Final Report

The Social Geography of Solar Renewable Energy Credits (SRECs) in Delaware

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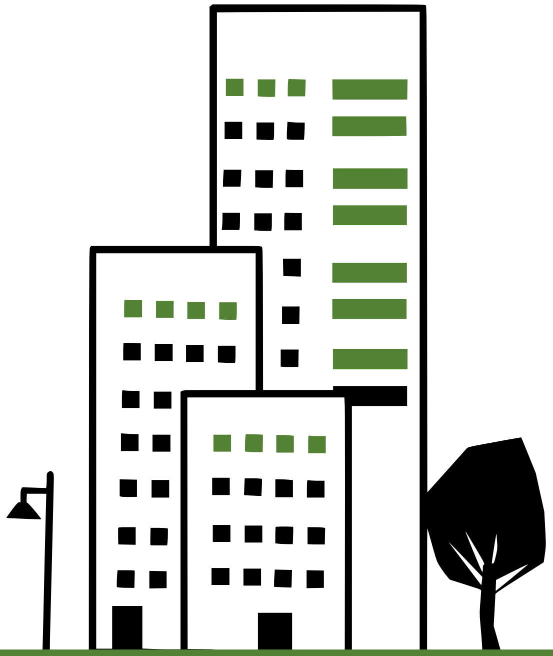

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Executive Summary

This report details work conducted to build a comprehensive and detailed database, including spatial information, of all solar energy facilities located in Delaware and all solar renewable energy credit (SREC) transactions logged by Delmarva Power in Delaware in accordance with the state's renewable portfolio standard (RPS). This work is a continuation of previous efforts documented in Byrne et al. (2022). The presented work expands on the analysis conducted in Byrne et al. (2022) by adding additional temporal, spatial, socioeconomic, environmental, and solar energy system-level coverage.

The social geography profile of solar energy markets is a critical building block of the fair energy transition. Unfair benefit or harm distribution within a market, or the existence of disproportionate policy incentives that accelerate some societal segments over others, call into question the concept of a sustainable future for all. The possibility of unequal distribution is not theoretical: conventional fossil fuel energy architectures have repeatedly been found to disproportionately harm already marginalized segments of society (Agyeman et al., 2003). Solar energy markets, while different in magnitude and scope, present a similar social geography challenge, of how to create inclusive market access for all (Bednar & Reames, 2020; Brockway et al., 2021; Lukanov & Krieger, 2019; O'Shaughnessy, 2022; Reames, 2020, 2021).

Primary Research Objectives

This research project aims to critically understand the Delaware solar energy market to determine the following:

1. The social geography of the state's solar energy market. In particular, we describe the distribution of installed solar energy capacity in the residential sector in relation to temporal, spatial, and socioeconomic considerations.
2. The social geography of solar renewable energy credit (SREC) transactions across the state. We trace the volume and value of the SREC procurements made by Delmarva Power from 2012 to 2021, with a particular focus on residential-scale solar energy facilities in order to determine the temporal, spatial, and socioeconomic distributions of these transactions.
3. The possible spatial, temporal, and socioeconomic profile of social geography that prevents inclusive access to the ongoing energy transition.

We focus on the residential portions of the solar energy and SREC markets as these small-scale facilities are procured by individual households. Purchasing decisions at the household level are sensitive to socioeconomic conditions, according to relevant literature (Bednar & Reames, 2020; Brockway et al., 2021; Lukanov & Krieger, 2019; O'Shaughnessy, 2022; Reames, 2020, 2021).

Data Integration and Geocoding Workflow

To achieve the stated research objectives, we cross-connected high-resolution and comprehensive databases and built a spatial, socioeconomic, and temporal overview of Delaware's solar energy and SREC markets. This cross-connection process offers detailed insight regarding the demographics and socioeconomic profile of the solar energy market. These insights serve to test the market's ability to inclusively work for all segments of society in the past, present, and future.

More specifically, we first built a facility-level database that principally contains:

1) Relevant facility-level information, including address, system capacity, year of established operation, and other attributes; and
2) A 'class' designation that identifies the residential portion of all known solar energy facilities operating within Delaware (detailed description contained in Appendix C). Specifically, we identify as 'residential' all PV systems that are equal to or less than 20 kilowatts (kW) in capacity.

The facility-level database was constructed using three sources of data (Figure ES- 1). These three sources of information include thousands of individual docket files, a publicly available database published by the Delaware Public Service Commission (PSC), and a publicly available database maintained by the PJM GATS.

Next, the facility-level database was converted to a spatial database by geocoding the address information obtained from individual docket applications, using Google's Geocoding API. The geographic facilities of each solar energy facility were then connected with known socioeconomic profiles of communities throughout the state to build a social geography map of the market.

A separate database organized at the SREC transaction level was constructed from publicly available RPS compliance reports published by DPL. Whereas each entry in the facility-level database refers to an individual renewable energy installation, each entry in the SREC database refers to an individual SREC transaction (which can include several individual SRECs). We cross-connected the two databases to link SREC transactions to the individual solar energy facilities. This cross-connection enabled the research team to gain detailed insights into the value, volume, and frequency of SRECs awarded to separate solar energy installations. In addition, since we possess socioeconomic detail regarding the community in which each solar energy installation is located, we were able to connect both facility and SREC profiles to socioeconomic attributes to track the social geography of the solar energy and SREC markets.

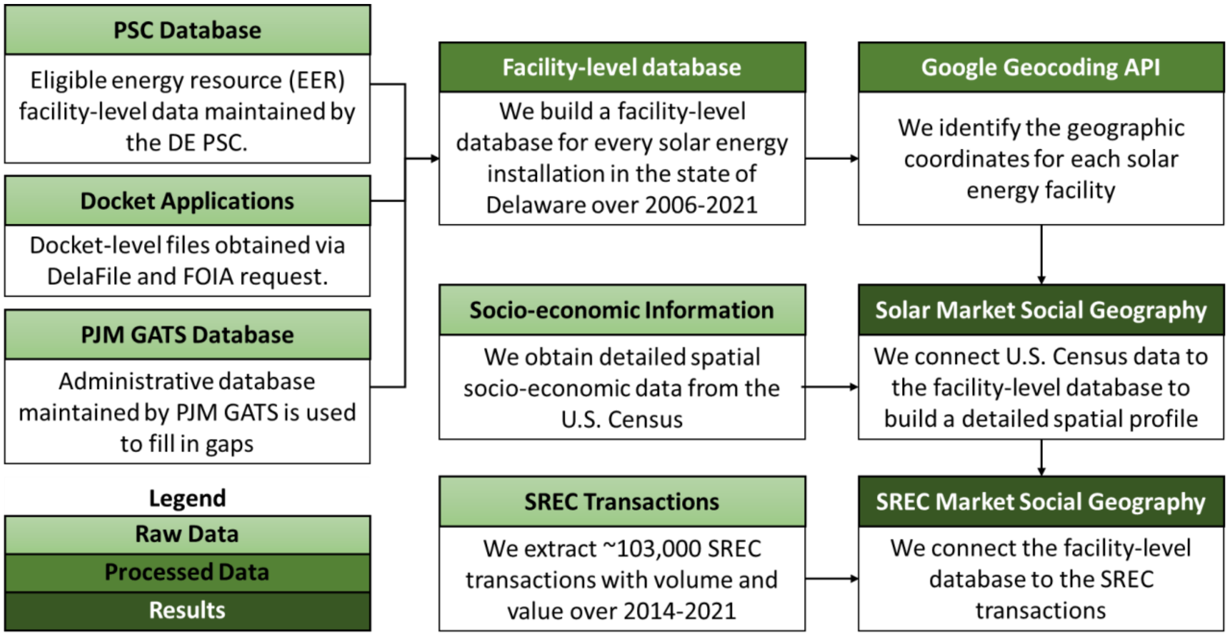

Figure ES- 1 Schematic of the analytical approach of the research

Delaware Solar Energy Market Results

The resulting facility-level database contains information on every known solar energy facility located within Delaware. [1] When considering only the solar energy facilities for which we were able to successfully obtain address-level information, the database contains information on 6,896 solar energy facilities. In other words, we successfully geocoded 89.8% of the data in terms of

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[1] The database also contains similar information on solar energy facilities that are physically located out of state but are certified to contribute to the Delaware RPS objectives. However, the present study focuses on the residential solar energy market within state boundaries.

facility count and 95.9% in terms of capacity. Combined, these 6,896 facilities represent 147.9 MW of solar energy capacity. Separated into the three classes of residential, commercial, and utility-scale solar energy facilities, the database contains 51.6 MW, 47.3 MW, and 49.0 MW, respectively.

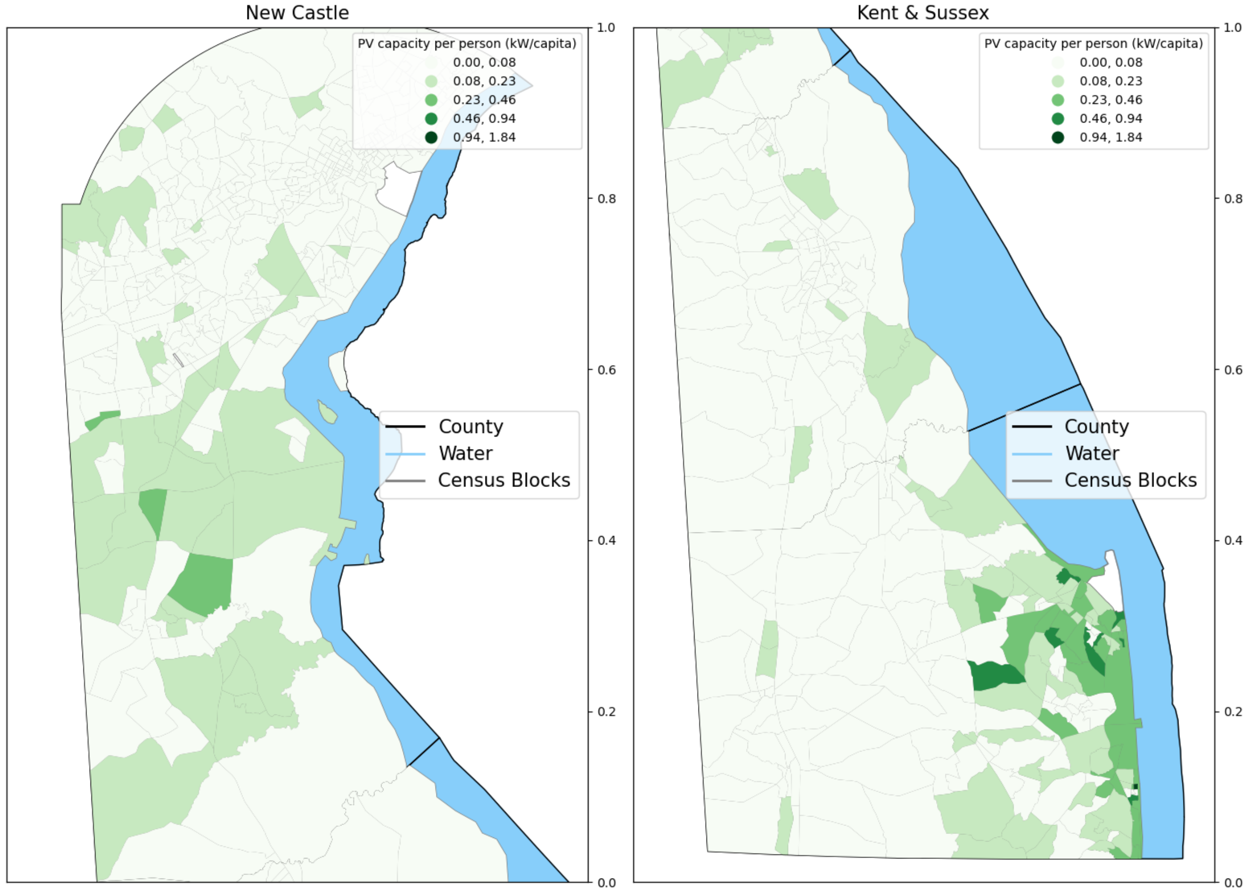

Figure ES- 2 Installed PV capacity per person in Delaware-based U.S. census block groups

We successfully identified the geographic coordinates for 6,415 residential-scale solar energy facilities. A key finding of this report is that the distribution of these residential-scale solar facilities are geographically concentrated. To illustrate this finding, we present the solar PV market penetration in terms of installed residential-scale capacity per person (kW per capita) for each U.S. census block group in the state (Figure ES-2). We find that installed capacity levels appear especially high in the coastal areas of the state (e.g. Rehoboth, Dewey, and Bethany beach) as well as in several of the urban areas of the state.

Scoring Delaware's Communities

To assess social geography conditions, the research uses an environmental and social scoring mechanism that can identify community-level vulnerabilities to socioeconomic and environmental risks. This mechanism is taken from previous research (Byrne et al. 2022). In this report, we deploy the mechanism to describe the geographical pattern of solar PV ownership and its socioeconomic characteristics. This scoring mechanism ranks the socioeconomic profile and environmental risk exposure of census block group level segments of Delaware. The result is an integrated score that separates communities with high levels of social risk and environmental pressure from those with comparatively low levels of such risks and pressures. In other words, we can segment the state's census block groups along a spectrum of "most vulnerable" to "least vulnerable."

To simplify the scoring mechanism, which produces a continuous numeric score for each of the state's 706 census block groups, we bin the resulting integrated score into ten separate bins, where the most vulnerable communities are in bin number 10 and the least vulnerable communities are in bin number 1 (Table ES- 1). The source of the data for the calculation of the integrated score is the U.S. Environmental Protection Agency (EPA)'s EJSCREEN tool. As such, we label these bins as EJSCREEN score bins. As given in Table ES- 1, there are approximately 122,000 people in the four most vulnerable bins across 99 census block groups.

Table ES- 1 Delaware Communities by Integrated Score

EJSCREEN Score Bin	Integrated Score	Number of Communities	Population	Description
1	0 – 695	86	77,461	Least
2	696 – 1399	130	180,068	vulnerable
3	1400 – 2099	136	218,484	|
4	2100 – 2799	99	142,644	|
5	2800 – 3499	81	122,849	|
6	3500 – 4199	75	103,431	|
7	4200 – 4905	49	66,823	|
8	4906 – 5599	31	35,683	|
9	5600 – 6499	15	15,415	|
10	6500 – end	4	4,821	Most vulnerable

Social Geography of the Delaware Solar Energy Market

Our previous research used a smaller dataset and found that the distribution of the solar energy market for installed capacity per person skewed towards census block groups with lower pollution pressure and lower social vulnerability (Byrne et al. 2022). [2] This research similarly showed that when all census block groups are binned based on their U.S. EPA EJSCREEN performance, the solar installation levels are highest in the census block groups that are among the least vulnerable communities (Figure ES- 3). Conversely, those living in the least favorable social and environmental conditions have been largely unable to participate in the solar energy market (Figure ES- 3).

This finding has direct consequences for a policy strategy that is interested in pursuing a "sustainable energy for all" objective. Current market performance suggests the reality is one of unequal access to the energy transition. For instance, at approximately 130 W of solar PV capacity per capita, the least vulnerable census block group has almost sixty times more capacity per capita deployed than the most vulnerable census block groups at 2.2 W of solar PV capacity per capita (Figure ES- 3). Indeed, there is an apparent progression towards lower and lower levels of solar energy installation as environmental and social risks and vulnerabilities increase.

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[2] In this research, we apply the same methodology that classifies the census block groups based on their environmental pressure and their social vulnerability but a) expand the dataset that is tested with the methodology and b) use an updated U.S. census block group representation that separates the state into 706 individual census block groups.

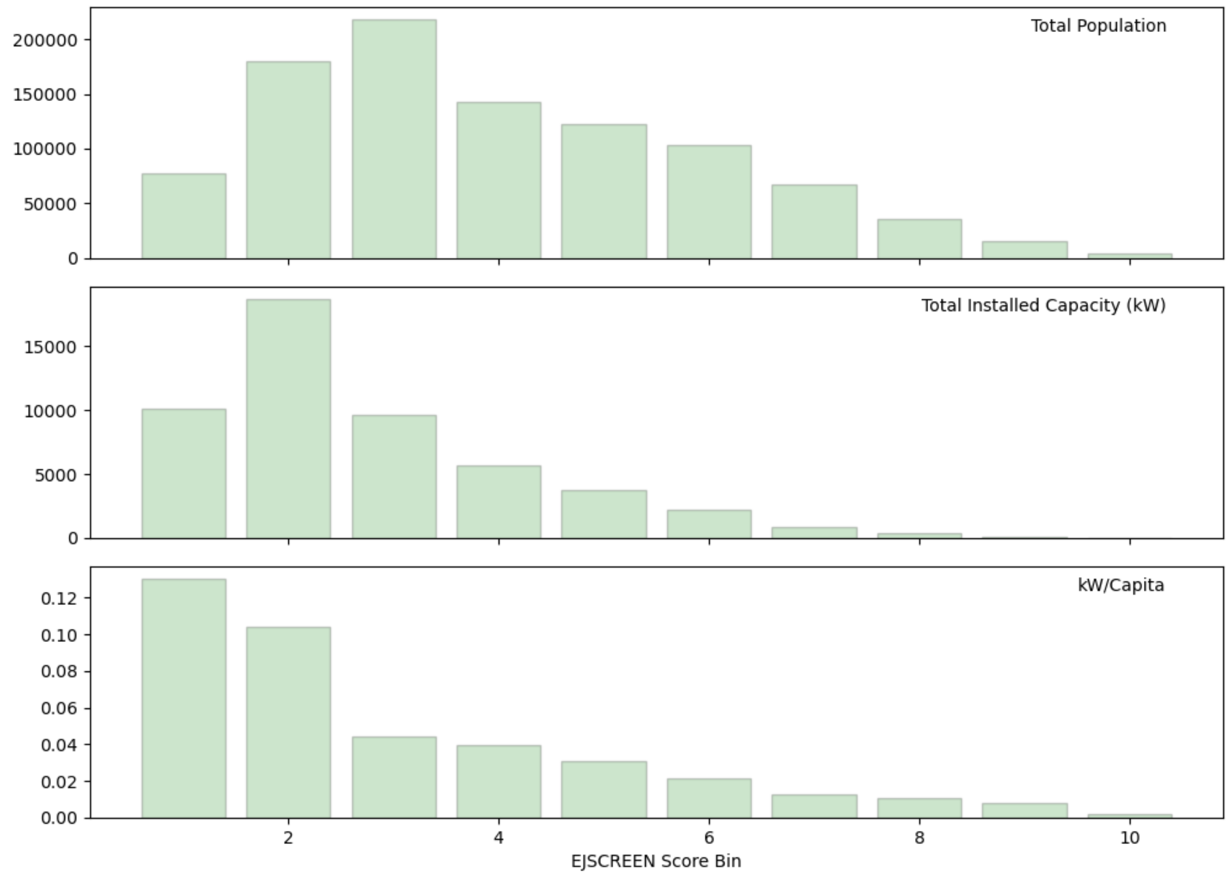

Figure ES- 3 Social geography of Delaware's residential solar energy market

Delaware SREC Market Results

In terms of the SREC transactions, the database identifies 103,180 individual SREC transactions made by Delmarva Power to solar energy facilities within state boundaries, from 2012-2021.[3] These transactions cover 536,541 SRECs, worth approximately $52.4 million. Out of the 103,180 individual transactions, we successfully geocoded 93,434 SREC transactions – a success rate of ~91%. Looking at only the residential facilities, the 82,517 SREC transactions that we geocoded represent ~$7 million and 127,135 SRECs. As such, the residential portion of the state SREC market is approximately 88% of the geocoded transactions but ~13.3% of the SREC market value

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[3] Note that the SREC database, like the facility-level database, includes data on SREC transactions made to facilities located outside of the state's boundaries and to different types of renewable energy facilities (e.g. wind energy). These SREC transactions are not included in the numbers represented here.

and ~24% of the volume. In recent years, as found in our previous study, the residential portion of the market is commanding an increasing market share (Byrne et al. 2022).

Social Geography of the Delaware SREC Market

SRECs function as a financial remuneration for solar energy production. Considering capacity is skewed towards the least vulnerable census block groups, it is expected that a similar profile exists for SREC transactions. We indeed identified a similar pattern, in which the least vulnerable census block groups sell a higher volume of total SRECs to DPL and receive a higher remuneration per person compared to the most vulnerable census block groups (Figure ES- 4). For instance, the three least vulnerable bins of census block groups received a nominal volume of SREC purchases equal to approximately $8-$16 per person, whereas the three most vulnerable census block groups each received less than $1 per person between 2012 and 2021.

The pattern remains when compared on a value received per SREC basis. The most vulnerable census block groups receive a lower value per SREC compared to the least vulnerable census block groups (Figure ES- 4). Whereas the three least vulnerable census block group bins, for instance, garner approximately $50-$70 dollars per SREC, the three most vulnerable census block group bins receive approximately $30-$38 per SREC.

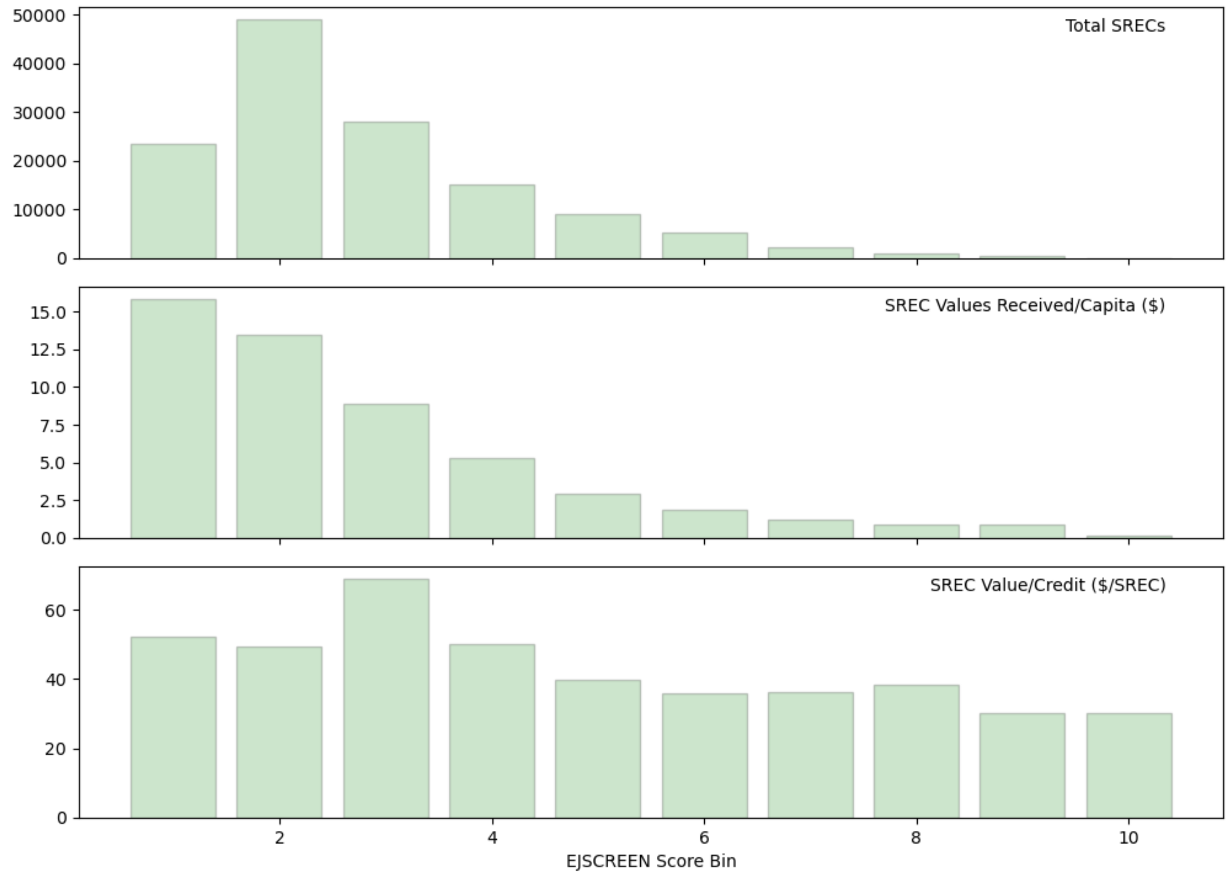

Figure ES- 4 Social geography of Delaware's residential SREC market

Temporal Considerations of the Delaware Solar and SREC Market

An important dimension in the aforementioned findings is the date of installation and receipt of SRECs. As the market has progressed, many parameters associated with the solar energy market have changed. For instance, technology costs have fallen rapidly over the timeframe studied here, from 2012-2021. Similarly, SREC values have fallen significantly over time (Byrne et al. 2022).

As illustrated in Figure ES- 5, SREC values have ranged throughout 2012-2021 between $1 and $260 per SREC. When separated by EPA EJSCREEN bins, it is apparent that SREC values generally are higher in the bins faced with the lowest vulnerability to environmental and social risk. For instance, bin numbers 1-3 received over $50 per SREC for at least 25% of those purchased from these groups. In some cases, as much as 49% of the SRECs purchased in one of these bins were sold for $50 or more. In contrast, bins 8-10 have less than 10% of their SRECs purchased for more than $50, with one bin selling all of their SRECs below $50/SREC.

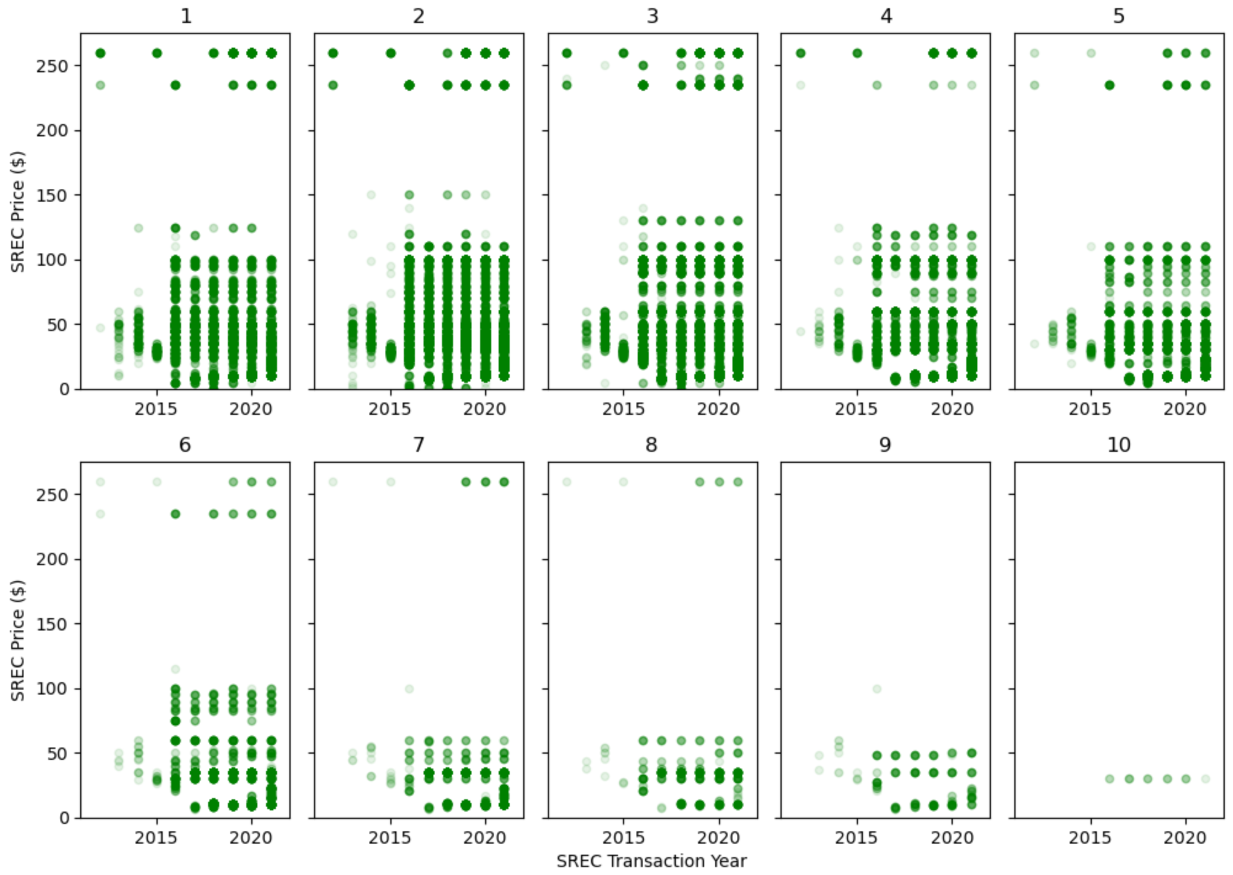

Figure ES- 5 SREC values and volume, 2012-2021, separated by EPA EJSCREEN bin for residential solar energy facilities, organized by year of SREC transaction

Figure ES- 5 above is organized by SREC transaction year. As such, there are solar energy facilities that, for instance, started operation in 2012 and have received the same SREC value over the following years since they were initially purchased under 20-year contracts (as was state law at the time). The principal conclusion to draw from the above is that communities exposed to higher levels of social and environmental stress receive lower levels of compensation. This is because they were unable to join the solar energy market when SREC values were highest and, as such, have not received the same level of compensation enjoyed by the communities able to join in the earlier years of the solar energy market. Primary obstacles limiting inclusive participation in the earlier years of the solar energy market include that PV technology costs were substantially higher and the market was comparatively nascent.

Principal Findings of the Present Research

The research described in this report successfully constructed a comprehensive database of both solar energy facilities operating within Delaware's state borders and the SREC transactions made by DPL to satisfy RPS obligations. The present research reveals that:

1. The distribution of solar energy facilities across the state is geographically constrained;
2. the distribution of solar energy capacity skews towards communities that already face lower social and environmental stress;
3. as SREC volume is dependent on the volume of solar energy generation which depends on the total installed solar panel capacity, we find that SREC volumes also skew towards those communities facing lower social and environmental stress; and
4. the values awarded to SRECs sold into the market likewise appear to skew toward the least vulnerable communities. This is likely due to the fact that these communities were able to join the Delaware solar energy market in the early years of its development.

In short, financial remuneration strategies designed to bridge financial barriers that trend down over time appear poised to most highly compensate communities that face comparatively low levels of environmental and social stress as these communities achieve higher participation levels earlier. This is perhaps expected, as it is a common characteristic of "early movers" – those willing to adopt new, more costly, technologies.

SREC policies successfully motivate market growth and expansion by enticing market adoption and mitigating the prohibitive cost associated with new technologies (Barbose, 2021; Ryan et al., 2019; Sarzynski et al., 2012; Steward & Doris, 2014). However, as the market matures and SREC prices are reduced to account for the maturation of the market, the design of the policy mechanism leads to lower incentives in nominal terms than those received by early adopters, meaning there is less financial assistance for late arrivals to the market, who are more likely to be from more vulnerable communities. On the other hand, later arrivers benefit from the much lower costs of PV installation. These trends might balance out for the most-vulnerable communities as access to the market may have improved over time as technology costs (and other costs associated with PV installation) have fallen sufficiently to counteract the declining SREC prices. Yet, latearriving, vulnerable communities suffer from pre-existing energy affordability issues. Moreover, the most vulnerable communities often rent their homes and do not, therefore, have the roof asset for PV installation. These countervailing factors suggest that solar policy mechanisms are needed to help develop an inclusive solar market that allows more parties to enter the market at lower cost.

Possible Policy Strategies to Make the Solar Energy Market More Inclusive

The findings uncovered in this research suggest that there are challenges in the Delaware solar energy and SREC markets for which new policy solutions could be helpful. While the intention of the SREC market was to motivate market growth it appears that policy designs that specifically target inclusive access as a policy objective are needed to ensure a sustainable energy for all future. In light of our findings, we briefly discuss several possible policy strategies that could produce a more inclusive solar energy market.

A first line of thinking could focus on the subsidization of solar energy technology for low- and moderate income (LMI) households. An example of this type of policy strategy can be found in Delaware's current two-year pilot test to provide 50 households annually with solar energy panels through two principal pathways: 1) for low-income residents of the state, the pilot provides solar PV panel packages up to 4 kW at no out-of-pocket costs to the resident; 2) for moderate-income residents, the pilot covers 70% of the upfront costs.[4] Expanding this 'Low- to Moderate-Income Solar Pilot Program' might yield a more inclusive market over time by increasing affordable access to the energy transition.

A second option is to integrate the fulfillment of energy equity objectives as a responsibility of the Delaware Sustainable Energy Utility (SEU). For instance, the SEU could develop a grant-based program as part of its ongoing 'Empowerment Transformation' program. The program originally targeted only low-income DPL customers, but has since expanded to a statewide initiative seeking to transform energy equity across the entire state. The SEU could operate a grant program

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[4] More details on the program can be found via the Department of Natural Resources and Environmental Control (DNREC) at https://dnrec.alpha.delaware.gov/climate-coastal-energy/renewable/lmi-solar-pilot-program/

to Delaware non-profit (NGOs), community-based organizations (CBOs), or other relevant organizations with the intention of broadening access to the solar energy market.

An extension of the SEU-focused strategy is to use the grant-based funds to enable community-scale solar energy strategies in which NGOs, CBOs, and others build programs that lead to inclusive solar energy build-out within communities, in particular the LMI segment. Such a "community solar" strategy provides meaningful options to the entire community to participate in the ongoing energy transition. Previous research uncovered the significant advantages that accompany such a strategy (Byrne et al., 2020, 2021).

1.0. Introduction

The U.S. energy transition is rapidly proceeding with the country's solar energy sector enjoying substantial year-over-year growth (Feldman et al., 2022). Recent research on the solar energy transition has found, however, that the transition may not be benefiting all segments of society. In particular, low- and moderate-income households and disadvantaged communities may remain largely underserved by the solar energy transition (O'Shaughnessy, 2022; Reames, 2020, 2021).

The extent of the inclusivity deficit in the Delaware solar energy market is evaluated and discussed in this final report of this research effort. An inclusivity deficit challenges stated public policy goals to realize the aims of a 'sustainable energy transition for all'. To explore the extent of the potential deficit, we first need an accurate picture of current conditions in terms of the spatial, temporal and socioeconomic distribution of both the solar energy market and the solar renewable energy credit (SREC) market. This and our previous year's research (Byrne et al., 2022) on these topics hopes to assist policy makers, community organizations, business leaders, researchers and others to facilitate the state's pursuit of an economy and society based on affordable, accessible sustainable energy.

To determine the details of the Delaware solar energy market, we construct a comprehensive database containing information regarding each solar energy installation in the state of Delaware that qualifies for the renewable energy portfolio standard (RPS). For each solar energy facility, for instance, the database contains the spatial location, year of implementation, capacity, ownership, PJM generation attribute tracking system (GATS) certification number, and other relevant information. Subsequently, each solar energy installation is connected to U.S. census block group data to determine relevant socioeconomic information for the surrounding area. This type of information yields insight into, for example, the average income of the area, the social profile of the households in the area, and other key data points. The census block group is the smallest geographic entity maintained by the U.S. census for which the decennial census tabulates and publishes sample data. Finally, the database is connected to annual SREC transactions logged by Delmarva Power for the Delaware Public Service Commission.

1.1. Our Challenge

Solar energy markets across the United States are growing rapidly and, as of fall 2021, 11 U.S. states achieved solar electricity penetration rates over 6% with leading states like California realizing rates as high as 25% (Feldman et al., 2022). To achieve carbon-free electric grids at a pace responsive to the scale and urgency imposed by climate change, however, the country's solar photovoltaic (PV) market needs to significantly expand. Consider, for instance, the 2021 U.S. Department of Energy (DOE) Solar Futures Study which urges a four times increase in the annual PV installation rate, reaching at least 60 gigawatt (GW) per year between 2025 and 2030 (Ardani et al., 2021). Many states have set their sights on a future of this kind: as of the time of this writing, 21 U.S. states, Washington DC, and Puerto Rico have introduced 100% clean energy objectives that signal a full renewable energy transition for their economies by no later than mid-century (Clean Energy States Alliance (CESA), 2023).

Supportive policy frameworks are commonly credited with at least part of the observed rapid growth. As a case in point, by one estimate, roughly half of all U.S. renewable energy market expansion since 2000 is associated with the state-level Renewable Portfolio Standard (RPS) policy framework (Barbose, 2021; Ryan et al., 2019; Sarzynski et al., 2012; Steward & Doris, 2014). The RPS policy option has been successful in part due to the high levels of compliance with RPS mandates across the U.S., the frequent upward revising of RPS targets, and the competition between states to set higher targets than competing states (Barbose, 2021; Byrne et al., 2007; Byrne, Taminiau, & Nyangon, 2022). Estimates suggest, for instance, that a 1% increase in RPS targets is accompanied by an estimated increase of 0.2%, 1% and 0.3% in renewable energy, solar generation and renewable energy capacity, respectively (Carley et al., 2018). Similarly, cities subject to the RPS mandates are found to install considerably more solar PV capacity compared to cities located in states without RPS obligations (Li & Yi, 2014).

The supportive policy frameworks achieve other impressive benefits. Retrospective analysis of RPS performance in 2013 estimated carbon emission reductions equivalent to $2.2 billion in avoided costs, saving consumers a combined $1.3-$4.9 billion and even greater health and environmental benefits were found (Wiser et al., 2016). Prospective analysis estimated up to 23%

decreases in cumulative life-cycle GHG emissions - equivalent to as much as $599 billion in global benefits (Mai et al., 2016). State RPS policies could reduce cumulative U.S. power sector carbon dioxide emissions by as much as 5.4% over the 2020-2050 study period (Mai et al., 2021). State-level and city-level renewable energy and energy efficiency policies achieved emission reductions as much as 77% below a business-as-usual scenario (Byrne, Taminiau, & Nyangon, 2022).

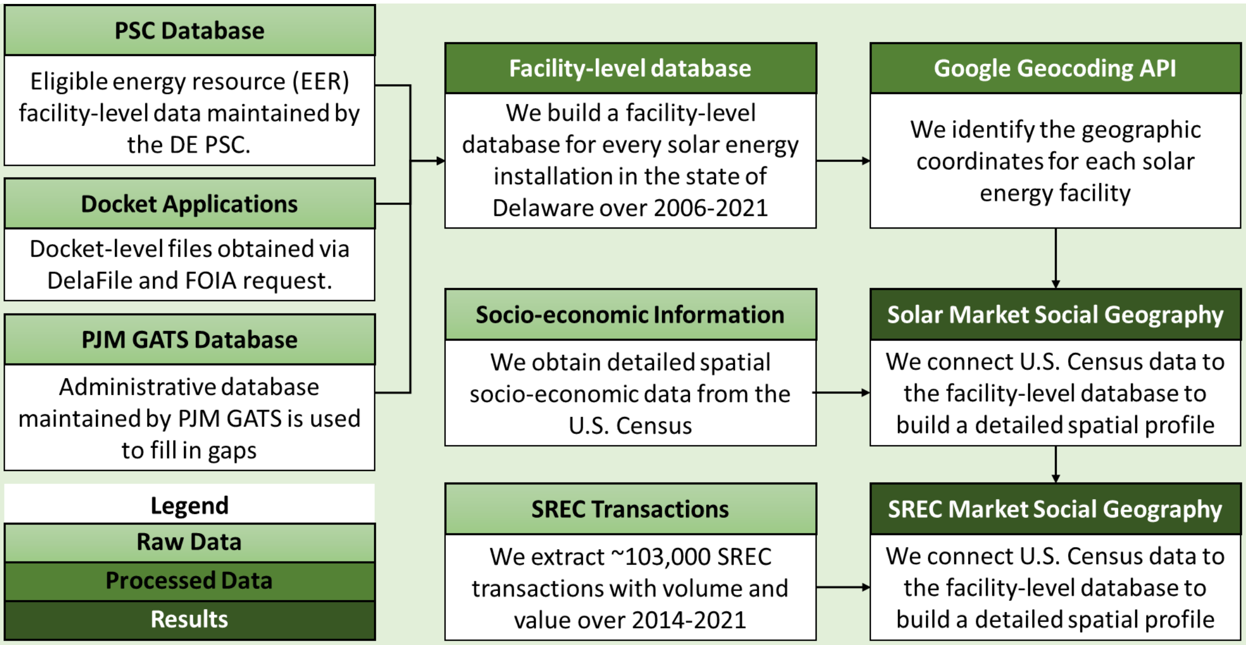
Yet, an emerging criticism of current solar energy markets across the U.S. is their apparent inability to ensure all segments of society have access to the market (Bednar & Reames, 2020; Brockway et al., 2021; Lukanov & Krieger, 2019; O'Shaughnessy, 2022; Reames, 2020, 2021). Recent investigations have found inclusivity deficiencies in major solar energy markets, revealing that especially low- and moderate-income (LMI) families and households are left behind as solar adoption accelerates. Even visions of 100% renewable energy, where the entire state relies on renewable electricity, might not alleviate this concern. If the 100% value is obtained from the wealthier segments of a population while maintaining existing barriers to solar energy market participation, exclusivity could remain a problem. By extension, supportive policy frameworks, especially ones that offer financial remuneration for solar adoption, are not necessarily designed to address this deficit. PV adoption equity as a policy priority, therefore, must include consideration for how policies impact and include LMI households (O'Shaughnessy, 2022).

1.2. Analytical Approach

To build a detailed understanding of the social geography of Delaware's solar energy and SREC market, we constructed a comprehensive database that contains, among other items:

a) facility-level information such as address, system capacity, and year of operation start;
b) SREC transaction data including the volume and value of the SRECs received by the solar energy facility per year; and
c) socioeconomic information at the relevant resolution of U.S. census data.

This database was constructed in accordance with the schematic included in Figure 1.



PSC Database

Eligible energy resource (EER) facility-level data maintained by the DE PSC.

Docket Applications

Docket-level files obtained via DelaFile and FOIA request.

PJM GATS Database

Administrative database maintained by PJM GATS is used to fill in gaps

Facility-level database

We build a facility-level database for every solar energy installation in the state of Delaware over 2006-2021

Google Geocoding API

We identify the geographic coordinates for each solar energy facility

Socio-economic Information

We obtain detailed spatial socio-economic data from the U.S. Census

Solar Market Social Geography

We connect U.S. Census data to the facility-level database to build a detailed spatial profile

SREC Transactions

We extract ~103,000 SREC transactions with volume and value over 2014-2021

SREC Market Social Geography

We connect U.S. Census data to the facility-level database to build a detailed spatial profile

Figure 1. Schematic of the analytical approach of the research

As indicated in Figure 1, the analysis produces three primary outputs:

1. A profile of the solar energy market in Delaware in terms of its social geography;
2. A profile of the SREC market in Delaware in terms of its social geography; and
3. An understanding of the possible spatial, temporal, and socioeconomic trends that are occurring in the market.

1.3. Structure of the Report

The technical elements associated with the construction of high-resolution databases is discussed in the appendices. We applied these databases to develop a detailed understanding of Delaware's current solar energy market (Section 1) and the SREC market (Section 2). In section 3, we cross-connected the two databases to build a social geography analysis of the solar energy and SREC markets. The structure of the report, as such, is as follows:

- **Section 1. The Delaware Solar Energy Market:** The first component of the report introduces the status of the solar energy market in Delaware. We focus in particular on the residential portion of the solar energy market.

- **Section 2. The Delaware Solar Renewable Energy Credit (SREC) Market:** The second section of the report discusses the SREC market volume, trend, status, and other relevant items. In particular, we discuss the analysis of ~103,000 individual SREC transactions.
- **Section 3. Social Geography of Delaware's Solar Energy and SREC Market:** Detailed analysis of the solar energy and SREC market in relation to the socioeconomic landscape.
- **Section 4. Concluding Remarks:** We identify possible findings of interest to Delaware's decision-makers.
- **References**
- **Appendix A. Methodology:** Detailed description of the methodology we applied throughout the research, in particular regarding the geocoding process.
- **Appendix B. Facility-level database:** Detailed overview of the methods and data sources used to build a database at the individual solar energy facility level.
- **Appendix C. Classification:** Overview of how we separated the solar energy market into its respective classes of 'residential', 'commercial', and 'utility-scale' solar energy facilities.
- **Appendix D: SREC database:** Discussion of the methods and data sources used to obtain detailed records of previous SREC transactions made by DPL.

2.0. The Delaware Residential Solar Energy Market

Delaware is home to an active solar energy market. As per the United States Energy Information Administration (EIA), small- and large-scale solar energy facilities located within state boundaries together generated about 5% of the state's total in-state net electricity generation (U.S. EIA, 2022), placing the state ahead of the national 3.9% average (Feldman et al., 2022). A major reason for this success is the state's renewable energy portfolio standard (RPS). As documented in detail in Byrne et al. (2022), the state RPS recently set a new objective of realizing a renewable energy share of 40% of electricity retail sales by 2035, with at least 10% coming from solar energy.

This section of the report details the Delaware solar energy market, focusing in particular on the residential portion of the market. Appendix C covers how we classify 'residential', 'commercial', and 'utility-scale' solar energy facilities. The methodology outlined in this appendix finds that it is appropriate to classify all facilities equal to or lesser than 20 kW in capacity as 'residential' facilities.

In this report, we focus on the solar energy facilities we were able to pin-point to an individual address (i.e. 'geocode'). We successfully geocoded 6,415 residential solar energy facilities located within the state (see Appendices A, B, and C for methodology, database, and classification, respectively).

2.1. Growth of the Residential Solar Market (2006-2022)

Using the 6,415 residential solar energy facilities as a dataset, we find that, overall, the residential solar energy market in Delaware is characterized by a pattern of accelerating growth. For instance, annual capacity additions in 2021 and 2022 exceed 5 MW/year while capacity additions in 2019 and 2020 hovered around 4 MW/year (Figure 2). The last five years has seen successive growth in annual capacity additions, up from under 4 MW/year in 2018 to over 6 MW/year in 2022. In total, we find that the residential solar energy market capacity stands at approximately 51.6 MW. As per Figure 2, 2016 was a banner year for the Delaware solar energy market. Indeed, there were so many applications by homeowners in 2016 for the Delmarva Power Green Energy Fund program that grant levels subsequently had to be reduced to ensure continued program viability

(Murray, 2016). The scaling down of the incentive levels lead to a lower level of annual capacity additions in subsequent years. Recent years have been substantially below the 2016 peak installation volume.

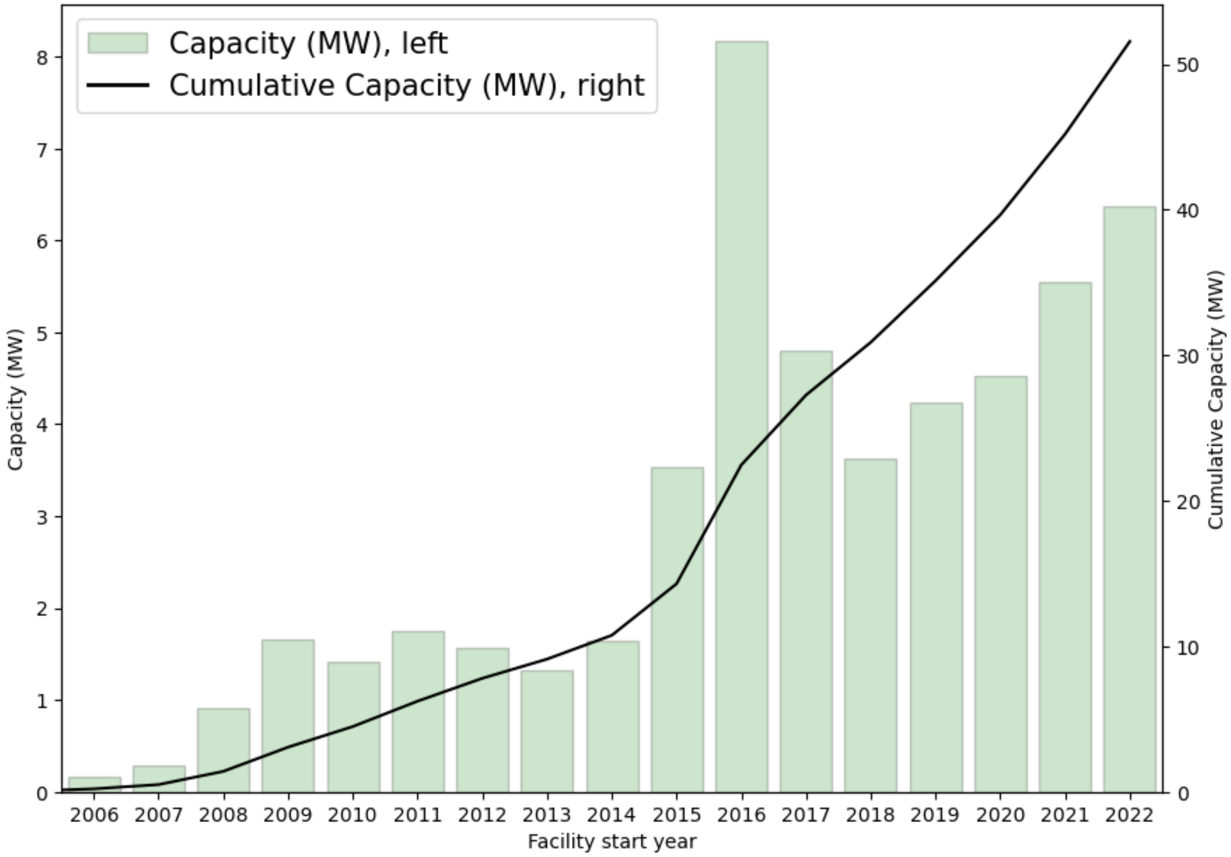


Figure 2 Annual and cumulative residential solar capacity additions, in MW

2.2. Capacity Distribution of the Residential Solar Energy Market

The average capacity of a residential solar energy facility in Delaware is about 8 kW while the median capacity is approximately 7.3 kW (Figure 3, left). The majority of the residential solar energy facilities are between 5 and 10 kW in size. In addition, the average facility size is increasing over time (Figure 3, right). For instance, the average capacity size was about 6.5 kW in 2010 and has since increased to almost 10 kW in 2022. The increase in facility sizes correlates with falling upfront costs associated with the purchase and installation of solar energy systems. This trend of larger system sizes also corresponds with nationally observed trends. For instance, an annual research report series published by Lawrence Berkeley National Laboratory (LBNL) documents a steady rise in residential solar PV system sizes over the past two decades. The report particularly cites in particular declining technology costs and rising module efficiencies as leading factors (Barbose et al., 2022b).

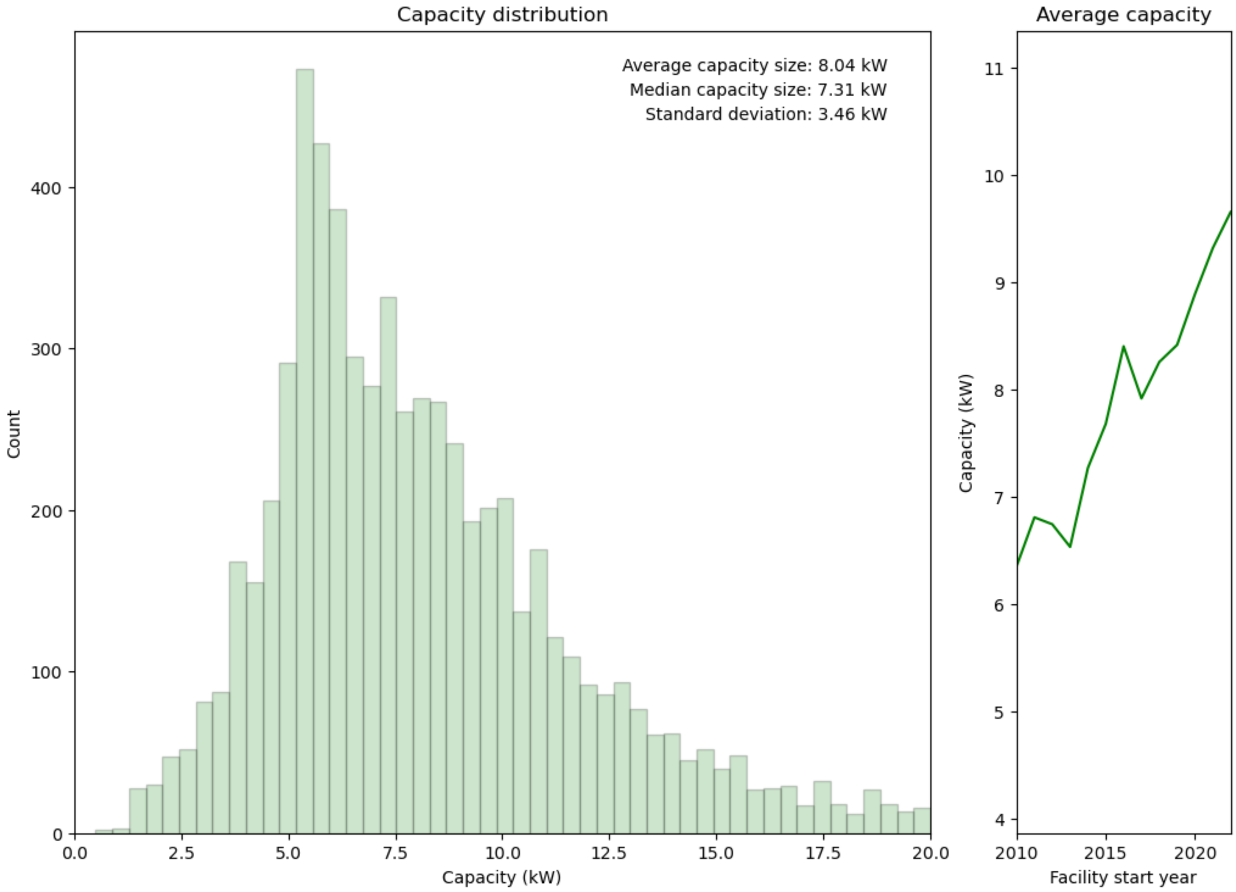


Figure 3 Capacity distribution of the residential solar energy market

2.3. Geographic Distribution of the Residential Solar Energy Market

The 6,415 residential solar facilities located within state boundaries are geographically concentrated in Delaware’s population centers like Lewes, Wilmington, and Newark (Figure 4). The rural areas of the state have sparse deployment of residential-scale solar PV systems as these regions contain comparatively few buildings and households.

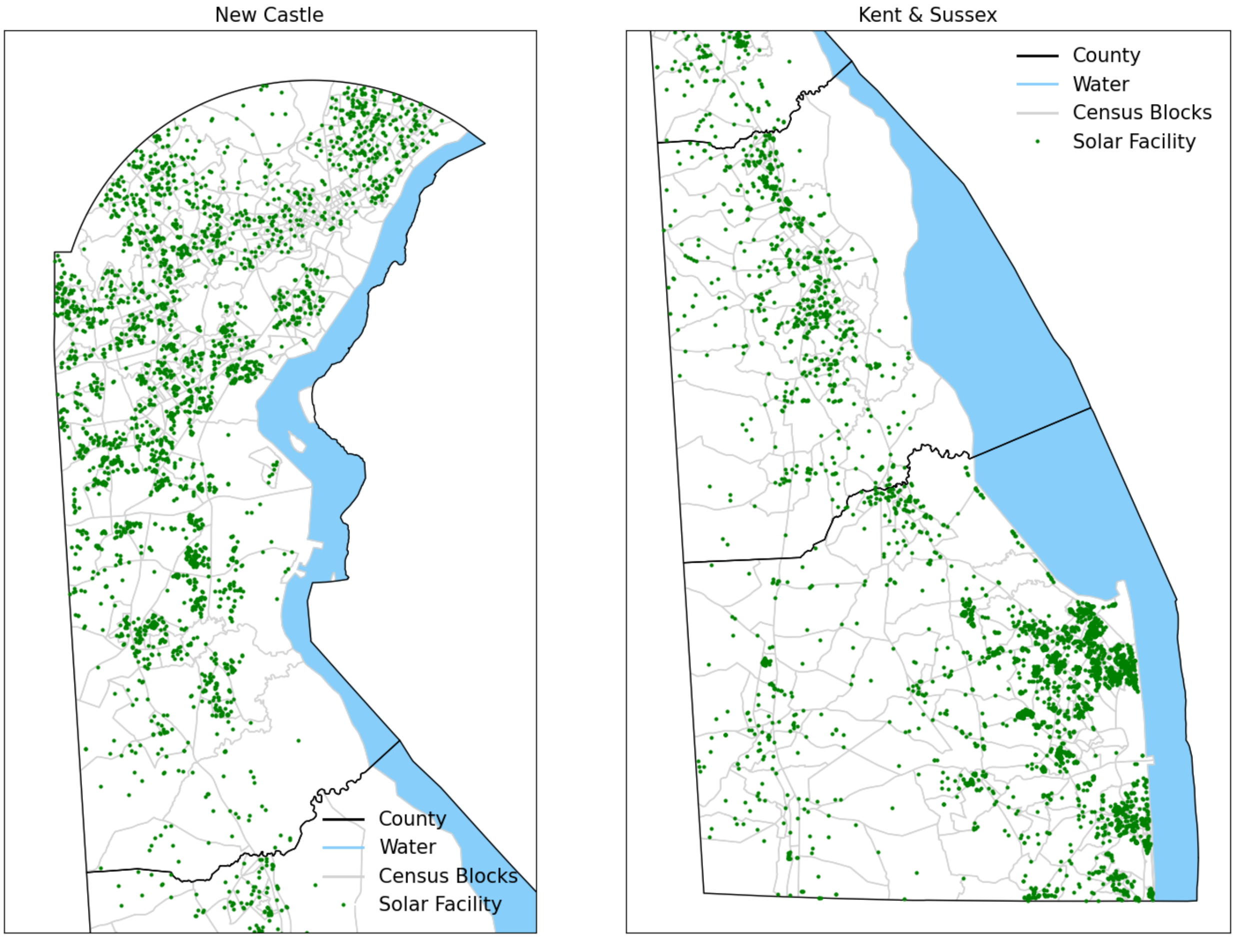


Figure 4 Geographic distribution of solar PV facilities in the state of Delaware

We can further illustrate the geographic concentration of solar energy facilities in urban areas and population centers by focusing on the 13 cities that each house an excess of 1 MW of solar energy capacity. As seen in Figure 5, these 13 cities combined represent over 75% of the residential solar energy market in the state. Lewes, Newark, and Middletown are the three cities with the largest portion of the residential solar energy market (Figure 5). Just over 20% of the market share is represented by the remaining cities that do not reach a 1 MW aggregate installed capacity.

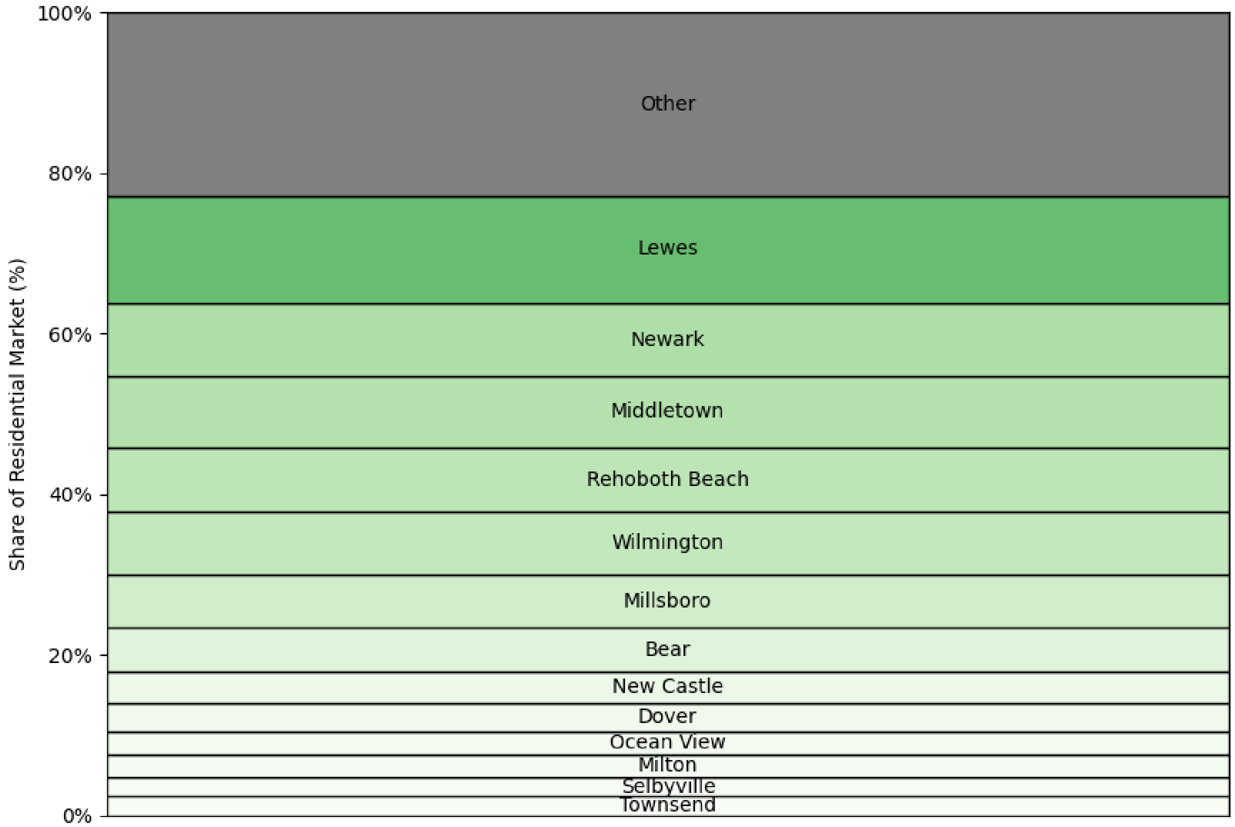


Figure 5 Residential solar capacity share by city

3.0. The Delaware SREC Market

The SREC market accelerates the adoption of solar energy throughout Delaware by offering financial remuneration for electricity generated from solar energy facilities. As described in detail in Appendix D, we extracted just under 104,000 individual transactions - equal to a total SREC transaction volume of approximately 870,000 SRECs worth about $58 million (Table 1). Annual transaction volumes of at least $5 million are recorded in the below table. The number of transactions and the number of SRECs are both rising over time as well.

Table 1. SREC transactions included in our database over 2014-2021.

Transaction year	Number of transactions	Number of SRECs	Total dollar value ($)
2014	1,725	53,573	$7,102,644
2015	1,288	67,431	$6,272,829
2016	11,114	83,694	$7,781,940
2017	12.553	102,093	$5,241,230
2018	14,625	120,136	$6,041,603
2019	19,836	130,428	$8,150,289
2020	19,335	144,927	$8,332,451
2021	23,456	167,123	$8,971,807
Total	**103,932**	**869,405**	**$57,894,794**

Note: dollar amounts given in nominal terms.

3.1. Growth of the Residential SREC Market (2012-2021)

We traced the SRECs to individual solar energy facilities. Looking at only the facilities classified as ‘residential’ facilities (see Appendix C), we identified 82,517 SREC transactions totaling 133,718 SRECs, valued at a total of approximately $7 million. As illustrated in Figure 6, the residential SREC market now exceeds an annual volume of 30,000 SRECs. The steady pattern of growth regarding both SREC volume (i.e. the number of SREC credits) and SREC value (i.e. the total dollar amounts associated with the annual SREC market) is observed in Figure 6. For the years 2019-2021, as documented in Figure 6, the residential portion of the SREC market stands at an annual value well over $1 million per year. This finding was likewise detailed in Byrne et al. (2022).

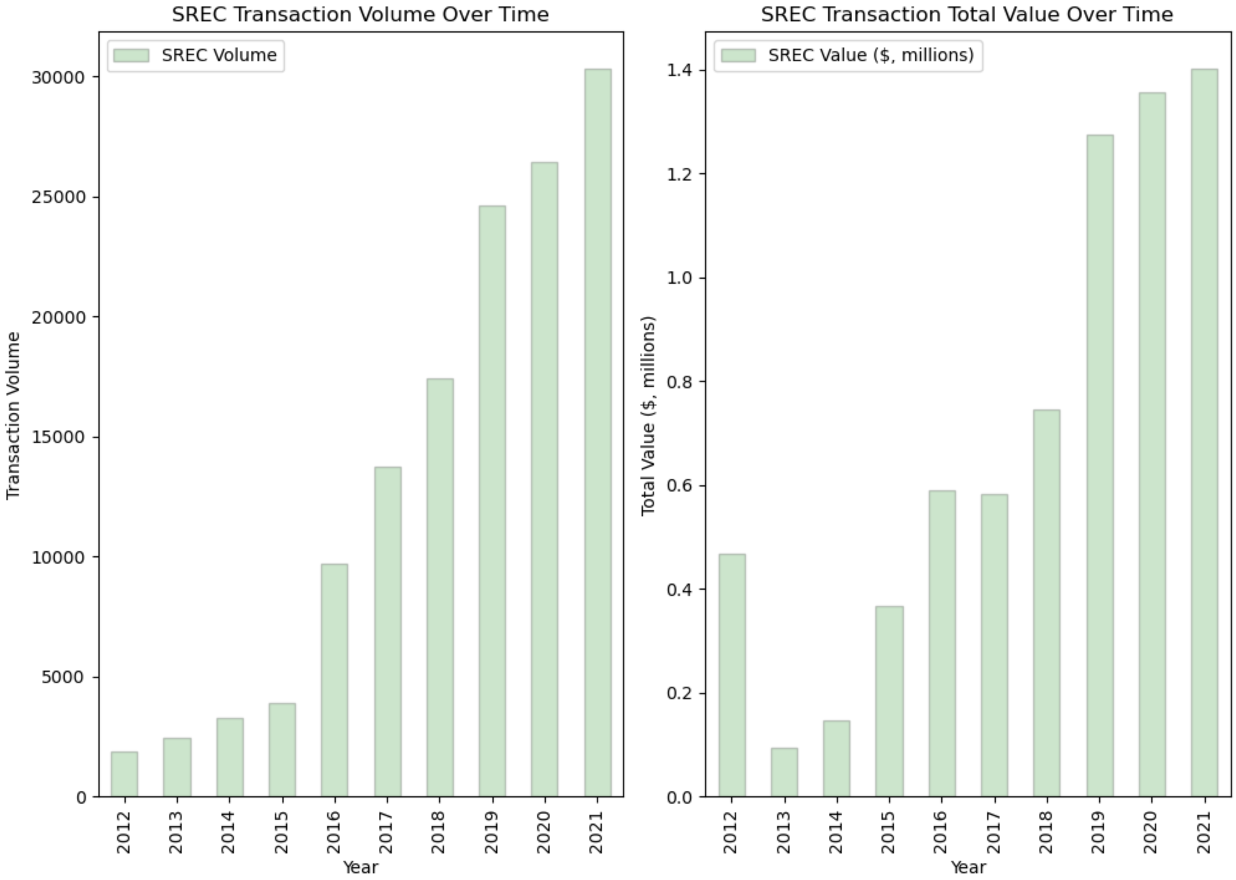


Figure 6 Residential SREC annual market volume and value over time (2012-2021)

3.2. SREC Prices over Time

We find that solar energy facilities that were more recently operationalized typically receive lower values for their SRECs. This is illustrated in Figure 7. Facilities that began operation in the early 2010s received higher nominal compensation values for their generated solar electricity and maintained similarly high prices over the course of their SREC market participation. Conversely, facilities that were deployed in more recent years received lower compensation levels and continued to receive these compensation amounts moving forward. A variety of factors can be identified as possible causes: a) the changes in Delaware's SREC market strategy likely involved a downward pressure on SREC prices; b) falling technology costs likely motivated solar energy projects to submit lower bids in SREC auctions; and c) market maturation might have spurred increased competition for SRECs, likewise leading to lower bids in SREC auctions.

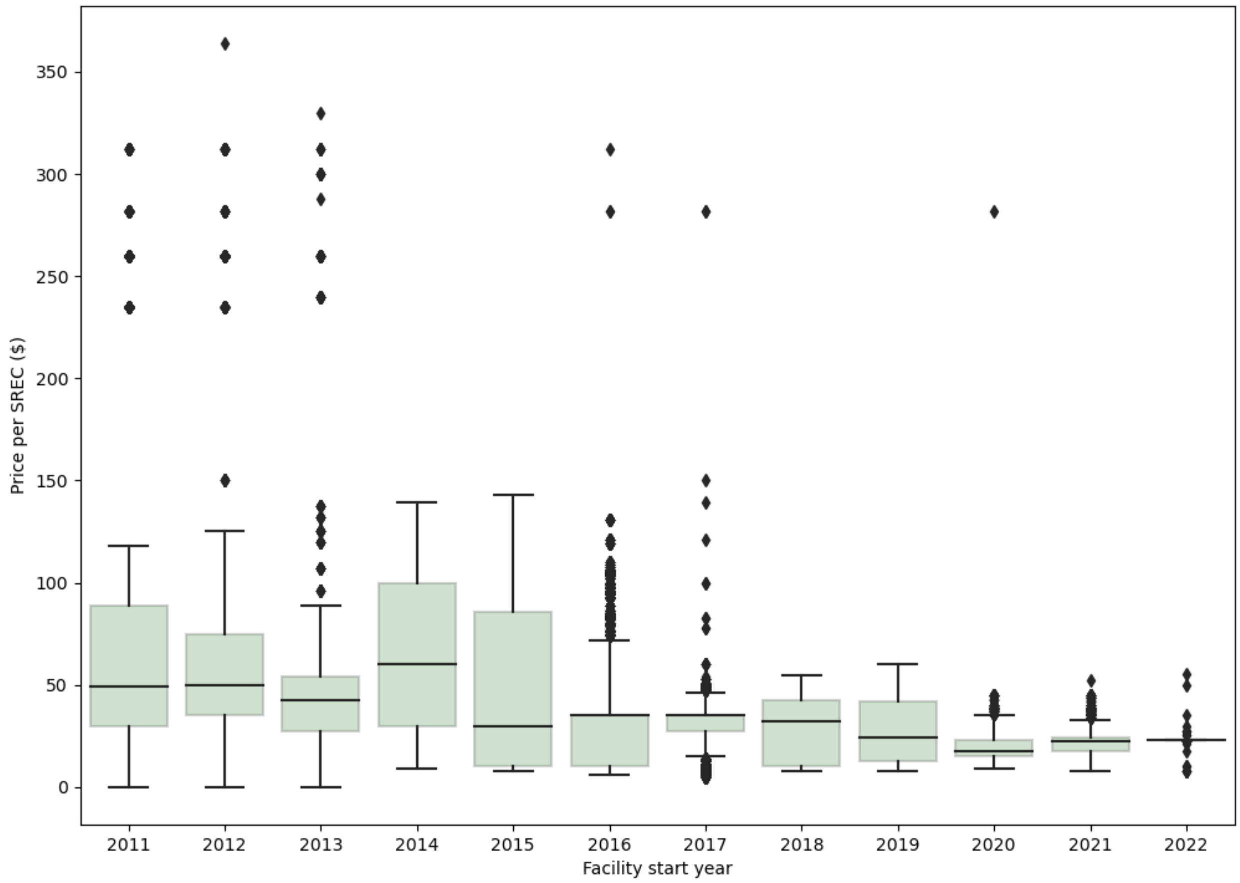


Figure 7 SREC price distribution per solar energy facility start year

4.0. Social Geography of Delaware’s Solar Energy and SREC Market

In our previous research (see Byrne et al., 2022), we produced a mapping framework capable of identifying communities across Delaware that face comparatively high levels of adverse economic and environmental conditions compared to all other communities in the state.[5] We applied the same mapping framework in this research effort. In particular, we relied on the same integrated scoring mechanism. However, for simplicity’s sake, we represented the community’s vulnerability score as part of one of ten bins that together encompass all communities in the state. In this approach, the communities with the highest integrated risk concerns are in bin number 10 while the communities with the lowest integrated risk concerns are in bin number 1 (Table 2). We label these bins ‘EJSCREEN score bins’ to indicate that the data source for the calculation of the integrated score is the U.S. Environmental Protection Agency (EPA)’s EJSCREEN tool. As shown in Table 2, there are approximately 122,000 people in the four most vulnerable bins across 99 census block groups.

Table 2 Delaware Communities by Integrated Socioeconomic and Environmental Score

EJSCREEN Score Bin	Integrated Score	Number of Communities	Population	Description
1	0 – 695	86	77,461	Least vulnerable
2	696 – 1399	130	180,068	
3	1400 – 2099	136	218,484	|
4	2100 – 2799	99	142,644	|
5	2800 – 3499	81	122,849	|
6	3500 – 4199	75	103,431	|
7	4200 – 4905	49	66,823	|
8	4906 – 5599	31	35,683	|
9	5600 – 6499	15	15,415	|
10	6500 – end	4	4,821	Most vulnerable

Note: integrated score range per bin determined by equal width scores.

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[5] Recall that we consider ‘community’ to equal a census block group segment.

4.1. Geographic Distribution of EJSCREEN Bins

As in our previous research effort, we identified that the communities in and around the I-95 corridor (Wilmington, Newark, and other cities and towns) are among those most vulnerable to environmental and socioeconomic risks and exposures (Figure 8). Several communities in Kent and Sussex counties likewise are especially vulnerable to these pressures (Figure 8).

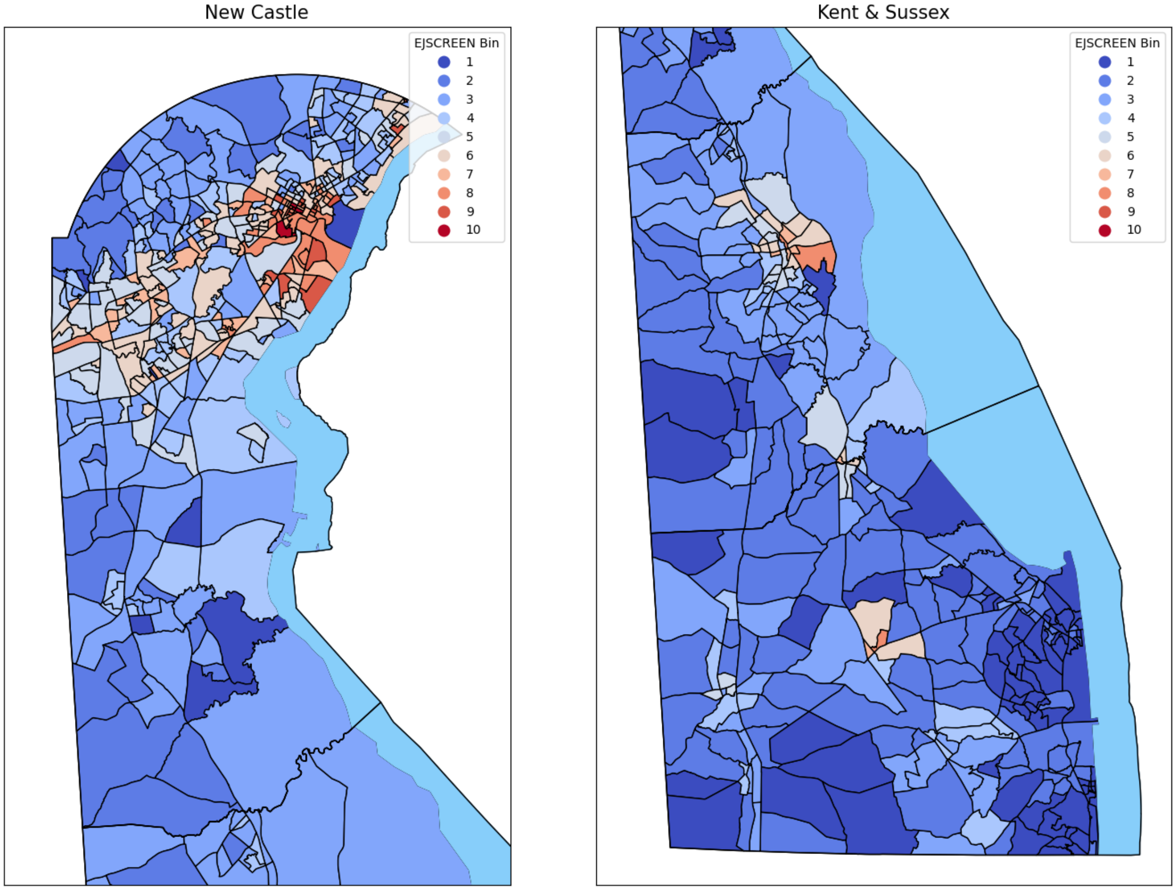

Figure 8 Environmental justice score by census block group in terms of the EJSCREEN score bin

4.2. EJSCREEN Score Bins and the Delaware Solar Energy Market

In our previous research effort, which relied on a smaller database compared to the research effort documented in this report, we found that the distribution of the solar energy market skewed towards census block groups with lower pollution pressure and lower social vulnerability (Byrne et al. 2022).[6] This research documents a similar finding. When all census block groups are binned based on their U.S. EPA EJSCREEN performance, the solar installation levels are highest in the least vulnerable census block groups – note, a low score means low levels of pollution and low levels of social vulnerability (Figure 9). Conversely, those living in the least favorable social and environmental conditions have been largely unable to participate in the solar energy market (Figure 9). For instance, at approximately 130 Watts per capita, the least vulnerable census block group bins perform almost sixty times better than the most vulnerable census block group bins at 2.2 Watts of solar PV capacity per capita (Figure 9). Indeed, there is an apparent progression towards lower and lower levels of solar energy installation as the environmental and social risks and vulnerabilities increase.

This finding has direct consequences for any policy interested in pursuing a 'sustainable energy for all' objective: current performance suggests a reality of unequal access to the energy transition.

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[6] In this research endeavor, we applied the same methodology that classifies the census block groups based on their environmental pressure and their social vulnerability but a) expanded the dataset that is tested with the methodology and b) used an updated U.S. Census Block Group representation that now separates the state into 706 individual census block groups.

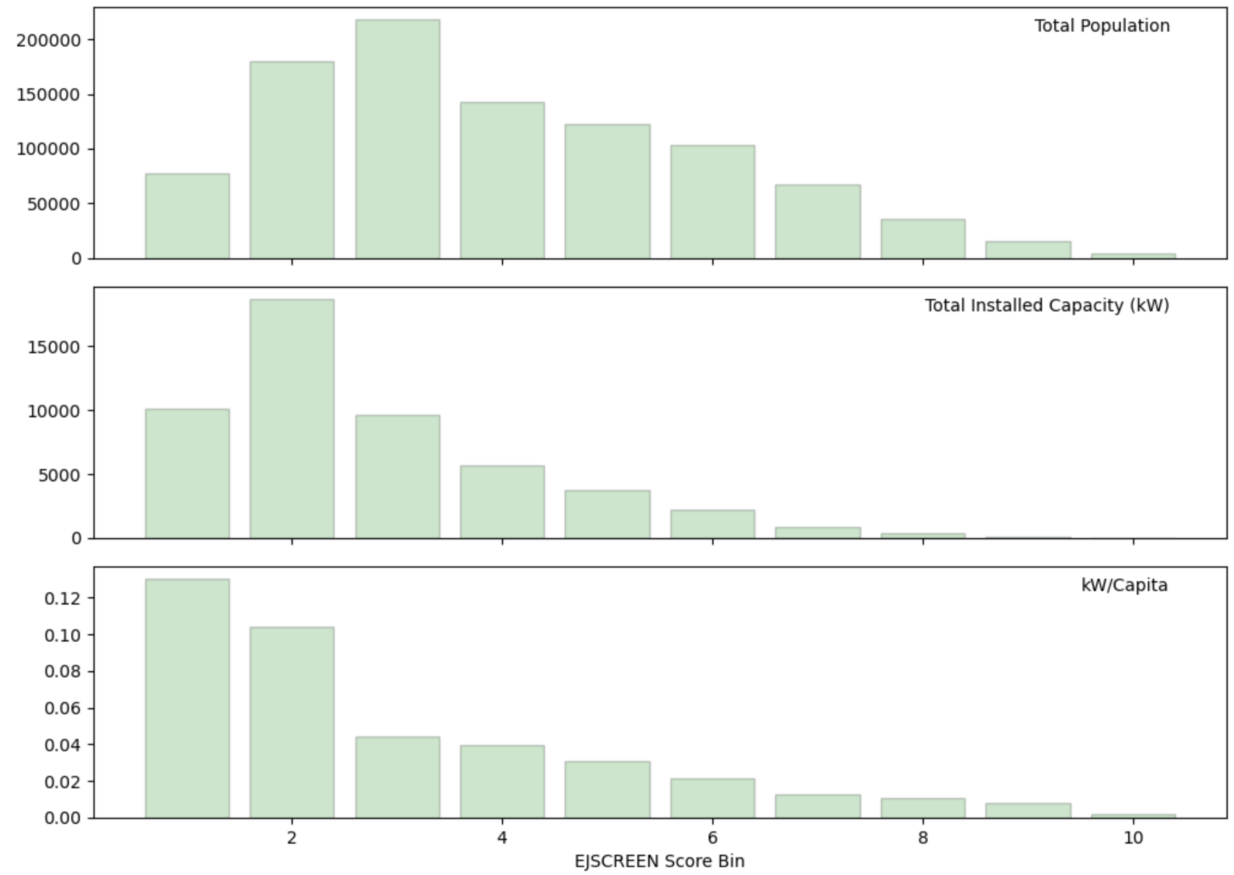

Figure 9 Social geography considerations in Delaware’s residential solar energy market

4.3. EJSCREEN Score Bins and the Delaware SREC Market

SRECs function as a financial remuneration for solar energy production. Considering capacity is skewed towards the least vulnerable communities, it is expected that a similar profile exists for SREC transactions. We indeed identify a similar pattern where the least economically and environmentally vulnerable census block group bins sell a higher volume of total SRECs to DPL and receive a higher remuneration per person compared to the more vulnerable census block group bins (Figure 10). For instance, the three least vulnerable census block group bins received a nominal volume of SREC purchases equal to approximately $8-$16 per person. In comparison, the three most vulnerable census block group bins each received less than $1 per person throughout the 2012-2021 timeframe.

When compared on per SREC basis, the pattern remains the same. The three least vulnerable census block group bins, for instance, garner approximately $50-$70 dollars per SREC while the three most vulnerable census block group bins in terms of environmental and social vulnerability receive approximately $30-$38 per SREC (Figure 10).

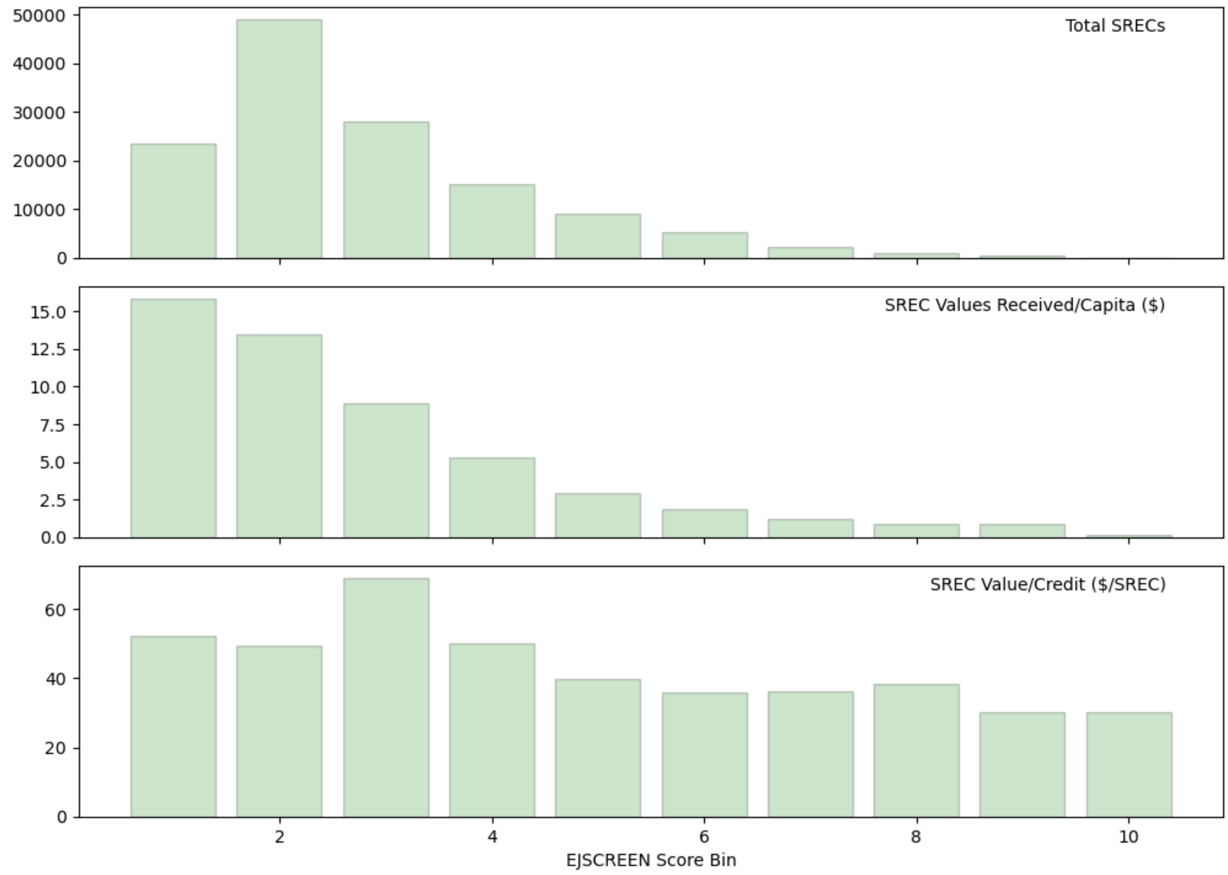

Figure 10 Social geography considerations in Delaware's residential SREC market

4.4. The Delaware Solar and SREC Social Geography over Time

An important dimension in the aforementioned findings is the notion of time. As the market has progressed, many parameters associated with the solar energy market have dramatically changed. For instance, technology costs have fallen precipitously from 2012-2021(Barbose et al., 2022b). Similarly, SREC values have fallen over time (Byrne et al. 2022).

As illustrated in Figure 11, SREC values varied from 2012-2021 between $1 and $260 per SREC. When separated by each EPA EJSCREEN bin, it is apparent that SREC values generally are higher in the bins with less environmental and social stress. For instance, bins 1 to 3 receive more than $50 per SREC for at least 25% of the credits purchased. Moverover, as much as 49% of the SRECs garnered over $50 per SREC in one of these bins. In contrast, less than 10% of SRECs in bins 8 to 10 were purchased for a price over $50 with bin 10 selling all their SRECs below $50/SREC.

Figure 11 SREC values and volume over time (2012-2021) by EPA EJSCREEN bin for residential solar energy facilities, organized by year of SREC transaction

Figure 11 above is organized by SREC transaction year. As such, there are solar energy facilities that, for instance, began operation in 2012 and have received the same SREC value throughout the following years as they negotiated when they first started selling the credits. The principal conclusion to draw from this statement is not that communities exposed to higher levels of social and environmental stress receive lower levels of compensation *because* they face more demanding socioeconomic risks and environmental challenges. Instead, the relevant finding is that these communities were unable to join the solar energy market when SREC values were highest and, as such, have not received the same level of compensation as enjoyed by the communities able to join in the earlier years of the solar energy market.

This notion can be clarified by looking at the SREC prices enjoyed by solar energy facilities per EJSCREEN score bin over time but now organized by facility start year (as opposed to SREC transaction year). As illustrated in Figure 12, organizing the data by facility year shows that the SREC prices were higher in the earlier years of the market.

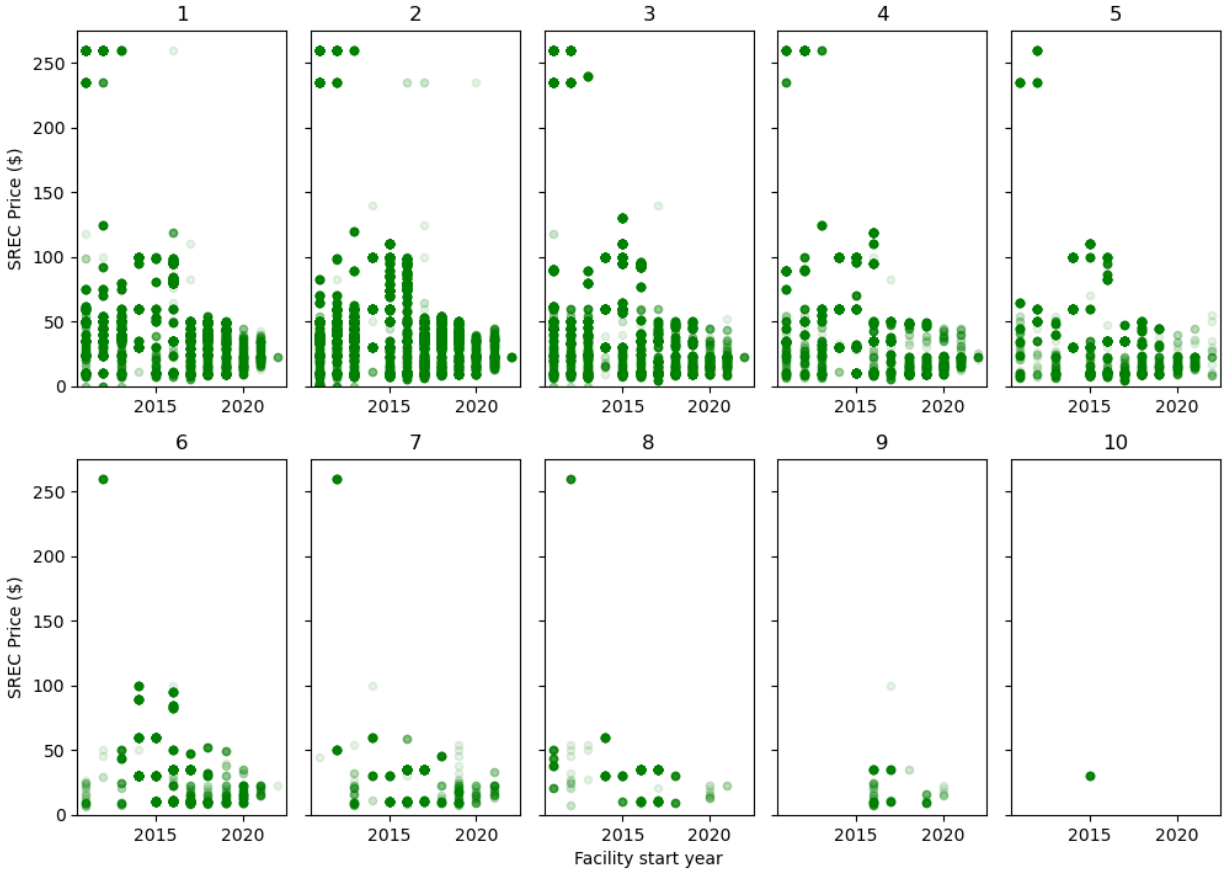

Figure 12 SREC values and volume over time (2012-2021) by EPA EJSCREEN bin for residential solar energy facilities, organized by facility start year

Another way to review this notion is to test whether the most vulnerable communities, on average, receive the same SREC compensation compared to the least vulnerable communities, ceteris paribus. Here we face some challenges in the current dataset. For instance looking only at the facilities that started operation in 2020 or 2021, it appears the average SREC value achieved across all the communities is indeed of essentially equal value (Figure 13). This finding confirms that the SREC mechanism is not exhibiting a bias towards the most vulnerable communities: as these communities initiate participation in the solar energy market, they gain approximately equal

SREC compensation values compared to the communities that are least vulnerable. However, taking individual years like done in Figure 13 yields small number samples in several of the bins that make a clear-cut comparison more difficult. This is an available avenue for future research.

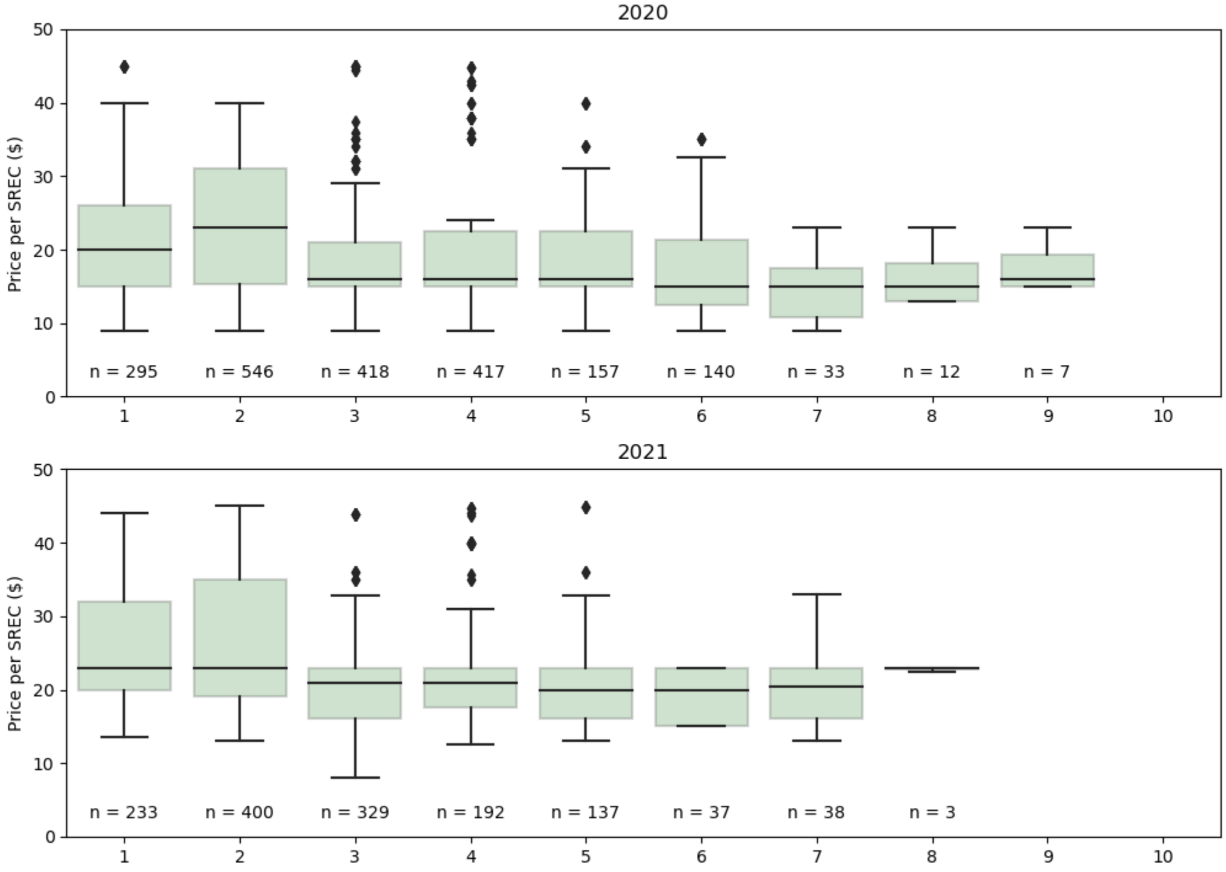

Figure 13 SREC prices for residential solar energy facilities with starting year in 2020 (top) and 2021 (bottom) by EJSCREEN score bin

5.0. Concluding Remarks

The research described in this report successfully constructs a comprehensive database of both solar energy facilities operating within Delaware's state borders and the SREC transactions made by DPL to satisfy RPS obligations. In addition, we connect the resulting database to our previously made database of environmental justice indicators to obtain a social geography assessment of the Delaware solar and SREC markets.

Focusing on the question whether the solar energy market, and the associated SREC market, is inclusive, has produced interesting insights that are listed and discussed in Section 5.1 as our principal findings of this research. We next briefly discuss the SREC policy mechanism specifically in Section 5.2. before turning to the discussion of several ideas that might aid in closing the inclusivity gap identified in this research in Section 5.3. In Section 5.4., we provide an initial outline of future research ideas that are now possible due to the formation of the granular and high-resolution dataset.

5.1. Principal Research Findings

The renewable portfolio standard and the SREC policy instrument were introduced to accelerate solar energy market growth. As indicated in Figure 2, the residential solar energy market is expanding rapidly. However, in order to attain the intended sustainable energy for all future, policy designs that specifically set inclusive access to the market as the policy objective are needed to overcome the inclusivity deficit uncovered in this research.

Overall, we apply the database to demonstrate that:

1. The distribution of solar energy facilities across the state is geographically concentrated in high population census block groups;
2. The distribution of solar energy capacity skews towards communities that face lower social and environmental stress;
3. As SREC volume is dependent on installed capacity values, we find that SREC volumes also skew towards those communities that face lower social and environmental stress;

4. The values awarded to SRECs sold into the market likewise appears to skew toward least vulnerable communities, likely due to the fact that these communities were able to join the solar energy market earlier than communities that joined later or not at all; and

These findings identify a inclusivity deficit in the Delaware solar energy market: the most vulnerable communities, those that face high levels of adverse conditions, are less able to participate in the ongoing solar energy transition. In other words, the solar energy market is not inclusive which hinders the attainment of other stated policy objectives such as the achievement of a sustainable energy future for all.

To account for rapidly falling technology costs, SREC prices over time are trending down. It follows that communities that join the solar energy market later in time receive lower SREC prices compared to those that were among the early adopters. Based on our research, we posit that especially the most vulnerable communities are among those that adopt the technology later in time.

Overall, due to the rapidly falling costs associated with solar energy technology, it is possible that the access conditions to the solar energy market might improve on balance – i.e. that costs have fallen faster than that policy benefits have been reduced. The most vulnerable communities can benefit from this dynamic and reach participation in the solar energy market. However, these communities face wide-ranging adverse conditions that span beyond a simple balance of costs and benefits for which new policy designs that specifically pursue inclusive access as a goal might still be needed. For instance, homeownership rates within the most vulnerable communities typically are below those in the least vulnerable communities. Conventional solar energy deployment strategies that follow a model of private procurement and on-site installation, therefore, might be of less value to these communities. Policy designs that enable and accelerate other models of solar energy participation might be needed for these communities to overcome the homeownership rate difference. This consideration is not limited to homeownership as other barriers are part of the conventional solar energy deployment strategy of private procurement for on-site installation. Examples of such barriers include credit scores, up-front capital availability, knowledge and information limitations, and others for which a policy specifically targeting inclusion could offer remedies.

5.2. SREC Policy Impact

While states around the country rely on financial remuneration strategies to accelerate solar energy adoption, it appears that such strategies are poised to compensate especially those communities that face comparatively lower levels of adverse environmental and/or social stress. This finding of the present research is partially explained by a common characteristic of 'early movers' in technology adoption life cycles who are able to adopt technologies that are new and, typically, costly. For instance, detailed research on technology adoption performed in Oregon census tracts finds that, typically, census tracts with comparatively high income and education levels are more likely to adopt solar energy technology (Cho et al., 2019). In addition, it has been broadly established in recent literature that many solar energy markets in the U.S. experience a similar pattern of adoption (Reames, 2020).

The extant literature finds that SREC policies successfully push market growth and expansion by enticing market adoption and by mitigating the prohibitive cost associated with new technologies (Barbose, 2021; Ryan et al., 2019; Sarzynski et al., 2012; Steward & Doris, 2014). However, as the market matures and SREC prices are reduced to account for the maturation of the market, the design of the policy mechanism is such that those who enter the market at a later date will receive less compensation for the same volume of electricity generation. SREC prices are typically trending down in the PJM GATS market (Byrne et al. 2022). Considering that 'late majority' adopters include those with less means or facing higher social and environmental stress, the policy mechanism as it is designed potentially fails to provide meaningful support paths to those less well-off.

5.3. Mitigating the Lack of Inclusion in the Delaware Solar Energy and SREC Markets

These findings suggest that there are challenges in the Delaware solar energy and SREC markets for which policy solutions might be worth considering. While policy specifics are outside of the scope of this report, we briefly discuss several possible policy strategies.

5.3.1. Expanding the Delaware Pilot Program

The provision of solar energy technology at lower cost – or perhaps even at no cost – to LMI households should be examined. Delaware's two-year 'Low- to Moderate-Income Solar Pilot Program' follows this path as the pilot aims to provide 50 households annually with solar energy panels through two principal pathways: 1) for low-income residents of the state, the pilot provides solar PV panel packages up to 4 kW at no out-of-pocket costs to the resident. Included in the cost-free installation of a up to 4 kW system is the weatherization of the home.; 2) for moderate-income residents, the pilot covers 70% of the upfront costs.[7] The program fact sheet shows that eligibility for low-income households is determined via the federal poverty level (FPL) metric. For instance, a four-person low-income household can make no more than $55,500 per year in order to be eligible for the incentive. [8] However, only homeowners living in a single-family home (including mobile homes on privately owned land) are eligible to participate in the program.

Among LMI families, the rate of homeownership is below the rate experienced by higher-income households. As such, while pilot programs of this kind could expand access to the solar energy market, substantial limitations apply when only considering homeowners as eligible participants to the program. Additional policy strategies that can integrate LMI households that do not own a home are needed.

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[7] More details on the program can be found via the Department of Natural Resources and Environmental Control (DNREC) at https://dnrec.alpha.delaware.gov/climate-coastal-energy/renewable/lmi-solar-pilot-program/

[8] The fact sheet of the program is available via: https://documents.dnrec.delaware.gov/energy/renewable/lmi-solar-fact-sheet.pdf

5.3.2. Building on the Delaware SEU Empowerment Transformation Grant

The Delaware SEU operates an ongoing 'Empowerment Transformation' program that seeks to address energy inequity concerns primarily through the provision of funds to drive energy efficiency and energy savings. An option to successfully expand the solar energy market to previously underserved communities is to enable the Delaware SEU to integrate on-site or off-site renewable energy generation into its energy equity programing. In particular, the Delaware SEU could initiate a grant-based program for non-profit and community-based organizations, among others, to develop solar energy projects with the intent to serve the entire community, in particular its LMI segment. For example, funding could be made available by the Delaware SEU for local community-based organizations (CBO) to develop flagship solar energy installations within the community. The benefits of these projects can be distributed to all community members served by the CBO (see Byrne et al, 2020 and 2021 for details on 'community solar' models capable of delivering solar inclusion, which are discussed immediately below).

5.3.3. Pursue Community Solar Markets

In line with the previous research on a policy strategy to improve energy equity considerations is the option to enable 'community solar' strategies where communities are granted abilities to develop solar energy programs that serve their community. Aggregation to the community-scale provides meaningful options to the entire community to participate in the ongoing energy transition. Enabling community-scale solar energy strategies where LMI households can benefit from the advantages of solar energy without requiring individuals to navigate the purchasing, installation, and other challenges of solar energy systems. It also can eliminate a key factor excluding high-vulnerability communities from the solar market -- their lack of roof ownership as renters.

Previous research uncovered the significant advantages that accompany such a strategy (Byrne et al., 2020, 2021) as these programs typically can, among others:

1. Realize lower net costs to participating community members relative to strategies deployed by investor-owned utilities;

2. Vastly accelerate the deployment of renewable energy, particularly solar energy;
3. Overcome existing participation deficits by aggregating all community members into the program ahead of the program start by default. For instance, participation rates of 90% across the entire community are found to be common in other states where this model has been adopted (Byrne et al., 2020, 2021).

5.4. Future Research

The database established by the research effort enables key future research avenues worth exploring. In particular, we observe that at least the following could be established with the database:

1. Detailed in-city assessments of solar energy technology diffusion, adoption, and other spatial considerations. For example, knowing the residential solar energy facilities by address enables analysis of case study analysis of Wilmington, Newark, Dover, or other cities of the state. These analyses could include location-specific considerations that have been excluded from the present analysis such as specific inheritances from historical injustices in terms of homeowner status distributions, recipients of socioeconomic support policies, etc.
2. Analysis of diffusion patterns and their principal determinants. The extant literature suggests a strong peer adoption effect is present in many solar energy markets where, if one household in, say, a neighborhood, purchases and installs solar energy technology, many neighbors follow suit. Such peer adoption diffusion processes can be studied with the database we produced for this report. Research findings suggesting a similar peer diffusion process is at work in Delaware could inform ‘just transition’ policy as ensuring initial PV adoption in a neighborhood might jump-start a diffusion process across that neighborhood.
3. Annual updating of the database can help track RPS compliance, achievements, and establish the likelihood of meeting the RPS goals and timelines.

4. The database includes consideration of the companies involved in the applications for RPS certification. An analysis of this information could help us to understand the existing solar energy business sector in Delaware (installers, certifiers, etc.).
5. Analysis of the commercial and utility-scale solar energy markets could produce valuable insights into the growth, trends, spatial representation, etc. of these market segments.
6. Through investigation of known solar energy facilities, further investigation could identify commonalities that, combined, provide insight into the potential future adoption of, for instance, other households. Such an assessment could estimate the future growth trajectory of the Delaware solar energy market.
7. Using established methodologies to estimate electricity generation, we can combine known solar energy facilities with known electricity consumption profiles in order to estimate the proportion of the residential market that is currently covered by solar electricity.

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Appendix A: Methodology

To extract the necessary data and integrate the various data sources into an overarching database, the research team applied multiple distinct methodologies, which are discussed in some detail here.

A1. Automatic Web Crawling and Data Extraction

A considerable amount of data is extracted from online web portals such as the Delaware PSC's 'DelaFile' portal. To automatically download this data, we relied extensively on Python's Selenium module (https://github.com/SeleniumHQ). Selenium is an open source automation testing tool commonly used by website developers to ensure all aspects of their website work as intended, in particular in relation to user interactions with the website.

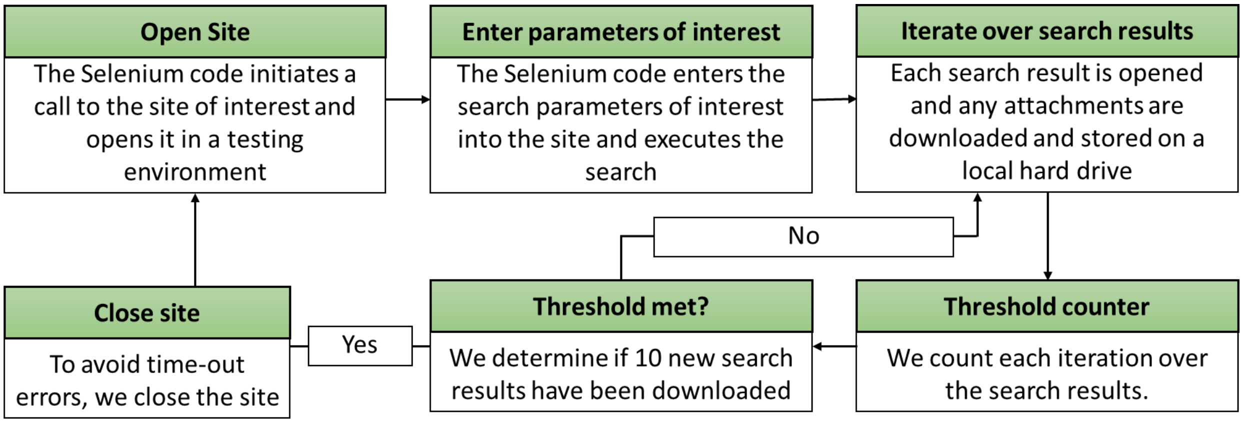


Figure 14. Overview of the automatic web data extraction process using Selenium

The overall web extraction methodology is provided in Figure 14. We apply the Selenium module, in conjunction with other common Python modules, to automatically open, for instance, the DelaFile site and enter relevant information like dates, categories, and other necessary components to search the DelaFile archive. As the search terms have been entered, the code executes the search and navigates to the first docket listed in the results page. Each attachment to the docket is downloaded, automatically renamed to an appropriate filename, and stored on a local hard drive. This process is repeated numerous times until all relevant data on the site is downloaded. However, to avoid time-outs on the website, a common practice is to interrupt the downloading of material every, say, 10 downloads. We then automatically re-initiate the process and continue downloading.

A2. Automatic SREC Report Data Extraction

The SREC data used for this report is published in a series of annual RPS compliance reports by the Delaware PSC. The newer reports (2017 to present) are published as machine-readable PDFs while the older reports (before 2017) are published as image-based PDFs. The former category is automatically read using Python's Camelot module (https://camelot-py.readthedocs.io/en/master/). Camelot is a configurable and flexible library and offers users substantial control over the automated table data extraction from PDFs. We successfully apply Camelot in conjunction with other Python modules to extract the SREC (and REC) transaction tables from the 2017 to 2022 compliance reports.

For the image-based PDFs, we explored an automated process of Optical Character Recognition (OCR) to extract the table-based information. The OCR process transforms a two-dimensional image of text, that could contain machine printed or handwritten text from its image representation into machine-readable text. The process includes several sub-processes such as pre-processing of the image to create more contrast, text localization, character segmentation, character recognition, and character extraction. We relied on Python's TesseractOCR (https://github.com/tesseract-ocr/tesseract) for this purpose.

However, due to the low quality of the image-based PDFs, the quality of the output was low with substantial built-in error. As such, we instead relied on an artificial intelligence service that performed OCR but includes machine learning elements to improve the output. The service we relied upon was AlgoDocs (https://www.algodocs.com/). This service produced a series of Excel files containing the extracted data. These Excel files were then manually corrected where necessary.

A3. Geocoding Address Information

To connect the various data items to their precise spatial location, we relied on a process called 'geocoding'. Geocoding is the process of transforming a description of a location—such as a pair of coordinates, an address, or a name of a place—to a location on the earth's surface. You can geocode by entering one location description at a time or by providing many of them at once in a table. The resulting locations are output as geographic features with attributes, which can be used for mapping or spatial analysis. To geocode the thousands of locations we extracted from the available dockets, we relied on Google's Geocoding API (https://developers.google.com/maps/documentation/geocoding).

We developed a Python script to iteratively submit each address trough HTTP request to Google's Geocoding API. The API returns geographic coordinates at a high level of accuracy. The Geocoding API developed by Google returns "rooftop accurate" results. This means that the geocoding of the address is cross-connected with other datasets such as building outlines on Google Maps to ensure the returned coordinates are right on top of a building (when the supplied address is for a building). This is the most accurate category of possible geocoding results and is one reason why Google's Geocoding API is the standard-bearer for geocoding processes.

Appendix B: Building a Facility-level Database

To capture the social geography of the solar energy and Solar Renewable Energy Credit (SREC) markets in the state of Delaware, we develop a detailed and comprehensive database of each solar energy facility that is eligible to receive SRECs as part of the Delaware Renewable Portfolio Standard (RPS). These eligible energy resources (EERs) are tracked by the Delaware Public Service Commission (PSC) in a publicly available database. We focus in particular on solar energy facilities located within the state's boundaries in order to support our analysis of the geographic distribution of SRECs throughout the state.

The database we construct is an improved version of a previous database we used to support our analysis in Byrne et al. (2022). This new version of the database substantially expands its coverage of solar energy facilities as well as SREC transactions. The database is built by relying on three primary sources:

1. A database maintained by the Delaware (PSC) of each renewable energy facility that qualifies for participation in the RPS;
2. We extract the initial docket application files for every renewable energy facility that qualifies for participation in the RPS. The dockets for 2015-2022 are publicly available via the Delaware PSC online portal ('DelaFile') while a Freedom of Information Act (FOIA) request was used to obtain the same documents for dockets over the 2006-2014 timeframe.
3. The PJM Generation Attribute Tracking System (GATS) maintains a large database of facilities within the PJM region that track their generation in order to accrue energy credits. This includes facilities within Delaware. This database is used to fill in the gaps remaining after automatic text extraction of the docket applications.

For each facility, we cross-link these three datasets into an integrated database. In addition, we use address information in combination with the Google Geocoding API to locate each facility's geographic coordinates. This spatially aware database contains each solar energy installation for which an address could be obtained together with its spatial coordinates and other relevant attributes.

B1. Delaware Public Service Commission (PSC) Database

The database maintained by the Delaware PSC documents at the facility-level all the eligible energy resources (EER) that can participate in the Delaware RPS. The database is periodically updated with the latest facility information as new facilities are certified as eligible to participate in the program. In terms of solar energy facilities that are located within the state, the database used for this analysis contained information on 7,292 individual solar energy facilities. For each of these facilities, the database contains a PSC docket number, the city the facility is located in, the zip code, the capacity and the generation unit's start date. For those solar energy facilities qualifying for bonus incentives due to use of local equipment or labor, the data includes a binary variable that confirms whether the facility receives each SREC multiplier. The PSC docket number is used to connect to the individual docket application information.

B2. Docket Applications

The PSC database represents a main starting point for the analysis of Delaware's solar energy market. However, the data does not contain exact locational information for each facility. Instead, the database is limited to reporting the city and the zip code. Our analysis is interested in a finer level of resolution – that of the census block group. As such, it is necessary to geocode each facility to a specific location in order to assign census block group and other information to the facility.

To obtain additional facility-level information, we turn to each docket application for every facility. In particular, the approval letter issued by the PSC granting the docket a PJM Generation Attribute Tracking System (GATS) number as well as describing the facility's address is used for geocoding each facility. In our previous assessment, we relied on the publicly available docket applications as posted on the Delaware PSC website 'DelaFile'. However, this data was only available for 2015 onwards. As such, to ensure better coverage of the overall data, we filed a Freedom of Information Act (FOIA) request to obtain the same docket-level information for 2006-2014 which was granted by the PSC.

For the publicly available records, we developed a Python script to automatically download and process all the relevant PDF files for the 2015-2022 timeframe. The table below indicates the number of PDF files that were downloaded and processed using this method. The FOIA request returned 1,961 2-page files that were scanned and run through a Python code to extract the relevant information (Table 3). Via DelaFile, we used a Python script to download an additional 17,693 files of various sizes. This set of files was processed through a Python script to extract address, PJM GATS number, name of the facility, and the docket application year. The automatic extraction process yields 6,504 individual records with the needed information.

Table 3. Number of files used to identify relevant facility-level information.

Data Year	Number of PDF documents	Data Extraction Method
2006	14	FOIA Request: 1,961 files
2007	64	
2008	165	
2009	316	
2010	221	
2011	320	
2012	345	
2013	334	
2014	182	
2015	1,395	Extracted via Python code: 17,693 files
2016	2,678	
2017	2,524	
2018	3,758	
2019	2,306	
2020	2,326	
2021	2,706	
Total	**19,654**	

B3. PJM GATS Database

The third and final database connected into our comprehensive and spatially aware database is published and maintained by PJM GATS. This database contains, among others, PJM GATS identifying numbers, GATS unit IDs, county information, and other facility or unit-level identifiers. This database is predominantly used to fill any gaps in the information where possible, in particular to fill in PJM GATS numbers that might have been omitted in the other files available to the research team.

B.4. Coverage of the FREE Solar Energy Facility Database

The resulting database, built through the integration of the PSC list of facilities, docket-level applications, and the PJM GATS database, represents a spatially aware dataset with specific locational information, facility-level descriptors, and unique identifiers that enable cross-connection with the SREC market data as well as with U.S. Census data.

The coverage is illustrated in Figure 15, for both solar energy facility count and capacity. The coverage is substantially improved compared to our previous effort: in terms of the number of facilities for which we now have data relative to the total number of solar energy facilities in the state, our current iteration of the database achieves an impressive 89.6% coverage. In terms of the installed capacity that we have been able to geocode, we realize a 95.1% performance level.

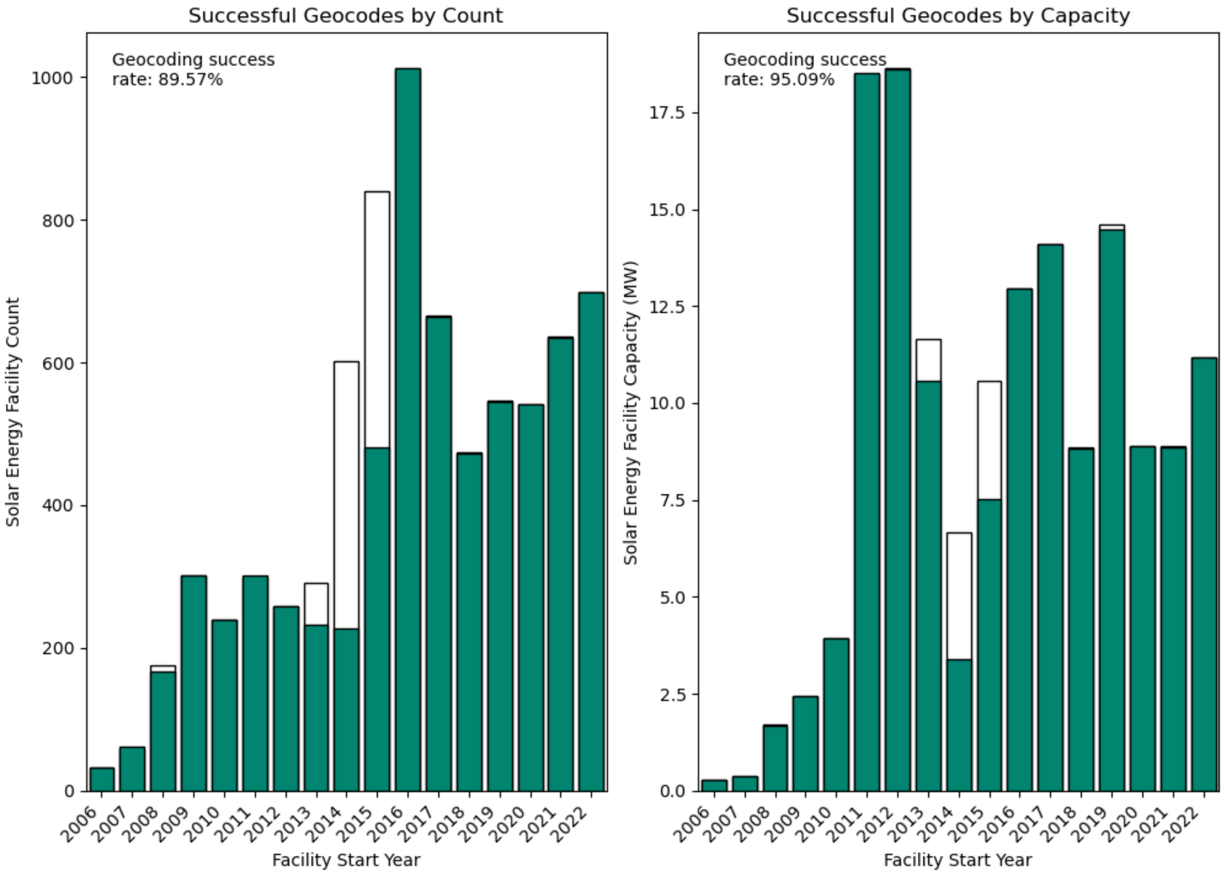


Figure 15 Geocoding success by year for facility count (left) and total capacity (right).

Due to the presence of several utility-scale and commercial-scale facilities, the database has a better level of performance when evaluated in terms of the capacity of the facilities (Figure 15, right). In particular, several large-scale solar energy facilities began operation in 2011 and 2012. These are two years with 18+ MW of solar energy capacity coming online.

Appendix C: Classification of Market Sectors in the Delaware Solar Energy Market

An important element in the present research is its focus on the residential solar energy sector. It is the residential sector where solar energy purchasing decisions are expected to correlate with socioeconomic and environmental risk profiles: communities facing higher levels of adverse conditions are hypothesized to be less likely to purchase solar energy technology. As such, we present a classification strategy that distinguishes between residential, commercial, and utility-scale solar energy installations.

C1. Residential and Non-residential Solar PV System Size

According to the Tracking the Sun annual report (2022 edition), solar systems in the United States can be divided into residential and non-residential installations.

Residential solar system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies, among other factors (Barbose et al., 2022a). Residential rooftop solar PV system sizes range from 5 to 20 KW (Benny, 2022), with a typical capacity of 5 kW (EIA, 2015). In the U.S., the median residential system sizes steadily increased from roughly 2 KW in 2010 to 7 KW in 2021, with most systems ranging from 4-10 KW in size (the 20th to 80th percentile band) (Barbose et al., 2022a).

Non-residential (e.g., office buildings, malls, retail stores, and utility-scale) system sizes have also risen over time, especially at the upper end of the size range, though trends have flattened over the past decade. While the median non-residential system size was just 33 kW in 2021, the distribution has a long upper tail, with 20% of systems in 2021 larger than 150 kW, and an average size of 255 kW. Solar systems installed in non-residential settings are commonly divided into Small non-residential, Large non-residential and utility-scale facilities.

In the Tracing the Sun annual report (2022 edition), solar systems sizes ≤100 KW are defined as **Small non-residential** systems and solar systems generating >100 kW as **Large non-residential**

(Barbose et al., 2022a). Moreover, The Solar Energy Industries Association (SEIA) uses a 1 MW threshold to qualify **Utility-scale** solar projects (Urban Grid, 2019).

C2. The logic of separating Residential from Non-residential Solar PV System Sizes in Delaware

Since the focus of this report is on understanding the distribution of socioeconomic characteristics in relation to solar energy capacity in Delaware, the status of access to residential solar PV systems is the foundation of our evaluation. Therefore, it is of paramount importance to define a suitable threshold that distinguishes residential and non-residential solar facilities. As Figure 16 and Figure 17 illustrate, residential and non-residential system sizes vary across states, reflecting regional factors such as typical consumption and insulation levels, among other factors (Barbose et al., 2022a). According to these figures, in Delaware, the average size of non-residential solar system sizes is 200 KW and the average, median, 20th and 80th percentiles of residential ones are approximately 8 KW, 7 KW, 5.5 KW and 12 KW, respectively.

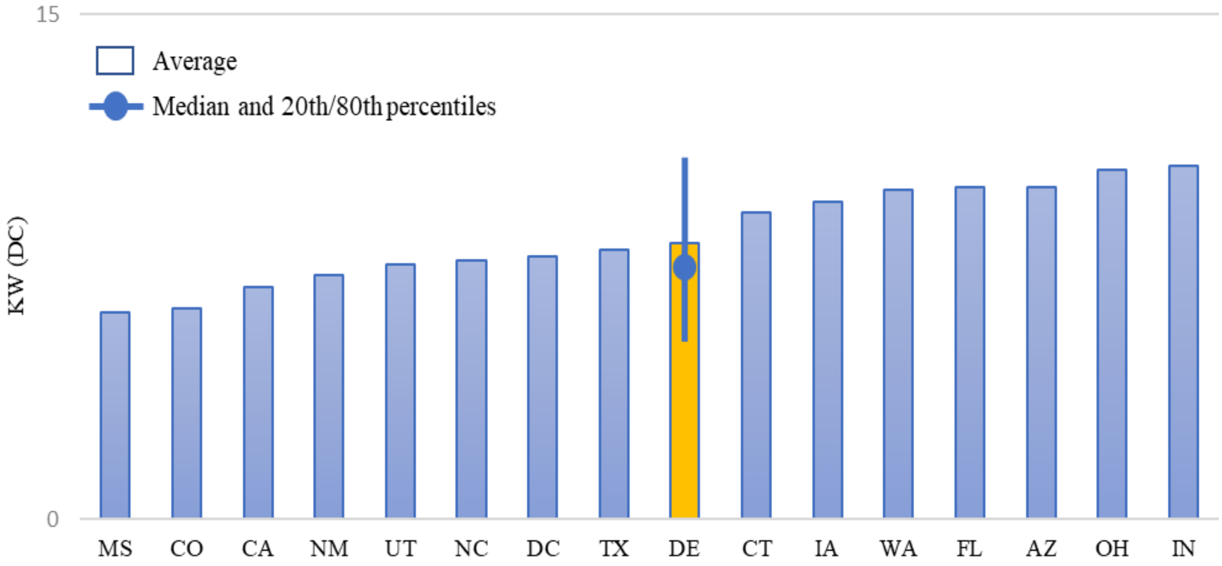


Figure 16 Residential system size by state (Adopted from Barbose et al. (2022)

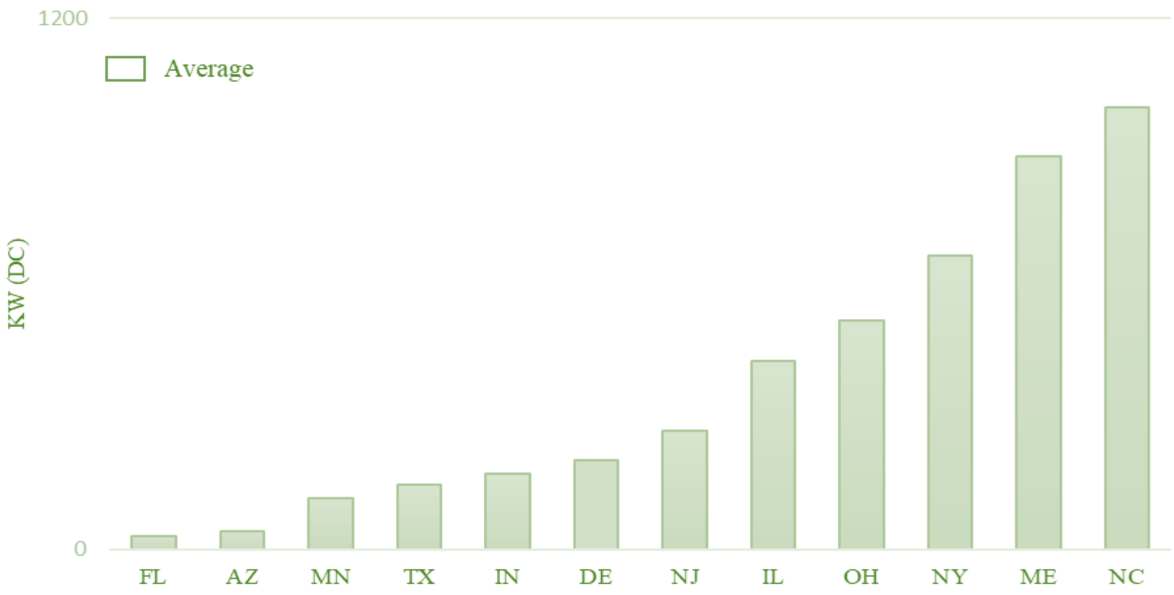
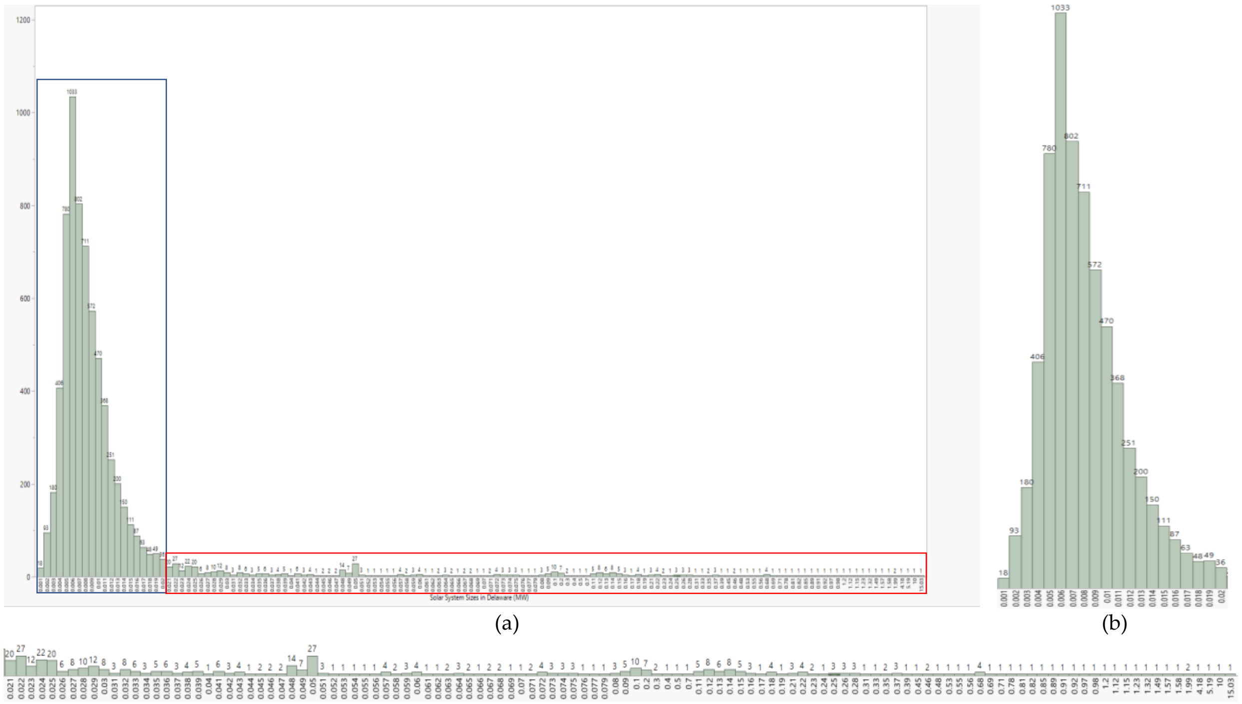


Figure 17 Non-residential system size by state (Adopted from Barbose et al., 2022)

According to these numbers, 80 percent of residential solar system sizes in Delaware are ≤ 12 KW. It is necessary, however, to raise this threshold from 12 KW to something higher in order to include the remaining 20 percent (all residential systems in the state). Based on the reviewed literature, residential solar system sizes typically range from 5 to 20 KW. Thus, to choose the best threshold number between 12 KW and 20 KW, a distribution of the sizes of solar systems in Delaware was also developed using our data set (Figure 18). This figure illustrates that system sizes between 1 KW (0.001 MW) and 20 KW (0.02 MW) follow almost a normal distribution (Fig. 18b), while beyond 20 KW a non-normal distribution with fluctuations is observed (Fig. 18c). Thus, to separate residential and non-residential solar systems in Delaware, 20 KW seems a reasonable threshold.



(a)

(b)

(c)

Figure 18 Distribution of solar energy installation sizes in Delaware

a) Total distribution of solar energy system sizes;

b) Proposed distribution for residential-scale systems

c) Distribution for remaining classes

Note: The system sizes in this figure (vertical axis) have been rounded up to three decimal places to give a better sense of the distribution pattern.

Moreover, if considering system sizes ≤ 20 KW as residential systems, the average and median are 0.00804 MW (≃ 8 KW) and 0.00730 MW (≃ 7 KW), respectively, very close to the figures calculated by Barbose et al. (2022) for residential system sizes in Delaware. Besides, if considering system sizes > 20 KW as non-residential systems, the average equals 0.20723 MW (≃ 200 KW), which is similar to the Delaware non-residential system size calculated by Barbose et al. (2022). Therefore, based on the reviewed literature and documents, especially Tracking the Sun (Barbose et al., 2022a), and the distribution pattern of solar system sizes in Delaware, Table 4 and Figure 19 show the size thresholds used in this report to separate the four types of solar systems.

Table 4 Classification of Delaware's solar systems based on system sizes

Solar systems	**System sizes threshold**	**Total number of systems in each category**
Residential	**Sizes ≤ 20 KW (0.02 MW)**	**6414**
Small Non-residential	20 KW (0.02 MW) < Sizes ≤ 100 KW (0.1 MW)	340
Large Non-residential	100 KW (0.1 MW) < Sizes ≤ 1000 KW (1 MW)	106
Utility-scale	Sizes > 1000 KW (1 MW)	14

Adopted from Barbose et al., 2022 and Urban Grid, 2019

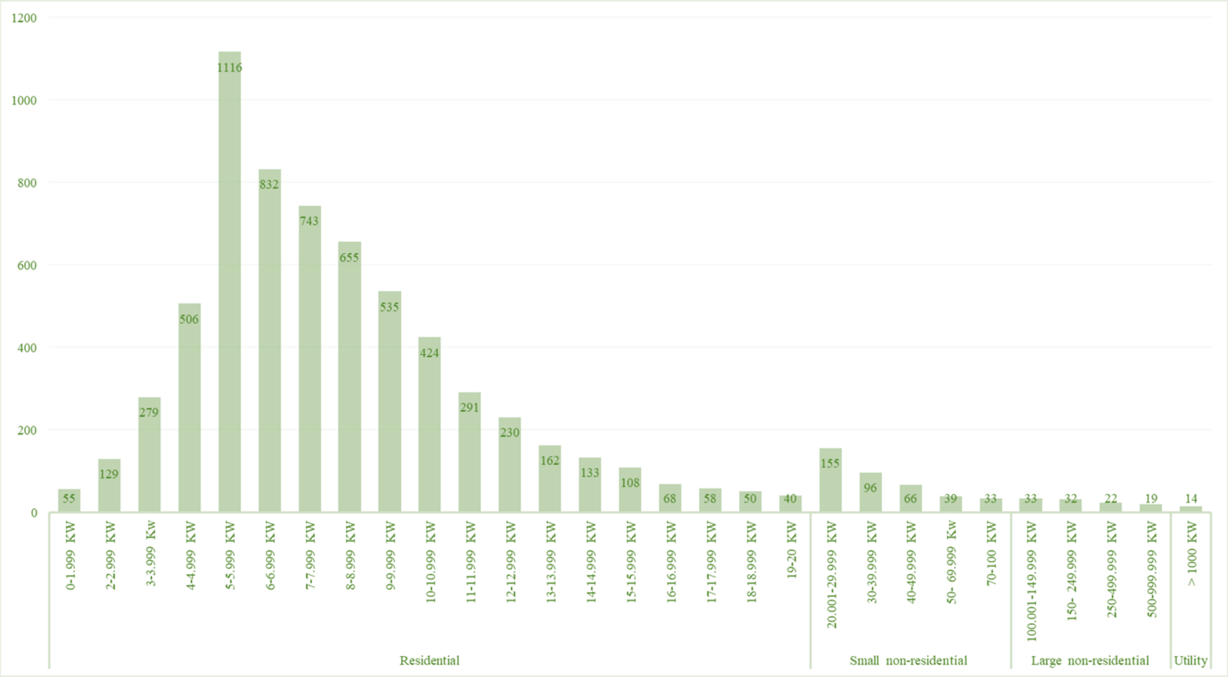


Figure 19 The distribution of Delaware's solar systems in four system size classes

Appendix D: Building a Database of SREC Transactions

To understand the social geography of the SREC market in Delaware, it is necessary to build a detailed and comprehensive database of past SREC transactions that have occurred as part of the state's RPS program. This research builds on previous work on this topic (see Byrne, Taminiau, Cristinzio, et al., 2022), mainly by expanding the size of the dataset and the temporal coverage as well as by improving the ability to connect the data to our facility-level dataset through a detailed process to extract precise and unique identifiers.

D1. Delmarva Power & Light (DPL) Annual RPS Compliance Reports

The SREC transactions made by Delmarva Power & Light (DPL) are recorded in their annual RPS compliance reports to the Delaware PSC. At the time of this writing, these reports cover 2014-2021. Using multiple Python scripts, we successfully extracted all SREC transactions made by DPL over the 2014-2021 timeframe. More specifically, we extracted data from 25 PDF documents containing the SREC transaction data - a total of 1,595 pages.

As indicated in the table below, we have extracted just under 104,000 individual transactions - equal to a total SREC transaction volume of ~870,000 SRECs worth ~$58 million (Table 5). An annual transaction volume of at least $5 million is recorded in the below table. The number of transactions and the number of SRECs is rising over time as well.

Table 5. SREC transactions included in our database over 2014-2021.

Transaction year	Number of transactions	Number of SRECs	Total dollar value ($)
2014	1,725	53,573	$7,102,644
2015	1,288	67,431	$6,272,829
2016	11,114	83,694	$7,781,940
2017	12.553	102,093	$5,241,230
2018	14,625	120,136	$6,041,603
2019	19,836	130,428	$8,150,289
2020	19,335	144,927	$8,332,451
2021	23,456	167,123	$8,971,807
Total	**103,932**	**869,405**	**$57,894,794**

Note: dollar amounts given in nominal terms.

D2. Geocoding the SRECs to the Address-level

We geocode the SREC transactions down to the individual address level by connecting the databased on their PJM GATS designation. Each facility is designated a PJM GATS number that includes a unique identifier for that facility. Similarly, the SREC transaction database extracted from the DPL annual compliance reports includes the unique identifier from which the SREC is purchased. As such, by connecting the two databases together based on the unique identifier we can assign the facility address to each SREC transaction made by DPL.

D3. SREC Market Coverage

We successfully geocoded the majority of the SREC market in terms of count, value, and number of credits (Figure 20). While there are portions of the market that remain un-identified down to the address level, the success rate of our research effort is sufficient to draw robust findings from the analysis.

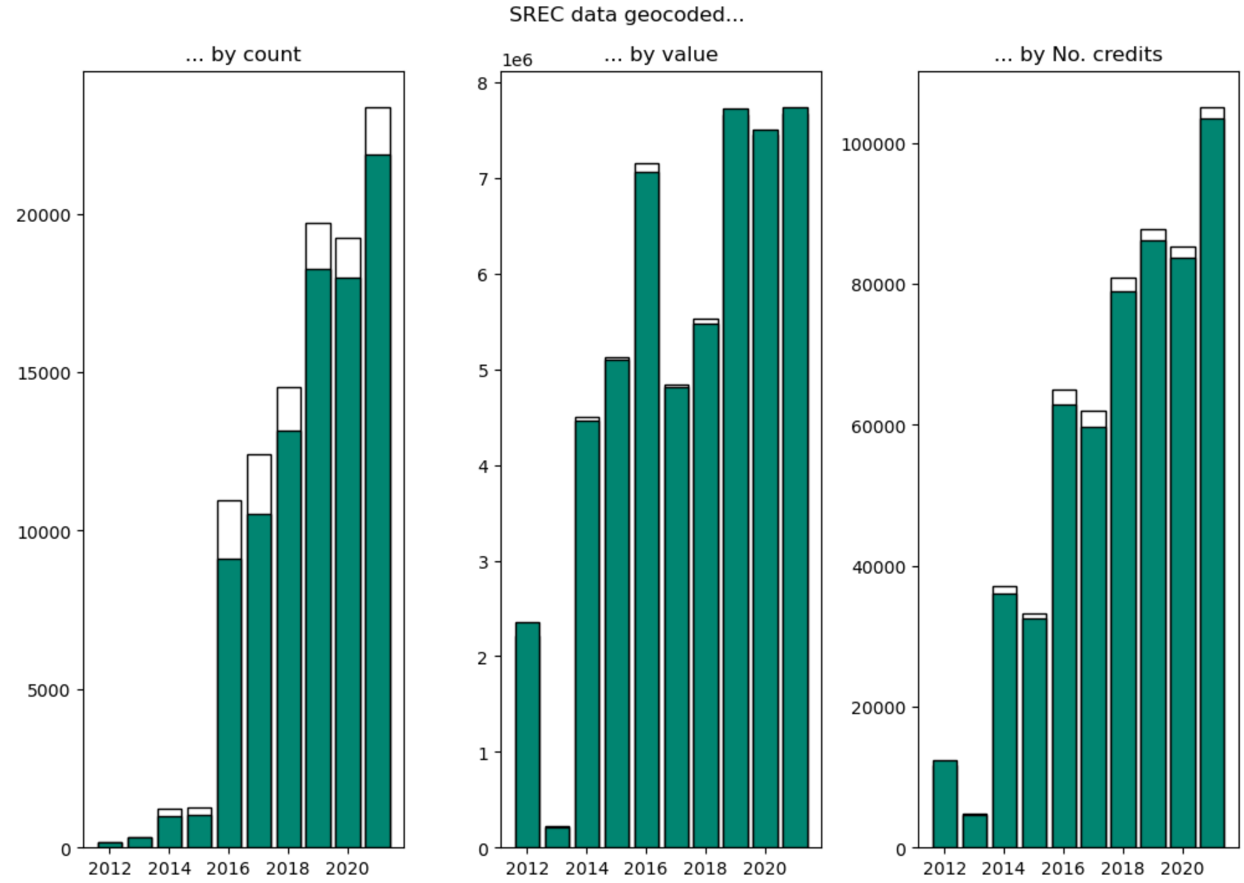


Figure 20 Geocoding success by count, value, and number of credits for the SREC market