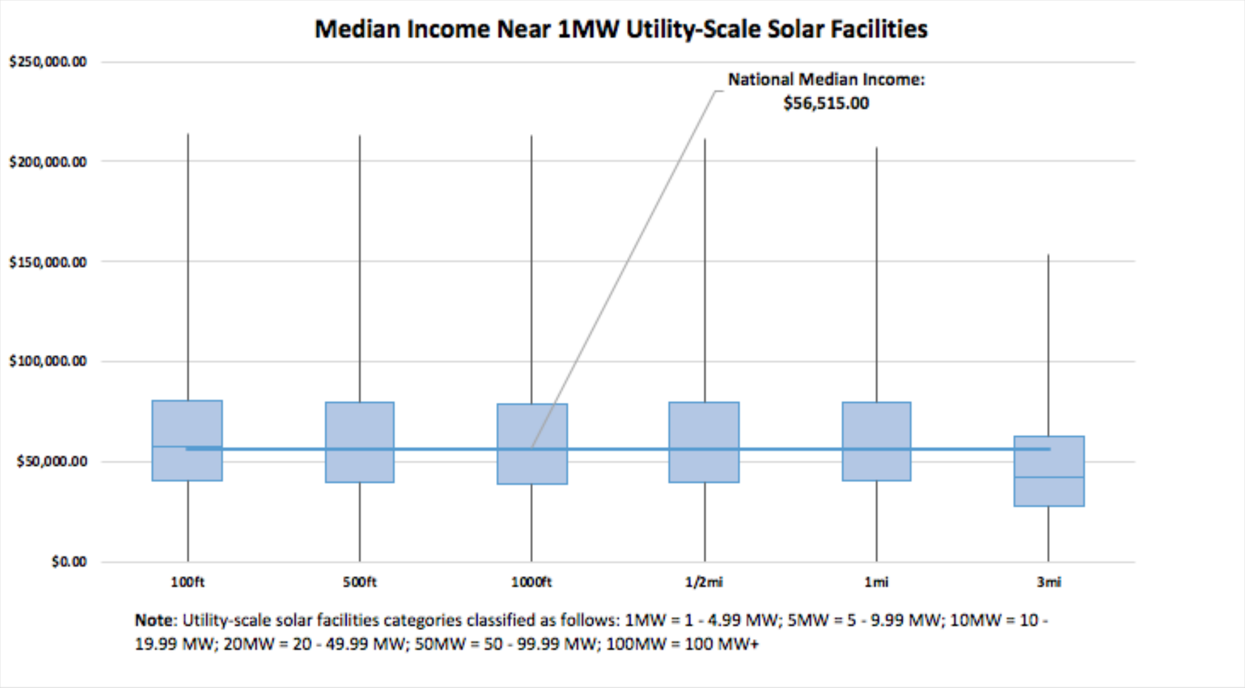
Distance from Installation	Facility Size					
	1 - 4.99MW	5 - 9.99MW	10 - 19.99MW	20 - 49.99MW	50 - 99.99MW	100 MW+
100 feet	348	244	79	77	27	19
500 feet	1,550	592	170	131	39	25
1000 feet	4,421	1,253	368	217	57	32
1/2 mile	26,709	5,187	1,778	828	145	63
1 mile	110,446	18,267	6,324	2,656	385	137
3 miles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

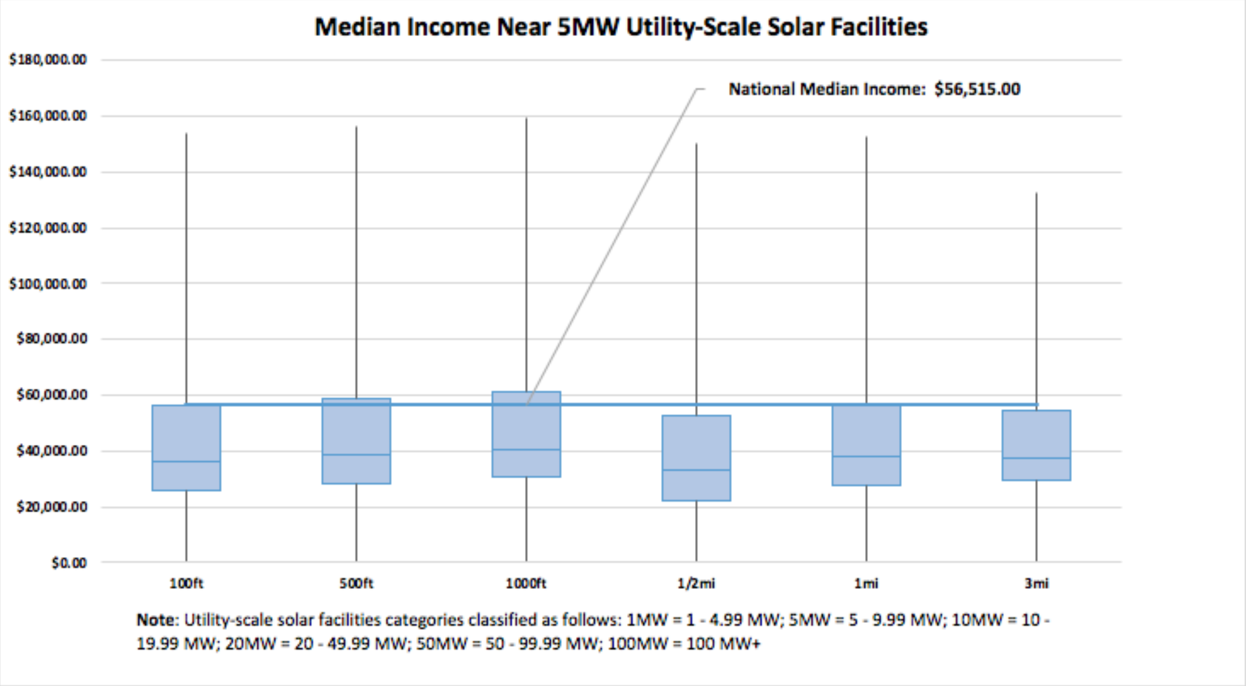
C.9: *Median income near all 1MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income corresponds with the median income near 1MW facilities relatively well.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



Median Income Near 1MW Utility-Scale Solar Facilities

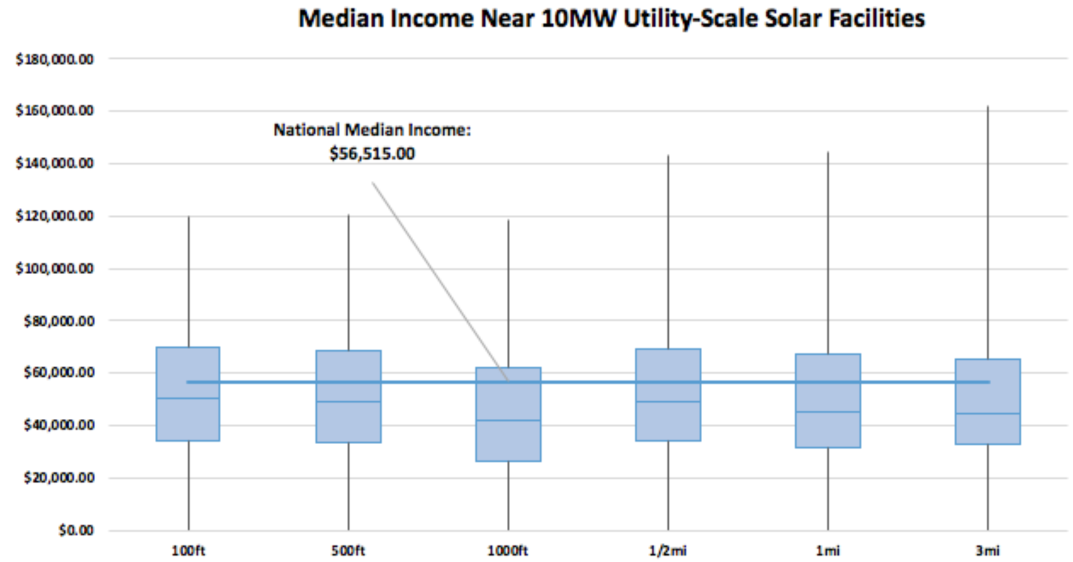
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.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.*



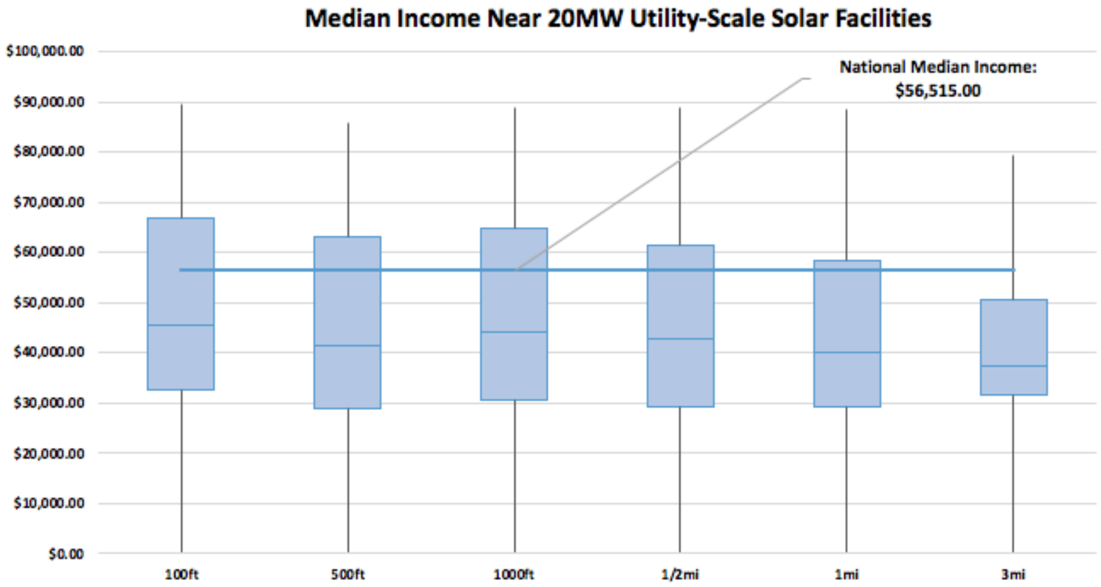
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

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+

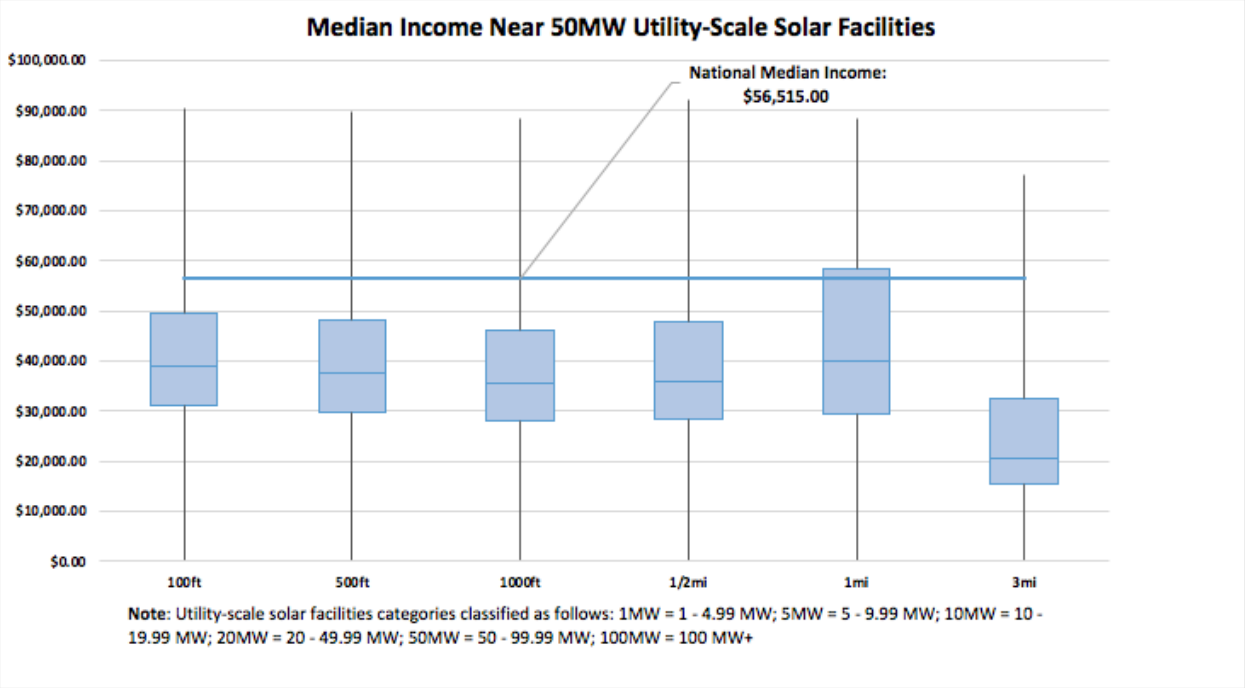
C.12: *Median income near all 20MW facilities in the United States is shown as box plots. Distance from facility increases from right to left. The national median income is displayed as a horizontal line. The national median income appears to be higher than that of residents who live in proximity to 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.*



Median Income Near 20MW Utility-Scale Solar Facilities

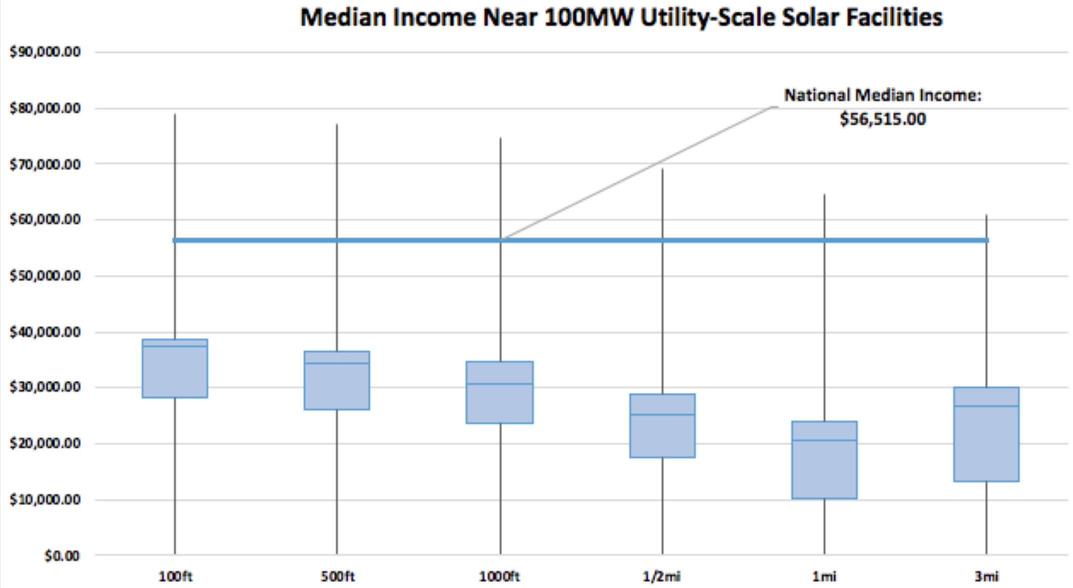
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

***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.*



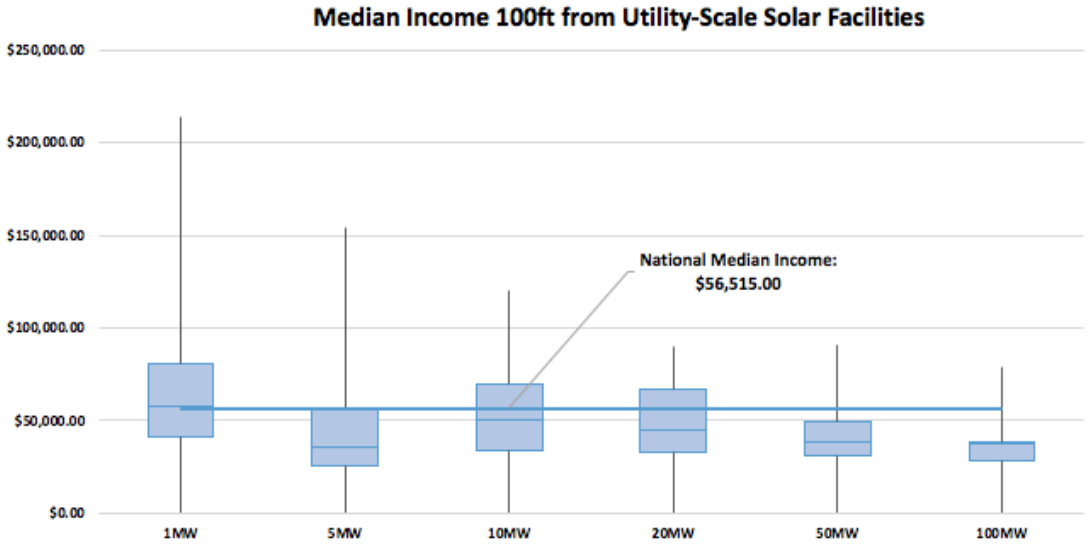
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

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.*



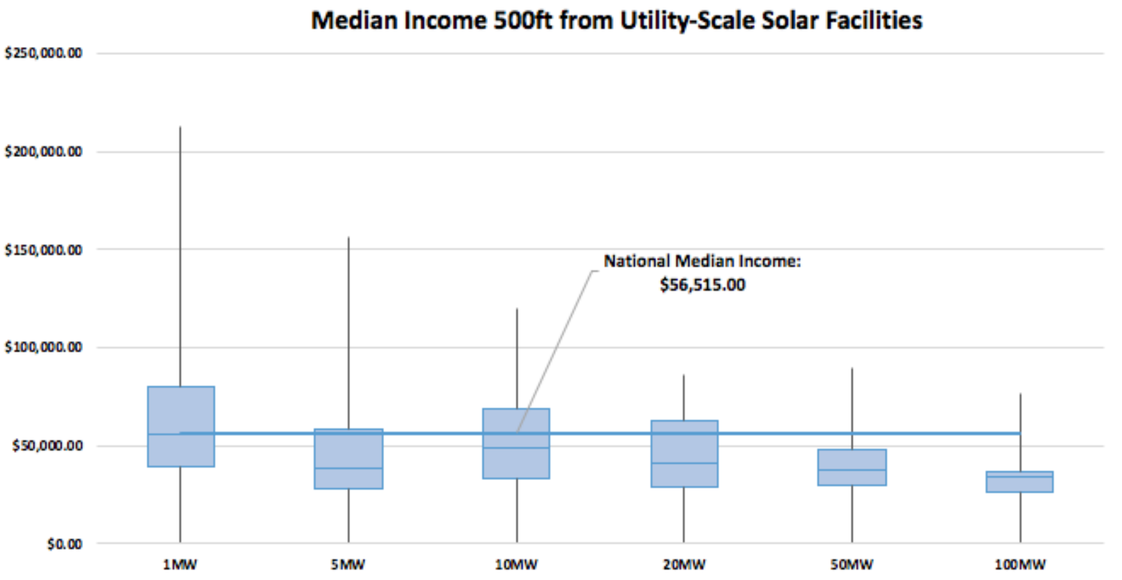
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.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.*



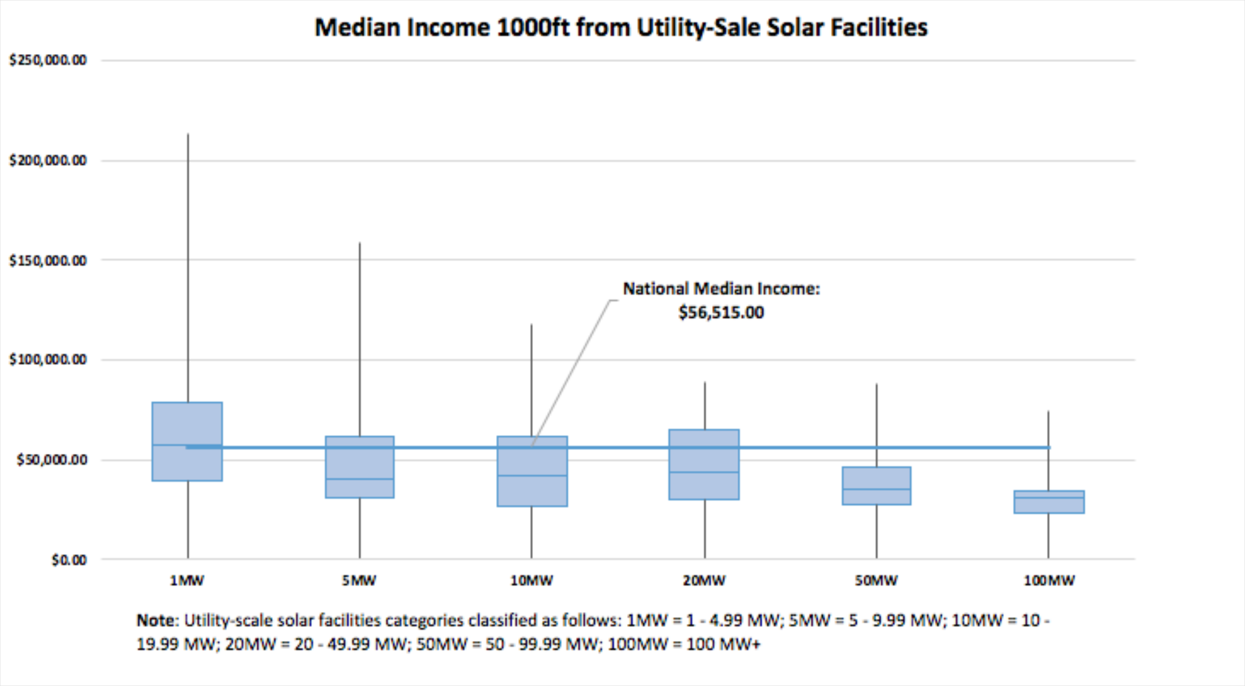
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW +

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.*



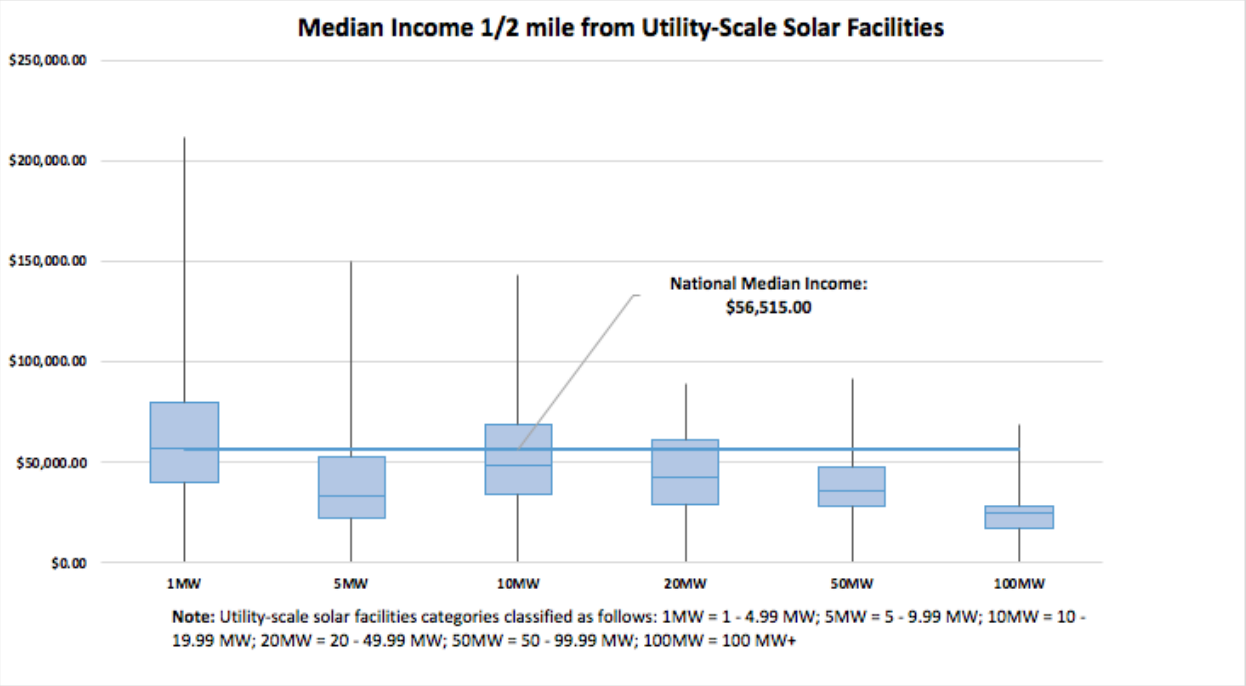
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

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.*



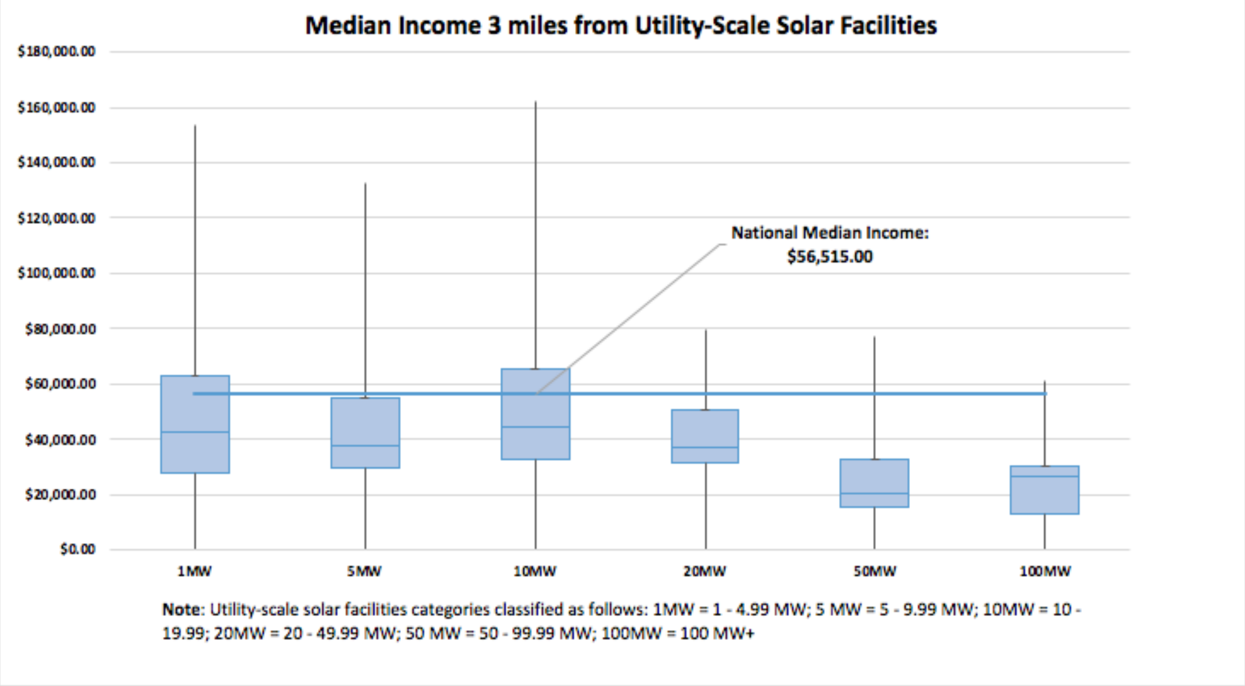
Note: Utility-scale solar facilities categories classified as follows: 1MW = 1 - 4.99 MW; 5MW = 5 - 9.99 MW; 10MW = 10 - 19.99 MW; 20MW = 20 - 49.99 MW; 50MW = 50 - 99.99 MW; 100MW = 100 MW+

C.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.*



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+

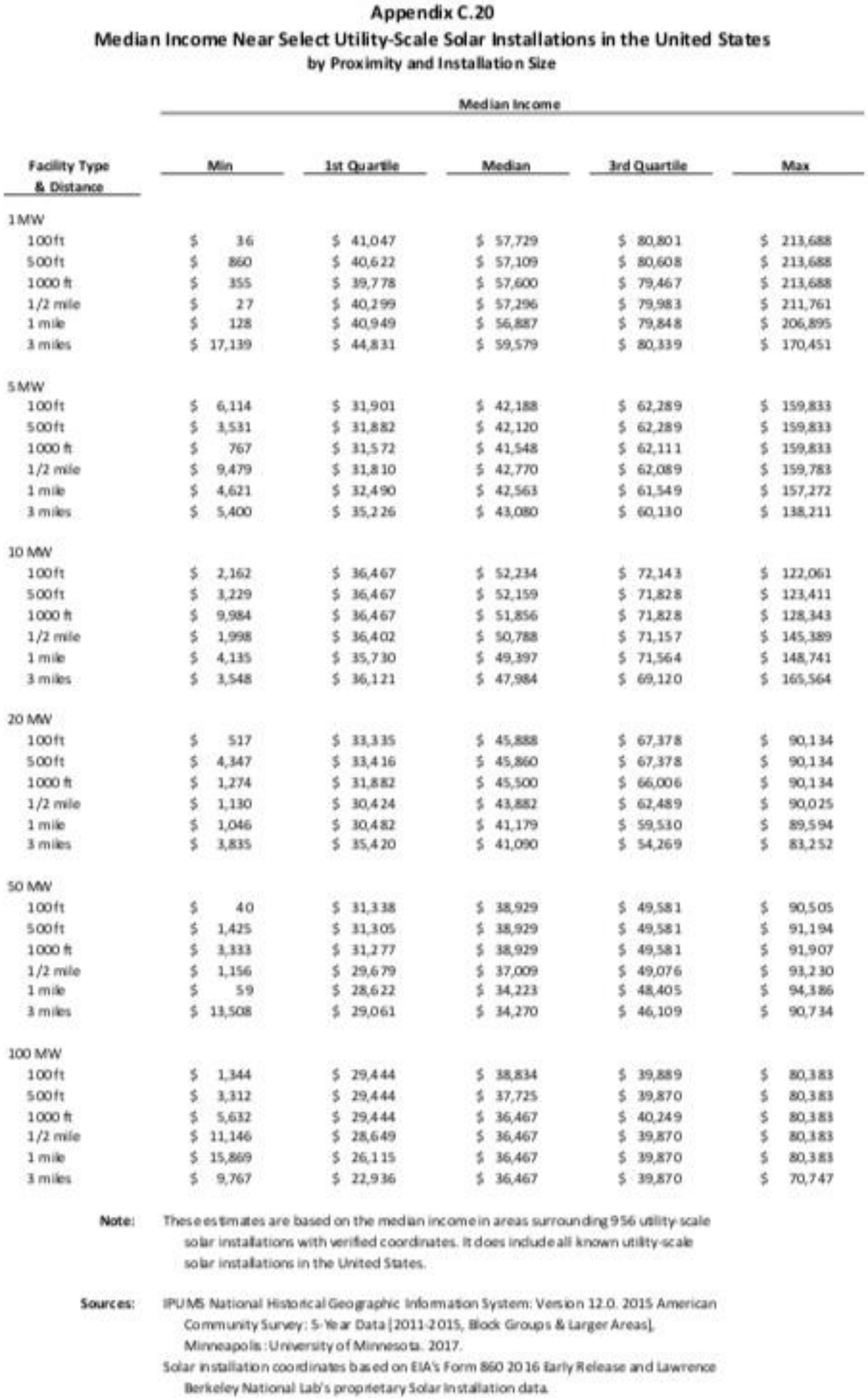
C.19: *Median income three miles from all facilities in the United States is shown as box plots. Installation size increases from right to left. The national median income is displayed as a horizontal line. The interquartile range for median income appears to roughly decrease as facility size increases. 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					
100ft	$ 36	$ 41,047	$ 57,729	$ 80,801	$ 213,688
500ft	$ 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					
100ft	$ 6,114	$ 31,901	$ 42,188	$ 62,289	$ 159,833
500ft	$ 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					
100ft	$ 2,162	$ 36,467	$ 52,234	$ 72,143	$ 122,061
500ft	$ 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					
100ft	$ 517	$ 33,335	$ 45,888	$ 67,378	$ 90,134
500ft	$ 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					
100ft	$ 40	$ 31,338	$ 38,929	$ 49,581	$ 90,505
500ft	$ 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					
100ft	$ 1,344	$ 29,444	$ 38,834	$ 39,889	$ 80,383
500ft	$ 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

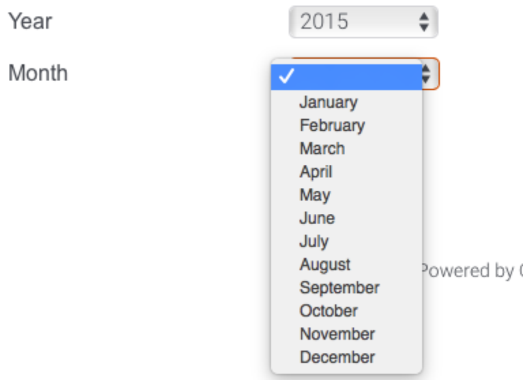
○ I have **never** been an assessor or appraiser for the public sector

○ 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."*

____

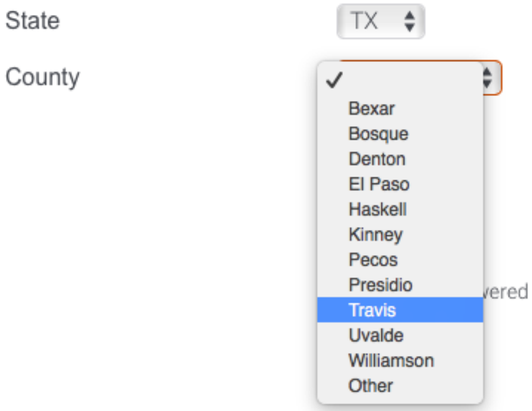
What was the approximate date of the most recent residential assessment you completed?



Year 2015

Month

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



State TX

County

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

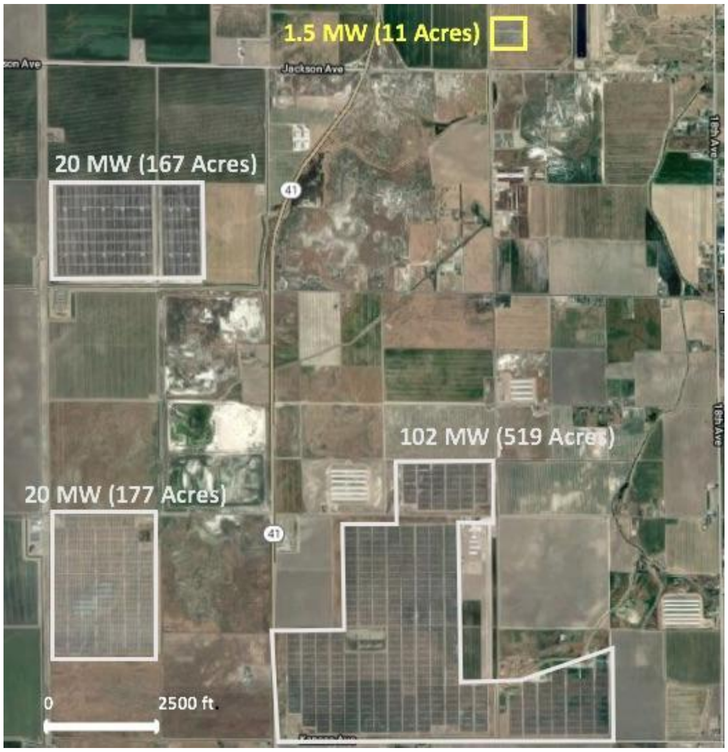
○ I don't have a manual or other professional materials

○ I prefer not to answer

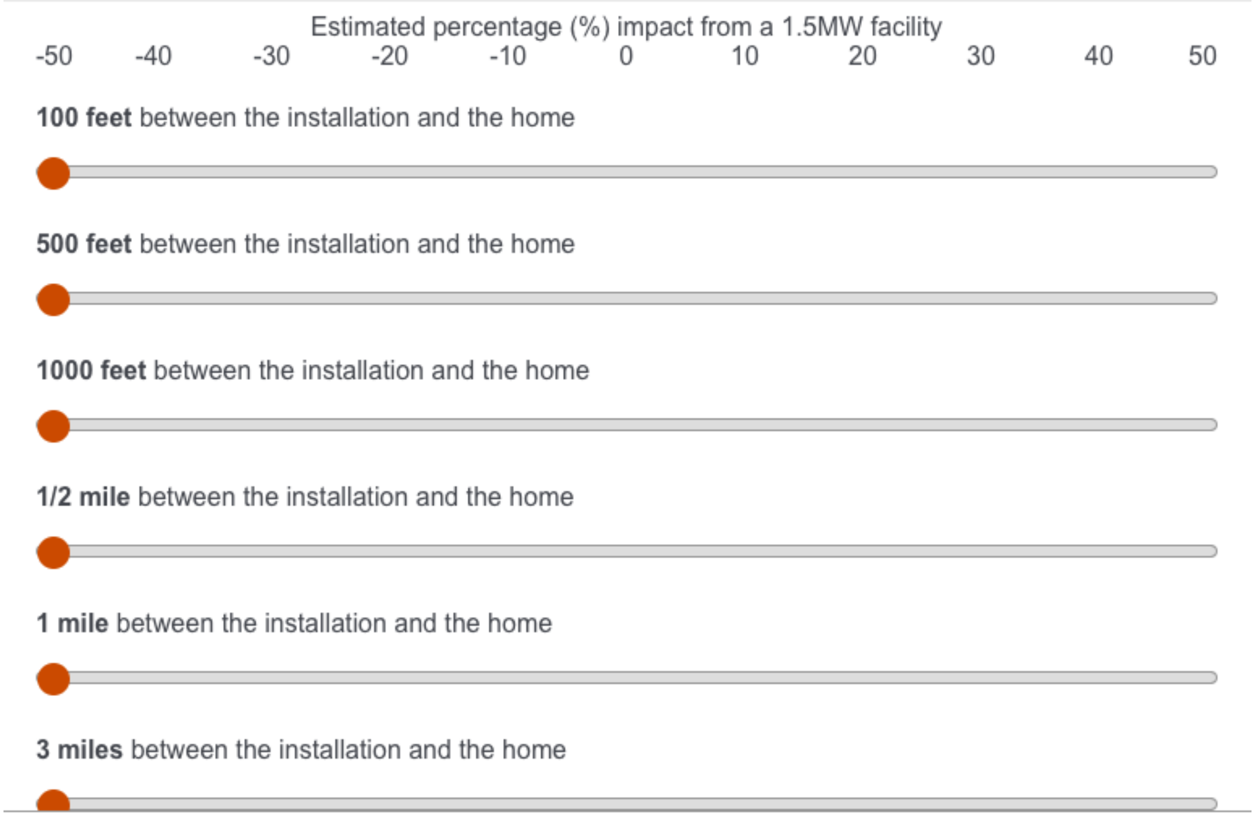
Part I: 1.5MW Facilities

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

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

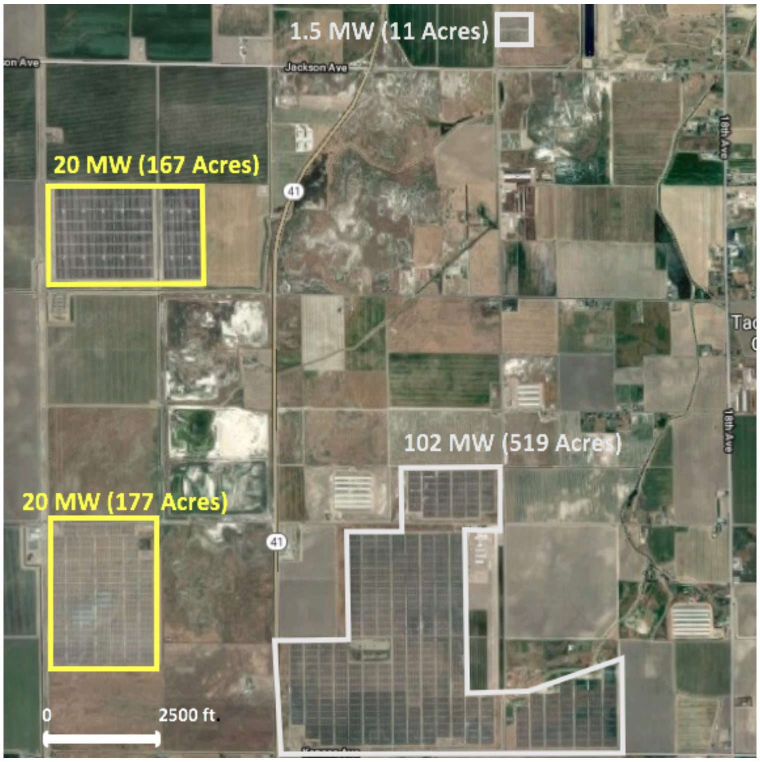
1 mile between the installation and the home

3 miles between the installation and the home

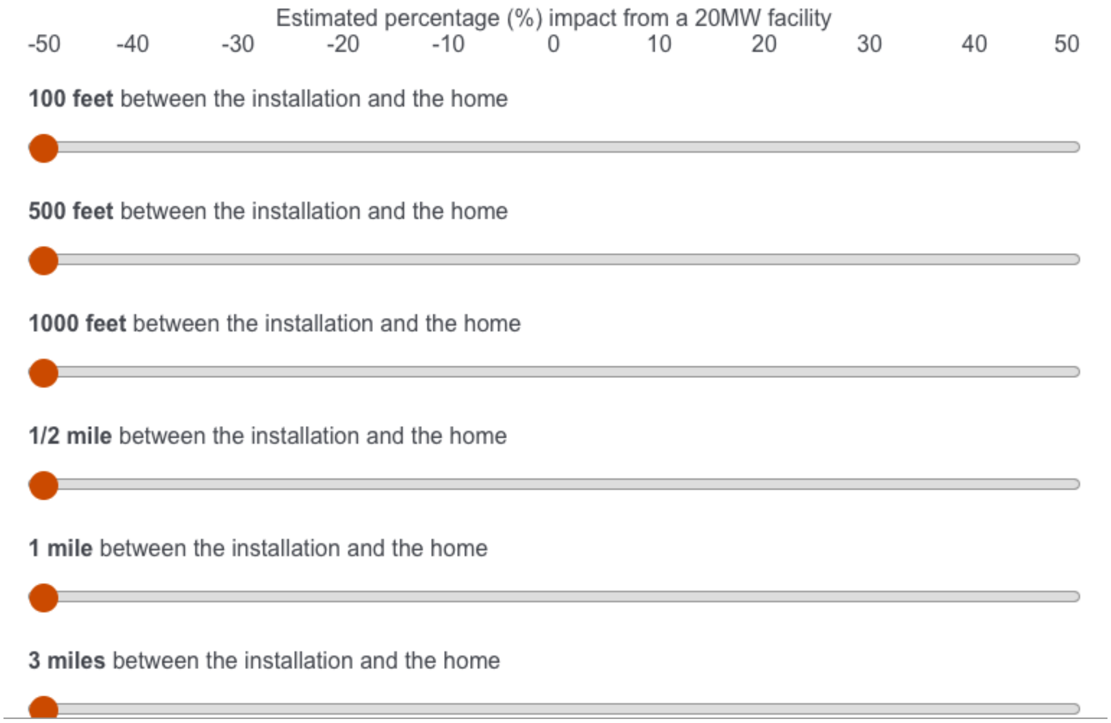
<u>Part II: 20MW Facilities</u>

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

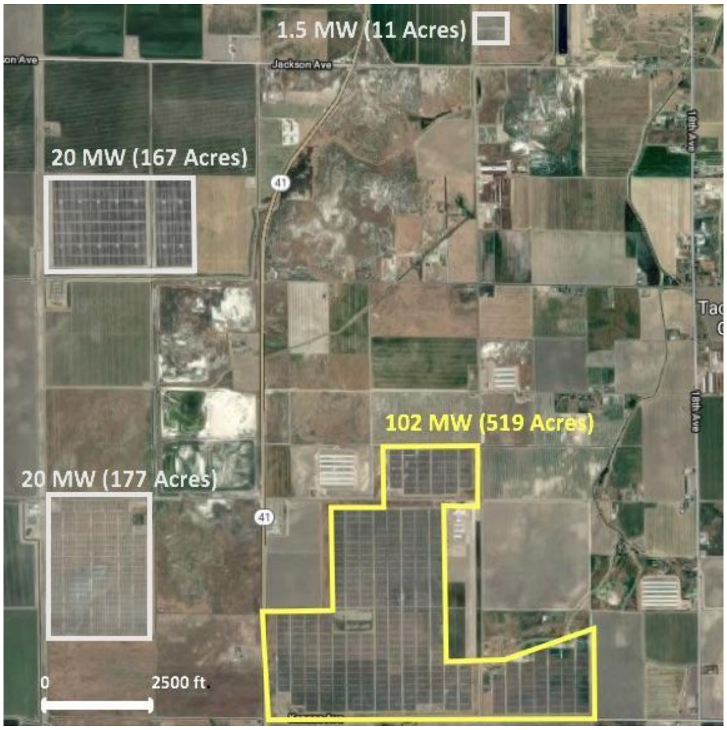
1 mile between the installation and the home

3 miles between the installation and the home

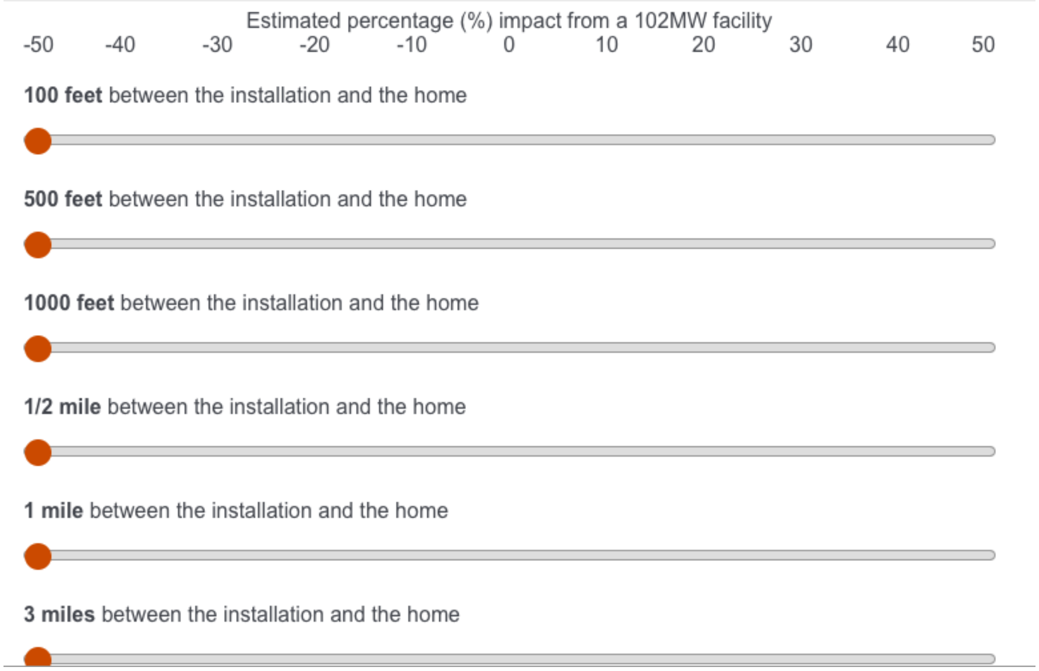
Part III: 102MW Facilities

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

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

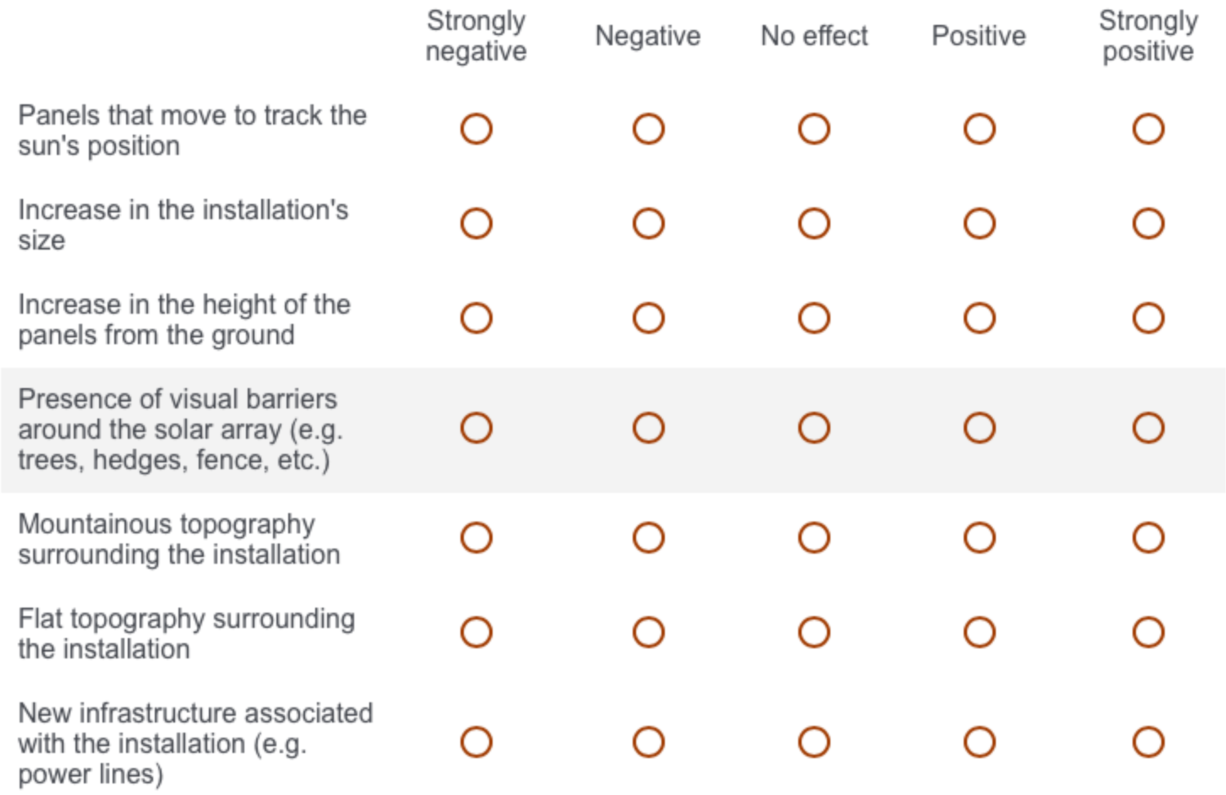
1 mile between the installation and the home

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

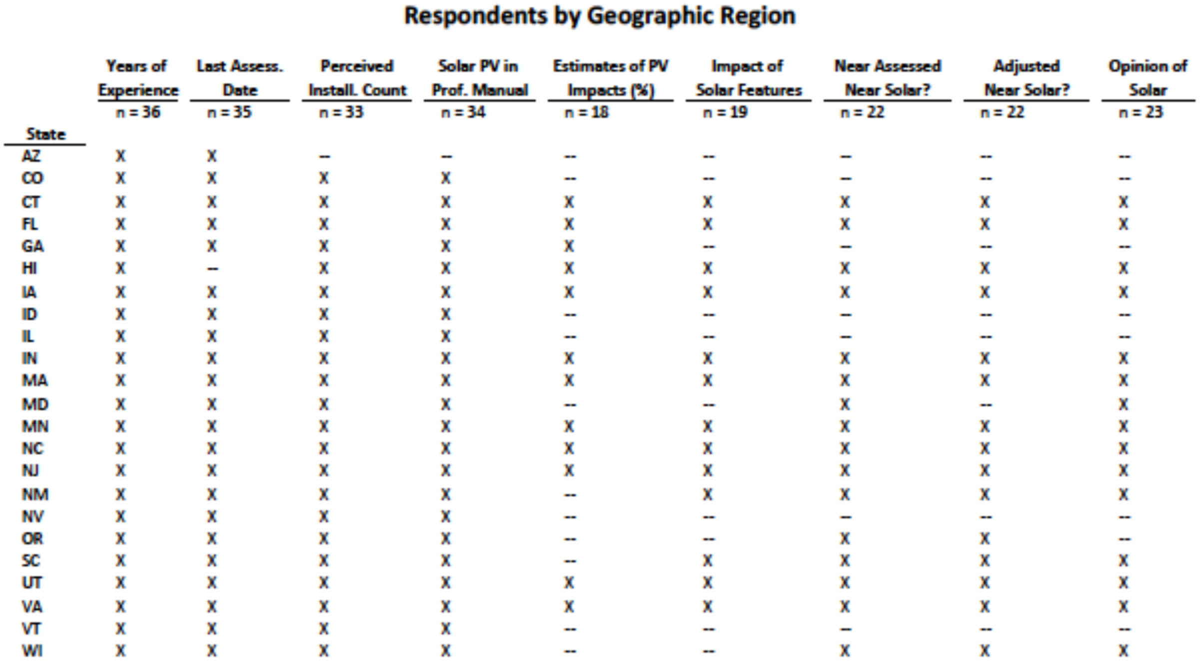
What is your email address?
Your email address will not be shared and will be used for survey validation and related communication purposes only.

____

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.*

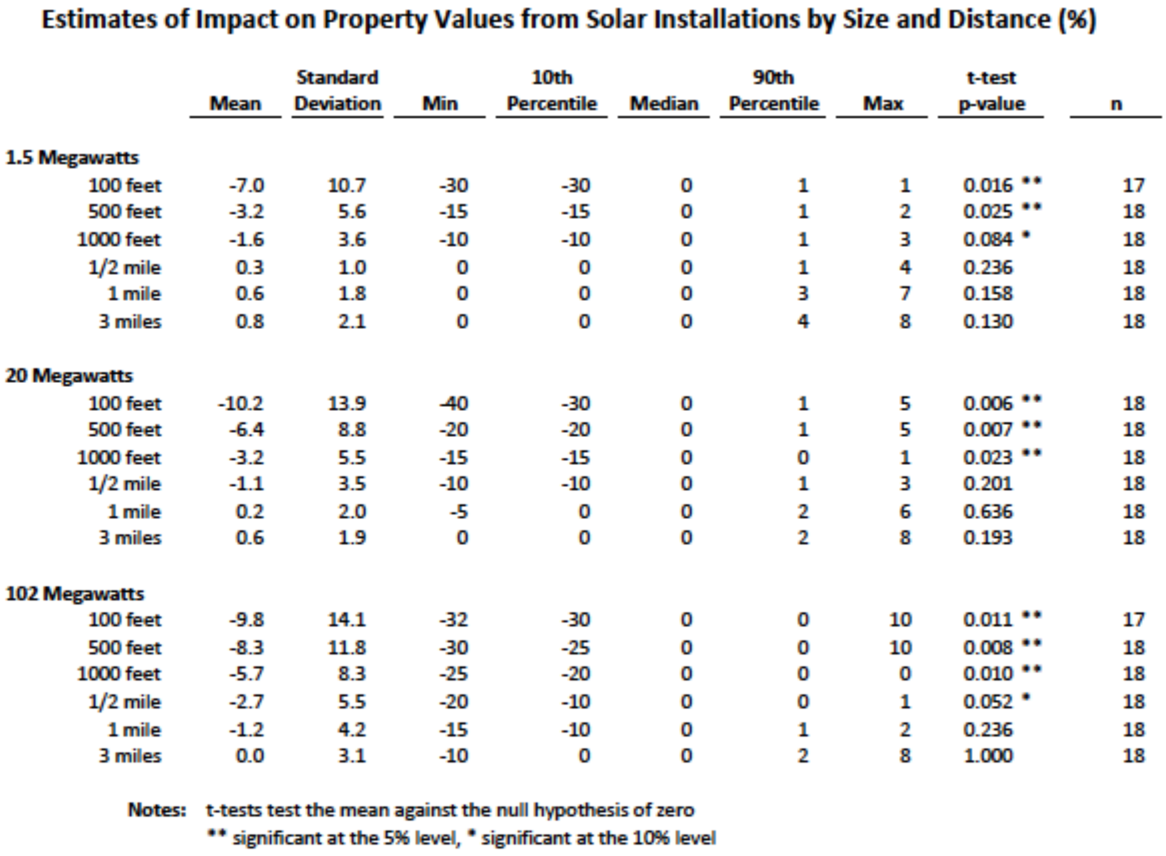


Respondents by Geographic Region

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 (%)

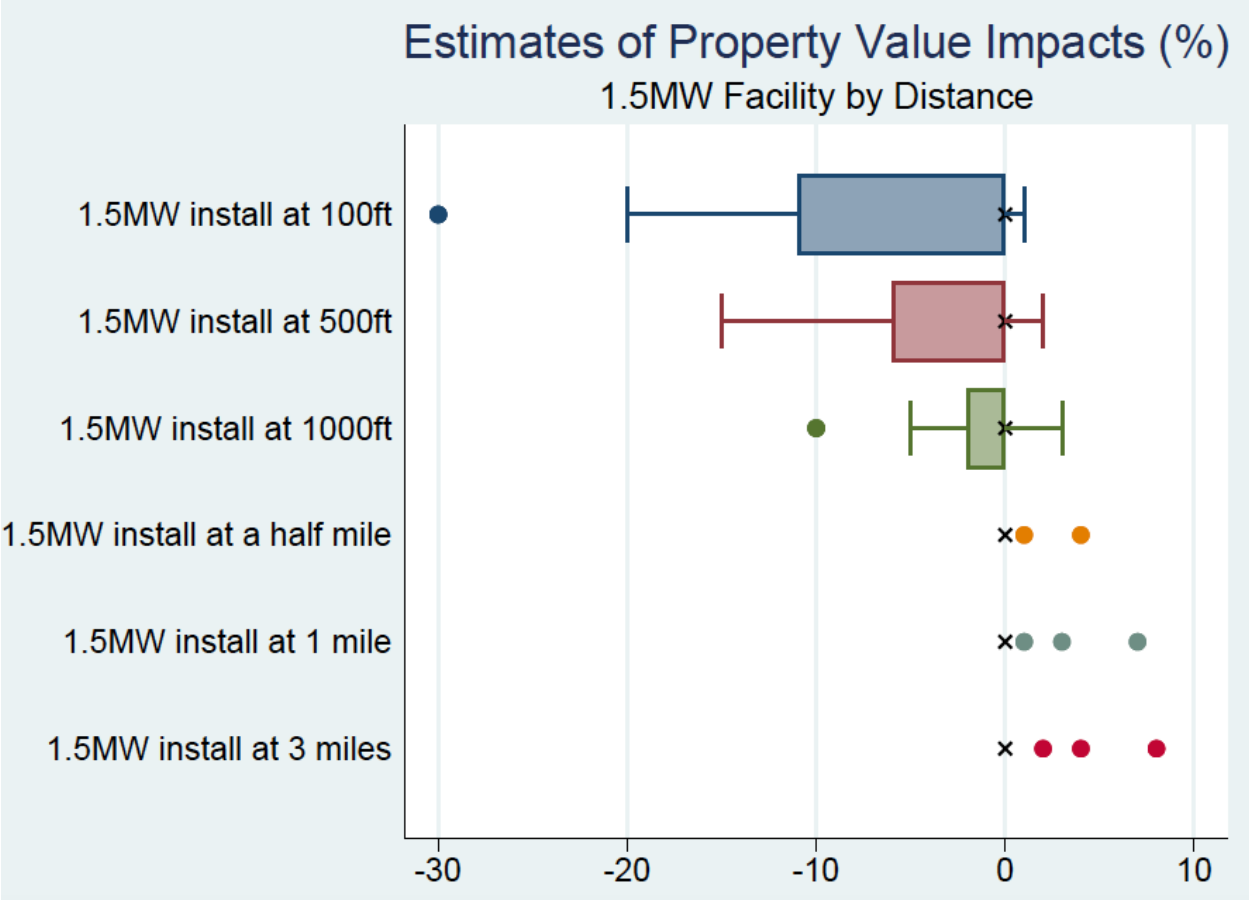
	Mean	Standard Deviation	Min	10th Percentile	Median	90th Percentile	Max	t-test p-value	n
1.5 Megawatts									
100 feet	-7.0	10.7	-30	-30	0	1	1	0.016 **	17
500 feet	-3.2	5.6	-15	-15	0	1	2	0.025 **	18
1000 feet	-1.6	3.6	-10	-10	0	1	3	0.084 *	18
1/2 mile	0.3	1.0	0	0	0	1	4	0.236	18
1 mile	0.6	1.8	0	0	0	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

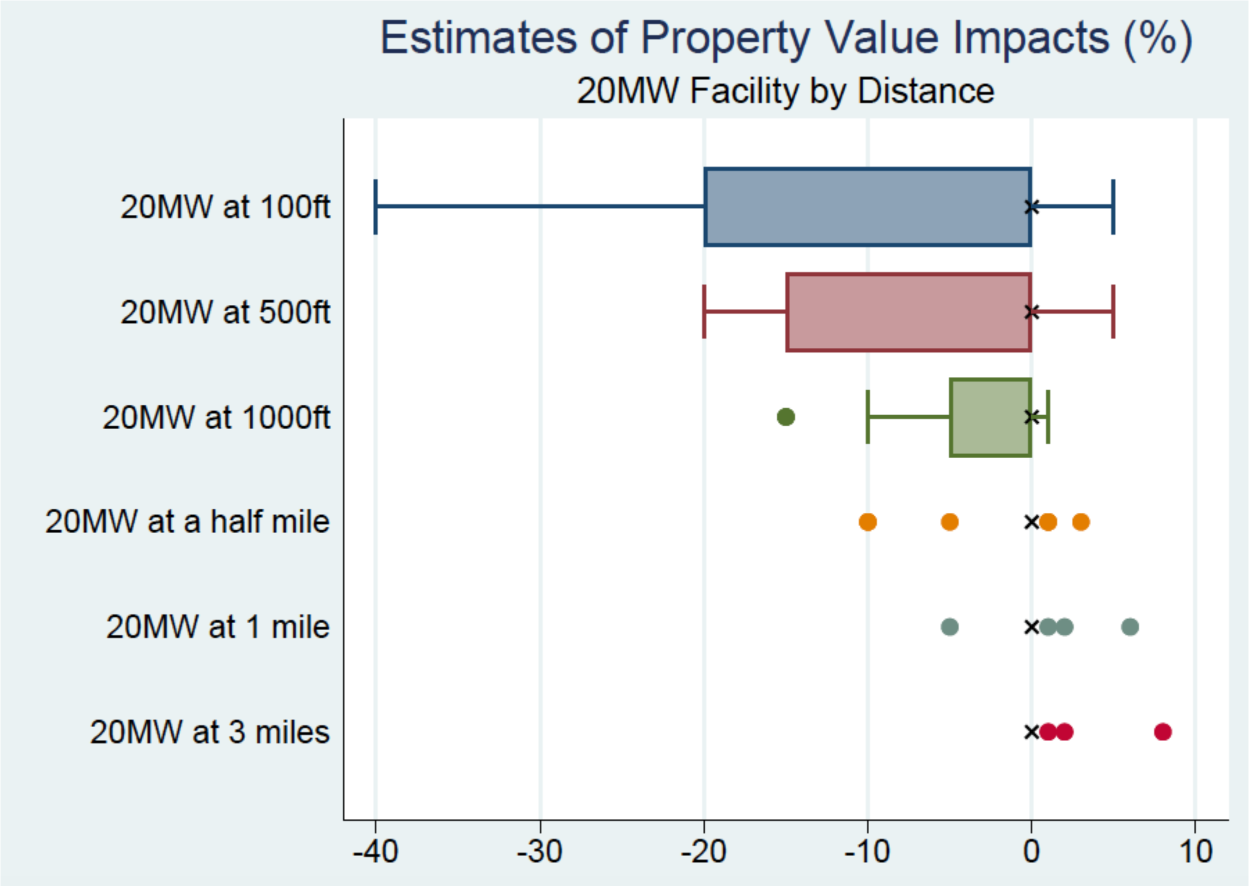
Appendices D.4 - D.6 - Estimates of Property Value Impacts in Boxplots

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

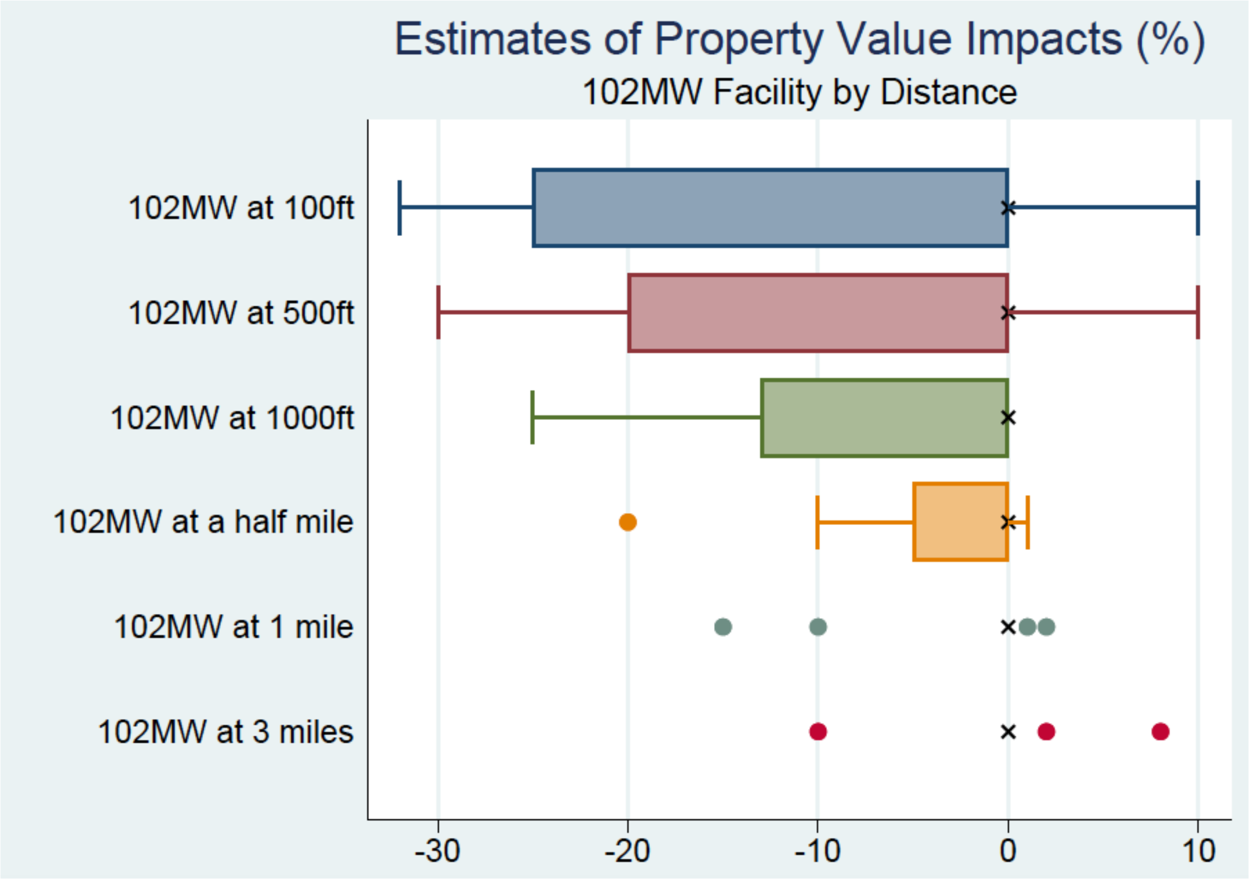
Appendix D.4: *The below boxplots indicate the range of estimates from survey respondents for property value impacts near a 1.5MW facility. The median is indicated with an "X".*



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".*



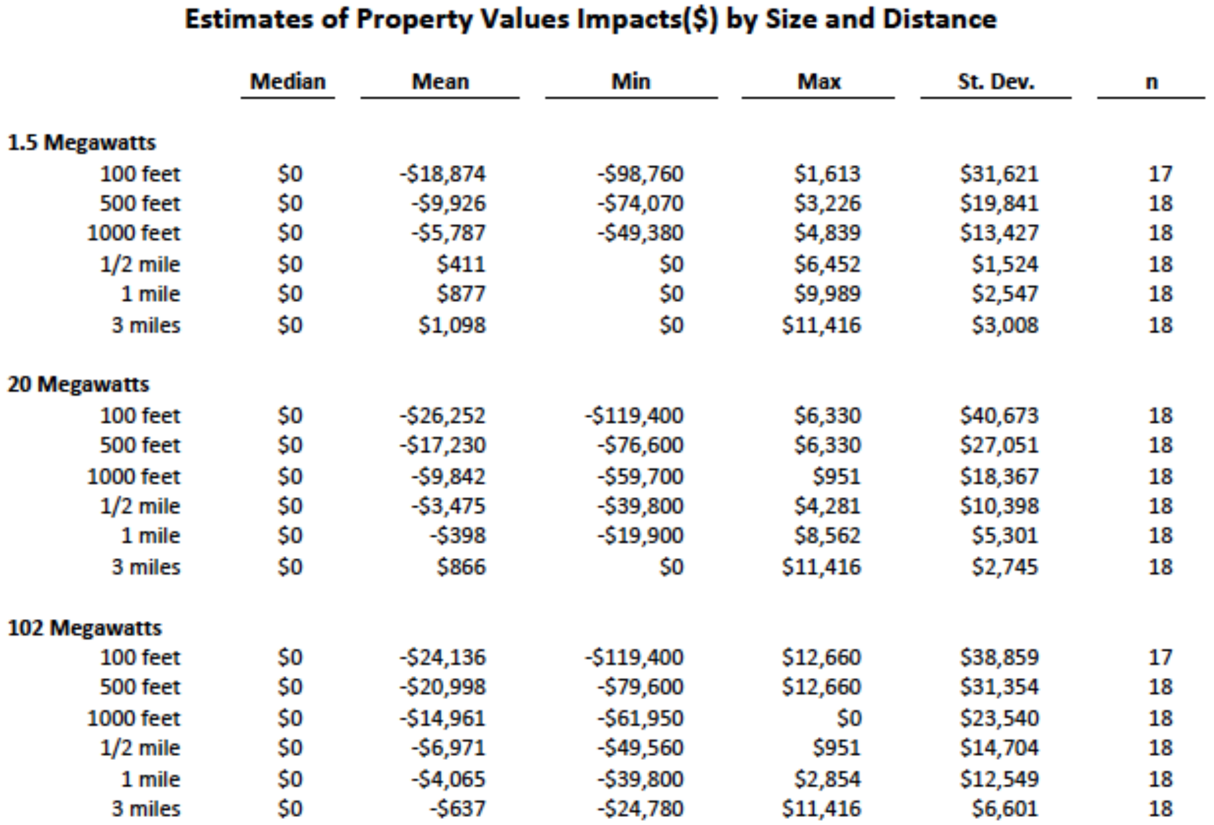
Appendix D.6: *The below boxplots indicate the range of estimates from survey respondents for property value impacts near a 102MW facility. The median is indicated with an "X".*



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

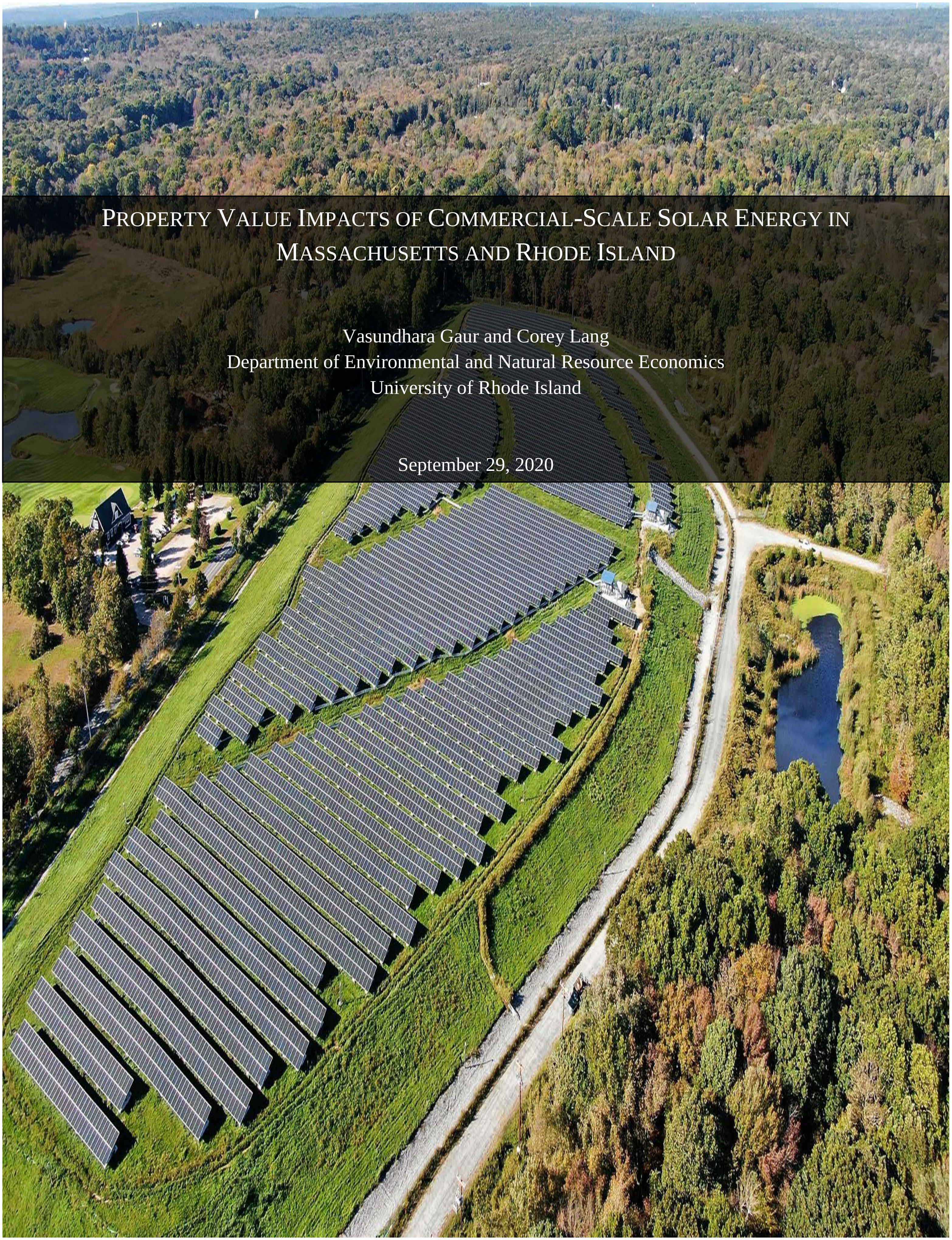
To estimate property value impacts in dollar terms, we pulled county-level median home value from the U.S. Census Bureau's 2016 American Community Survey. The below table converts the estimates of property value impacts provided by survey respondents into dollars, based on the median home value in each 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



PROPERTY VALUE IMPACTS OF COMMERCIAL-SCALE SOLAR ENERGY IN MASSACHUSETTS AND RHODE ISLAND

Vasundhara Gaur and Corey Lang
Department of Environmental and Natural Resource Economics
University of Rhode Island

September 29, 2020

ABSTRACT

While utility-scale solar energy is important for reducing dependence on fossil fuels, solar arrays use significant amounts of land (about 5 acres per MW of capacity), and may create local land use disamenities. This paper seeks to quantify the externalities from nearby solar arrays using the hedonic method. We study the states of Massachusetts and Rhode Island, which have high population densities and ambitious renewable energy goals. We observe over 400,000 transactions within three miles of a solar site. Using a difference-in-differences, repeat sales identification strategy, results suggest that houses within one mile depreciate 1.7% following construction of a solar array, which translates into an annual willingness to pay of $279. Additional results indicate that the negative externalities are primarily driven by solar developments on farm and forest lands in non-rural areas. For these states, our findings indicate that the global benefits of solar energy in terms of abated carbon emissions are outweighed by the local disamenities.

ACKNOWLEDGEMENTS

We thank Ben Hoen, Salma Elmallah, and conference participants at AERE and NAREA for useful feedback. This work was supported by the USDA National Institute of Food and Agriculture, Agricultural and Food Research Initiative Competitive Program, Critical Agricultural Research and Extension, grant number 2019-68008-29826.

CONTACT

Please direct questions to Corey Lang at 401-874-4569 or clang@uri.edu.

CITATION

Please cite this report as:
Gaur, V. and C. Lang. (2020). Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island. Submitted to University of Rhode Island Cooperative Extension on September 29, 2020. Accessed at https://web.uri.edu/coopext/valuing-siting-options-for-commercial-scale-solar-energy-in-rhode-island/.

1 INTRODUCTION

Solar energy in the United States has grown at an average rate of 49% per year since 2009, making the US the second largest producer of solar energy in the world (EIA International Energy Outlook 2019). In 2019, solar energy accounted for 40% of all new capacity additions in the country, the largest ever in its history, and exceeding all other energy sources (Perea et al., 2020). By June 2020, the cumulative installed capacity of solar in the United States reached 81.4 gigawatts (GW), which is enough to power 15.7 million homes (Perea et al., 2020). Solar is predicted to overtake wind to become the largest source of renewable energy in the US by 2050, accounting for 46% of all energy produced from renewable sources (EIA Annual Energy Outlook 2018).

While there is a broad support for renewable energy in the United States (Bates & Firestone, 2015; Farhar, 1994; Firestone et al., 2018; Hoen et al., 2019; Krohn & Damborg, 1999), and for solar energy in particular (Carlisle et al., 2014, 2015; Farhar, 1994; Greenberg, 2009; Jacobe, 2013; Pew Research Center, 2019), the development of large-scale solar installations has not been obstacle free. One major hurdle to overcome before construction begins is the siting process. Solar installations require over ten times more land area than non-renewable sources to generate the same amount of energy, and the requirement of large tracts of land for their construction has become the largest cause of land use change in the United States (Trainor et al. 2016; Ong et al. 2013). Recently, the siting of large solar projects has become contentious in some parts of the country due to concerns about visual disamenities, impacts on ecosystems, siting of transmission lines, loss of a town’s rural character, water pollution, fire risk, water use, and reduction in property values (Farhar et al., 2010; Gross, 2020; Lovich & Ennen, 2011). The debate is especially heated when solar development is proposed on existing farm and forest lands, which is common because these are the cheapest locations for development (Kuffner, 2018; Naylor, 2019).

The purpose of this paper is to quantify the externalities associated with proximity to utility-scale solar installations using hedonic valuation. Theory indicates that property values will reflect people’s willingness to pay to avoid the cumulative disamenities of solar development (Bishop et al., 2019; Rosen, 1974). Our study focuses on the states of Massachusetts (MA) and Rhode Island (RI), which are ideal for two reasons. First, both states have recently experienced a sudden boom in the development of large-scale solar installations. This trend has been driven by the Renewable Portfolio Standards (RPS), regulations that require increased energy production from renewable energy sources, which have been adopted by both states. MA's RPS calls for 25% of electricity generated by renewable sources by 2030 and RI's RPS calls for 38.5% by 2035. Second, both states have high population density, ranked 2nd and 3rd among U.S. states. This level of development means that most solar sites are proximate to residential areas, which yields many observed transactions for precise estimates.

We analyze the impact of utility-scale solar installations sized 1 MW and above on nearby property prices in MA and RI.[1] We use a difference-in-differences (DID) identification strategy, which compares changes in housing prices after construction for nearby properties with those further away. We empirically estimate the spatial extent of treatment to be one mile from the solar installation and choose a cutoff for control properties of three miles. Our primary sample consists of 208 solar installations, 71,337 housing transactions occurring within one mile (treated group), and 347,921 transactions between one to three miles (control croup).

Across a variety of specifications, our results suggest that solar installations negatively affect nearby property values. Our preferred specification, which includes property fixed effects (i.e., repeat sales), month-year fixed effects, and county-year fixed effects, indicates that property values in the treatment group decline 1.7% (or $5,751) relative to the control group, and this estimate is statistically different from zero at the 1% level. These findings suggest that solar arrays create local, negative externalities, and the average household annual willingness to pay to avoid these externalities is $279. This helps explain local concerns and opposition and gives pause to current practices of not including proximate residents in siting decisions or compensating them after siting has occurred. While we cannot estimate producer and consumer surplus, we can compare external benefits and costs. Our estimates imply that the global positive external benefits of carbon mitigation are outweighed by local externalities costs at a ratio of 0.46. However, renewable energy in New England usually displaces natural gas use by power plants. Solar in more rural places (thus affecting fewer households) and solar that displaces coal would have a more favorable benefit-cost ratio.

We also examine heterogeneity in treatment effects in several ways. First, with respect to proximity, we find substantially larger negative impacts on homes located within 0.1 mile of

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[1] Following the U.S. Energy Information Administration (EIA), we define large-scale solar installations as those with an installed capacity of 1 MW or larger.

solar installations (-7.0%). Second, we estimate a series of models exploring heterogeneity based on prior land use (farm or forest vs. landfills or industrial areas) and rural character of a municipality (defined based on population density). The results suggest that the overall negative effects of solar arrays on nearby property values are driven by farm and forest sites in non-rural areas (non-rural is most akin to suburban, as there are very few solar sites in urban areas). Solar developments on landfills and industrial areas or in rural areas have smaller and statistically insignificant effects on prices. We posit that solar arrays on farm and forest lands cause greater externalities, given the dual loss of open space amenities and gain of industrial disamenities, and that this effect hinges on the scarcity of open space typical in non-rural areas.

2 CONCEPTUAL FRAMEWORK

Environmental goods and services are often 'non-market goods', meaning they are not traded in any market. However, that does not mean that they have no value. Using economic theory, we can estimate environmental values by examining people's decisions and how they make choices and tradeoffs regarding such goods.

One way of valuing environmental goods and services is through the revealed preference method where the preferences of individuals are inferred through their actual buying and selling decisions in a related market. For example, air quality is not transacted in any market, but people 'reveal' their value for it when they buy homes away from urban and industrial areas with high traffic volumes and poor air quality. In this example, air quality is the non-market good, the 'actual buying and selling decision' is the choice of purchasing a house with specific characteristics, and the 'related market' is the housing market.

A common application of the revealed preference method is the hedonic housing price technique. First theorized by Rosen (1974), the hedonic price model (HPM) measures the implicit price of each attribute of a bundled good. Applied to the housing market, the idea is that the price of a property can be broken down into the price of its various attributes. These attributes can be structural (e.g. lot size, living area, number of bedrooms and bathrooms, presence of air conditioning or pool, etc.), neighborhood (e.g. school quality, proximity to shopping, etc.), and environmental (e.g. air and groundwater quality, tree cover, proximity to brownfield, etc.). More formally, let us consider a house i, and let P_i denote its price, S_i the set of structural characteristics, N_i the neighborhood characteristics, and E_i the environmental characteristics of that house. Then the hedonic price function of the house can be represented mathematically as a function of its characteristics:

$$P_i = f(S_i, N_i, E_i) \tag{1}$$

When purchasing a house, the consumers make tradeoffs between their desired quantities of each of these attributes and price. Further, in equilibrium, prices adjust to reflect willingness to pay for the bundled attributes. By examining transacted properties with sales price and attributes, the implicit value of each attribute can be estimated. In the context of solar development, the value that people place on solar arrays can be estimated by examining transactions in close proximity to solar arrays compared to those further away.

The HPM is a well-established and frequently used tool for measuring nonmarket values. It has been used extensively in the literature for estimating the willingness to pay for environmental amenities like air quality (Bajari et al., 2012; Bayer et al., 2009; Bento et al., 2014; Chay and Greenstone, 2005; Grainger, 2012; Lang, 2015; Ridker and Henning, 1967) and open space (Anderson and West, 2006; Black, 2018; Geoghegan et al., 1997; Irwin, 2002; Lang, 2018), and also environmental disamenities like brownfields (Haninger et al., 2017; Lang and Cavanagh, 2018; L. Ma, 2019) and electrical transmission lines (Hamilton and Schwann, 1995). Several hedonic studies also estimate the public's valuation of non-renewable energy sources and infrastructure, particularly coal plants (Davis, 2011), nuclear energy (Gawande and Jenkins-Smith, 2001; Tanaka and Zabel, 2018), petroleum storage (Zabel and Guignet, 2012), and hydraulic fracturing (Boslett et al., 2016, 2019; Gopalakrishnan and Klaiber, 2014; Muehlenbachs et al., 2015).

The HPM produces intuitive and policy relevant results. For example, Haninger et al. (2017) analyze federal brownfield remediation and find that properties in close proximity to EPA-funded remediated brownfields appreciate 5-11% following cleanup, and that in aggregate this valuation exceeds the costs of remediation and hence the federal program passes a benefit-cost test. Lang (2018) examines municipal land conservation spending in the United States, and estimates that properties on average appreciate 0.68–1.12% for every $1000 per household of open space spending authorized. The positive appreciation implies that the valuation of open space amenities exceeds the costs of additional taxes, and further that land conservation is underprovided. Muehlenbachs et al. 2015 analyze hydraulic fracturing ("fracking") in Pennsylvania and find that properties within 1km of a well pad decline in value 16.5%, but only when the properties use well water, public water supply houses are unaffected. These results suggest that perception of risk is focused on contaminated drinking water.

The HPM has become increasingly popular for the valuation of renewable energy in recent years, with the most frequent applications focusing on wind energy. Within the United States, studies that use data with large numbers of observations close to turbines find no significant impact on property prices. Hedonic studies that find no negative externalities from onshore wind energy development include Hoen et al. (2011) for 24 wind facilities across the United States; Lang et al. (2014) for 10 wind turbine sites in Rhode Island; Hoen et al. (2015) for 67 wind facilities (with over 45,000 turbines) installed all over the United States through 2011, and Hoen and Atkinson-Palombo (2016) for 41 turbines in densely populated areas of Massachusetts. In contrast, studies in European countries find that wind turbines have a significantly negative impact on nearby properties, though the magnitude of the effect differs by region (Dröes & Koster, 2016; Gibbons, 2015; Sunak & Madlener, 2016). Vyn (2018) finds the Canadian experience to be heterogeneous and dependent on community acceptance. More recently, hedonic methods have focused on estimating externalities from offshore wind turbines. While this literature is still in its infancy, early studies indicate no negative impacts to property values in the vicinity of offshore wind turbines (Jensen et al., 2018) and positive impacts to tourism (Carr-Harris & Lang, 2019).

Hedonic valuation has also been applied to residential rooftop solar. General consensus is that houses installed with rooftop photovoltaic (PV) panels sell for a premium, though there is regional variation in the size of the effect: 3.5% in California (Dastrup et al., 2012; Hoen et al., 2012), 5.4% in Hawaii (Wee, 2016), 17% in Arizona (Qiu et al. 2017), and 3.2% in Western Australia (Ma et al. 2016). However, this literature is only tangentially related as it is about quantifying internalities (valuation of personal financial benefits), not externalities, and has nothing to do with land use.

In sum, there exists little information on the externalities associated with large-scale solar installations within the United States. It is therefore necessary to understand the value people place on solar structures in order to help state and municipal policy makers implement policies and decisions that reflect public preferences.

3 DATA

To implement the hedonic analysis, we build a composite dataset that integrates: 1) the data on the location and attributes of all solar developments in MA and RI, and 2) the data on attributes and locations of residential properties in MA and RI.

3.1 Solar data

The dataset on solar installations is obtained from the Energy Information Administration's (EIA's) report EIA-860M, or the Monthly Update to the Annual Electric Generator Report. The EIA-860M contains data on the total capacity of electric generation facilities in the United States that have a capacity of 1 MW and above, their point location (latitude and longitude), and the month and year that generation begins. Figure 1 represents a map of 284 solar installations constructed prior to August 2019, which is when we set the cutoff for being in our sample. The installations are well dispersed across all regions in both states, which increases confidence that estimates will not be affected by unobserved regional differences. We exclude 76 solar installations (27% of all installations) that are built within 1 mile of each other, since property value impacts may be hard to measure for observations in the proximity of multiple installations.[2] This is similar to a sample cut made by Haninger et al. (2017).

Figure 2 graphs new and cumulative solar capacity by year. The first installation came online in December 2010. New capacity displays a continuous upward trend through 2014. There is a sharp fall in 2015, after which the trend rises again and peaks in 2017, before falling again in 2018. As of August 2019, the cumulative solar capacity in RI and MA is 817 MW. Capacity factors for this region are about 16.5% (EIA 2019), which means these solar installations are collectively producing 1180 GWh of electricity per year, which is enough to power 157,681 homes.

One limitation of our data is that we do not have shapefiles representing the exact footprint of the solar installations, thus we must approximate that using Geographic Information Systems (GIS) software. Solar installations require approximately 5 acres of land per MW of capacity (Denholm & Margolis, 2008; Ong et al., 2013). We assume that the point location is the

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[2] Figure A1 in the online appendix represents a map of the resultant 208 solar installations.

centroid of the installation and then create a circle around it with an area equal to 5 times the capacity (in MW) of each array.[3]

We hypothesize that prior land use may affect property value impacts. Specifically, houses in proximity to farms and forests that are developed into solar may depreciate more than houses in proximity to a brownfield or capped landfill that is developed into solar.[4] Since farms, forests, and other open space are amenities and boost home values (Irwin, 2002; Lang, 2018), conversion of these types of lands may lead to larger price decreases because it is the combination of a loss of amenities and the gain of disamenities. To infer prior land use, we overlay the estimated circular footprints on 2005 land use data obtained from Massachusetts Bureau of Geographic Information and 2011 land use data obtained from Rhode Island Geographic Information System for the respective states. We then assign each installation a prior land use: 'greenfield' if it was formerly either a farm or forest land, and 'non-greenfield' if it was either a commercial site or a landfill.[5] 63% of installations and 70% of capacity is classified as greenfield (see Figure A2 in the online appendix).

3.2 Property data

We use ZTRAX housing transaction data from Zillow (http://www.zillow.com/data), which include information on property location (latitude and longitude), sales price, date of transaction, and many property characteristics (lot size, square feet of living area, number of bedrooms, number of bathrooms, year built, number of fireplaces, central air-conditioning, and

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[3] We manually crosscheck the EIA data with Google Maps, and correct the latitude and longitude when they do not correspond to the centroid of the array. We recognize that this approach could lead some properties to be misclassified as treatment or control, inducing a small amount of measurement error in treatment status. As a result, our DID estimates may be slightly attenuated.

[4] Solar developers prefer farm and forest lands because they have substantially lower construction costs compared to alternative sites like brownfields, landfills, superfunds and industrial lands.

[5] Several solar installations cover an area with multiple land uses. We obtain exactly one land use type per solar site in five additional steps. First, we classify the land use as 'landfill' if the installations have the term 'landfill' in their name, or if they are listed in the EPA's dataset of contaminated land. Second, we use a stratifying logic to group all land-use types under seven major categories: commercial, farm, forest, landfill, recreational, residential, and wetland. Third, we place *'transportation'*, *'urban public/institutional'*, *'industrial'*, *'powerline/utility'*, and *'junkyard'* under commercial; *'orchard'*, *'cropland'*, *'pasture'*, *'nursery'*, and *'cranberry bog'* under farm; *'spectator recreation'*, and *'participation recreation'* under recreation, *'multi-family residential'*, *'low density residential'*, *'medium density residential'*, *'very low density residential'*, and *'high density residential'* under residential; and *'forested wetland'*, *'water'*, and *'non-forested wetland'* under wetland. Fourth, we rank all land use categories under each installation by area, such that the land use with the greatest area gets the highest rank. We drop all land use categories but the ones with the highest rank to obtain exactly one land use per installation in the following four major categories: commercial, farm, forest, and landfill.

swimming pool). The data include 2,095,835 property transactions from January 2005 to June 2019 in the states of RI and MA. Houses with missing observations for sales price, bedrooms, full bathrooms, and half bathrooms are dropped. We also drop groups of single-family residential properties with the same latitudes and longitudes, but different addresses. Sales prices are adjusted to 2019 levels using the Northeast regional housing Consumer Price Index from Bureau of Labor Statistics. After dropping transactions with prices of $100 or less, since these are clearly not arms-length transactions, we drop transactions in the bottom and top 5% of the sales price distribution to get rid of outliers. Further, we drop observations that have more than four stories, six bedrooms, five full bathrooms, or three half bathrooms. Houses that underwent major reconstruction are dropped since they may have different attributes in previous transactions. We exclude homes that sell before they were built, as there is evidence these are lot sales without improved property. We also drop single-family residential properties with lot sizes larger than 10 acres, since large plots could be potential sites for solar development and price impacts of nearby solar could be completely different. Condominiums are assigned a lot size value of zero acres and are identified with an indicator variable. The subjective condition of properties is defined by a dummy variable equal to 1 indicating above average condition.

Similar to prior land use, we hypothesize that existing development in areas surrounding solar arrays may impact property prices. Many rural areas pride themselves on their rural character and residents seek out that type of bucolic setting. Hence, construction of solar installations could be seen as an industrialization of the landscape and may cause larger negative impacts on property values. We proxy for rural character with municipality-level population density, which comes from the 2010 Census. We define an indicator variable $Rural$, which equals one if the town has a population density of 850 people per square mile or fewer. We chose this cutoff because 850 is the average population density of MA, which forms the bulk of the observations in our dataset, and, at this cutoff, almost a third of the properties and 60% of the solar installations are classified as rural, which we believe are reasonable proportions. However, we examine different cutoffs in the appendix. It is important to note non-rural properties should not be thought of as urban, but more suburban. Very few utility-scale solar developments are built in urban areas as there is just not space.

To build our main dataset, we spatially merge the solar data with the property dataset. We match every property to the nearest eventual site of solar development to infer proximity. We only include transactions occurring within three miles of any eventual solar installation to increase similarities in observable and unobservable characteristics for sample properties. For properties lying within three miles of two installations, we keep only those that transacted before both installations were built and those that transacted after both were constructed. This ensures cleaner identification of the pre-construction and post-construction periods in our model.

The final, composite dataset includes 419,258 property transactions representing 284,364 unique properties around 208 solar installations. Figure 3 shows the number of transactions by distance to nearest solar installation. We have roughly 18,000 transactions within half a mile, and 71,337 transactions within one mile of a solar installation. This is far more compared to many prior studies measuring externalities of wind energy, and it enables precise estimation of any effect that may be present. Further, 27.43% of transactions occur post-construction and 17.27% of the post-construction observations are within one mile.[6]

4 METHODS

We use the difference-in-differences (DID) method in the hedonic framework to analyze the causal impact of solar installations on housing prices. We compare treated properties located near large-scale solar installations to similar control properties that are further away from such installations. The treated properties are defined as those that lie within some distance *d* of a solar site, and control properties are greater than distance *d* (and less than three miles). Our basic empirical specification is:

$$P_{it} = \beta_1 Treated_i + \beta_2 Post_{it} + \beta_3 (Treated_i \times Post_{it}) + \gamma X_{it} + \epsilon_{it} \qquad (2)$$

Where P_{it} is the log sales price of house i at time t. $Treated_i$ is a dummy variable equal to 1 if a house is in the treatment group and 0 otherwise, $Post_{it}$ is an indicator for post-treatment, which equals 1 if a house sells after the construction of the nearest solar installation, X_{it} is a vector of housing variables (bedrooms, bathrooms, etc.), as well as census block fixed effects and month-year fixed effects. Month-year fixed effects capture macroeconomic trends that affect the entire region that could be correlated with solar development trends. Block fixed effects account for location-specific unobservable heterogeneity that could be correlated with solar development. Lastly, ϵ_{it} is the error term. β_1 is the pre-treatment price difference between treated and control

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[6] Figure A3 in the online appendix presents the number of post-construction transactions by distance bin.

houses, and β_2 is the price difference between control properties, before and after treatment. The coefficient of interest is β_3, which is the differential price change from before to after solar development for treated properties relative to control properties.

In addition, we also estimate repeat sales models that include property fixed effects:

$$P_{it} = \beta_2 Post_{it} + \beta_3(Treated_i \times Post_{it}) + \gamma X_{it} + \alpha_i + \epsilon_{it} \quad (3)$$

This model uses only within-property variation to identify β_3, and thus controls for time-invariant unobservables at the property level. In this specification, X_{it} only includes temporal fixed effects, as other housing variables are time-invariant. In addition to this specification, we also estimate a model that adds county-year fixed effects, which allows for different county-specific trends in the housing market. Across all specifications, our preferred model includes property, month-year, and county-year fixed effects, as it best controls for unobservable determinants of price and most flexibly controls for regional price trends, both of which could be correlated with solar development. In all models, we cluster standard errors at the census tract level to allow for correlated errors within a larger area.

Since the extent of treatment is unknown, we first seek to empirically identify *d*, the distance up to which the effects of constructing a solar installation persist, and this will define the boundary for our treatment group. Following similar strategies as Davis (2011), Muehlenbachs et al. (2015), and Boslett et al. (2019), we estimate a series of DID models similar to our preferred specification, except with treatment defined by successive tenth-mile increments and control always being 2-3 miles. Figure 4 plots the estimates for each tenth-mile increment ranging from zero to two miles; each point and confidence interval represents a separate regression. Results indicate large, negative impacts for houses within 0.1 mile, but with large standard errors. Point estimates bounce around some, but more or less show effects diminishing with distance as expected. Beyond one mile, all estimates are statistically insignificant. Given this evidence, in all future specifications, we define the treatment group to be within one mile and the control group to be 1-3 miles.

We extend the analysis to investigate heterogeneity in treatment effect in multiple ways. First, we estimate a model that allows for heterogeneity in the impact based on distance. We identified treatment extending to one mile with Figure 4, but Figure 4 also suggests that treatment effects could be substantially larger within 0.1 mile. To explore this possibility more formally, we develop a model that defines multiple distance bands. The first (outermost) band represents control properties located two to three miles away from the nearest solar installation (per usual). The second (outer-middle) band includes treated properties located 1 – 2 miles from the nearest solar installation. The third (middle) band includes treated properties located 0.5 – 1 mile from the nearest solar installation. The fourth (inner-middle) band includes treated properties located 0.1 – 0.5 miles from the nearest solar installation. Finally, the fifth (innermost) band consists of treated properties within a distance of 0.1 mile from the closest installation. Our specification is:

$$P_{it} = \beta_2 Post_{it} + \sum_{k=2}^{5} \beta_3^k \left(dist_i^k \times Post_{it} \right) + \gamma X_{it} + \alpha_i + \epsilon_{it} \qquad (4)$$

where $dist_i^k$ is a dummy variable equal to 1 if a property i lies within the k^{th} distance band. P_{it}, $Post_{it}$, X_{it}, and α_i are as defined in Equation 3. Our coefficients of interest are β_3^k, which are the differential changes in property prices from before to after the construction of solar installations, for homes in distance band k, compared to changes in property values of control houses (lying in distance band 1).

Second, we investigate heterogeneity in treatment effect by two more characteristics: prior land use and rural character. This is done by a triple difference analysis in which we interact the treatment effect term in Equation 3 with a variable for our characteristic of interest. The specifications are as follow:

$$\begin{aligned} P_{it} = {} & \beta_2 Post_{it} + \beta_3 (Treated_i \times Post_{it}) + \beta_4 (Post_{it} \times Greenfield_i) \\ & + \beta_5 (Treated_i \times Post_{it} \times Greenfield_i) + \gamma X_{it} + \alpha_i + \epsilon_{it} \end{aligned} \qquad (5)$$

$$\begin{aligned} P_{it} = {} & \beta_2 Post_{it} + \beta_3 (Treated_i \times Post_{it}) + \beta_4 (Post_{it} \times Rural_i) \\ & + \beta_5 (Treated_i \times Post_{it} \times Rural_i) + \gamma X_{it} + \alpha_i + \epsilon_{it} \end{aligned} \qquad (6)$$

where $Greenfield_i$ is an indicator variable equal to 1 if a property is located within the vicinity of a solar installation that was built on land that was formerly a farm or forest, and $Rural_i$ is an indicator variable equal to 1 if property i lies in a town with a population density of 850 people per square mile or fewer.

Our coefficients of interest in Equations 5 and 6 are β_3 and β_5. β_5 is interpreted as the difference in price impacts for greenfields relative to non-greenfield sites (Eq. 5) and the difference in price impacts for homes in rural areas relative to non-rural ones (Eq. 6). In Equation 5, we expect β_5 to be negative. We hypothesize that developments on farm and forest lands will lead to larger negative impacts on housing prices due to the more dramatic change in landscape compared to a commercial site or landfill and the loss of open space amenities. We also expect a negative sign on β_5 in Equation 6, reflecting a loss in the rural character of a town due to the construction of solar installations.

Intuition would suggest a positive correlation between $Greenfield$ and $Rural$, which indeed plays out in the data. To try to separate the effects and test for multiplicative effects, we estimate a quadruple difference model that includes both $Greenfield$ and $Rural$ fully interacted with $Treated$ and $Post$.

4.1 Summary statistics and assumptions

Having defined treatment and control, we now evaluate the comparability of those groups. The summary statistics for key variables are given in Table 1. The first column represents the mean values of our full sample. The mean sales price is \$338,320. The average property in our data has a lot size of half an acre, has living area of just under 3000 square feet, approximately 3 bedrooms, and is about 49 years old. About 21% of the properties are condominiums, 45% are located within 3 miles of a greenfield development, and 34% are rural.

The second and third columns in Table 1 compare pre-treatment housing attribute means between the 0 – 1 miles (treated) and 1 – 3 miles (control) observations to examine similarity between the treatment and control groups. In the last column, we report the normalized differences in means, which is the difference in means between the treatment and control groups divided by the square root of the sum of their variances. None of the covariates have a normalized difference exceeding 0.25, which is the limit beyond which the difference in means becomes substantial.

The critical assumption for the DID design to yield causal estimates is the parallel trends assumption, which requires that the treatment and control properties have the same trend in outcomes if treatment did not occur. A common way of assessing the plausibility of this assumption is to examine pre-treatment trends in sales prices for the treatment and control groups. In Figure 5 we plot pre-treatment average sales prices of treatment and control groups up to 2010, which is the year in which the first solar installations were constructed. The price trends are similar for both groups, thus boosting our confidence that the assumption holds, and the control group serves as a good counterfactual.

5 RESULTS

5.1 Main results

We present our main results in Table 2. Column 1 results are obtained from estimating Equation 2, which includes housing covariates (described in detail in the notes of the table), census block fixed effects, and month-year fixed effects. Columns 2 and 3 are results obtained from estimating repeat sales models described by Equation 3. Both columns include month-year fixed effects, and Column 3 additionally includes county-year fixed effects. The coefficient on *Treated* is insignificant in Column 1 suggesting that, controlling for housing characteristics and spatial and temporal fixed effects, treated properties are not statistically significantly different from control properties pre-construction. The DID coefficient of interest ranges between -0.016 to -0.026 and is statistically significantly different from zero across all models. Our preferred specification is Column 3 which includes property, month-year, and county-year fixed effects. This model indicates that on average, houses lying within one mile of solar installations sell for 1.7% less post construction relative to properties further away, all else equal. This finding confirms our hypothesis that nearby solar installations are a disamenity.

We convert the percentage reduction to dollars by multiplying the coefficient and the average property price for treated properties prior to construction ($327,700), which equals $5,571. Assuming capitalization can be converted to a welfare measure in this context (see Kuminoff & Pope, 2014), we can then translate this price discount into an annual willingness to pay for avoiding proximity to solar. Assuming a 5% interest rate, average annual willingness to pay is $279 per household.

There are no other property value studies of solar arrays for us to compare our estimates to. To date, Botelho et al. (2017) is the only study to examine the negative externalities from large-scale solar facilities. Using a contingent valuation framework, they find that local residents in Portugal are willing to accept $12.93 – $56.64 per month on average as compensation for being in the vicinity of solar installations. While their methods are different and vicinity is defined differently, their results are consistent with ours ($25.17/month). In addition, Botelho et al. conduct a discrete choice experiment to delve into aspects of siting that drive the disamenity and estimate that respondents are willing to pay $8.65, $7.57, and $5.15 per month to avoid negative impacts on flora and fauna, landscape, and glare effects, respectively. Second, we extend the hedonic valuation literature on renewable energy to include large-scale solar.

First, we provide the first estimates of the non-market valuation of large-scale solar installation externalities in the United States.

5.2 Robustness checks

In Table 3 we present results from a series of robustness checks to ensure that the results from our preferred model are consistent to alternative data samples. In Column 1 we drop all observations with sales prices in the top and bottom 1% of the distribution (as opposed to 5% in the main sample) to assess whether the results are robust to including more high and low value properties. In Column 2 we restrict the sample to include only properties with a lot size of 5 acres or lesser, decreasing the maximum from 10 acres in our main sample. While it is unlikely that a solar array would be sited on a parcel of 5 – 10 acres, it is possible and so these properties may appreciate based on expectations of possible lease payments. Column 3 excludes all condominiums from the sample. Column 4 includes all 284 solar installations from our full sample, which means properties could be exposed to multiple treatments. Columns 5 and 6 explore different amounts of land required per MW of installed capacity, 4 acres in Column 5, and 6 acres in Column 6. By contracting and expanding the assumed size of installations, the set of properties that are designated as treatment control is altered. Across all columns, our coefficient of interest is statistically significant and the magnitude ranges between -0.014 to -0.017. In sum, we find that our results are robust across all specifications.

5.3 Heterogeneity in treatment effect

In Table 4, we examine the heterogeneity in treatment effect by three characteristics: proximity to solar installations, prior land use, and rural character of towns. Each panel represents a different regression and all panels include property fixed effects, month-year fixed effects, and county-year fixed effects.

In Panel A, we estimate the model described by Equation 4 that allows for heterogeneity in the impact on prices based on distance. The coefficient on the 1 – 2 miles band is statistically insignificant, which is congruent with our assumption that treatment effects do not persist beyond 1 mile. The coefficients on the 0.1 – 0.5 miles and 0.5 – 1 mile bands are significant and similar magnitude to the main results. The coefficient on the 0 – 0.1 mile band is -0.070, which is 4 times larger in magnitude than the 0.1 – 0.5 miles and 0.5 – 1 mile bands, though only significant at the 10% level. This suggests that property prices for homes lying within 0.1 mile from a solar installation fall by 7.0% ($23,682) post-construction, compared to houses further away. These results suggest extremely large disamenities for properties in very close proximity.

In Panel B, we provide estimates from the model described by Equation 5 where we explore heterogeneity by prior land use. The triple-interaction coefficient of interest is negative as expected, and implies that farm and forest lands that are developed into solar arrays decrease property values 0.8% more than brownfields and industrial areas. However, this coefficient is statistically insignificant, meaning the differential impact is imprecise and could even be zero.

In Panel C, we examine heterogeneity by rural character of towns and report the coefficients from the specification defined in Equation 6. The coefficient on $Treated \times Post$ is larger in magnitude (-0.024) than the main results. The coefficient on $Treated \times Post \times Rural$ is essentially the same magnitude as the coefficient on $Treated \times Post$, but the opposite sign. Taken together, these results suggest that the treatment effect in rural areas is effectively zero (a statistically insignificant 0.1%), and that the negative externalities of solar arrays are only occurring in non-rural areas. These findings go against our intuition. One possibility is that land is abundant in rural areas, so the development of some land into solar does little to impact scarcity, whereas in non-rural areas it makes a noticeable impact. A second possibility is that there are unobserved visibility differences across sites. If visibility is a key driver of negative impacts and installations in rural locations are less visible on average (due to land abundance for vegetative buffers), then this could produce the results observed.

In Panel D we further explore heterogeneity by land use and rural character. This is done by estimating a quadruple difference model that interacts the treatment effect term in Equation 2 with both the $Greenfield$ and $Rural$ indicator variables.[7] The coefficient on $Treated \times Post$, which represents the effect of non-greenfield solar arrays in non-rural areas is -0.014, which is slightly smaller than the overall average effect observed in Table 2, but is also imprecisely estimated. The coefficient on $Treated \times Post \times Greenfield$, which applies to greenfield sites in non-rural areas, is -0.036 and is statistically significant. This suggests a large additional effect of greenfield sites in non-rural areas relative to non-greenfield sites, and a total effect of -5.0%.

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[7] Tables A2-A4 in the online appendix examine the robustness of the results presented in Table 4, including different regression specifications and different population density cutoff values that define $Rural$. The results are broadly consistent with the findings presented.

The coefficient on $Treated \times Post \times Rural$, which applies to non-greenfield sites in rural areas, is 0.002 and is statistically insignificant. This suggests no statistical difference between the property value effect of non-greenfield sites in rural versus non-rural areas. Lastly, the coefficient on $Treated \times Post \times Greenfield \times Rural$, which applies to greenfield sites in rural areas, is 0.056 and is statistically significant. This indicates a counter-effect to the negatives seen for $Treated \times Post$ and $Treated \times Post \times Greenfield$, and the total effect for greenfield sites in rural areas is a positive 0.008. The total effect is statistically indistinguishable from zero. Taken together, the results of Panel D suggest that the overall negative effects of solar arrays on nearby property values are driven by greenfield sites in non-rural areas. Similar developments on farm and forest lands in rural areas have no impact on nearby properties. These findings are consistent with the ideas that greenfield developments cause greater externalities, given the dual loss of open space amenities and gain of industrial disamenities, but that effect hinges on the scarcity of open space.

In the online appendix, we also present results that test for heterogeneity by size of installation and time since construction (see Tables A5 and A6). In both cases we find no evidence of differential property value impacts by size and by time.

6 CONCLUSION

This paper estimates the valuation of externalities associated with nearby utility-scale solar installations using revealed preferences from the property market. Using the DID empirical technique, we estimate regression models with treatment and control groups defined by distance to the nearest solar installation. We observe 71,337 housing transactions occurring within one mile (treated group), and 347,921 transactions between one to three miles (control croup) of 208 solar installations in MA and RI.

Our preferred model suggests that property values in the treatment group decline by 1.7% ($5,751) on average compared to those in the control group after the construction of a nearby solar installation, all else equal. This translates to an annual willingness to pay of $279 per household to avoid disamenities associated with proximity to the installations. However, this average effect obscures heterogeneity. We find substantially larger negative effects for properties within 0.1 miles and properties surrounding solar sites built on farm and forest lands in non-rural areas.

While a full cost-benefit analysis of solar arrays is beyond the scope of this paper, because we do not know anything about consumer and producer surplus, we can still compare the negative local externalities to the global benefits of carbon mitigation to gain a more holistic understanding of local opposition.[8] We therefore conduct the following back-of-the-envelope calculations. On the cost side, we first consider the point estimate from our preferred specification which translates to a loss of $5,751 per household for treated homes close to solar installations. Our complete sample (prior to any data cuts) consists of 289,254 unique properties located within 1 mile of all solar installations in the dataset. Put together, we estimate a net loss of $1.66 billion in aggregate housing value due to proximate solar installations in MA and RI.

To quantify the benefits from solar installations, we first calculate net generation from solar installations. Assuming a capacity factor of 16.5%, the 817 MW of installed solar capacity in MA and RI generates is 1,180,892 MWh (megawatt hours) of electricity per year.[9] Current non-renewable generation in MA and RI comes almost entirely from natural gas. According to the EIA, 0.42 mt (metric tons) of CO_2 are emitted from each MWh of electricity that is generated from natural gas, implying that a total of 495,975 mt of CO_2 are abated annually from solar energy generation. Assuming that an average solar installation lasts 30 years, we estimate 14.88 million mt of CO_2 are abated in their entire life-span. The EPA (Environmental Protection Agency) estimates a social cost of $51.80 per metric ton of CO_2, which translates to $771 million in lifetime benefits from the production of energy from solar installations (US EPA). We find that, considering only externalities, the benefit-cost ratio is 0.46, with a net loss of $893 million.

However, we caution against generalizing the benefit-cost findings to other regions in the United States for two main reasons. First, over 90% of the energy generated in MA and RI comes from natural gas, which emits only half as much CO_2 as coal. It is possible for benefits to outweigh the costs in states where coal dominates the fuel mix for electricity generation. Second, MA and RI are the 3rd and the 2nd most densely populates states in the country, respectively, which makes the siting of solar installations away from residential areas a herculean task. Careful siting of installations in states that have large tracts of open land available and around sparsely populated regions may allow for more favorable cost-benefit ratios.

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[8] To be sure, significant amounts of money are part of the market transactions. A developer quoted us that they offer landowners $15-20,000 per MW per year of installed capacity. It is unknown how much is profit and whether some portion of that could be used to compensate proximate households.

[9] $Net\ generation\ (MWh) =\ \%\ Capacity factor \times 365\ days \times 24\ hours \times Installed\ capacity\ (MW)$

The demographic and geographical differences across states have implications for their respective RPS goals. For densely populated New England states with ambitious RPS targets, wind energy may be the better choice. Onshore wind turbines require a fraction of the land area per MW of installed capacity compared to solar, while offshore turbines require none. Furthermore, unlike solar installations, wind turbines in the United States (both onshore and offshore), have been found to have no disamenities associated with their proximity (Carr-Harris & Lang, 2019; Hoen et al., 2011, 2015; Hoen & Atkinson-Palombo, 2016; Lang et al., 2014). Moving forward, states should customize plans to meet renewable energy targets that work best with their respective geographies.

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Figures and Tables

Figure 1: Map of solar installations across Massachusetts and Rhode Island

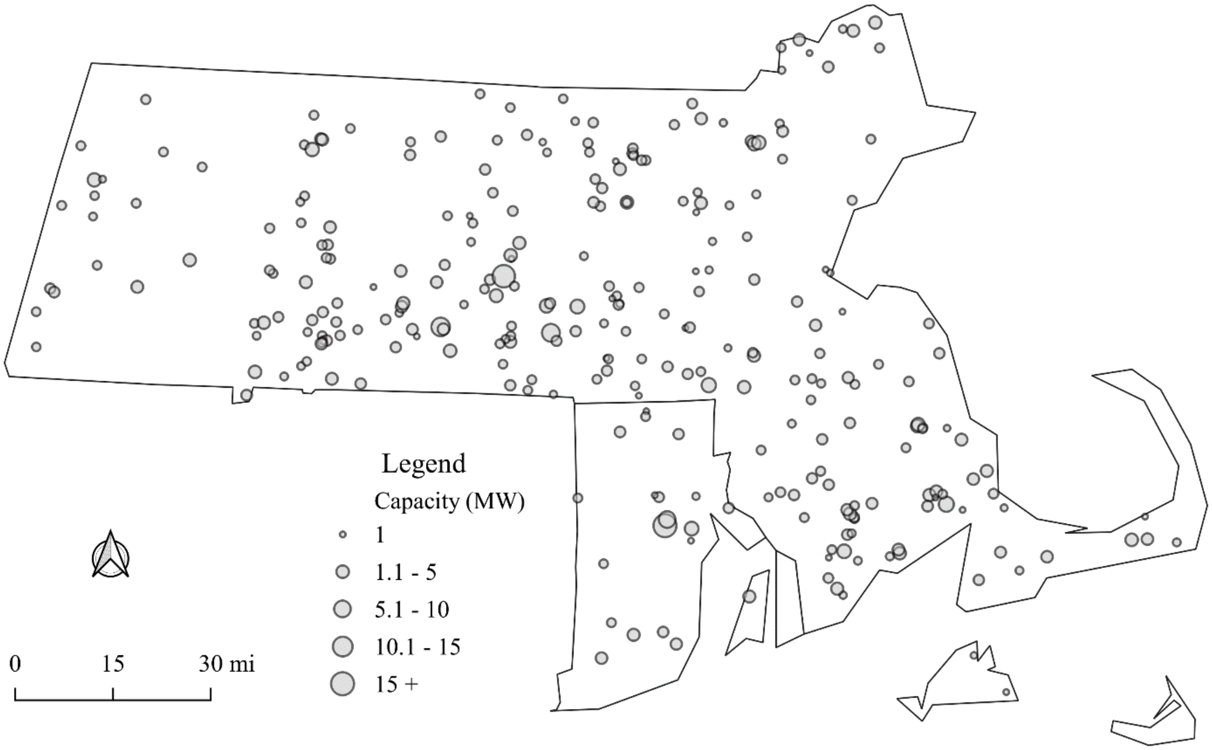


Figure 2: New and cumulative utility-scale solar capacity by year

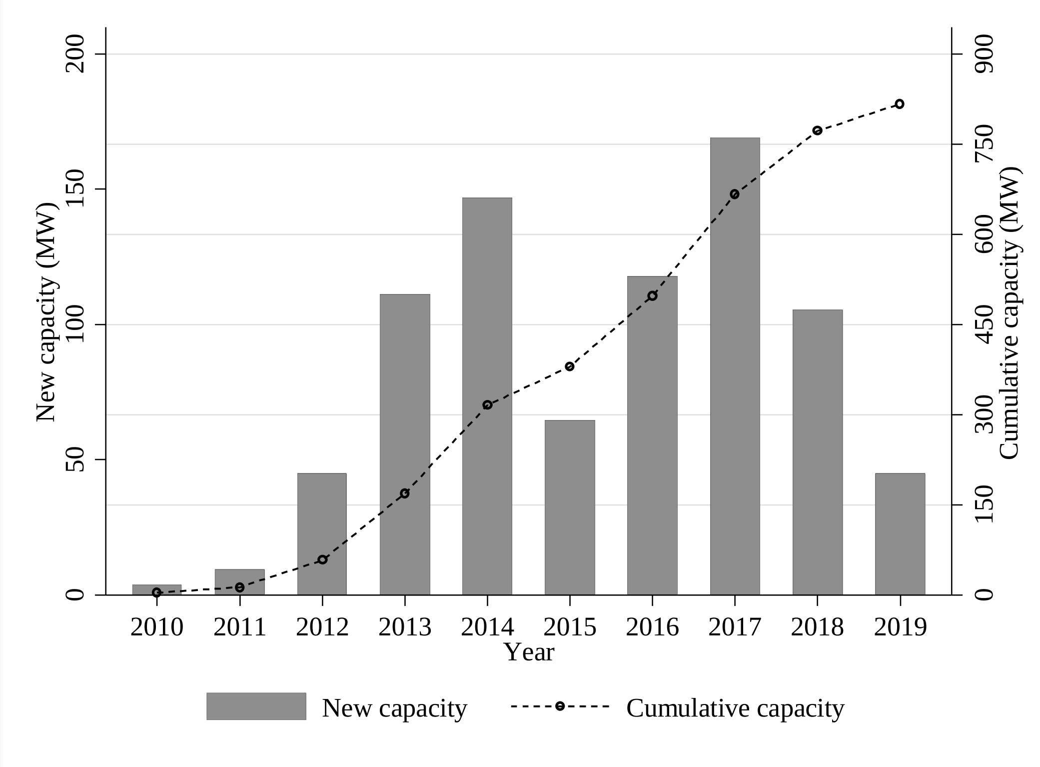
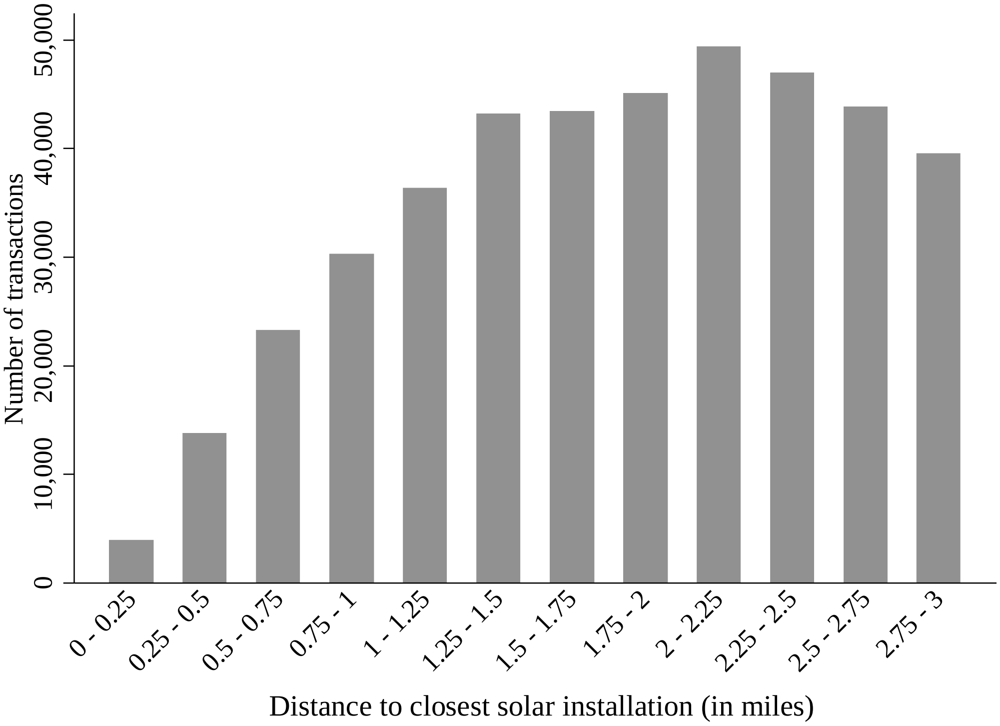
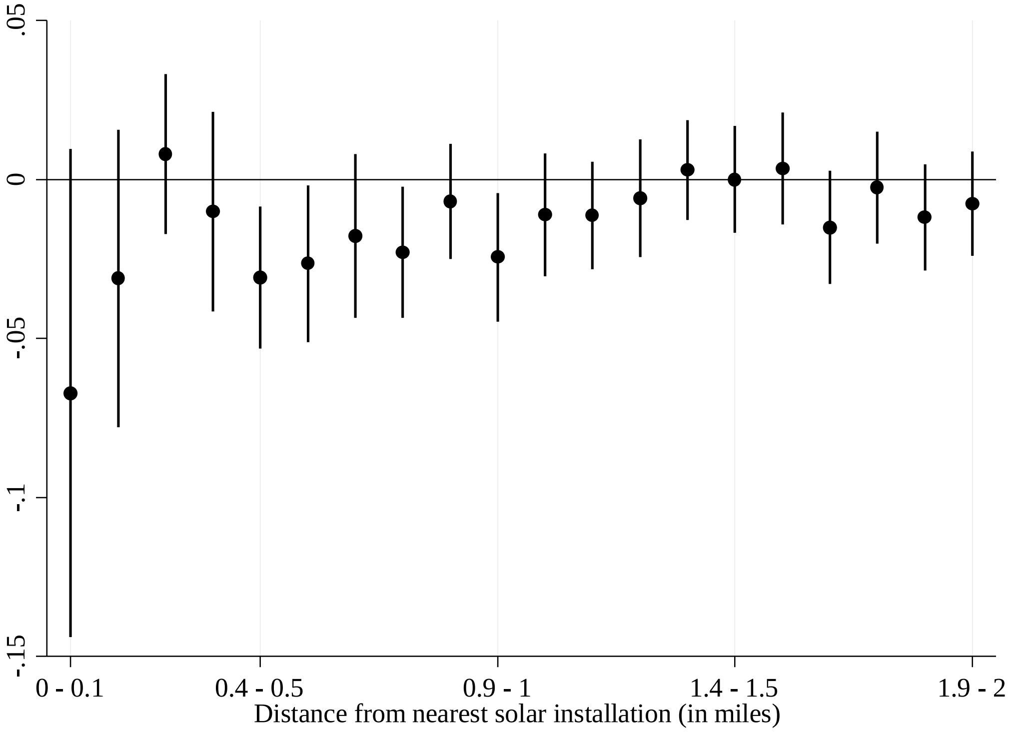


Figure 3: Number of transactions by distance to nearest solar installation



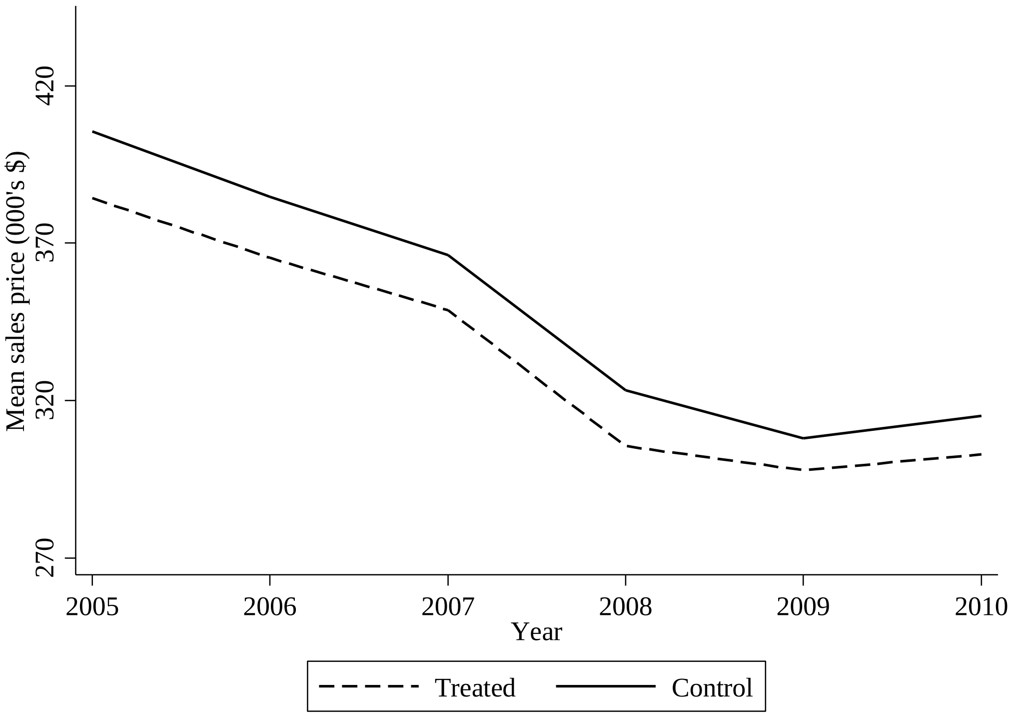
Notes: These transactions occur near eventual solar installations, since the data span across the years 2005 – 2019, and the construction of the installations is staggered throughout that time period.

Figure 4: Distance bin coefficient estimates



Notes: The treatment variable is defined as a bin variable, with treated properties lying within 1/10 mile distance bands up to 2 miles. Control properties are those lying 2 – 3 miles away from the nearest solar installation. The coefficients are obtained by estimating a series of DID models similar to Equation 2 that regresses log sales price on 1/10 mile distance bands up to 2 miles, along with month-year, county-year, and property fixed effects. Resulting coefficients and 95% confidence intervals are graphed.

Figure 5: Pre-treatment trends between treatment and control groups



Notes: The graph represents all transactions occurring pre-construction. Treated are properties within one mile of an eventual solar installation, and Control is between one and three miles. The sample size is 181,190.

Table 1: Housing attribute means by treatment status

Variables	Full sample	Pre-treatment means		Normalized difference in means
		0 - 1 mile	1 - 3 miles	
Sales price (000's)	338.32	327.70	340.74	-3.11e-07
Lot size (acres)	0.49	0.50	0.48	0.017
House area (sq. feet)	2874.92	2849.70	2865.73	-5.83e-06
Bedrooms	2.91	2.88	2.91	-0.027
Full bathrooms	1.56	1.56	1.56	-0.012
Half bathrooms	0.52	0.52	0.52	-0.009
Age of home (years)	49.23	43.06	48.11	-0.003
Condo (1=yes)	0.21	0.22	0.21	0.058
Pool (1 = yes)	0.04	0.04	0.04	-0.027
Air conditioning (1 = yes)	0.43	0.47	0.43	0.121
Fireplace number	0.41	0.38	0.42	-0.076
Condition (1 = above average)	0.26	0.22	0.26	-0.150
Greenfield (1 = yes)	0.45	0.46	0.46	0.021
Rural (1 = yes)	0.34	0.40	0.34	0.199
Observations	419,258	51,471	252,773	

Notes: Sales prices are adjusted to 2019 levels using the CPI. Normalized difference in means calculated according to Imbens and Wooldridge (2009). Normalized differences exceeding 0.25 in absolute value are considered statistically different.

Table 2: Difference-in-differences estimates of the impact of solar installations on property prices

Independent variables	Dependent variable: Sale price (ln)		
	(1)	(2)	(3)
Treated	0.002		
	(0.005)		
Post	0.015***	0.011**	-0.006
	(0.004)	(0.005)	(0.004)
Treated × Post	-0.016***	-0.026***	-0.017***
	(0.005)	(0.007)	(0.006)
Fixed Effects			
Month-year	Y	Y	Y
Block	Y		
Property		Y	Y
County-year			Y
Observations	419,258	231,503	231,503
R^2	0.804	0.889	0.893

Notes: Treat = 1 if a house is within 1 mile of a solar construction and Post = 1 if a house sells post-construction. Column 1 includes the following control variables: lot size, house area, number of bedrooms, full bathrooms, half bathrooms, and fireplaces, indicator variables for condos, the condition of the house, and for the presence of a pool and air conditioning, capacity of installation (in MW) and greenfield. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 3: Robustness checks

Independent variables	Dependent variable: Sale price (ln)					
	Price cuts at top and bottom 1% (1)	Lot size no more than 5 acres (2)	Drop Condos (3)	Keep all installations (4)	1 MW = 4 acres (5)	1 MW = 6 acres (6)
Treated × Post	-0.015**	-0.016***	-0.014***	-0.017***	-0.016***	-0.017***
	(0.007)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)
Observations	258,562	230,100	179,387	273,878	233,943	231,977
R^2	0.865	0.894	0.880	0.897	0.894	0.893

Notes: Treated = 1 if a house is within 1 mile of a solar construction, and Post = 1 if a house sells post-construction. All specifications include property, month-year, and county-year fixed effects. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 4: Heterogeneity of treatment effects

Independent variables	Dependent variable: Sale price (ln)
Panel A: Heterogeneity by proximity	
(1 – 2 miles) × Post	-0.005
	(0.005)
(0.5 – 1 mile) × Post	-0.019***
	(0.007)
(0.1 – 0.5 miles) × Post	-0.017*
	(0.009)
(0 – 0.1 miles) × Post	-0.070*
	(0.038)
Panel B: Heterogeneity by prior land use	
Treated × Post	-0.013*
	(0.008)
Treated × Post × Greenfield	-0.008
	(0.011)
Panel C: Heterogeneity by population density	
Treated × Post	-0.024***
	(0.008)
Treated × Post × Rural	0.025**
	(0.011)
Panel D: Heterogeneity by population density and land use	
Treated × Post	-0.014
	(0.009)
Treated × Post × Greenfield	-0.036**
	(0.014)
Treated × Post × Rural	0.002
	(0.017)
Treated × Post × Greenfield × Rural	0.056**
	(0.022)
Observations	231,503

Notes: Treated = 1 if a house is within 1 mile of a solar construction and Post =1 if a house sells post-construction. In Panel A, (1 – 2 miles), (0.5 – 1 mile), (0.1 – 0.5 miles) and (0 – 0.1 mile) are dummy variables = 1 if properties lie within the respective distances from the nearest solar installation, and distance bin for 2 – 3 miles is omitted. Greenfield = 1 if the prior land use is farm or forest land, and Rural = 1 if the population density per square mile is ≤ 850. Panel B includes an interaction term Post*Greenfield and Panel C includes Post*Rural. Additional interactions included in Panel D are: Treated*Rural, Treated*Greenfield, Post*Rural, Post*Greenfield, Rural*Greenfield, Post*Greenfield*Rural, and Treated*Rural*Greenfield. All models include month-year, county-year, and property fixed effects. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

APPENDIX

This appendix provides supplemental figures and tables to our main results.

Figure A1 maps the location and capacities (in MW) of the 208 solar installations that are included in our main results.

Figure A2 depicts the increase in new and cumulative solar capacity over time by prior land use.

Figure A3 represents the number of sample post-treatment transactions by distance to nearest solar installation, in quarter mile intervals.

Figure A4 shows the distribution of solar installations by capacity.

Table A1 provides post-treatment means and the normalized differences in means between the treated and control groups for key property attributes.

Table A2 assesses robustness of results presented in Table 4 of the main text. We present two additional specifications: month-year fixed effects and block fixed effects in Column 1, and month-year and property fixed effects in Column 2. Column 3 is the same as the results presented in Table 4. In Panel A, we find that the large, negative coefficient found for $(0 - 0.1\ miles)\ x\ Post$ is only found when property fixed effects are included. In Panels B, C, and D, results are largely similar across columns.

Table A3 explores how different population density cutoff values that define the variable $Rural$ affect the results presented in Panel C of Table 4 in the main paper. 850 people/square mile is the cutoff used in the main text. The results in the first three columns (500 people/square mile, 850 people/square mile, and 1000 people/square mile) are quite consistent. The results in columns 4 and 5 (1200 people/square mile, 1500 people/square mile) are qualitatively similar to the previous results, but the coefficient on $Treated\ x\ Post\ x\ Rural$ is smaller in magnitude and not statistically significantly different from zero. In the final column (2000 people/square mile), the coefficient on $Treated\ x\ Post\ x\ Rural$ is negative and statistically insignificant, and the coefficient on $Treated\ x\ Post$ is statistically insignificant as well. The trend in results is expected as more areas are classified as rural. Given that we find that negative property value impacts of solar are strongest in non-rural (suburban) areas, as these places are increasingly classified as rural, the coefficient on $Treated\ x\ Post\ x\ Rural$ is a mixture of the zero impacts in rural areas and the negative impacts in non-rural areas.

Table A4 explores how different population density cutoff values that define the variable $Rural$ affect the results presented in Panel D of Table 4 in the main paper, similar to Table A3. We specify different cutoff values of population density per square mile and report results using our main specification. The coefficients are consistent with the results of Panel D in Table 4, for all cutoff values except the highest one (2000 people/square mile).

Table A5 explores heterogeneity in treatment effect by the size of the solar installations. We define $LargeCapacity$ as an indicator variable = 1 if the size of the installation (in MW) is greater than the median value in our sample (2 MW). We find no evidence of heterogeneity by installation size, the coefficient is small and statistically insignificant, implying no additional disamenities from solar developments larger than 2 MW. We additionally explore an alternative specification (results not provided) where capacity is treated as a linear variable and is interacted with $Treated \times Post$. These estimates yield the same conclusion to those in Table A3. This result indicates that the presence of utility-scale solar is a disamenity regardless of size. Given that the smallest installations in our analysis are still quite large at five acres in size (about 3.8 football fields), it could be that there is no additional impact of size because it is difficult or even impossible to see beyond five acres from ground level. However, one limitation of this analysis is that the range of observed sizes is narrow. Of the 208 installations in our dataset, almost 50% have a capacity of 2 MW or lesser, and only 13 (6%) are 5 MW or larger.

Table A6 examines heterogeneity in treatment effect by time elapsed. We split our $Post$ variable into two sub-categories: $Post\ (Less\ than\ 3\ years)$ and $Post\ (3\ or\ more\ years)$, where $Post\ (Less\ than\ 3\ years)$ is a dummy variable = 1 if a property transacts less than three years post-construction, and $Post\ (3\ or\ more\ years)$ is a dummy variable = 1 if a property transacts 3 or more years post-construction. We interact both variables with $Treated$, and find that both coefficients are significant and almost equal across the board, implying no change in the effect over time.

Figure A1: Map of solar installations at least 1 mile apart across Massachusetts and Rhode Island

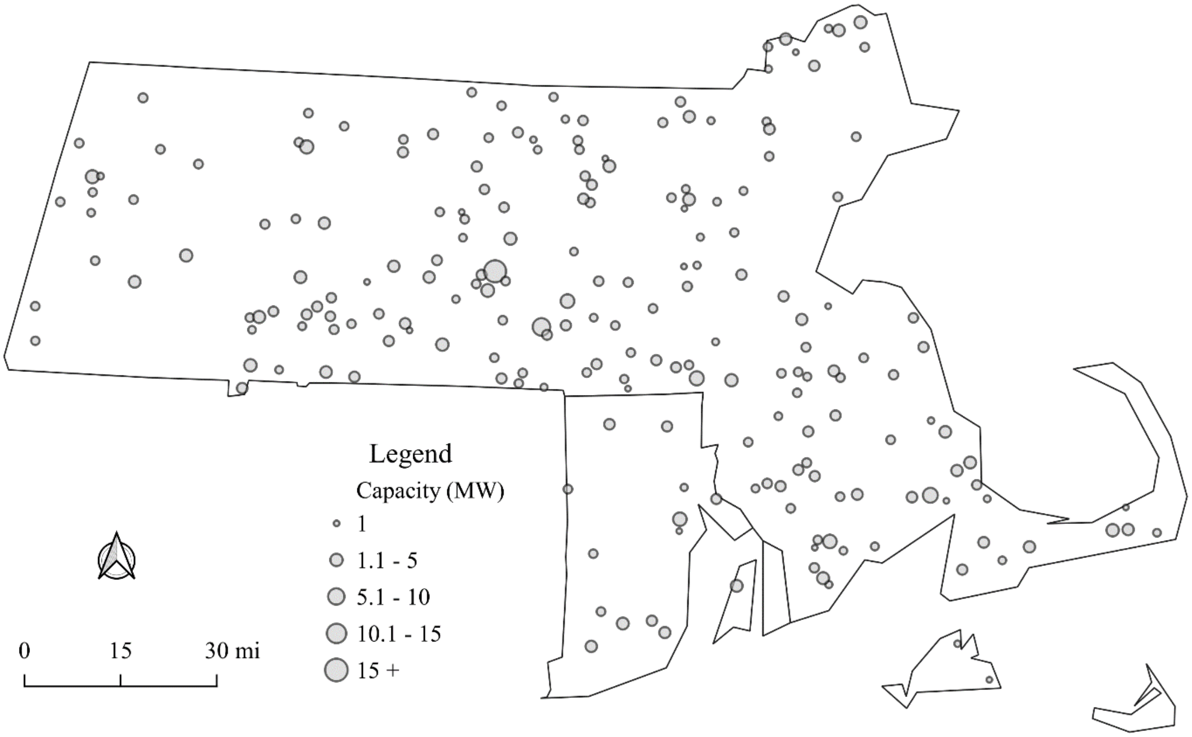


Figure A2: New and cumulative capacity by year and land use

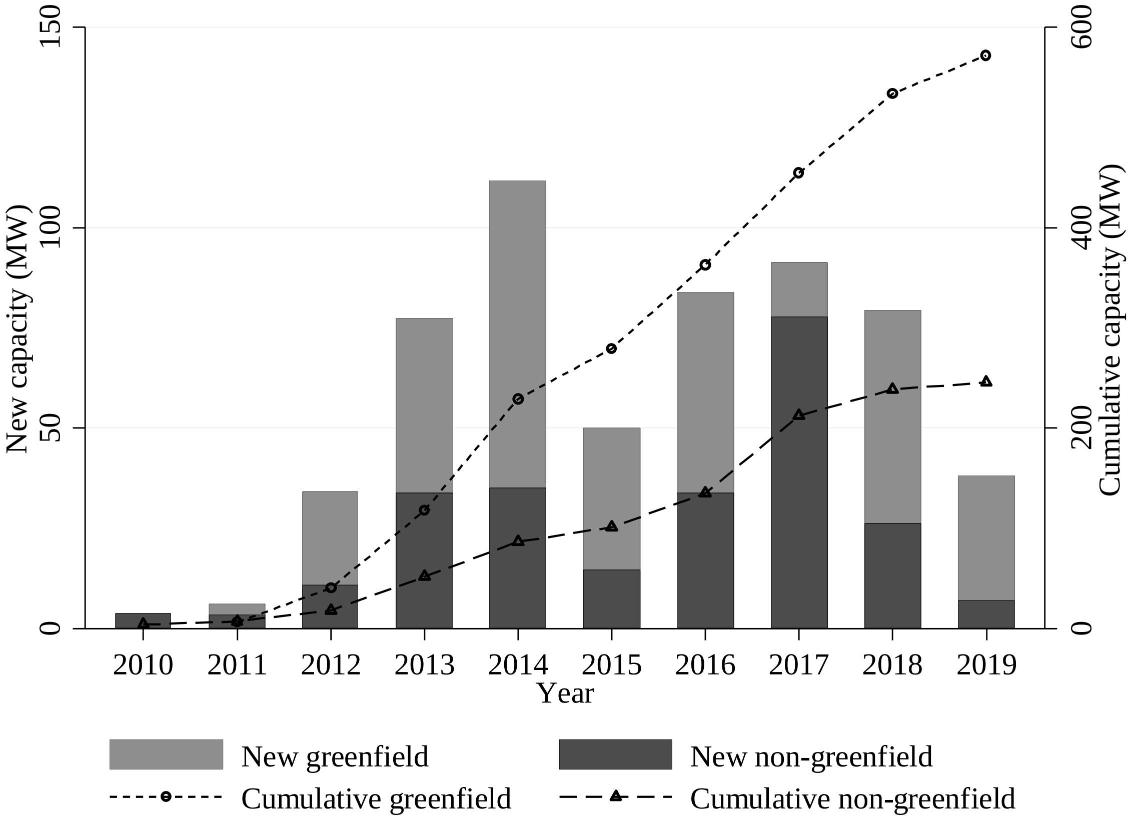
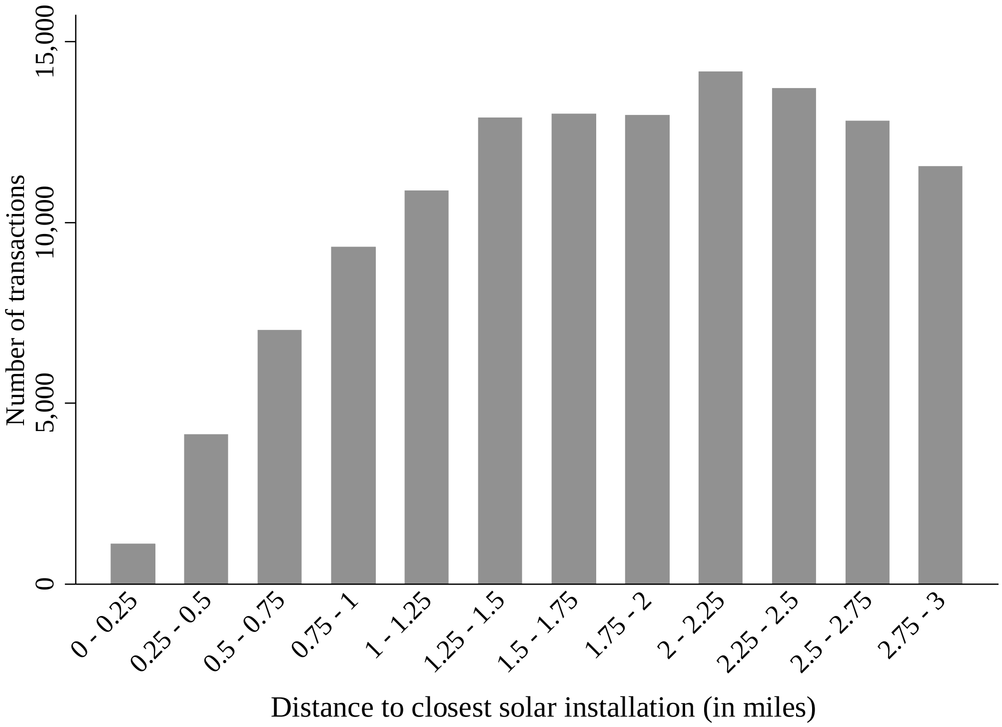


Figure A3: Number of post-construction transactions by distance to nearest solar installation



Notes: These transactions occur near eventual solar installations, since the data span across the years 2005 – 2019, and the construction of the installations is staggered throughout that time period.

Figure A4: Frequency of solar installations by capacity

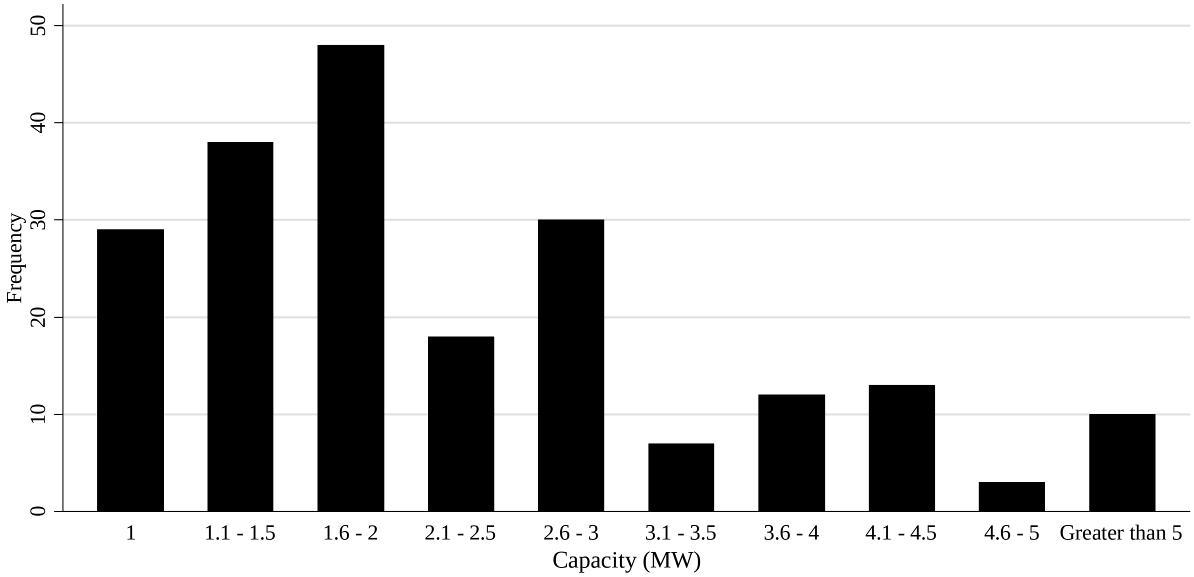


Table A1: Housing attribute means by treatment status, post construction

Variable	Post-treatment means		Normalized difference in means
	0 - 1 mile	1 - 3 miles	
Price (000's)	321.02	341.25	-4.64e-07
Lot size (acres)	0.48	0.50	-0.013
House area (sq. feet)	2872.97	2913.40	-1.47e-05
Bedrooms	2.90	2.93	-0.024
Full bathrooms	1.56	1.57	-0.020
Half bathrooms	0.53	0.53	0.001
Age of home (years)	52.17	54.95	-0.001
Condo (1=yes)	0.21	0.20	0.041
Pool (1 = yes)	0.04	0.04	-0.033
Air conditioning (1 = yes)	0.45	0.43	0.078
Fireplace number	0.35	0.40	-0.117
Condition (1 = above average)	0.25	0.28	-0.013
Greenfield (1 = yes)	0.39	0.42	-0.095
Rural (1 = yes)	0.40	0.32	0.239
Observations	19,866	95,148	

Table A2: Heterogeneity of treatment effects

Independent variables	Dependent variable: Sale price (ln)		
	(1)	(2)	(3)
Panel A: Heterogeneity by proximity			
(1 – 2 miles) × Post	-0.009*	-0.006	-0.005
	(0.005)	(0.006)	(0.005)
(0.5 – 1 mile) × Post	-0.019***	-0.027***	-0.019***
	(0.007)	(0.009)	(0.007)
(0.1 – 0.5 miles) × Post	-0.025***	-0.030***	-0.017*
	(0.008)	(0.011)	(0.009)
(0 – 0.1 miles) × Post	-0.037	-0.092**	-0.070*
	(0.028)	(0.036)	(0.038)
Panel B: Heterogeneity by prior land use			
Treated × Post	-0.013	-0.024**	-0.013*
	(0.008)	(0.010)	(0.008)
Treated × Post × Greenfield	-0.009	-0.005	-0.008
	(0.010)	(0.014)	(0.011)
Panel C: Heterogeneity by population density			
Treated × Post	-0.022***	-0.034***	-0.024***
	(0.008)	(0.010)	(0.008)
Treated × Post × Rural	0.024**	0.034**	0.025**
	(0.010)	(0.014)	(0.011)
Panel D: Heterogeneity by population density and land use			
Treated × Post	-0.013	-0.024*	-0.014
	(0.010)	(0.013)	(0.009)
Treated × Post × Greenfield	-0.029**	-0.030	-0.036**
	(0.014)	(0.019)	(0.014)
Treated × Post × Rural	0.008	0.011	0.002
	(0.014)	(0.019)	(0.017)
Treated × Post × Greenfield × Rural	0.041**	0.051**	0.056**
	(0.019)	(0.026)	(0.022)
Fixed Effects			
Month-year	Y	Y	Y
Block	Y		
Property		Y	Y
County-year			Y
Observations	419,258	231,503	231,503

Notes: Treated = 1 if a house is within 1 mile of a solar construction and Post =1 if a house sells post-construction. In Panel A, (1 – 2 miles), (0.5 – 1 mile), (0.1 – 0.5 miles) and (0 – 0.1 mile) are dummy variables = 1 if properties lie within the respective distances from the nearest solar installation, and distance bin for 2 – 3 miles is omitted. Greenfield = 1 if the prior land use is farm or forest land, and Rural = 1 if the population density per square mile is ≤ 850. Panel B includes an interaction term Post*Greenfield and Panel C includes Post*Rural. Additional interactions included in Panel D are: Treated*Rural, Treated*Greenfield, Post*Rural, Post*Greenfield, Rural*Greenfield, Post*Greenfield*Rural, and Treated*Rural*Greenfield. All models include month-year, county-year, and property fixed effects. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table A3: Heterogeneity of treatment effects by population density

Independent variables	Population density per square mile cutoff					
	500	850	1000	1200	1500	2000
Treated × Post	-0.020***	-0.024***	-0.024***	-0.023***	-0.018**	-0.006
	(0.006)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)
Treated × Post × Rural	0.022*	0.025**	0.023**	0.016	0.008	-0.013
	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Observations classified as rural						
Solar installations	40%	61%	69%	76%	82%	87%
Properties	16%	32%	39%	46%	53%	62%
Observations	231,503	231,503	231,503	231,503	231,503	231,503
R^2	0.894	0.894	0.894	0.894	0.894	0.894

Notes: Dependent variable is Sale price (ln) in all specifications. Treated = 1 if a house is within 1 mile of a solar construction, Post =1 if a house sells post-construction, and Rural = 1 if the population density per square mile is ≤ column heading value. All models include month-year, county-year, and property fixed effects. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table A4: Heterogeneity of treatment effects by population density and land use

Independent variables	Population density per square mile cutoff					
	500	850	1000	1200	1500	2000
Treated × Post	-0.014*	-0.014	-0.016	-0.014	-0.006	0.005
	(0.008)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)
Treated × Post × Greenfield	-0.018	-0.036**	-0.028*	-0.031**	-0.041***	0.005
	(0.012)	(0.014)	(0.015)	(0.015)	(0.016)	(0.010)
Treated × Post × Rural	0.000	0.002	0.008	0.002	-0.013	-0.055***
	(0.018)	(0.017)	(0.016)	(0.016)	(0.015)	(0.018)
Treated × Post × Greenfield × Rural	0.038*	0.056**	0.039*	0.040*	0.057***	-0.029**
	(0.023)	(0.022)	(0.021)	(0.021)	(0.021)	(0.014)
Observations classified as rural						
Solar installations	40%	61%	69%	76%	82%	87%
Properties	16%	32%	39%	46%	53%	62%
Observations	231,503	231,503	231,503	231,503	231,503	231,503
R^2	0.894	0.894	0.894	0.894	0.894	0.894

Notes: Dependent variable is Sale price (ln) in all specifications. Treated = 1 if a house is within 1 mile of a solar construction, Post =1 if a house sells post-construction, and Rural = 1 if the population density per square mile is ≤ column heading value. All models include month-year, county-year, and property fixed effects. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table A5: Heterogeneity of treatment effects by solar installation size

Independent variables	Dependent variable: Sale price (ln)		
	(1)	(2)	(3)
Treated × Post	-0.012*	-0.024***	-0.019***
	(0.007)	(0.009)	(0.007)
Treated × Post × LargeCapacity	-0.011	-0.005	0.004
	(0.011)	(0.015)	(0.012)
Fixed Effects			
Month-year	Y	Y	Y
Block	Y		
Property		Y	Y
County-year			Y
Observations	419,258	231,503	231,503
R^2	0.801	0.889	0.893

Notes: Treated = 1 if a house is within 1 mile of a solar construction and Post =1 if a house sells post-construction and LargeCapacity = 1 if the capacity of the installation is greater than 2 MW. Column 1 includes the following housing controls: lot size, house area, number of bedrooms, full bathrooms, half bathrooms, and fireplaces, a set of dummy variables for the age of the house at purchase, indicator variables for condos, the condition of the house, and for the presence of a pool and air conditioning. Standard errors are clustered at the tract level and shown in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table A6: Heterogeneity of treatment effects by years since construction of installation

Independent variables	Dependent variable: Sale price (ln)		
	(1)	(2)	(3)
Treated × Post (Less than 3 years)	-0.016**	-0.026***	-0.016**
	(0.006)	(0.009)	(0.007)
Treated × Post (3 or more years)	-0.016**	-0.024***	-0.016**
	(0.006)	(0.008)	(0.007)
Fixed Effects			
Month-year	Y	Y	Y
Block	Y		
Property		Y	Y
County-year			Y
Observations	419,258	419,258	231,503
R^2	0.491	0.801	0.889

Notes: Post (Less than 3 years) = 1 if a house sells within 3 years post-construction, and Post (3 or more years) = 1 if a house sells 3 or more years post-construction. Columns 1 includes the following controls: lot size, house area, number of bedrooms, full bathrooms, half bathrooms, and fireplaces, a set of dummy variables for the age of the house at purchase, indicator variables for condos, the condition of the house, and for the presence of a pool and air conditioning, capacity of installation (in MW) and greenfield. Standard errors, clustered at the tract level, are in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

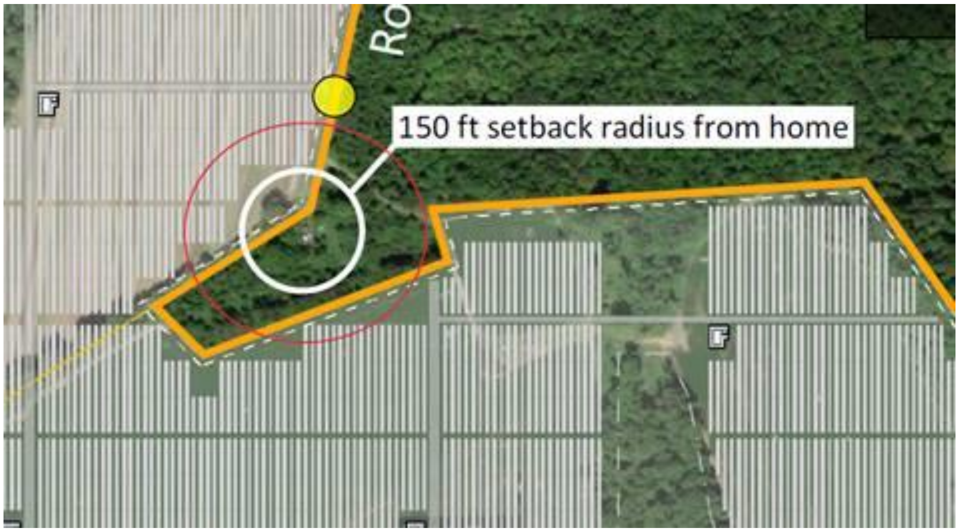
3. Identify the amount of time it will take for the pile driving process to install racking columns at a distance of 150 feet.

RESPONSE: In order to respond to this question, we will start with some information about the post driving process and timeline.

Depending on soil conditions and the type of racking posts being used, one pile driver can drive 8 to 20 posts per hour. As an approximate and conservative number, we estimate that one pile driver can install 100 posts per day. Depending on the type of racking system selected, each racking row has 8 to 13 posts. Therefore, each pile driver can conservatively install approximately 10 rows of racks per day. This will change based on weather and soil conditions, and better output will be achieved in optimal conditions.

Because Horseshoe Bend has committed to having no solar equipment closer than 150 feet from a neighboring, non-participating residential home, the amount of time that the pile driver will be 150 feet away from each home will be brief. Only the first post in the closest rows to each home will be 150 feet away from the home. In order to provide the Siting Board with an understanding for the amount of time it will take to install posts within an area near the homes, we provide the information below.

Looking at the two houses that are within 150 feet of Horseshoe Bend's project boundaries as shown on Attachment A to the SAR, we have drawn 300-foot circles around each house in red on the images below, and provide notes on the anticipated post installation times below each image. The smaller white circle around each house shows a 150-foot setback around the home, and as described in the SAR, the project has committed to having no solar equipment[1] closer than 150 feet from a neighboring, non-participating residential home.



For this home shown above, we estimate that it will take one day to install the posts inside the 300-foot circle south of the house, and another two days for the posts north of the house.

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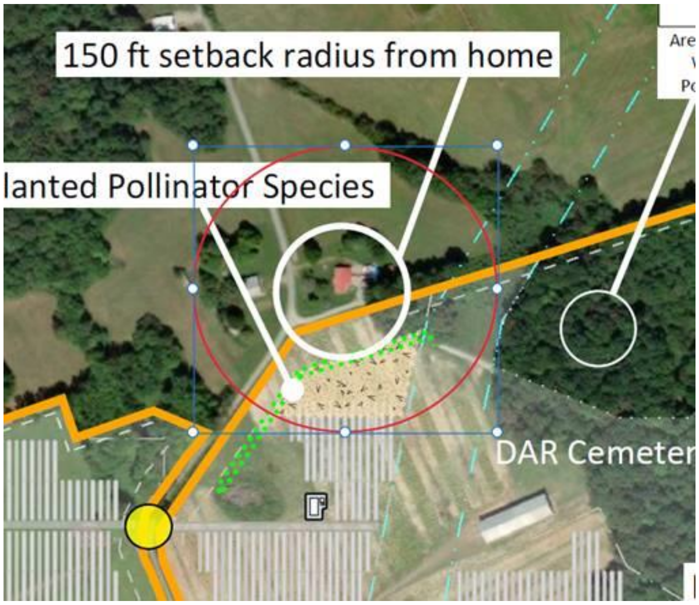
[1] This does not include fencing and vegetative buffers.



For this home shown above, depending on whether the planted pollinators are placed as shown on the preliminary site plan, creating a larger setback, it will take approximately one or two days of pile driving within 300 feet of the home.

To answer the Siting Board's question regarding the timeline for posts that are within 150 feet of the homes, if the final layout design matches the preliminary design, the first home shown above will have posts driven at 150 feet away for approximately one day, since the project area to the South of the home is more than 150 feet away, and only the nearest posts in the project area to the North of the home will be 150 feet away. The second home will have no posts driven at 150 feet away, since there are no solar panels as close as 150 feet to the home due to the location of the pollinator plantings.

WITNESS: Carson Harkrader

4. Identify any product(s) or means of construction that would be able to reduce or limit noise during the construction process, particularly during the pile driving portion of the construction process, and provide the approximate cost of each such product or means of construction.

RESPONSE: We reviewed this question with construction companies that work on solar projects, and the companies we talked with have not had this specific requirement for projects to date. Typically, if there has been a noise restriction, it has been to limit pile driving to specific hours during the day (for example, pile driving only between 7AM – 7PM).

Horseshoe Bend is aware of testimony in a recent hearing in Case No. 2020-00280 involving Ashwood Solar I, indicating that at least one contractor has used either a semi-tractor-trailer truck with canvas over the trailer, or sound blankets draped over the perimeter fencing of the site. The witness in that case indicated that these methods were used when the project was at a much closer distance than what was proposed in that case.

Our initial assessment of the first of these two potential technical solutions is that parking trucks at the perimeter of the site does not seem feasible at Horseshoe Bend because there are no roads that could carry a large truck located in the right places around the perimeter of the site. As described in the Application, there are two homes as close as 150 feet to Horseshoe Bend, and our assessment is that neither home has a road located between the home and the Project where a large truck could park.

We are investigating the possibility of using sound blankets draped over the perimeter fence during pile driving, to buffer noise from the two homes that are closest to the site. We will file a supplemental response regarding that potential solution by May 21, 2021.

WITNESS: Carson Harkrader

COMMONWEALTH OF KENTUCKY
BEFORE THE KENTUCKY STATE BOARD
ON ELECTRIC GENERATION AND TRANSMISSION SITING

In the Matter of the Application of Horseshoe Bend Solar, LLC, for a Construction Certificate to Construct a Merchant Electric Generating Facility	)))	**Case No. 2020-00190**

CERTIFICATION OF RESPONSES TO POST-HEARING DATA REQUESTS

This is to certify that I have supervised the preparation of Horseshoe Bend Solar, LLC's responses to the Post-Hearing Data Requests, and that the responses are true and accurate to the best of my knowledge, information, and belief after reasonable inquiry.

Date: 5/14/21

Carson Harkrader