5-8-2020

# The Impact of Photovoltaic Solar Panels on High- and Low-Income Areas

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By

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*A Thesis submitted for the fulfillment of the course Senior Seminar (EC 375) during the Spring semester of 2020*

*While completing this Thesis I have not witnessed any wrongdoing, nor have I personally violated any conditions of the Skidmore College Honor Code,*

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April 28th, 2020

**Abstract**

To determine the impacts of constructing PV solar panels on high- and low-income areas, this research utilized housing data from New York State since 1996, PV solar panel data from NYSERDA, and income data for New York in 2018. It used two difference-in-difference (DID) regression models covering three treatment groups to discover how high- and low-income housing values are impacted after the construction of PV solar panels. Previous research established a precedent in which a difference between these demographic groups could be expected. Utilizing accepted thought regarding energy systems and a disparate impact on differing income groups, as well as sustainable development principles and externality theory, this work expected high-income individuals to benefit from the construction. The results demonstrate such a relationship, with low-income areas generating less added housing value for the construction of solar panels, though still achieving a positive relationship for the construction. The results also found low-income areas see a greater financial return per solar project constructed, though most likely due to greater diminishing returns seen in higher income areas. The results demonstrate a justification for an increased use of solar panels and shed light on the differing impacts high- and low- income areas face, though the issue warrants further research.

**Acknowledgments**

I would like to thank, first and foremost, Professor Rodrigo Schneider for his continued support and feedback throughout the Thesis process. I would also like to extend my absolute thanks to my advisor, Professor Sandra Goff, for providing critical feedback and encouragement, as well as having an open-door policy for my sudden spouts of worry and doubt. I would like to thank Liz Horgan for her countless peer-reviews and for reminding me I'm not alone in writing a Thesis. Lastly, I would like to sincerely thank all the professors within the Economics Department, the Environmental Studies Department, the Mathematics Department, and the Skidmore community that I had the pleasure to learn from; each one contributed to my education in a unique and vital way, resulting in this Thesis.

## Introduction

This thesis will explore whether the construction of photovoltaic (PV) solar energy projects disproportionately impact high- and low-income areas using housing values as an indicator. Renewable energy is an expanding and adapting field that adheres to improving technology, changing perspectives, and increasingly imminent warnings from the scientific community for the use of new energy sources. Due to these unique circumstances renewable energy has transitioned from a novelty, luxury resource in high-income areas to a necessity product pushed by interest groups ranging from political figures and the scientific community to grassroots organizations led by concerned citizens. Original theory, at the beginning of renewable energy's adoption, suggests that the presence of renewable energy infrastructure in close proximity to a home would harm the housing value, but as the external benefits of renewable energy continue to improve the literature demonstrates a positive relationship between PV solar and housing values. The benefits of PV solar can be categorized through the classification of the term sustainable development, which looks to address environmental, economic, and social impacts of development. It is the expectations of this paper that in alignment with recent literature there will be a benefit to housing values to those that adopt PV solar panels, and in addition, the prediction that those in high-income areas will face a greater economic benefit in comparison to those in low-income areas.

Prevailing environmental and economic literature demonstrate a series of theories that allow us to come to the conclusions hypothesized in this paper. The adoption of renewable energy and specifically PV solar has been widely covered in environmental academic journals for its social, economic, and environmental impacts. Theory suggests the implementation of PV solar is vastly superior in terms of environmental impacts in comparison to our traditional sources of energy through non-renewable resources, primarily fossil fuels. This is due to both the extraction methods used to harness the energy, the lack of by-products from utilizing the energy, and the limitless supply we have available. The environmental impacts, like all other forms of impacts, rely heavily on the circumstances of each PV solar installation; however, in aggregate the environmental benefits far outweigh the costs.

The social implications of installing PV solar are more nuanced, connecting closely with environmental and economic impacts, though independent in their classification and equally important. Literature suggests social impacts can include health benefits should the PV solar be replacing harmful non-renewable energy sources, increased community development and participation, as well as a prosocial association with the development of renewable energy. The prosocial implications are often an instrumental characteristic of PV solar that convince individuals to install them on their homes.

The economic impacts are more distinct and can have a wide-spread impact. For example, there are the direct economic benefits of constructing PV solar in that it lowers electricity costs and will, over time, cover the costs of installation. There are also the tax incentives and indirect savings associated with the installation, which may vary depending on where one lives. Economic benefits also include the jobs created from the installation and maintenance as well as the reduced health costs should the energy be replacing harmful non-renewables.

The economic theory that supports this paper's hypothesis and conclusion is seen in externality theory as well as past literature measuring impacts of renewable energy systems. Using housing value information and the varying impacts of renewable energy sources seen in literature we can safely assume there will be a significant impact from constructing PV solar on the housing values associated with that construction.

This research holds validity because it could establish a precedent for the allocation of renewable energy through policy. As well as in providing further evidence that investment in renewable energy should be a prerogative not just for the general environmental improvement of society but for the advancement of low-income areas. The goal of this paper is to aid in establishing an understanding for PV solar's role in our economy and its impacts on its consumers.

## Literature Review

### *Energy Sources*

To begin analyzing how renewable energy sources impact the socioeconomics of the community around them, it is important to first understand the position of renewable energy in the energy market. Energy sources are often split into two broad categories, referred to as renewable or non-renewable, the latter consisting primarily of fossil fuels. The distinctions between the energy sources are broadened through political, economic, or environmental divisions and result in a general viewpoint that the two types of energy live in two different worlds. The reality however is that renewable energy and fossil fuel energy operate to fulfil the same goal but have distinctly different means and limitations to do so. Fossil fuel resources have become so ubiquitous in our society that often the social costs associated with their operations have become equally commonplace. Given fossil fuel resource's extensive use, the negative impacts are plentiful throughout our ecosystem and communities, harming those of lower economic standing more so than the economically well-off (Perera 2017).

Our current energy grid is designed to operate at peak demand at all times, for those moments when demand spikes. The need for constant energy availability requires our electrical grid to perpetually operate at peak capacity and thus have a steady input of power. Due to this necessity our dependence on inexpensive and accessible power remains prevalent and therefore so does our use of fossil fuel energy (Covert et al. 2016). The introduction of renewable energy as not just a possible energy source but an increasingly affordable and necessary energy source was therefore met with ample skepticism and scrutiny. Therefore, renewable energy resources were dissected, and the potential energy output and environmental impacts were introduced through the possible harm renewable energy may provide; specific to the type of renewable energy, whether it be solar, wind, or hydro. Wind turbines are said to bring noise complaints (Lang et al. 2014), disrupt the natural environment (Lang et al. 2014; Mann & Teilmann 2013), or cause harm to rare bird migratory patterns (Kunz et al. 2007; Lang et al. 2014). Solar arrays may require land use and have biodiversity impacts (Hernandez et al. 2013; Tsoutsos 2005). Hydro can cause substantial environmental damage depending on the form of hydro plant used (Bakken et al. 2012; Raadal et al. 2011). These criticisms are joined with claims that renewable energy is not fully dependable nor practical (Covert et al. 2016). However; copious research proves these concerns invalid or negligible in impact for renewable energy as a broad energy source and demonstrates the array of benefits provided (Hernandez et al. 2013; Kabir et al. 2018).

Once renewable energy established itself as a valid and effective form of energy generation, the scientific community began analyzing the individual impacts specific renewable sources generate. Renewable energy is a sufficient classification for energy sources that are naturally occurring  in our environment such as wind, solar, hydro, or geothermal and are inexhaustible in their use.[1] Renewable energy sources therefore share key benefits for those that utilize them, such as clean energy generation and the health benefits associated, green jobs both in construction and maintenance, and energy independence from the grid, to name a few (Akella et al. 2009). However, once the individual energy source is considered, the impacts begin to shift, and the potential benefits and costs become subject to each individual circumstance of construction.

*Explaining PV*

There are two types of solar energy projects; photovoltaic (PV) and concentrated solar panels (CSP). PV is traditionally used in a residential or industrial capacity, while CSP is mainly industrial and involves directing light off mirrors towards a fluid to generate steam and thus electricity (Hernandez et al. 2013). The use of photovoltaic panels is much more widespread and can be utilized by individuals, corporations, or community development and therefore is typically the type of solar energy analyzed in economic assessments (Brinkley et al. 2019).

Literature dictates that not every renewable energy project is feasible in every situation; this is important to understand how PV solar projects could impact a community. Each form of renewable energy contains criteria that make it more effective to generate electricity and establish benefits for its user. Some of these criteria are more intuitive than others; such as wind turbines being more effective in areas with higher wind speeds (Dvorak et al. 2010), and solar arrays having more effect in large fields with little cloud cover (Kabir et al. 2018). While others are more subtle, such as the local or state policy regarding construction and economic incentives, or the politicized interests of those that would benefit and those that may not (Kabir et al. 2018).

[1] https://www.eia.gov/energyexplained/renewable-sources/

*Externalities of PV*

To determine the overall impact of PV solar panels there are certain characteristics of each project that must be assessed. First, is to establish the environmental impact of the PV installation. At the residential level PV solar panels have minimal negative impacts; the greatest harm being the extraction of the material, Silica, needed for production, and the energy input required for that extraction and production (Stoppato 2008). Putting this into perspective by comparing it to alternative energy sources such as coal, oil, or natural gas, this is a negligible impact. If the PV solar panels were utility scale and covered a large area of ground in an array, there are additional impacts including water usage to clean the panels, disruption of biodiversity, and land-use (Hernandez et al. 2013). Again, putting this into perspective of other energy sources this is limited in its environmental impact. After considering the environmental impacts associated with the construction of PV solar panels, we come to the understanding of its environmental benefits, largely the reduced dependence on non-renewable fuels that generate high pollution levels, the ability to generate continuous renewable energy, and reduce the necessity for wasted energy output from the grid. Given the different environmental impacts of PV solar electricity the net impact of the energy source on the environment is positive (Stoppato 2008).

The second criteria for assessing the impacts of PV solar are the socio-economic impacts. In looking at these effects, the differences between types of renewable energy sources can be seen in the costs more so than the benefits. The disadvantages associated with PV solar are typically aesthetic and initial economic burdens (Kabir et al. 2018; Von Möllendorff et al. 2017). The aesthetic issues can be solved by installing fencing or other natural visual barriers, though in general pose no significant negative effects (Brinkley et al. 2014; Qiu et al. 2017; Von Möllendorff et al. 2017). The economic burdens lessen as the technology improves and becomes less expensive to produce with government incentives and tax breaks that allow for the construction at reduced cost to the consumer (Kabir et al. 2018).

The socio-economic benefits associated with PV are similar to other forms of renewable energy. When renewable energy is adopted, the owner is producing energy of their own, if there is a surplus of energy produced it is returned to the electric company as a new source of energy. This means that their energy bill is reduced and they typically experience tax incentives subject to their particular state or local governmental rules.[2] Often there are also economic incentives to lessen the burden of initial construction as there are grants and funding set aside by organizations and government bodies to increase renewable energy production (Kabir et al. 2018). In addition to the pure economic benefits there are also social advantages to solar energy. Independence from traditional energy sources results in less impact from fluctuating energy prices or availability as a result from an aging energy grid. The construction of solar arrays requires construction and maintenance jobs, as well as long term operational jobs. And there is a positive moral association for those generating clean energy, typically because they feel they are limiting their impacts on climate change or as a desire to adhere to peer's influence (Kabir et al. 2018; Mundaca et al. 2020).

The previous characteristics of PV solar demonstrate the impacts for those constructing it; however, there are also externalities for those in the surrounding area. Renewable energy's negative externalities are mostly aesthetic, auditory, and land-use impacts. (Welsch 2016). PV solar in particular could potentially have issues with glare and high land use (Welsch 2016)

[2] New York State's initiatives can be found through NYSERDA: https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun

though it also sparks a phenomenon called "not-in-my-backyard" or NIMBY (Von Möllendorf et al. 2017; Welsch 2016), which refers to an individual's desire not to see or be near these electrical generation sites. Literature has demonstrated the externalities associated with solar panels could be negative for the wellbeing of adjacent areas, while overall beneficial for those that install them (Von Möllendorf et al. 2017). This is most likely due to the fact that those that install them see the economic benefits, while those adjacent to them do not.

*Net Effects of Externalities*

Given the scope of this paper, and the extent of data available, the individual impacts of the construction of PV solar panels will not be possible. Instead, using housing data at the ZIP code level will require utilizing externality theory. Essentially this will assume the construction of PV solar will have effects, both positive and negative, on not only the adopters of the energy, but those in close approximation to the energy source. Electrical generation historically has negative externalities (Welsch 2016). Externalities differ depending on the type of energy generation and the specific source as well.

Just as previously covered literature demonstrated the externalities of PV solar, it is important to apply externality theory to all forms of energy for perspective on the issue. Fossil Fuel energy generation has negative externalities on the health and wellbeing of individuals through noxious air pollutants, as well as having negative impacts on climate change through CO2 and other greenhouse gas emissions (Welsch 2016). The long-term impacts of such externalities influence health costs for individuals, as well as the cost of climate change mitigation and pollution reduction. However; established infrastructure allows fossil fuels to generate continuous, high-output energy, a necessity in today's society. These sites of energy generation are traditionally far from high-income areas and therefore directly impact low-income areas at a greater rate. Another form of non-renewable energy, nuclear energy, eliminates any of the harmful pollutants and climate effects, though it produces high levels of risk and nuclear waste which must be safely contained indefinitely (Welsch 2016).

Previous literature has made numerous efforts to analyze how renewable energy projects may impact community development. Housing values are the traditional indicator used to assess an individual's willingness to pay to live within proximity to renewable energy projects (Brinkley et al. 2018; Qiu et al. 2017). The assumption being that if there were a negative correlation associated with the construction of renewable energy the housing values would see a paralleled loss. Depending on the specific type of renewable energy there are different methods used to determine whether the energy source could interfere with housing values. Some past literature used a well-being analysis, which is intended to encompass a more holistic approach to measure impacts. The specific criteria of this well-being analysis were a survey indicating life satisfaction, which is intended to represent a wide array of impacts on one's life. Therefore, the results of using a well-being analysis may be subject to individual opinion and may differ from a housing value assessment. Literature demonstrates that, in aggregate, PV solar is one of the most abundant renewable energy sources and contributes to an increase in housing value (Brinkley et al. 2014; Qiu et al. 2017).

*Heterogeneous Effects*

Encompassing everything discussed thus far in the literature is a term called "sustainable development," which is a theory that takes into consideration three components: environmental, economic, and societal impacts.[3] This theory is used to assess if development has long term potential and is aimed to improve society in all metrics and not in singular gain. This theory applies directly to PV solar projects; the environmental gains stem from the transition to renewable energy, the economic improvement from jobs and tax incentives, and the societal advantages from community inclusion and development. Within each of these three categories the potential benefits will vary depending on where the specific project is located, who the characters of interest are, and what the parameters of the project entail (del Rio 2008). As an example, the creation of jobs is important to all members of society, but whether those jobs require high skill or are few in number has changing values to different demographic groups. To those in rural areas a higher quantity of long-term, low skill jobs has been seen to be more important than few high-skill jobs (del Rio 2008). Similarly, younger populations have been seen to be more active in the community and stimulated through development in renewable energy, the same way older generations embraced agricultural development (del Rio 2008). The value here is to see the unique effect each individual renewable project has for the community surrounding it.

Given that the results of adopting renewable energy differ for varying demographic groups, the literature has found populations actively adopt renewable energy for different reasons as well. The potential benefits of PV solar, both financial and otherwise, are made clear upon adoption. Literature demonstrates differing motivations for adoption of renewable energy throughout demographic groups. Those that earn higher than $50,000 annually are willing to pay twice as much as those in the lower economic bracket for environmental benefits (Reed et al. 2014). However; the higher income bracket also required on average three times the potential

[3] Sustainable Development Overview: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sustainable-development

return on investment in order to adopt renewable technology. While those of the lower income bracket were willing to pay more for community engagement (Reed et al. 2014). The literature therefore establishes a precedent in which differing populations and demographic groups hold different motivations for adopting renewable energy and expect different outcomes from said adoption. This supports the theory that the impact of adopting renewable energy would then differ among high- and low- income groups.

The past literature has established three critical strands of thought that support the efforts of this paper. First is the complex and nuanced relationship renewable energy has within our society. Unlike traditional fossil fuel resources there are a range of impacts and possibilities for implementation of renewable energy depending on the type of energy and the location of implementation. PV solar in particular can have varying impacts depending on the demographics of those constructing it, such as income status, rural or urban setting, and local policy for implementation. Second is the method used to assess the PV solar impacts. Housing values have been a staple in economic assessments of renewable energy and have shown to be a valid assessment of people's willingness to pay to live in an area. In relation to PV solar, recent literature has demonstrated there is a positive correlation between the construction of PV solar and the housing values of those that install them. Third is externality theory, that when tied to PV suggests there will be clear positive and negative externalities after the construction of PV. Given this past literature, it is reasonable to assume the construction of PV solar will have varying impacts on housing values depending on the income level of the area.

**Data**

This thesis utilizes three data sets to address the questions posed in the hypothesis. The first data set is the housing value information. The housing data was found on Zillow.com and is composed of their *Zillow Home Value Index* for all homes. The information used in this thesis consists of all housing values from March of 1996 to December 2019 in New York at the ZIP code level. An assumption made in this research was that low-income families would be well represented in the housing value index. The alternative would be to obtain renting data, since often, low-income families rent homes; however, renting data at the ZIP code level was not available. This assumption is reasonable, as typically homeowners will be the one to construct solar energy, and the value of the renter's home should still be included in housing data collected.

The second key set of data for this thesis is the solar project data. This data set was obtained through the New York State Energy Research and Development Authority, or NYSERDA. The data consists of all solar projects in New York since 2001. It includes all funded and unfunded projects, as well as project location, size, cost, and date of completion. It considers a solar project both residential and industrial, therefore these solar projects range in size and potential output. According to the data collected for this study, the average cost of a residential project is $33,488.3 and the incentive provided is $5,162.23. For non-residential projects the cost is on average $394,632.9. with an incentive of $89,096.64. There are 93,202 residential projects and 6,243 non-residential projects in this study. This study will include both residential and industrial projects in its analysis, as both forms of energy will have impacts on home values. This research will also be accounting for the impact of constructing multiple solar projects in a single ZIP code, though the size of each solar project cannot be accurately weighted in the evaluation. This will allow for a more accurate representation for how embracing solar energy could impact housing values compared to that of a single investment.

The final set of data was secured through the US Census Bureau and consists of median household income at the ZIP code level. Though this data only represents 2018 it will allow for the separation of ZIP codes into high- and low-income areas. There was difficulty obtaining income data over multiple years, though despite this, the overall trends of high- and low-income areas should show negligible change.

In order to run a regression analysis to measure the impacts of solar project construction on various income levels, the three datasets had to be manipulated for regression analysis. The housing value data is the core of the final data set used in this analysis. There was a total of 1,754 different ZIP codes with housing value information available, out of a total of 2,150 in the whole of New York State.[4] For each of these ZIP codes the housing value changed on a monthly basis since 1996. The income data was then merged into the housing value data. The income set used displayed the 2018 median income at the ZIP code level and therefore does not change across the monthly and annual time changes. Lastly, the solar project construction data was used to indicate when a solar project was constructed and how many were constructed in each ZIP code. There are over 100,000 different solar projects included in this data set, therefore certain ZIP codes will have numerous solar projects within them, allowing for an analysis of the impact individual solar panels have on the housing values.

The final data set used contains numerous variables. *ZipCode* represents the ZIP code of each location tested, this will include all information tested within the study. *Month* and *Year* represent the given month and year for each housing value. *Value* is the housing value at that

[4] https://www.zip-codes.com/state/ny.asp

given ZIP code, month and year. *Income* is the 2018 median household income at each given ZIP code. *MrgnError* is the income margin of error. *Treat1, Treat2,* & *Treat3* are each treatment variables representing different income cut-offs to establish high- and low-income; those cut-offs are $36,450, $51,250, $61,714 respectively. Should a ZIP code have an income lower than $36,450, *Treat1* will equal 1, otherwise 0; this is the same for *Treat2* & *Treat3*. *TotalPV* is the aggregate number of solar projects constructed in each ZIP code at each month and year (i.e. after one solar panel is constructed in a ZIP code *TotalPV* = 1, after two solar projects are constructed *TotalPV* = 2, etc.). *After* is the dummy variable for each respective ZIP code; once a solar panel is constructed *After* = 1, otherwise *After* = 0. Lastly *PValue* was generated to perform an analysis of the elasticity of the housing values given the different parameters of the tests.

Performing preliminary statistical analysis, we find that for New York, the mean housing value is $226,125.6 with a standard deviation of $252,860.5. The maximum ZIP code home value reported was $4,470,027 and the minimum $12,726. While 50% of the home values were below $138,702. This demonstrates that although the value of homes has increased on average over the 23 years of data, the majority of those houses remains around $250,000. It also shows that 50% of the home values are $82,423.6 below the average home value. This is important because if a home value is exceptionally high the impact of solar would be negligible, but ample data within a diverse range of income and housing data will allow for more significant analysis.

**Table 1: Descriptive Statistics of Housing Values**

| Variables | Obs | Mean | Std.Dev. | Min | Max | p1 | p99 | Skew. | Kurt. |
|---|---|---|---|---|---|---|---|---|---|
| Value | 524069 | 244000 | 254000 | 12726 | 4470027 | 37873 | 1207233 | 3.977 | 31.837 |

Figure 1 – Housing Values by Percentage Across ZIP codes

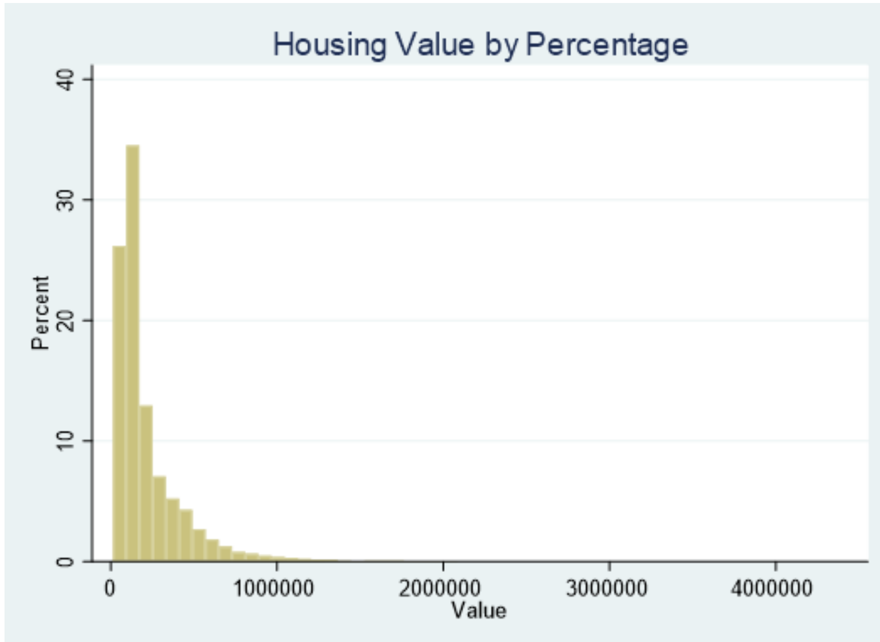



Figure 2 – Average Housing Value Over Time

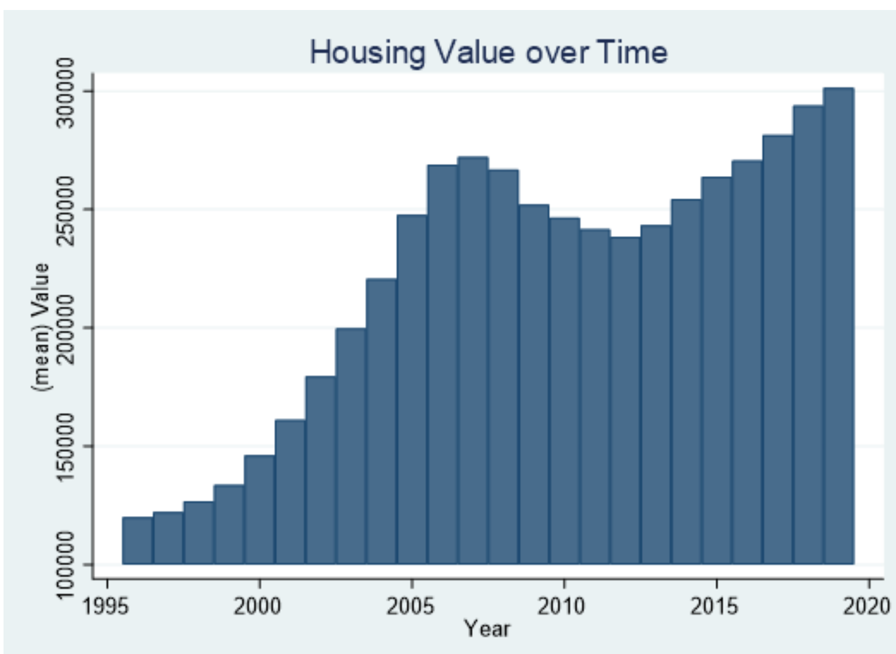
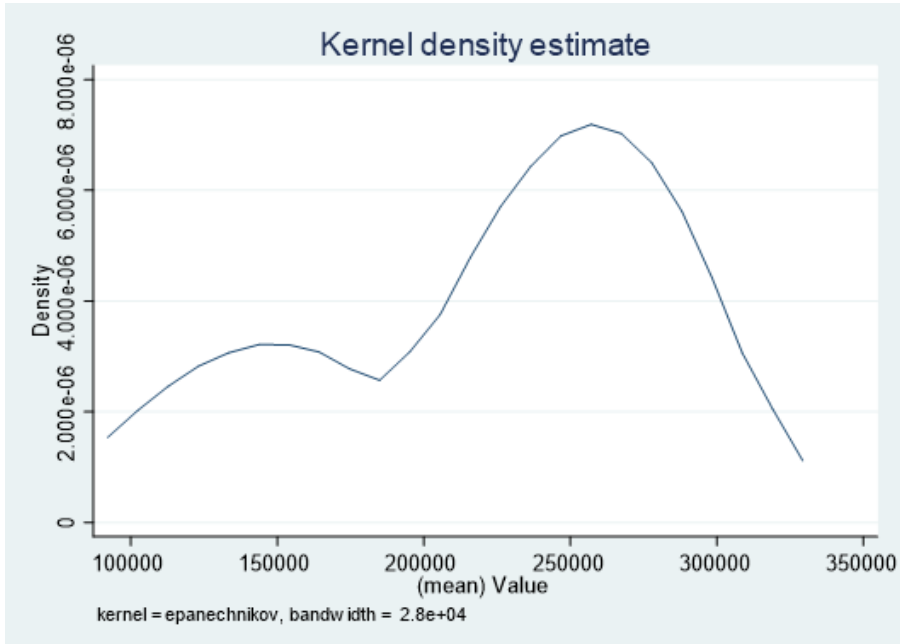


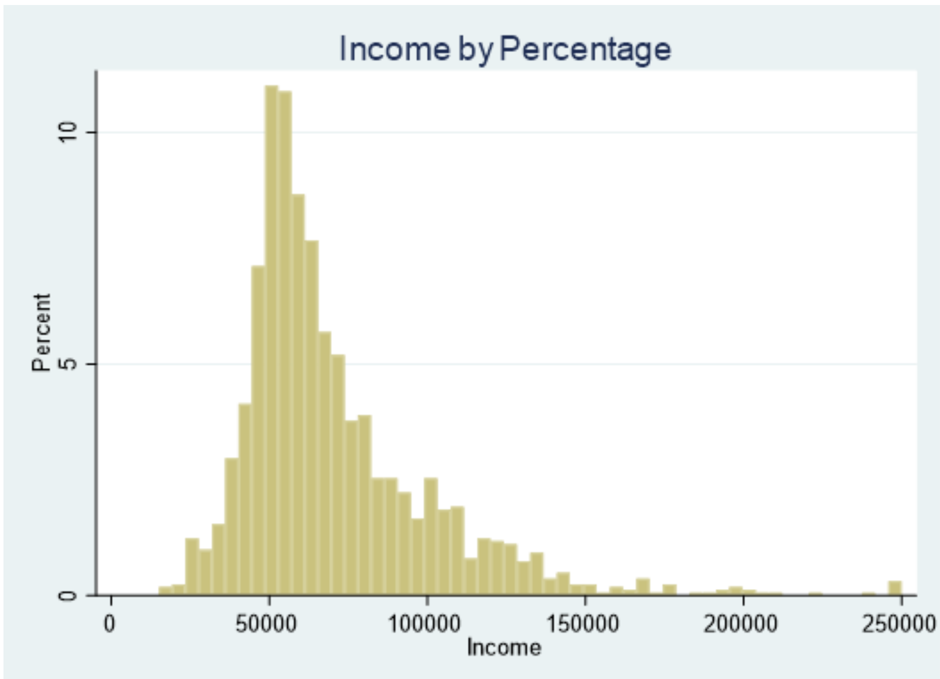
Figure 3 – Kernel Density Estimate of Population




For the income statistics, the average income level was $70,738.97 with a standard deviation of $31,055.16. The maximum income is reported at $250,000, though the dataset marks any income that is actually greater than or equal to $250,000 as exactly equal to $250,000. The minimum income however is $15,089. The 25th percentile of median income is $51,250 and the 50th percentile of median income is $61,714, both of which are represented as two of the three treatment cut-offs, the third of which is New York state's classification of being considered low-income. Each of these three values hold significance and warrant an analysis. New York's low-income level of $36,450 would represent how those that are classified low-income would be impacted, however those individuals are unlikely to install a significant number of solar panels due to a lack of disposable income. Though, there are government support programs and community programs designed to provide these neighborhoods the financial assistance needed for installation. The $51,250 value holds significance in previous literature that explored similar impacts using income levels above and below $50,000. The 50th percentile income level of

$61,714 is also analyzed because it evenly distributes those on either side of the income spectrum.

Figure 4 – Average Income by ZIP Codes in 2018




**Methodology**

To run the regression analysis, I performed multiple difference-in-difference analyses. The first of which was observing the housing value change before and after the initial construction of solar panels, represented by the following equation:

$$(1)\ \gamma_{it} = \beta_0 + \beta_1 Treat1_i + \beta_2 After_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

This model uses ZIP code fixed effects. $\gamma_{it}$ is the value of the home at the given ZIP code i and month t. $Treat1_i$ is a dummy variable to assign each ZIP code and date as either above or below the income threshold, Treatment 1 being $36,450. $Treat1_i$ will be omitted in the results tables as it will be absorbed in the fixed effects. $After_t$ is the dummy variable for before and after the construction of a solar panel at a given time and ZIP code equal to 1 after initial construction and 0 otherwise. $Inter_{it}$ is the interaction variable between the time and treatment variables. And $\varepsilon_{it}$ is the error term. This regression was repeated twice more with different treatment variables indicating higher levels of incomes at $51,250 and $61,714 respectively:

$$(2)\ \gamma_{it} = \beta_0 + \beta_1 Treat2_i + \beta_2 After_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

$$(3)\ \gamma_{it} = \beta_0 + \beta_1 Treat3_i + \beta_2 After_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

The following regression models are measuring the same effects as those previously, however, looks to test the elasticity of the housing value. Using the logarithmic function will give the percentage change of housing values and indicate how those housing values in lower income areas are affected in comparison to high-income areas. It is again repeated for each treatment variable for the varying income levels.

$$(4)\ ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat1_i) + \beta_2 ln(After_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

$$(5)\ ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat2_i) + \beta_2 ln(After_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

$$(6)\ ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat3_i) + \beta_2 ln(After_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

The final set of models used indicate the aggregated effect of constructing an additional solar panel for those considered high- versus low-income. This will adjust the model so that a ZIP code that has constructed hundreds of solar panels is not considered the same as a ZIP code that has constructed merely a few solar panels. This will also utilize the passage of time, as the previous models considered the first construction of a solar panel within a ZIP code as the sole indicator. Now a ZIP code that prolifically constructs solar panels in recent years will be adequately corresponded to its recent housing values.

$$(7)\ \gamma_{it} = \beta_0 + \beta_1 Treat1_i + \beta_2 TotalPV_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

$$(8)\ \gamma_{it} = \beta_0 + \beta_1 Treat2_i + \beta_2 TotalPV_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

$$(9)\ \gamma_{it} = \beta_0 + \beta_1 Treat3_i + \beta_2 TotalPV_t + \beta_3 Inter_{it} + \varepsilon_{it}$$

The only change from the previous regression is the variable $TotalPV_t$ which indicates the total number of solar panels constructed at the given ZIP code and date in time. The treatment variables maintain the same values and the interaction variable is still the interaction between the time and treatment variables. This regression was then repeated with the logarithmic function to achieve the percent differences between the high- and low-income areas.

$$(10)\qquad ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat1_i) + \beta_2 ln(TotalPV_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

$$(11)\qquad ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat2_i) + \beta_2 ln(TotalPV_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

$$(12)\qquad ln(\gamma_{it}) = \beta_0 + \beta_1 ln(Treat3_i) + \beta_2 ln(TotalPV_t) + \beta_3 ln(Inter_{it}) + \varepsilon_{it}$$

**Results**

The first model analyzed the housing value differences between high- and low-income areas with the treatment variable equaling $36,450. This represents New York State's low-income population. The results demonstrate after the construction of a solar panel within a ZIP code the housing values will increase by $89,891.77 ($296.4959) more than if those solar panels were not constructed, with the standard error represented in parenthesis. It also shows those in the low-income bracket see housing development growth of $53,671.04 ($1,565.841) less than the average increase of a ZIP code's housing value after constructing solar panels. All results were statistically significant and can be seen in column 1 of Table 2. Note in the tables that follow that the column numbers correspond with the regression model number found in the "Methodology" section.

In testing for elasticity of the first treatment it found that the average housing value increased by 37.12% (0.0733%) more than those that did not construct solar panels, with statistical significance as seen in the column marked 4 of Table 3. Those that were below the income level saw growth of 13.52% (3.87%) less than the average increase seen to housing values that constructed solar panels, again with statistical significance.

The second model tested the second treatment group of an income cut-off of $51,250 and is seen in column marked 2 of Table 2. For all ZIP codes, the average increase in housing value after installation was $100,165.4 ($326.6281) with statistical significance. And those below the income level of $51,250 saw a reduced increase in housing values equal to $56,868.52 ($705.254) less than the average increase in housing values, again with statistical significance.

The elasticity of this model showed growth of 37.70% (0.081%) for the average housing value in the second treatment's income level. And 4.96% (0.1753%) less growth for those that constructed solar panels in the lower income bracket than the average value increase. Both of these results are statistically significant as seen in the column marked 5 of Table 3.

The third regression used the income level of $61,714. It found that the average ZIP code saw an increase in housing values of $124,354.7 ($388.0461) more than those that have not constructed solar panels. While those below the income level saw an increase in housing values of $79,443.11 ($573.3725) less than the average of all income levels, both with statistical significance as seen in column 3 of Table 2.

In testing for elasticity, the regression model found that the average of all income brackets saw a housing value increase of 39.079% (0.0977%), with statistical significance as seen in column 6 of Table 3. Those below the income level had a reduced growth of 5.329% (0.14435%) less than the average of all ZIP codes, with statistical significance.

The results of this first set of regression models, indicate that the first treatment group, in which the income cut off was at $36,450, saw the greatest discrepancy in housing value effects. On average, those that constructed solar panels saw their housing values increase by ~37% while those considered low-income saw their housing values increase by ~24%. This demonstrates that those with a higher income see a greater benefit for the construction of solar panels than those that are low-income. As the income level was increased the impact on housing values saw a greater percent improvement, and those below the income level saw a reduced improvement of about ~5%. This is understandable because as the income level increases, more ZIP codes, seeing greater improvements will be considered under the income threshold and begin to reduce the differences between the two income groups.

**Table 2 : Regression results of Models 1 - 3**

| | (1) | (2) | (3) |
|---|---|---|---|
| | Value | Value | Value |
| After | 89891.775*** | 100165.410*** | 124354.676*** |
| | (296.496) | (326.628) | (388.046) |
| Inter 1 | -53671.043*** | | |
| | (1565.841) | | |
| Inter 2 | | -56868.520*** | |
| | | (705.254) | |
| Inter 3 | | | -79443.109*** |
| | | | (573.373) |
| Obs. | 467749 | 467749 | 467749 |
| R-squared | 0.166 | 0.175 | 0.197 |

Standard errors are in parenthesis

**** p<0.01, ** p<0.05, * p<0.1*

**Table 3 : Elasticity of Regression results of Models 4 - 6**

| | (4) | (5) | (6) |
|---|---|---|---|
| | PValue | PValue | PValue |
| After | 0.371*** | 0.377*** | 0.391*** |
| | (0.001) | (0.001) | (0.001) |
| Inter 1 | -0.135*** | | |
| | (0.004) | | |
| Inter 2 | | -0.050*** | |
| | | (0.002) | |
| Inter 3 | | | -0.053*** |
| | | | (0.001) |
| Obs. | 467749 | 467749 | 467749 |
| R-squared | 0.359 | 0.358 | 0.359 |

Standard errors are in parenthesis

**** p<0.01, ** p<0.05, * p<0.1*

The next set of regressions (7-12) demonstrate another perspective on the issue. They indicate how the construction of an additional solar project impacts the value of a home in high- and low-income areas. In the first regression, analyzing treatment 1, the construction of a single solar project causes home values to increase an average of $21.33 (0.401) per solar project for all income groups. While those in the treatment group, below the income threshold, saw a housing increase of $248.82 (24.45). Both variables were statistically significant as is seen in the column marked 7 of Table 4.

The elasticity of the model, indicating the percent effect of constructing an additional solar project, demonstrates a change in housing value of 0.00637% on average for all income groups. Those within the treatment group, and below the income level of $36,450, saw a percent change of 1.032% in their housing value after the construction of an additional solar project. Again, these results are statistically significant and are seen in column 10 of Table 5.

The second treatment group saw an average impact of $20.899 (0.402) on their housing values for the construction of an additional solar project in all income brackets, with statistical significance. With those under the treatment level of $51,250, seeing a statistically significant value of $106.1516 (5.85) per solar project constructed, as seen in column 8 of Table 4.

The elasticity of this model shown in column 11 of Table 5 demonstrates that percent change for the average of all housing values was 0.00615% and the change for those below the treatment effect was 0.0525%. This again was statistically significant.

The final treatment group saw an average housing value change of $20.8056 (0.418) for the average of all income values. While those below the treatment level of $61,714 saw an average change of $7.59 (1.49) per solar project constructed. Both variables were statistically significant as seen in column 9 of Table 4.

The elasticity of the third treatment variable showed a value housing change of 0.00587% for the average of all income groups, and 0.00678% per solar project for those below the treatment variable threshold. This model had both values as statistically significant and is seen in column 12 of Table 5.

The new set of results indicates that those in the lower income bracket see greater benefits to their housing values for the construction of solar energy projects. As the level of income increases, the added benefit of constructing solar panels diminishes. This provides context to the previous set of results in that the value of a home may be less in the lower income levels, but the rate that it is benefited from each solar panel is greater.

**Table 4 : Regression results of Models 7 - 9**

| | (7) | (8) | (9) |
|---|---|---|---|
| | PValue | PValue | PValue |
| After | 21.334*** | 20.899*** | 20.806*** |
| | (0.401) | (0.402) | (0.418) |
| Inter 1 | 249.822*** | | |
| | (24.449) | | |
| Inter 2 | | 106.152*** | |
| | | (5.846) | |
| Inter 3 | | | 7.593*** |
| | | | (1.492) |
| Obs. | 467749 | 467749 | 467749 |
| R-squared | 0.006 | 0.007 | 0.006 |

Standard errors are in parenthesis

**** p<0.01, ** p<0.05, * p<0.1*

**Table 5 : Elasticity of Regression results of Models 10 - 12**

| | (10) | (11) | (12) |
|---|---|---|---|
| | PValue | PValue | PValue |
| TotalPV | 0.0001*** | 0.0001*** | 0.0001*** |
| | (0.0000) | (0.0000) | (0.0000) |
| Inter 1 | 0.0010*** | | |
| | (0.0001) | | |
| Inter 2 | | 0.0005*** | |
| | | (0.0000) | |
| Inter 3 | | | 0.0001*** |
| | | | (0.0000) |
| Obs. | 467749 | 467749 | 467749 |
| R-squared | 0.0073 | 0.0090 | 0.0074 |

Standard errors are in parenthesis

**** p<0.01, ** p<0.05, * p<0.1*

## Discussion

The results support much of the previous literature, and the hypothesis of the thesis is validated through the findings. Namely those in higher income areas see financially greater benefit from the construction of solar panels but those in lower income areas are benefited proportionally more from individual solar panel construction. This was seen in the two different regression models. In the first set, testing housing value differences after the construction of solar panels for those in high- and low-income areas, the high-income areas saw greater development. In each of the treatment groups those in lower income areas saw a reduced increase in the percentage of their housing values than the average housing increase after the construction of a solar project. This alone would suggest the high-income areas benefit at a greater rate than those in lower income areas.

This is supported by the literature. There is evidence that those in the higher income bracket can make more financially secure investments and that the return of investment for solar panel construction is typically much greater in high-income areas. It is also seen that those in higher income areas look for direct economic returns in the construction of solar panels. This would suggest that after the construction of solar panels in these areas, there would be an expected correlation to higher economic gain.

It is also noted that in the first set of regression models the greatest discrepancy in housing value effects was in the first treatment group. This can be expected as those considered low-income (less than $32,450) would see far less mobility in their housing values so the construction of a solar panel would see overall less value added to their homes. However, the discrepancy between treatment 2 and 3 is much more nuanced. This suggests the ZIP codes in the middle- and high-income bracket see similar results and it is in fact those in the lowest income areas that see the greatest difference. In this instance middle-income is considered those that are not classified as low-income with treatment 1, but as the treatment changes they are considered low-income.

The second set of regression models demonstrate another perspective on the situation. The benefit of a single solar panel is greater in low-income areas, whereas when income increases, the added benefit of a solar panel diminishes. There are a number of reasons this could be the case. First is the assumption that those that earn a lower income place greater value on a dollar than those with a higher income, therefore, the construction of a solar panel holds greater value for those in lower income areas than higher income areas. So, when a solar panel is constructed the weight it has on the housing value will be proportionally greater to the value of the house, even if the dollar value is less than in higher income areas.

The second reasoning would suggest a limitation with the study, which is the indication of diminishing returns. Those in higher income areas can construct a much higher quantity of solar panels, and therefore the value of adding an additional solar panel becomes much less than in lower income areas in which they are a novelty. Either of these assumptions are supported by the trend in the results. In the first treatment group, the difference between the two variables is the greatest, suggesting the lower income areas see the greatest benefit. In the second treatment group the value of an additional solar panel is almost halved from the first, and in the third treatment the difference between the control and treatment are minimal. Since treatment 3 includes incomes below $61,714, and it is at this level that the values become relatively equal in low- and high-income areas, it can be construed that at an income below $61,714 the value of an additional solar panel will benefit one's housing value more significantly. All of this is to suggest that as income increases the value added for constructing an additional solar panel continually becomes more minimal.

The limitations of this study are present from a technical and a practicality standpoint. First is the collection of data. The study collected data solely from New York State for simplicity in running the regression analysis. Although national data may be more indicative to an overall trend, each state has different laws regarding renewable, and solar, energy. By limiting the data to New York, it allows for accuracy on this small scale. Another consideration taken was regarding the housing data. Since so many low-income residents rent rather than buy property, a strong indicator to how solar panels impact low-income people would be by measuring changes in rent value; however, that information was unavailable and housing prices were used as an approximation for overall changes in land value. Finally, this study considered all PV solar sites constructed in New York. This means it includes industrial sites, which are most likely in high income areas and may skew the data to show higher value changes in high-income areas.

Next was a limitation in the regressions used. As indicated in the results, all models had a rather low R-squared value. This indicates the models were representing a small portion of the results. However; given the objective of this particular study a low R-squared is not unusual, nor enough to fully discount the validity of the results. More important to this study is the indication that there was a change in values at the given point in time, which was achieved and is represented in the findings. The final limitation of this study regards world events impacting the ability to proceed further. Given circumstances following the outbreak of COVID-19 and the constraints placed on students, this study was limited to work and resources available at a specific point in time.

The overall implications of this study represent a mixed set of expectations and outcomes. The first indications of this study suggest high-income areas will see the greatest outcome from the construction of solar panels. This is most likely due to their ability to be more stringent in their specific expectations for the construction of solar panels. With this assumption, policy should continue following a similar path as it has. The traditional market in which solar and renewables are adopted mainly by high-income individuals as a luxury resource will result in the highest return in investment. However, despite this, low-income areas see growth from the construction of solar panels as well. Though it is a smaller percentage of housing value than in high-income areas, the impacts are still positive. This would suggest that instead of gearing policy merely towards high-income areas, creating incentives for low-income areas to install solar panels won’t only benefit the solar industry but will bolster the economic and social outcomes of low-income areas as well.

In considering the results of the second regression model in this study, the incentive for designing policy to assist low-income areas becomes stronger. As was seen, the added benefit of providing an additional solar project to low-income housing is exponentially higher than in high-income areas. This would suggest that providing solar panels to low-income areas would be far more beneficial than supplying additional solar panels to high-income areas in the short term. With this understanding, creating policy that embraces bringing solar panels to new low-income areas would be immensely beneficial. This opens the door to a new line of thinking; traditionally the adoption of solar panels is an investment designed to provide a combination of environmental, economic, and social gains, depending on those constructing them. This is usually reserved for high-income areas with policy providing some of the same benefits to low-income areas. If instead it was the direct effort of initiatives to use the adoption of solar and other renewables as a method to develop low-income areas in a sustainable and efficient manner, then the result would be two-fold; a strengthened low-income community and the expansion of the solar industry.

To gain a better understanding of the full potential impacts, further research in this area should be considered. However; the results of this study suggest that high-income areas see an overall greater return from solar panels, but low-income areas see stronger initial returns from each solar panel. Should policy be put in place that not only incentivizes the construction of new solar panel projects, but the continued support of solar panel projects in low-income areas, the results would be an expansion for the solar industry and a pathway for growth in low-income areas.

## References


Akella, A. K., Saini, R. P., & Sharma, M. P. (2009). Social, economical and environmental impacts of renewable energy systems. *Renewable Energy*, *34*(2), 390–396. https://doi.org/10.1016/j.renene.2008.05.002

Bakken, T. H., Sundt, H., Ruud, A., & Harby, A. (2012). Development of Small Versus Large Hydropower in Norway– Comparison of Environmental Impacts. *Energy Procedia*, *20*, 185–199. https://doi.org/10.1016/j.egypro.2012.03.019

Bergmann, A., Colombo, S., & Hanley, N. (2008). Rural versus urban preferences for renewable energy developments. *Ecological Economics*, *65*(3), 616–625. https://doi.org/10.1016/j.ecolecon.2007.08.011

Brinkley, C., & Leach, A. (2019). *Energy next door_ a meta-analysis of energy infrastructure impact on housing value | Elsevier Enhanced Reader*. https://doi.org/10.1016/j.erss.2018.11.014

Brown, D. P., & Sappington, D. E. M. (2017). Designing Compensation for Distributed Solar Generation: Is Net Metering Ever Optimal? *The Energy Journal*, *38*(3). https://www.iaee.org/en/Publications/ejarticle.aspx?id=2925

Covert, T., Greenstone, M., & Knittel, C. R. (2016). Will We Ever Stop Using Fossil Fuels? *Journal of Economic Perspectives*, *30*, 117–138.

del Río, P., & Burguillo, M. (2008). Assessing the impact of renewable energy deployment on local sustainability: Towards a theoretical framework. *Renewable and Sustainable Energy Reviews*, *12*(5), 1325–1344. https://doi.org/10.1016/j.rser.2007.03.004

Dvorak, M. J., Archer, C. L., & Jacobson, M. Z. (2010). California offshore wind energy potential. *Renewable Energy*, *35*(6), 1244–1254. https://doi.org/10.1016/j.renene.2009.11.022

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S., & Allen, M. F. (2014). Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews*, *29*, 766–779. https://doi.org/10.1016/j.rser.2013.08.041

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K.-H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, *82*, 894–900. https://doi.org/10.1016/j.rser.2017.09.094

Kolev, A., & Riess, A. (2007). Environmetal and technology externalities: Policy and investment implications. *EIB Papers*, *12*(2), 134–162.

Kunz, T. H., Arnett, E. B., Erickson, W. P., Hoar, A. R., Johnson, G. D., Larkin, R. P., Strickland, M. D., Thresher, R. W., & Tuttle, M. D. (2007). Ecological impacts of wind energy development on bats: Questions, research needs, and hypotheses. *Frontiers in Ecology and the Environment*, *5*(6), 315–324. https://doi.org/10.1890/1540-9295(2007)5[315:EIOWED]2.0.CO;2

Lang, C., Opaluch, J. J., & Sfinarolakis, G. (2014). The windy city: Property value impacts of wind turbines in an urban setting. *Energy Economics*, *44*, 413–421. https://doi.org/10.1016/j.eneco.2014.05.010

Mann, J., & Teilmann, J. (2013). Environmental impact of wind energy. *Environmental Research Letters*, *8*(3), 035001. https://doi.org/10.1088/1748-9326/8/3/035001

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

Perera, F. P. (2017). Multiple Threats to Child Health from Fossil Fuel Combustion: Impacts of Air Pollution and Climate Change. *Environmental Health Perspective*, *125*, 141–148.

Qiu, Y., Wang, Y. D., & Wang, J. (2017). Soak up the sun: Impact of solar energy systems on residential home values in Arizona. *Energy Economics*, *66*, 328–336. https://doi.org/10.1016/j.eneco.2017.07.001

Raadal, H. L., Gagnon, L., Modahl, I. S., & Hanssen, O. J. (2011). Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power. *Renewable and Sustainable Energy Reviews*, *15*(7), 3417–3422. https://doi.org/10.1016/j.rser.2011.05.001

Reed, C. D., & Scott, W. H. (2014). *Willingness-to-Pay for Renewable Wind Energy: Differences in Preferences Between Demographic Groups*. 14.

Stoppato, A. (2008). Life cycle assessment of photovoltaic electricity generation. *Energy*, *33*(2), 224–232. https://doi.org/10.1016/j.energy.2007.11.012

*Sustainable Development—An overview | ScienceDirect Topics*. (n.d.). Retrieved February 20, 2020, from https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sustainable-development

Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy*, *33*(3), 289–296. https://doi.org/10.1016/S0301-4215(03)00241-6

von Mollendorff, C., & Welsch, H. (2017). Measuring Renewable Energy Externalities: Evidence from Subjective Well-Being Data. *Land Economics*, *93*(1), 109–126.

Welsch, H. (2016). *Electricity externalities, siting, and the energy mix: A survey* (Working Paper V-394–16). Oldenburg Discussion Papers in Economics. https://www.econstor.eu/handle/10419/148229

Yenneti, K., Day, R., & Golubchikov, O. (2016). Spatial justice and the land politics of renewables: Dispossessing vulnerable communities through solar energy mega-projects. *Geoforum*, *76*, 90–99. https://doi.org/10.1016/j.geoforum.2016.09.004