Solar Siting Opportunities for Rhode Island

An analysis of potentials and costs of rooftop, landfill, gravel pit, brownfield, commercial and industrial ground-mounted and carport solar

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EXECUTIVE SUMMARY

As of Spring 2020, over 250 megawatts (MW) of solar have been interconnected with Rhode Island's distribution system. In an effort to assist with planning future solar photovoltaic (PV) development within the context of other land-use interests such as conservation, agriculture, and housing development, the Rhode Island Office of Energy Resources (OER) contracted Synapse Energy Economics to develop an estimate of the likely solar potential available within a number of solar siting categories. We conducted this statewide study using a granular bottom-up approach, primarily through the use of geospatial data and geographic information system (GIS) software. We used data obtained from the Rhode Island Geographic Information System (RIGIS) clearinghouse, National Grid, RI Commerce Corporation, local solar developers, RI Housing, University of Rhode Island, RI Department of Environmental Management (DEM), United States Geological Survey (USGS), National Renewable Energy Laboratory (NREL), United States Environmental Protection Agency (US EPA), and parcel and zoning data from nearly all cities and towns in the state.[1]

Methodology and data sources

Synapse examined and quantified solar potential for the following six siting categories:

- Rooftop solar (including rooftops of residential single family, residential multifamily, commercial, industrial, municipal, and other building types)
- Ground-mounted solar in the following four categories: (1) Landfills, (2) gravel pits, (3) brownfields, and (4) commercial and industrial developed and undeveloped lots
- Parking lot / carport solar

These categories were identified by OER as types of locations that could aid in policymakers' decisions for balancing future solar PV development with other land use interests such as conservation, farming/agriculture and housing development.

All data and analysis in this study was carefully assembled with stakeholder engagement, including town planning agencies, state agencies, National Grid, solar developers, University of Rhode Island, and members of the public. This stakeholder engagement was done through a kickoff presentation and Q&A session with stakeholders, an interim project update document circulated to stakeholders, a survey sent to solar developers, and telephone outreach to town planners, solar developers, and state agencies. Wherever possible, we spoke with a variety of stakeholders in order to provide a broad set of views on

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[1] Note that data on existing solar installed in Block Island Power Company and Pascoag Utility District service territories were not used in this analysis.

specific assumptions such as incremental solar costs for specific categories, typical project setbacks, topology requirements, and other topics.

We used geospatial analysis to examine the following types of potentials for each category of solar:

- **Total Potential,** an estimate of the solar potential for the entire area under consideration, with no exceptions.
- **Technical Potential,** an estimate of the potential excluding areas not suitable for solar development. Figure 1 and Figure 2 highlight some challenges facing rooftop solar and certain ground-mounted solar installations. These challenges may reduce technical potential, relative to total potential.

For residential rooftop solar, we also analyzed:

- **Economic Potential,** an estimate of the solar potential that is likely to be installed, given the current cost of the technology, the current financial incentives available, and the household economics specific to a municipality.

In addition, for each category of solar, we compiled estimates of these MW potentials translated into gigawatt-hour (GWh) generation potential, solar costs (based on costs available as of late 2019 / early 2020), avoided greenhouse gas emissions, and possible impacts on distribution system hosting capacity.

Figure 1. Siting challenges that may reduce technical potential for rooftop solar

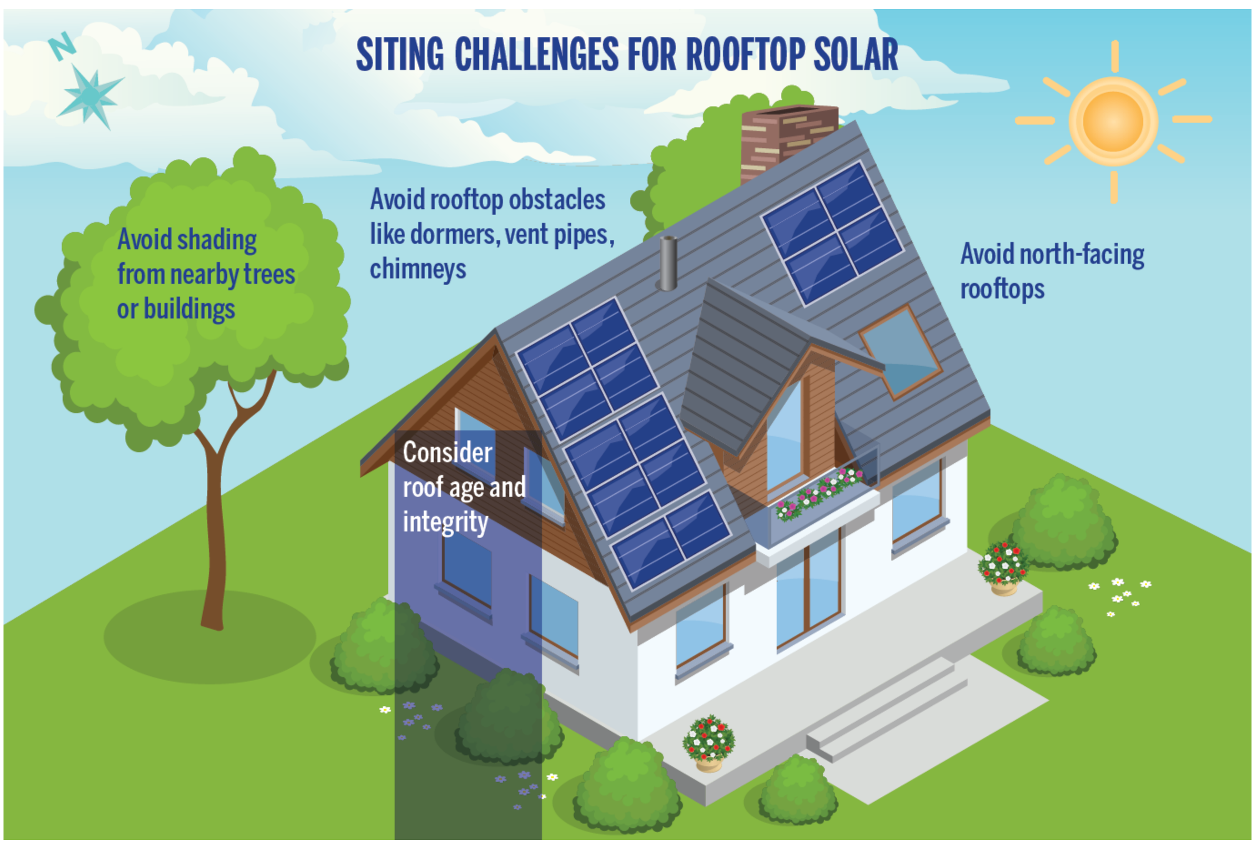
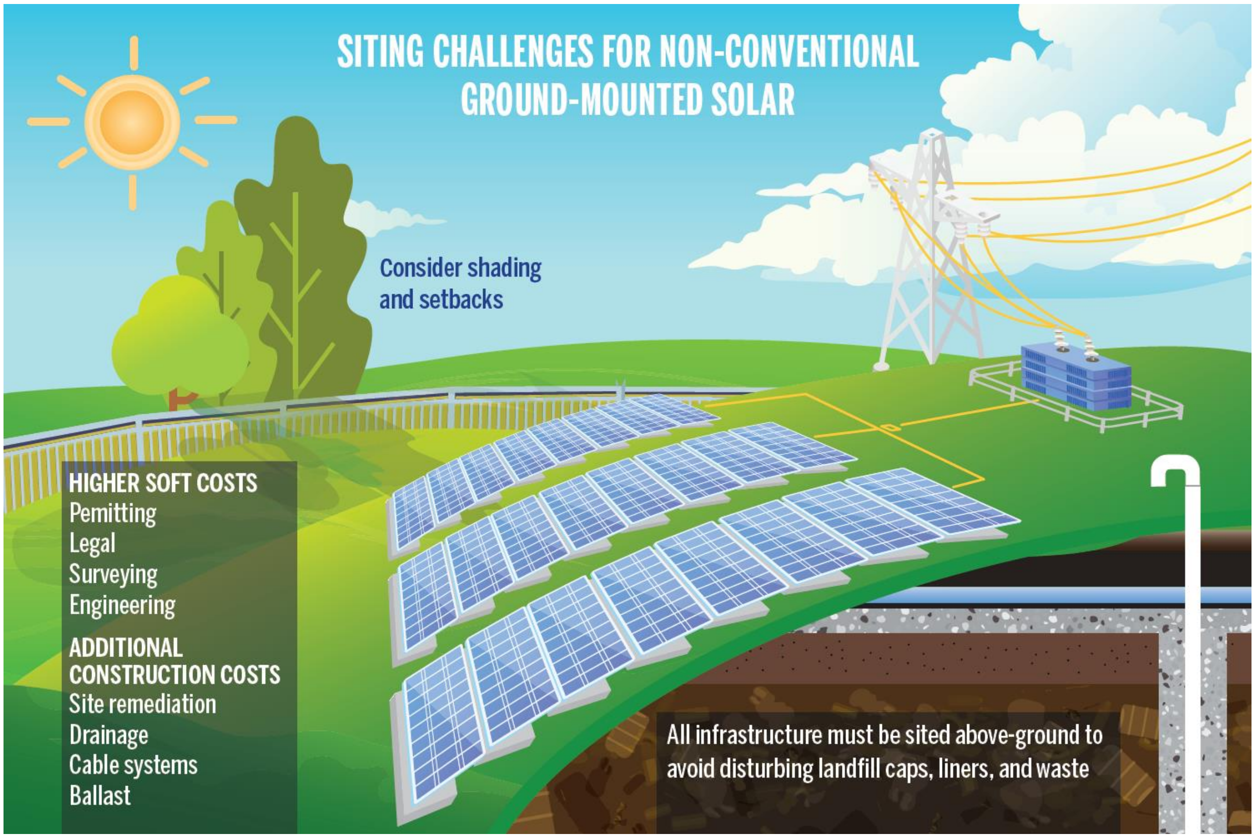


Figure 2. Siting challenges that may reduce technical potential for non-conventional ground-mounted solar (e.g., on landfills, gravel pits, or brownfields)



Findings

Table 1 displays a high-level summary of the results of our analysis for all types of solar, while Table 2 displays the summary of solar potentials (including economic potential) for residential rooftop solar. Ranges under technical potential illustrate the range of possible potential assuming different input parameters; ranges for rooftop solar costs illustrate the median costs for non-residential (low number) and residential systems (high number). Wherever possible, we have assembled cost data specific to each category; for ground-mounted solar categories, detailed, comprehensive cost data for each category were not available, and a typical cost for ground-mounted solar is shown instead.

We find that in aggregate across all six categories analyzed, technical potential for solar is between 3,390 megawatts (MW) and 7,340 MW, or 13 to 30 times the amount of solar that is currently installed in Rhode Island. This translates into 5,560 gigawatt-hours (GWh) to 12,600 GWh of electricity able to be produced. Median estimated upfront prices for these categories range from about $3 to $5 per watt. If this entire technical potential were installed, we estimate that up to 7.65 million metric tons of carbon dioxide ($MMTCO_2$) could be displaced, equal to about 70 percent of Rhode Island's total, current greenhouse gas emissions.

Table 1. Summary of potentials and costs

Category	Technical potential (MW)	Technical potential (GWh)	Estimated cost ($/Watt-DC)	Estimated cost ($/MWh-AC)	Potential avoided GHG emissions (MMTCO2)
Rooftop	850	1,130	$3.07 – $4.15	$153 – $208	0.74
Landfills	70 – 260	120 – 450	$3.21	$122	0.07 – 0.27
Brownfields	260 – 650	450 – 1,120	$3.21	$122	0.27 – 0.69
Gravel pits	30 – 90	50 – 160	$3.21	$122	0.03 – 0.10
Commercial and industrial parcels	1,160 – 4,600	1,990 – 7,920	$3.21	$122	1.21 – 4.83
Parking lots	1,060	1,820	$5.09	$188	1.19
Total	**3,390 – 7,340**	**5,560 – 12,600**	**-**	**-**	**3.47 – 7.65**

Table 2. Summary of total, technical, and economic potentials for residential rooftop solar

Subcategory	Total potential (MW)	Technical potential (MW)	High Economic Potential (MW)	Low Economic Potential (MW)
Residential Single Family	2,100	440	220	90
Residential Multifamily	480	100	40	20
Total	**2,580**	**540**	**260**	**110**

Finally, we compared the hosting capacity of 3-phase distribution lines in Rhode Island to the technical potential of solar in each town. We find that about 85 percent of towns in the state have an average hosting capacity that is less than its average technical solar potential. This exercise may be useful in determining where distribution system upgrades should be prioritized.

Caveats and limitations

All numbers provided in this report are intended to be high-level, first-pass estimates. In many solar categories, the accuracy of our estimates is limited by the data available. For example, we reached out to all 39 towns and cities and received zoning and parcel data from 35 municipalities. For municipalities that provided data, we contended with data in different formats, of different zoning vintages, and of various levels completeness. For the municipalities for which we did not receive zoning and parcel data, we used U.S. Census data (including housing density, median income, and population) to identify similar municipalities to apply known zoning category breakdowns. This implies that the actual rooftop and commercial and industrial-sited solar potentials may be higher or lower than estimated in this report, depending on the actual zoning in place in each municipality. Other datasets used in our GIS analysis, including data describing landfills, brownfields, gravel pits, and parking lots may be incomplete or partially out-of-date, creating uncertainty in the solar potentials estimated here. Some information—such as the historical data used to inform dollar-per-watt costs—may be based on a limited number of data points. For carports in particular, our cost estimates were based on two installations that existed in Rhode Island as of Fall 2019. Costs may change as more projects are built and the market matures.

In addition, in order to simplify the study, we applied several general assumptions on solar siting. These include the quantity of solar that can be built on a single rooftop or parcel (measured in kilowatts per square meter), the effective electrical output of a solar facility (measured in megawatt-hours), the slope of land that is practical for solar construction, and the setbacks required on each parcel (required by zoning or shading from adjacent buildings and trees).

Importantly, solar potentials at individual locations should be calculated based on any additional site-specific information available. Further caveats and limitations are detailed in the report.

Conclusions

Though Rhode Island is host up to 4,680 MW of solar potential on rooftops, brownfields, landfills, gravel pits, and parking lots, the cost of developing these sites may be higher than equivalent installations on conventional ground-mounted sites due to additional permitting, construction, and site remediation costs. These incremental costs are likely to be site-specific and vary across sites with different characteristics. Though siting solar on these types of sites may address siting or environmental concerns, there are potential tradeoffs given potentials for additional costs and lower-than-average annual generation. Furthermore, hosting capacity limitations may also pose a tradeoff when deciding where to site solar projects. Our analysis indicates there are many towns across the state where distribution hosting capacity upgrades may be advantageous for interconnecting the state's future solar potential.

This study was commissioned by the Rhode Island Office of Energy Resources. Please contact Chris Kearns at christopher.kearns@energy.ri.gov with any questions.

1. INTRODUCTION TO SOLAR POTENTIALS AND COSTS

In this analysis, we evaluated the potential of solar photovoltaic (PV) in Rhode Island in the following six siting categories:

- Rooftop solar (including rooftops of residential single family, residential multifamily, commercial, industrial, municipal, and other building types)
- Ground-mounted solar in the following four categories:
  - Landfills
  - Gravel pits
  - Brownfields
  - Commercial and industrial (C&I) developed and undeveloped lots
- Parking lot / carport solar

These categories were identified by Rhode Island's Office of Energy Resources (OER) as types of locations that could aid in policymakers' decisions for balancing future solar PV development with other land use interests such as conservation, farming/agriculture and housing development. For all ground-mounted categories, we analyzed parcels that are both completely undeveloped (e.g., devoid of any existing buildings), as well as parcels that currently have existing buildings in place. For this latter type of parcel, we examined the available area after removing any area associated with building footprints or existing solar installations. Note that we did not analyze any parcels that were zoned for residential use.

For these six siting categories, we assess three different types of solar potentials: total, technical, and economic. For the purpose of this analysis, these terms are defined as follows:

- **Total potential** refers to the entire area under consideration, with no exceptions (i.e., what if a parcel were completely covered in solar panels, irrespective of topography, setbacks, or other site restrictions?), less solar capacity currently installed through Fall 2019. As a result, this category is likely to be an overestimate of all solar that could be built in any one parcel. We do not remove any "in progress" solar capacity—this means we are ignoring projects that are awaiting activation or are under construction, as well as projects that are merely proposed. We evaluate total potential for every solar category.
- **Technical potential** is a subset of total potential that includes only geographic areas that are suitable for solar development. Unsuitable areas might include areas that are too close to adjacent parcels (and thus impacted by shading or setback requirements), roof areas that are primarily shaded or occupied by poor rooftop geometry, areas with very steep slopes, areas currently occupied by wetlands or other non-compatible land uses (such as rivers, ponds, and rock outcroppings), or available hosting capacity on the distribution system. We evaluate technical potential for every solar category.

- **Economic potential** is a subset of technical potential that evaluates the amount of solar that is likely to be installed given the current cost of the technology, available financial incentives, and municipal household economics.[2] Economic potential was only calculated for residential buildings (both single family and multifamily).

For each potential category above, we report both capacity and energy generation results. Capacity values throughout the report are described in terms of megawatts alternating current (MW_{AC}), unless otherwise specified. Table 3 displays the known quantity of solar installed in Rhode Island through Fall 2019.[3] As described above, this solar was removed from all estimates of potential. We did not remove any solar capacity that is "in progress" (i.e., projects that are awaiting activation or are under construction). For a full list of existing solar installations in Rhode Island by municipality, see Appendix A.

Capacity and generation

Throughout this report, we report results for both capacity and energy generation results. **Capacity**, measured in megawatts (MW), describes the maximum electric output a generator can produce at one point in time. Meanwhile, **generation**, measured in megawatt-hours (MWh) or gigawatt-hours (GWh)—equal to one thousand MWh—is the estimated electricity that can be produced over a period of time. For example, if a solar facility with a capacity of 1 MW can generate electricity at its maximum value over 1 hour, it will produce 1 MWh of electricity. In practice, the output from solar facilities varies over the course of the day, with peak capacity being reached mid-day.

Capacity and generation values in this report are described in terms of alternating current (MW_{AC} and GWh_{AC}), the type of electricity used by the grid, rather than direct current (DC), which is the type of electricity produced by solar facilities. Most solar facilities convert DC electricity into AC electricity through the use of an inverter, although some output is often lost during this conversion.

[2] This category does not consider non-economic drivers such as a customer's desire for lower emissions or aesthetics.

[3] Throughout this report, we refer to existing quantities as of solar that were installed as of Fall 2019. Data provided by National Grid indicates that as of March 31, 2020, an additional 53 MW of solar was also installed. However, detailed data on the program categories or locations of these facilities has not been provided. Note that data on existing solar installed in Block Island Power Company and Pascoag Utility District service territories were not used in this analysis.

Table 3. Rhode Island solar installations and capacity by type, as of Fall 2019[4]

Type	Subtype	Total Installations	Total MW-AC
Rooftop	Residential	7,341	44
Rooftop	Commercial	208	21
Ground-mounted	All	164	121
Other (carports, brownfields)	All	10	12
Total		**7,723**	**198**

Note: The data above comes from the following programs: Renewable Energy Fund, Renewable Energy Growth (Small), Renewable Energy Growth (Medium, Large, and Commercial), Virtual Net Metering Program, Distributed Generation Standard Contracts Program, the 30 MW Community Solar Virtual Net Metering Pilot Program, and earlier non-programmatic net-metering. This does not include solar installed between Fall 2019 and March 2020, which is estimated to total around 53 MW. Source: RI Commerce Corporation and National Grid.

All data and analysis in this study was carefully assembled with stakeholder engagement, including town planning agencies, state agencies, National Grid, solar developers, University of Rhode Island, and members of the public This stakeholder engagement was done through a kickoff presentation and Q&A session with stakeholders, an interim project update document circulated to stakeholders, a survey sent to solar developers, and telephone outreach to town planners, solar developers, and state agencies. Wherever possible, we spoke with a variety of stakeholders in order to provide a broad set of views on specific assumptions such as incremental solar costs for specific categories, typical project setbacks, topology requirements, and other topics.

In the following sections we describe how we calculated the total, technical, and economic potentials for each of the six siting categories of solar (rooftops, brownfields, landfills, gravel pits, developed and undeveloped

Key sources

This analysis relies on data and methodologies from several other recent solar analyses. Several of the most relevant studies include:

- Boving, T., P. Cady, D. Musher, T. Davis, and C. Damon. 2011. "Rhode Island Renewable Energy Siting Partnership Final Report, Volume 2 Technical Reports, RESP Technical Report #8." University of Rhode Island. Available at https://www.crc.uri.edu/download/resp_volume_2_final.pdf.
- Brown, A., P. Beiter, D. Heimiler, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf.
- Gagnon, P., R. Margolis, J. Melius, C. Philips, and R. Elmore. 2016. "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment." National Renewable Energy Laboratory. Available at: https://www.nrel.gov/docs/fy16osti/65298.pdf.

[4] Data was obtained at different points in the study process. For example, data on the REF program is up-to-date through August 31, 2019. Meanwhile, data on the REG program is up-to-date through November 1, 2019. Data on all other project categories are up-to-date through November 30, 2019.

commercial and industrial parcels, and parking lots). Note that this includes analysis of sites (such as defunct landfills and brownfields) that may appear very green though years of natural regrowth and mask what the underlying land actually is. Wherever possible, we strived to present potentials for all categories on an apples-to-apples basis, so that each type of potential is comparable across the types of solar. For most categories, we present ranges of results. The purpose of these ranges is to reflect the uncertainty in some of the key drivers of our potential calculations.

Note that all numbers provided in this report are intended to be high-level, first-pass estimates. Solar potentials at individual locations should be calculated based on any additional site-specific information available.

2. ROOFTOPS

The first category analyzed is rooftop solar. For the purposes of this analysis "rooftop solar" refers to any solar facility constructed on the roof of a building. In this analysis, we subcategorize buildings as residential single family, residential multifamily, commercial, industrial, municipal, mixed use, and other.[5]

Table 4. Summary of potentials and costs, rooftops

Subcategory	Total potential (MW)	Technical potential (MW)	Technical potential (GWh)	Technical potential avoided GHG emissions (MT CO2)
Residential Single Family	2,100	440	580	377,600
Residential Multifamily	480	100	140	89,900
Commercial	360	13	170	110,200
Industrial	230	110	150	96,600
Municipal	50	20	20	15,400
Mixed Use	50	10	20	9,700
Other	140	40	60	38,500
Total	**3,400**	**850**	**1,130**	**737,800**

Note: In this table, and throughout the report, all values have been rounded to the nearest 10.

2.1. Rooftop solar potential

For the calculation of total, technical, and economic rooftop solar PV potentials in this study, we primarily relied on three data sources: a polygon shapefile of building footprint areas obtained from the RI GIS[6], polygon shapefiles of parcels and zoning designations provided by towns and cities throughout Rhode Island,[7] and a 2016 study on rooftop solar by National Renewable Energy Laboratory (NREL).[8] The following sections describe the methodology used to estimate total, technical, and economic potential for each of the rooftop subcategories considered.

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[5] "Other" may include buildings owned by the state, federal government, or an unknown entity.

[6] Rhode Island Geographic Information System. 2018. Building Footprints. Available at: http://www.rigis.org/datasets/building-footprints.

[7] See Appendix B for detail on GIS data provided by municipalities.

[8] Gagnon, P., R. Margolis, J. Melius, C. Philips, and R. Elmore. 2016. "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment." National Renewable Energy Laboratory. Available at: https://www.nrel.gov/docs/fy16osti/65298.pdf.

Total potential

Total potential refers to the entire quantity of rooftop solar possible, less the solar capacity currently installed through Fall 2019.

Data and methods

First, we used a GIS shapefile from RI GIS containing polygons of building footprints across the state.[9] This dataset, which encompassed buildings in every city and town in Rhode Island, was used as a proxy for rooftop area. We then combined this polygon shapefile of building footprints with the shapefiles of parcel and zoning data, provided by towns and cities in Rhode Island, to code each building footprint to a particular zoning type.[10] Each zoning type was then coded to one of the seven types of building categories. Building size (small, medium, large) was assigned for each building using a GIS function that calculates the area of each polygon. In total, we analyzed approximately 367,000 rooftops statewide.

What is a shapefile?

The solar siting analysis performed in this report relies on data readable in geographic information systems (GIS) software. This software is commonly used by town planners and other analysts to examine the relationships between data commonly used to create geographical maps. This data is often organized into "shapefiles" which can attach spreadsheet-based data (e.g., addresses, population, zoning designations, building age) to the data of geographic attributes. In this analysis, we typically use two types of shapefiles:

- **Polygon shapefiles**, which contain an aggregation of aggregate many different individual shapes or areas. Example shapefiles include building footprints and municipality parcels.
- **Point shapefiles**, which contain an aggregation of sites represented by single points (often the geographic center of a site). Example shapefiles include gravel pit center points.

Next, we relied on several rooftop-related parameters calculated by NREL to convert building footprint area into MW. In 2016, NREL published a comprehensive assessment of rooftop solar technical potential for the United States in different U.S. metro areas (including Providence and other metro areas in southern New England). Within this study, the authors developed a methodology to assess rooftop characteristics based on building type (i.e., small, medium, large) and municipality type (e.g., midsize city, large suburb) for nationwide building data. NREL categorized each building by total square footage: small (less than 5,000 square feet), medium (greater than 5,000 but less than 25,000 square feet), and large (25,000 square feet or greater).

We calculated total capacity potential (in MW) for rooftops by multiplying the total rooftop area of each building size category in each municipality by the capacity values (kW/m^2) from the NREL study specific to each combination of building size and municipality type. Finally, we subtracted the MW quantity of

[9] Rhode Island Geographic Information System. 2018. Building Footprints. Available at: http://www.rigis.org/datasets/building-footprints.

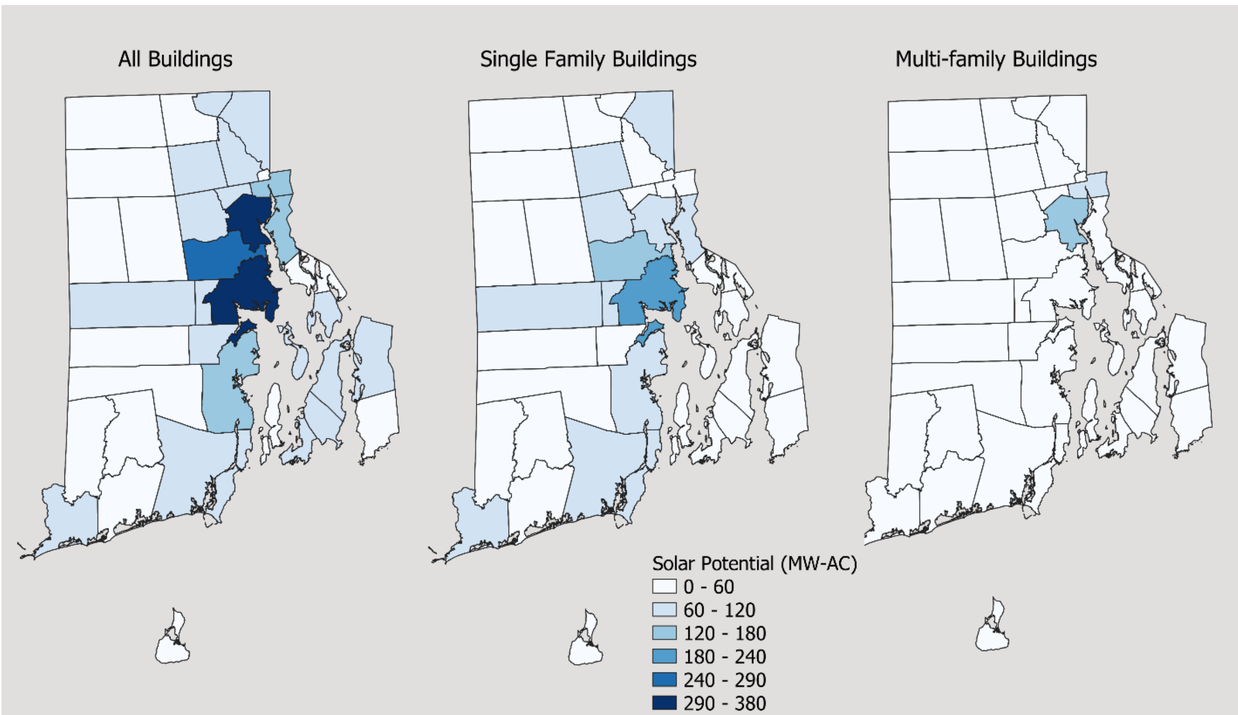
[10] Parcel and zoning shapefiles were provided to us by individual city and town governments.

rooftop solar that was installed in Rhode Island as of Fall 2019, according to data provided by National Grid and the RI Commerce Commission.[11]

Findings

Using this approach, we find that all municipalities have at least 13 MW of total rooftop solar potential (see Figure 3). The average municipality has about 90 MW of rooftop solar potential. Statewide, there is a total potential of about 3,400 MW with nearly half of that in the residential single-family category (see Figure 4 and Figure 5). This total potential value is in line with an estimate for Rhode Island derived in NREL's 2016 analysis of 3,800 MW.[12]

Figure 3. Map of rooftop solar total potential by municipality and building type (MW)



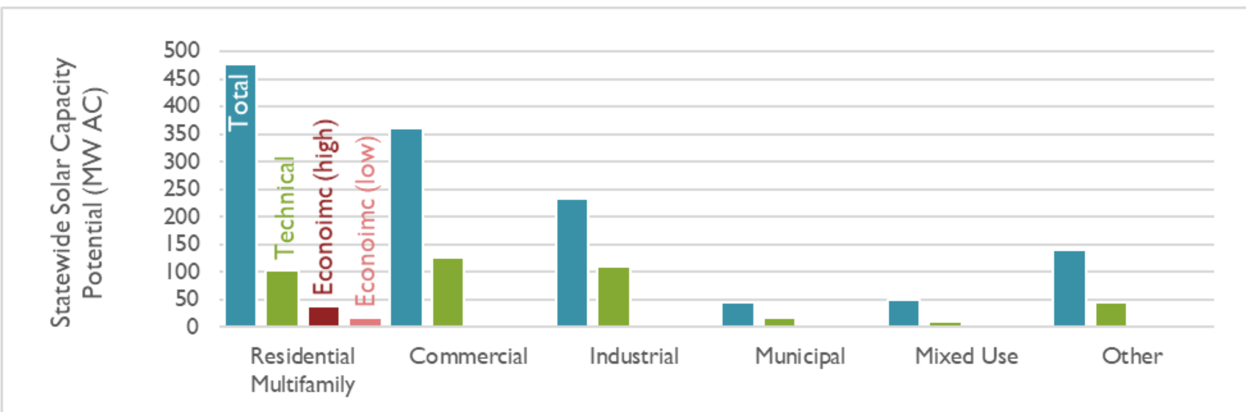
[11] This includes rooftop solar installed under the Renewable Energy Fund (REF) with net metering program, the Renewable Energy Growth (REG) program, and other installations not affiliated with either program.

[12] This difference (3,800 MW versus 3,400 MW) is within the range of expected difference between two studies with fundamentally different approaches to estimating rooftop solar potential. Possible causes of the difference include using different datasets for building footprints, and the fact that NREL's estimate is calculated only for the Providence metro area then extrapolated to the rest of the state, whereas this analysis has been performed using municipality-specific data for all 39 municipalities.

Figure 4. Rooftop solar capacity potential results (residential single family only)

Note: ***Total potential*** *refers to the entire area under consideration, less the solar capacity currently installed through Fall 2019.* ***Technical potential*** *is a subset of total potential that includes only areas that are suitable for solar development.* ***Economic potential*** *is a subset of technical potential that evaluates the amount of solar that is likely to be installed given the current cost of the technology, available financial incentives, and municipal household economics.*

Figure 5. Rooftop solar capacity potential results, by building category (all other rooftop categories)



Note: "Other" contains federal, state, and other miscellaneous or unknown building types.

Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

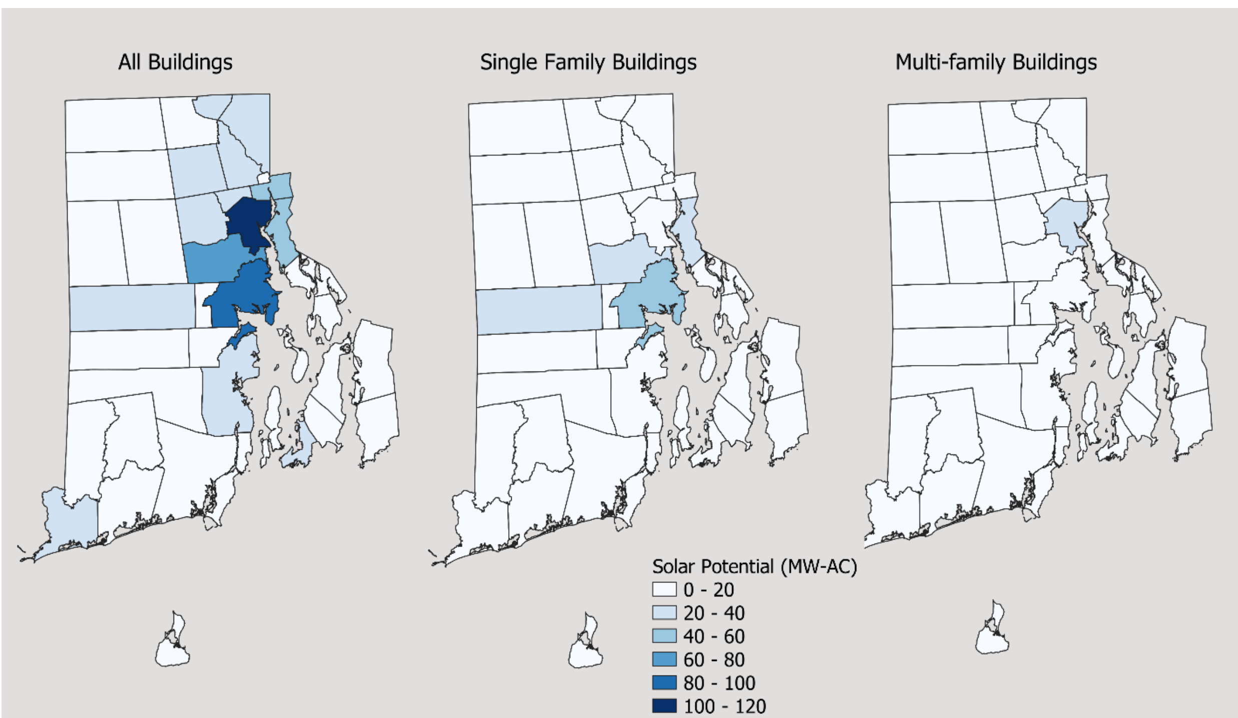
To calculate the technical solar PV potential, we used the same methodology described above for total potential, but also incorporated a factor to account for the subset of rooftop areas that are suitable for solar. For each combination of building and municipality type (e.g., small buildings in a midsize city), NREL calculated the fraction of rooftop space that is likely to be suitable for solar PV (based on building shading, tilt, azimuth, and the solar PV capacity (reported in kW_{AC}) per square meter of rooftop space using LIDAR data in NREL study obtained from the U.S. Department of Homeland Security (DHS)

Homeland Security Infrastructure Program for 2006–2014.[13] The resulting fractions of building area determined to be suitable varies depending on the municipality in which the building is located and the size of the building (small, medium, large). The fractions range from 17 percent to 79 percent, with smaller buildings tending to have a smaller share of rooftop area suitable for solar, and larger buildings tending to have a larger share of rooftop area suitable for solar.

Findings

The technical screening reduces the total rooftop solar potential to about 25 percent of the original estimate—about 850 MW (Figure 4). All municipalities have at least 3 MW of technical rooftop solar potential. The average municipality has about 22 MW of rooftop solar technical potential (Figure 6). According to the dataset used, about 3 to 5 percent of residences are not suitable for any solar (about 12,000 households). These are buildings with have effectively no roof planes suitable for installing even a small amount of solar. The technical screening reduces residential (single and multifamily) rooftop solar potential from a total potential of 2,580 MW to a technical potential of 550 MW.

Figure 6. Map of rooftop solar technical potential by municipality and building type (MW)



[13] Additional detail on this DHS study can be found in section 3.1 of the 2016 NREL Report "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessments." LIDAR is a method for measuring distances with laser lights, and is commonly used to develop GIS shapefiles that articulate the change in elevation of a particular area.

Economic potential

Economic potential is a subset of technical potential that evaluates the amount of solar that is likely to be installed given the current cost of the technology, available financial incentives, and municipal household economics.

Data and methods

We relied on three parameters to provide a range of how much of the technical potential might be economic : (1) range of solar costs, (2) range of incentives Renewable Energy Fund (REF) with net metering or Renewable Energy Growth (REG) incentives, and (3) range of median household income according to U.S. Census data.[14, 15, 16] Given the large variation in these parameters, we calculate two economic potential values—a low and a high—representing a range of possible economic solar potential for each city or town.

First, we estimated total project to determine the simple payback period of an average-sized solar PV system, under (a) the REF program with net metering and (b) the REG program, as they existed in early 2020 (see Appendix C for more information on the REG and REF programs). A "payback period" refers to the length of time it will take for an investor to recover their initial investment cost. The payback period used in this analysis is a simple payback period and does not include any discounting. We examined the estimated payback for both the REF program with net meter and the REG program, each under two different assumed upfront solar costs: a low cost equal to the 20th percentile cost of small-scale rooftop installed in the REF and REG programs since 2018, and a high cost equal to the 80th percentile cost of cost of small-scale rooftop installed in the REF and REG programs since 2018. This payback analysis yielded four different estimated payback periods.

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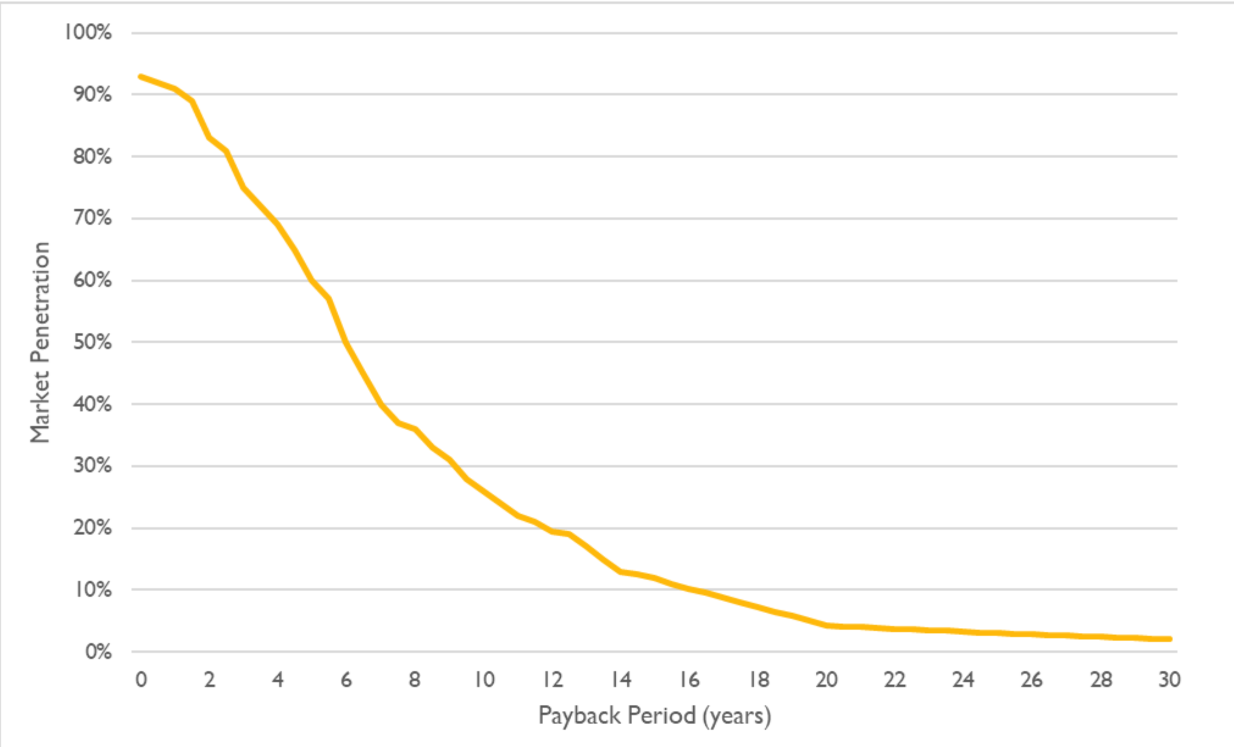
[14] Additional information on the REF net metering program: Rhode Island law requires National Grid to offer a net metering tariff for customers with distributed generation. Net metering can be paired with grants from the Renewable Energy Fund, but not with the Renewable Energy Growth program. The current implementing law was passed in 2011, and as of 2014 there was no cap on the total amount of renewable capacity that can participate. When a customer enrolls in net metering, any generation they export to the grid offsets an equivalent amount of electricity consumed from the grid and reduces the customer's electric bill. Customers are credited at a value equal to the sum of the current supply and delivery costs, except for the energy efficiency and renewable energy charges. Excess generation beyond a customer's total consumption is compensated at the utility's avoided cost rate up to an additional 25 percent of a customer's consumption. Distributed generation must be connected to the grid at the same place as the customer's load to be eligible for net metering, though there are exceptions through virtual net metering and the community solar pilot.

[15] REF incentive assumptions are based on a Request for Projects dated December 30, 2019 (See https://commerceri.com/wp-content/uploads/2019/05/Small-Scale-Solar-Requests-for-Projects-12.30.19.pdf). The incentive value used was $850/kW. The REG incentives are from the 2019 approved values that were in effect between April 1, 2019 and March 31, 2020 (See http://www.ripuc.ri.gov/eventsactions/docket/4892-DGBoard-NGrid-2019REG-Ord23827%205-7-2020.pdf, Appendix A). We used the small-scale solar incentive of $0.2845/kWh for a duration of 15 years.

[16] For more information on all current solar policies, see Appendix C. Current Solar Policies in Rhode Island.

Next, for each of these payback periods, we used a market penetration curve from a 2016 NREL report to translate the payback period into an expected statewide adoption rate.[17] For example, under this curve, a payback period of 5 years corresponds to about 60 percent of homeowners adopting solar, whereas a payback of 10 years corresponds to an adoption rate of 25 percent (Figure 7). Using this market penetration curve, our lowest calculated payback periods of 7.1 equates to a market penetration of 19 percent, while our highest calculated payback period of 13.0 years corresponds to a market penetration of 40 percent.

Figure 7. Residential solar market penetration relative to payback period



Next, for each municipality, we scaled both the low and high estimates of market penetration by a scalar corresponding to the difference between each town or city's median income and the statewide median income. This allowed us to estimate variations in market penetration by municipality. Finally, the resulting level of market penetration was applied to the municipality-specific technical potential value calculated in the previous section to determine both a low and a high estimate for economic potential for each municipality.[18]

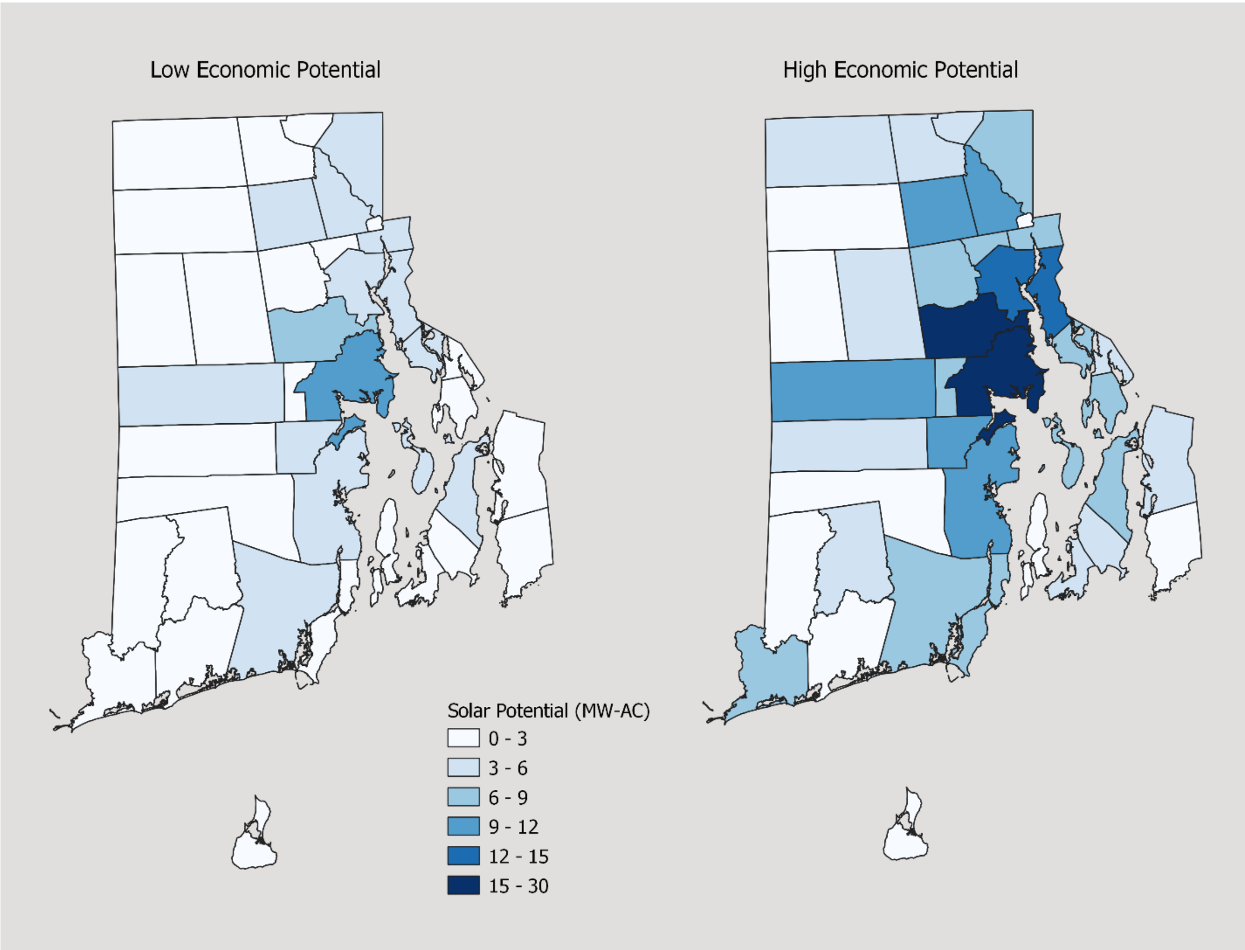
[17] National Renewable Energy Laboratory. 2016. The Distributed Generation Market Demand Model (dGen): Documentation. Page 23. Available at: https://www.nrel.gov/docs/fy16osti/65231.pdf.

[18] REF provides an upfront incentive payment, but this payment does not cover the cost of the entire PV system. REG does not provide an upfront incentive payment. The derived payback period is dependent on relative size of solar array to household

Findings

Statewide, our economic potential analysis reduces residential rooftop potential from 2,580 MW (total) to 550 MW (technical) to 110–250 MW (economic). Even at the lowest end of economic analysis, all 39 municipalities are estimated to at least some economical potential for residential rooftop solar. Note that not all of this economic potential may be realized. There are other factors that may impact whether or not solar is developed, including education and outreach, access to capital or financing, and disconnects between available solar incentives and renting.[19]

Figure 8. Map of residential rooftop low and high economic potential by municipality (MW)



load. This analysis assumes median solar arrays and household load. All potential numbers are calculated independently from requirements under current net metering that limits generation to 125 percent of onsite usage for non-virtual net metered projects. All potential numbers are calculated independently from a municipality's eligibility to participate in current state programs

[19] See NREL's website on "Low- and Moderate-Income Solar Policy Basis" at https://www.nrel.gov/state-local-tribal/lmi-solar.html for more information on barriers that may impede solar adoption.

Estimated annual generation

The estimated annual generation (measured in GWh) for total, technical, and economic potential on rooftops was calculated using an NREL-derived capacity factor of 15 to 16 percent.[20] Compared to capacity potential (measured in MW), which describes the peak amount of power that is possible to output at any one point in time, annual generation describes the total amount of electricity that is available to be produced over the course of an entire year.

The aggregated technical potential across all rooftop categories totals 1,130 GWh. As a point of reference, according to ISO New England, wholesale electricity load for Rhode Island in 2020 totaled 7,826 GWh.[21] Although this technical potential represents 14 percent of the current electricity load for Rhode Island, the ability for solar to completely meet in-state electricity demand is limited by timing of generation and demand, hosting availability (see Chapter 5), and other factors.

Table 5. Estimated annual rooftop generation (GWh)

Subcategory	Total potential	Technical potential	Economic potential
Residential Single Family	2,740	580	120-280
Residential Multifamily	630	140	20-50
Commercial	480	170	-
Industrial	310	150	-
Municipal	60	20	-
Mixed Use	60	20	-
Other	180	60	-
Total	**4,470**	**1,130**	**140-330**

Costs

Table 6, Table 7, and Figure 9 summarize the estimated historical costs of rooftop solar, for both residential and non-residential installations. Costs are presented using two different metrics:

- Dollars per Watt, direct current ($\$/W_{DC}$), a metric commonly used in the solar industry to compare the installed costs of solar across different facilities
- Dollars per megawatt-hour, alternating current ($\$/MWh_{AC}$), a metric that is commonly used to compare the lifetime, levelized costs of different types of generating facilities (e.g., solar, wind, and natural gas combined cycle).[22] Calculation of a $\$/MWh_{AC}$ cost

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[20] Capacity factors are represented as a range depending on building size (small, medium, and large), and building location (e.g., rural, urban, suburban). Capacity factors were estimated using Gagnon, P., R. Margolis, J. Melius, C. Philips, and R. Elmore. 2016. "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment." National Renewable Energy Laboratory. Available at: https://www.nrel.gov/docs/fy16osti/65298.pdf

[21] ISO New England's 2020 CELT Forecast, available at https://www.iso-ne.com/static-assets/documents/2020/04/forecast_data_2020.xlsx. Note that this number refers to net demand, after taking into account the impact of existing energy efficiency and distributed PV resources.

[22] Data on REF costs provided by Rhode Island Commerce Corporation in Fall 2019; data on REG costs provided by National Grid in Spring 2020. All other costs are based on REG data provided by National Grid.

requires assumptions about capacity factors, DC-to-AC conversion ratios, operating and maintenance costs, and financing costs which may vary in reality for each solar installation.[23]

For example, the median cost of residential solar installations is $4.15/W$_{DC}$, or $208/MWh$_{AC}$. Conversely, non-residential rooftop solar installations are slightly cheaper, with a median cost of $3.07/W$_{AC}$ and $153/MWh$_{DC}$. In addition to median values, we also report the following percentiles—5th, 20th, 80th, and 95th—in order to indicate the range of solar costs reported by the REF and REG programs. All costs only include projects installed since 2018, and all costs are presented in 2018 dollars.

Table 6. Upfront costs of solar, rooftops ($/W$_{DC}$)

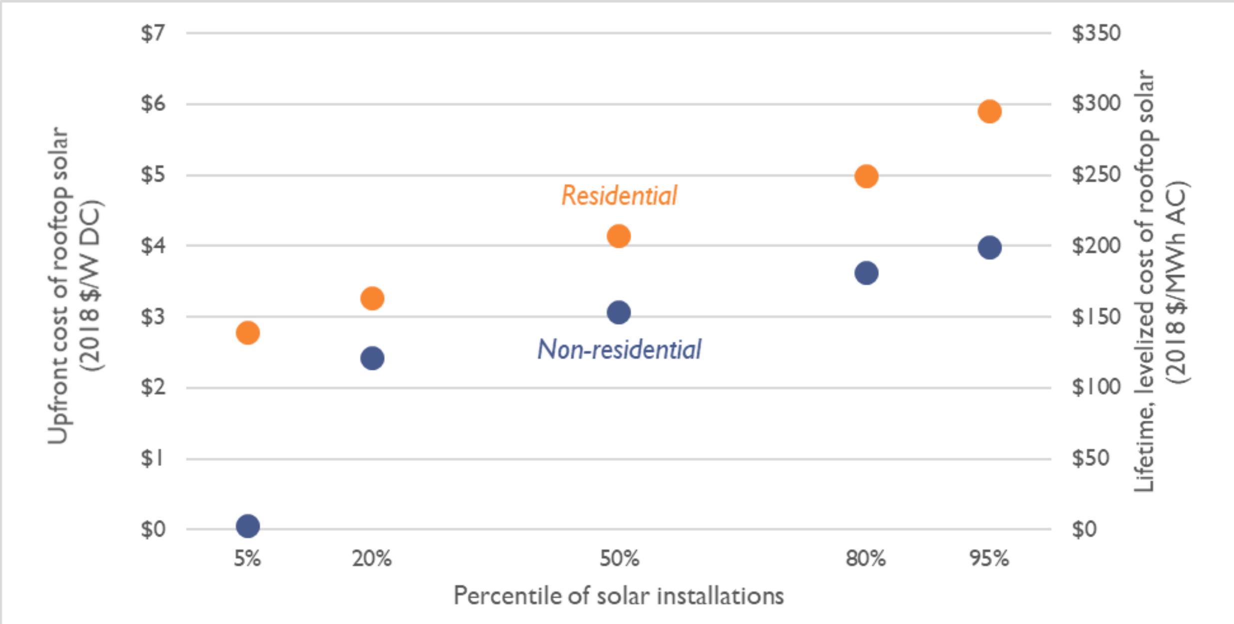
Subcategory	Minimum (5%)	Low (20%)	Mid (50%)	High (80%)	Maximum (95%)
Residential	$2.80	$3.27	$4.15	$5.00	$5.91
Non-residential	$0.07	$2.42	$3.07	$3.64	$3.99

Table 7. Lifetime levelized costs of solar, rooftops ($/MWh$_{AC}$)

Subcategory	Minimum (5%)	Low (20%)	Mid (50%)	High (80%)	Maximum (95%)
Residential	$146	$168	$208	$247	$288
Non-residential	$17	$124	$153	$179	$195

[23] For rooftop solar, we assume a 15 percent capacity factor (based on data from NREL's 2016 report "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment"), an 87 percent DC-to-AC conversion rate, based on data provided to Synapse by National Grid, a fixed operating and maintenance cost of $18/kW for non-residential solar and $24/kW for residential solar (based on data from NREL's 2019 "Alternative Technology Baseline" study, available at https://atb.nrel.gov/electricity/2019/data.html), a variable operating and maintenance cost of $0/kWh for non-residential solar and $0/kWh for residential solar (based on data from NREL's 2019 "Alternative Technology Baseline" study), and a financing cost of 5 percent (based on data from NREL's 2019 "Alternative Technology Baseline" study).

Figure 9. Costs of rooftop solar in Rhode Island 2018-2019



Note: Each point on this figure represents the cost for rooftop solar installations in Rhode Island for a particular set of installations. For example, the upper-left point indicates that 5 percent of all residential solar installations cost less than $2.80 per W_{DC} (or $146 per MW_{AC}). Meanwhile, the lower-right point indicates that 95% of all non-residential solar installations cost less than $3.99 per W_{DC} (or $195 per MWh_{AC}). The lifetime, levelized cost considers both the upfront cost, as well as assumptions about capacity factors, DC-to-AC conversion ratios, operating and maintenance costs, and financing costs which may vary in reality for each solar installation.

Avoided emissions

To calculate the avoided emissions associated with each category of solar PV, we used U.S. EPA AVoided Emissions and geneRation Tool (AVERT). AVERT uses statistical dispatch of individual power plants to estimate regionally, hourly electric power sector impacts resulting from energy efficiency and renewable energy programs. We applied distributed solar PV carbon dioxide (CO_2) emissions factors from AVERT's Northeast region to the estimated generation values to calculate the avoided emissions. In total, we estimate that the 850 MW rooftop potential is capable of avoiding about 737,800 metric tons of CO_2, or 0.7 million metric tons ($MMTCO_2$).

Table 8. Avoided emissions, rooftop technical potential (metric tons CO_2)

Subcategory	Avoided GHG emissions
Residential Single Family	377,600
Residential Multifamily	89,900
Commercial	110,100
Industrial	96,400
Municipal	15,400
Mixed Use	9,700
Other	38,500
Total	**737,600**

Caveats and data limitations

A major caveat for the rooftop solar potentials is the use of building footprint area as a proxy for rooftop area. The area of a rooftop may be smaller than the building footprint, therefore our estimates may underestimate the actual total potential for rooftop solar. Furthermore, due to data constraints, we did not consider the structural integrity or age of the buildings—two important aspects of a building when siting solar on a rooftop. Accounting for structural integrity or building age would reduce the amount of overall technical potential, as some buildings may be unable to structurally support the weight of solar panels. In addition, or perhaps instead, it could impact economic potential—structural upgrades may be physically possible, but could increase costs, leading to fewer installed MW.

Several caveats exist relating to the coding of zoning data:

- The building categories (e.g., single family residential, commercial, etc.) were determined based on the zoning data provided by each municipality in the state. Because each municipality's zoning data are coded differently, the extrapolation of the zoning data into broader categories is only as accurate as the data provided. One notable example of this is the way in which multifamily buildings are zoned—some municipalities may consider a two-family building to be multifamily, while others may consider it an attached single family (as an example). This is unlikely to substantially impact the sum of the overall total or technical potential, but does lend uncertainty as to how much total or technical potential is in one category of building versus another (e.g., residential single family vs. mixed use).

- Zoning and parcel data are of different vintages, and in some cases vintage information does not exist. Data with more recent vintages may be more up-to-date, while older data may include zoning designations that are no longer correct.

- Out of the 39 municipalities in Rhode Island, Synapse received zoning and parcel data from 34. For the municipalities for which we did not receive zoning and parcel data, we used U.S. Census data (including housing density, median income, and population) to identify similar municipalities to apply known zoning category breakdowns.

We assume the same capacity factors to convert each potential category capacity (MW) into potential energy (GWh). However, these capacity factors assume that solar is sited on the feasible parts of roofs, rather than the parts deemed infeasible by NREL (e.g., parts of roofs that contain HVAC equipment, are shaded, or have complex rooftop geometry). As a result, it is likely that the total potential energy is lower than what is estimated here.

3. GROUND-MOUNTED SOLAR

We analyzed potentials for four categories of ground-mounted solar: landfills, brownfields, gravel pits, and Commercial and Industrial (C&I) parcels. Each of these categories was analyzed using a different methodology, although each category shares some similarities in data sources and approaches. Each of the following discussions details the overarching methodology used to calculate solar potential followed by sections that describe the aggregate results of costs, generation, and emissions for all ground-mounted solar categories.

Table 9. Summary of potentials and costs, ground-mounted

Subcategory	Total potential (MW)	Technical potential (MW)	Technical potential (GWh)	Technical potential avoided GHG emissions (MT CO2)
Landfills	430	30 – 90	120 – 450	26,800 – 95,700
Brownfields	1,060	260 – 650	450 – 1,120	273,000 – 686,000
Gravel pits	150	30 – 90	50 – 160	29,300 – 96,300
Commercial and Industrial	9,040	1,160 – 4,600	2,000 – 7,930	1,200,000 – 4,830,000
Total	**10,680**	**1,480 – 5,430**	**2,620 – 9,660**	**1,530,000 – 5,710,000**

3.1. Landfill solar potential

Based on the dataset used, there are 63 landfills in Rhode Island (see Figure 10. 33 municipalities have at least one landfill, whereas 6 municipalities do not. In aggregate, we estimate the aggregate technical potential of landfills to be 70 to 260 MW (Table 10 and Figure 11).

Figure 10. Map of landfill counts by municipality

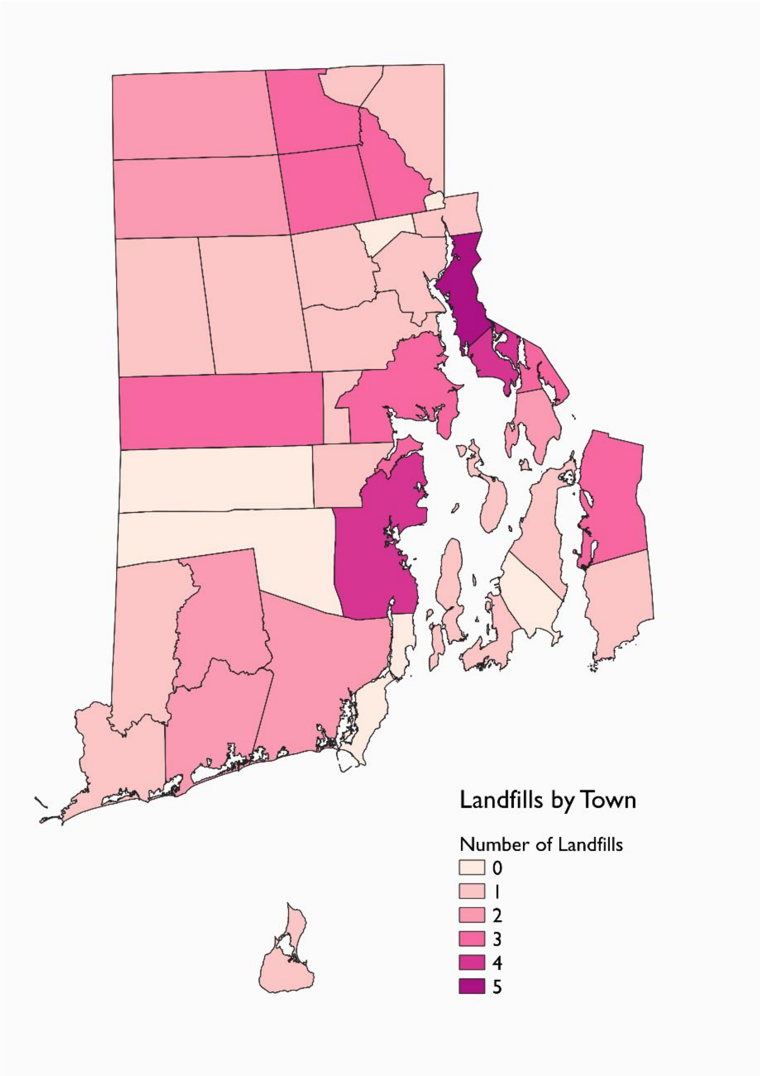
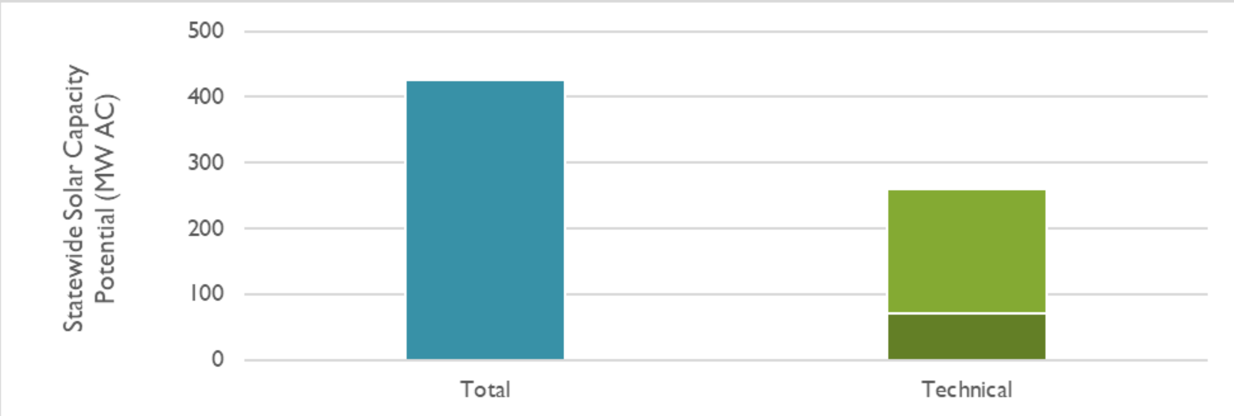


Table 10. Summary of landfill solar potential

Subcategory	Total potential (MW)	Technical potential (MW)	Avoided GHG emissions (MT CO2)
Landfills	430	70 – 260	74,500 – 273,500

Figure 11. Landfill solar PV total and technical potentials (MW)



Total potential

Total potential refers to the entire quantity of solar possible, less the solar capacity currently installed through Fall 2019.

Data and methods

The area of all landfills in Rhode Island was calculated using Geographic Information Systems (GIS) software. First, researchers at University of Rhode Island (URI) provided an existing geospatial dataset of Rhode Island landfills, with one polygon for each of the 63 known landfills in Rhode Island.[24] Using a dataset from RIGIS on building footprints (used above in rooftop potential analysis), we removed any building footprints from the landfill polygons and calculated the remaining area for each landfill polygon. These area values were then multiplied by an NREL-derived value describing the number of MW that can be built per square kilometer of land.[25]

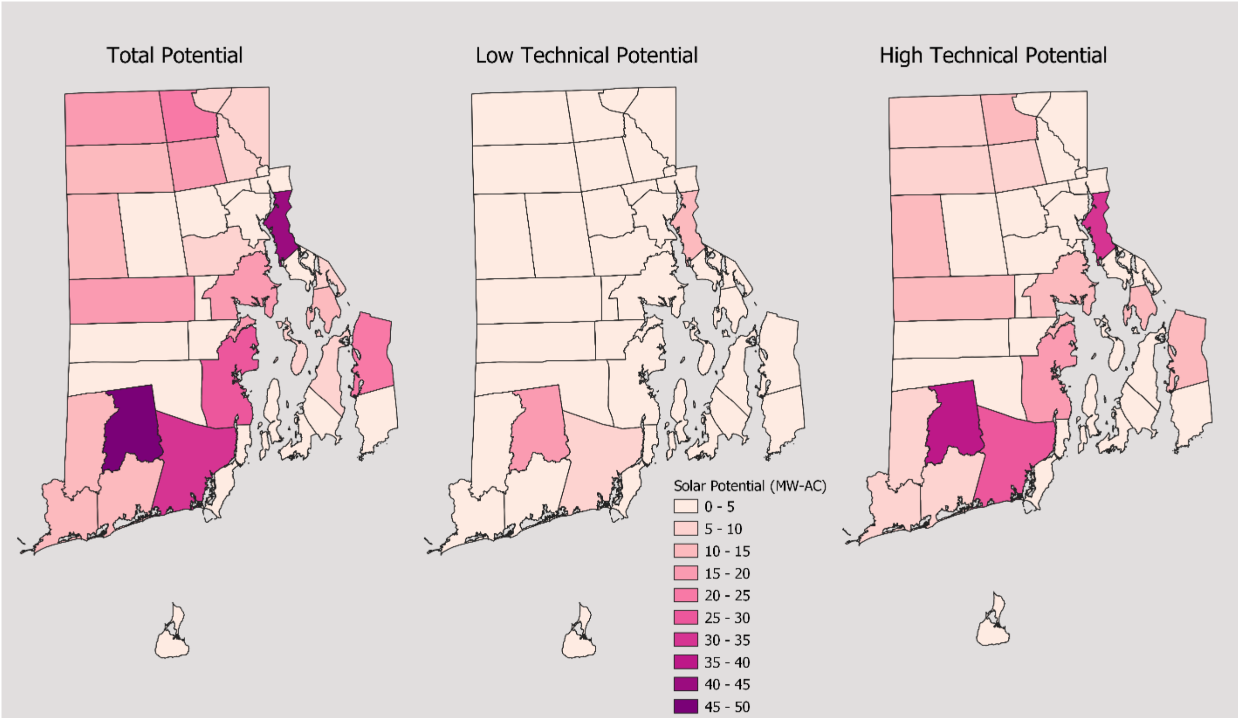
Findings

The total solar potential on all landfills in the state is approximately 430 MW. The Town of Richmond, which has two landfills, has the highest total potential at 60 MW (Figure 12).

[24] The existing geospatial data was provided by researchers at the University of Rhode Island, who conducted a landfill solar potential study in 2011. For more information, see Boving, T., P. Cady, D. Musher, T. Davis, and C. Damon. 2011. "Rhode Island Renewable Energy Siting Partnership Final Report, Volume 2 Technical Reports, RESP Technical Report #8." University of Rhode Island. Available at https://www.crc.uri.edu/download/resp_volume_2_final.pdf. .

[25] See Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf. NREL estimates a utility-scale solar PV potential in the United States of 27.9 GW_{AC} over 715.9 square kilometers of land. This yields an installation density of 39 MW_{AC} per square kilometer for Utility for fixed systems.

Figure 12. Maps of total, low technical, and high technical potentials of landfill solar (MW)



Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

Technical potential for solar PV on landfills is defined as the amount of solar PV that can be built given restrictions on certain types of land and physical qualities of the land that increase the installation cost of the panels. We calculated technical potential by trimming the total potential area of landfills in GIS with the following geographic restrictions:

- **Building setbacks**: Solar panels are typically setback from buildings in order to avoid shading and facilitate site maintenance. While these type of setbacks are highly site-specific, for purposes of simplicity, our analysis assumed a building setback of 50 feet for any landfills that have a building on co-located on the parcel (see sidebar for more information on estimating setbacks). This setback estimate was developed through surveys and telephone conversations with Rhode Island's town planning agencies and solar developers.
- **Property edge setbacks**: Solar PV panels may not be able to be built up to the edge of the property line. Each of Rhode Island's 39 municipalities has its own individual zoning ordinances governing what types of facilities can be built within a parcel, and where. However, for purposes of simplicity, we examined two different setback possibilities: 50 ft and 375 ft (see sidebar for more information). This setback range was developed

through surveys and telephone conversations with Rhode Island's town planning agencies and solar developers.

- **Land-use restrictions:** Solar PV panels cannot be built on certain types of land, including water bodies (e.g., rivers, ponds), rock outcroppings, and wetlands. We also reviewed each landfill using satellite data from Google Maps to exclude any areas that were obviously no longer suitable for solar (e.g., baseball fields, existing solar, and more). Where a landfill overlaps with any of these types of land, the area was removed from the analysis.

- **Land slope**: LIDARdata was converted into slope data for each landfill in the state.[26] We removed land with a slope greater than 10 degrees because solar installation is assumed to be impractical on steeper slopes.[27]

Estimating setbacks

A "setback" refers to the smallest distance to a boundary at which ground-mounted solar may be constructed. We estimated two different setback types: setbacks from buildings, and setbacks from property lines.

First, to estimate setbacks from buildings, we assumed the average building was 20 feet in height (equivalent to a 2-story house with 10-foot tall stories). According to input from solar developers, solar facilities are typically sited at a distance of at least 3X the height of a nearby building when sited North-South relative to the building. When located East or West of a building, this metric is 2X. We assumed that half of solar installations will be built North-South, and half will be built East-West (in reality, solar installations will be built in many directions relative to buildings). This assumption translates into a height multiplier of 2.5X. We then multiplied 2.5 by 20 feet to get a building setback of 50 feet.

Second, we estimated a range of setbacks for property lines. At the low end, we used input from solar developers indicating that properties located next to commercial or industrial parcels may only need to be setback 50 feet to arrive at our low estimate. At the high end, we relied on input from solar developers that properties located next to residential parcels must be set back 200 feet. We also assumed the existence of 70 feet tall trees around the edge of the property that require an additional setback. Using the same 2.5 ratio from the building setback, we added another 175 feet to the total required set back, adding to a total 375-foot setback.

The setbacks from buildings and parcel lines are estimates based on existing literature and input from solar developers. However, the geography and tree locations vary, and municipalities may have individual setback requirements that are different from the ones we have defined here.

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[26] Rhode Island Geographic Information System. Spring 2011 Statewide Lidar – DEM in UTM. Available at: http://www.rigis.org/pages/2011-statewide-lidar-utm-dem.

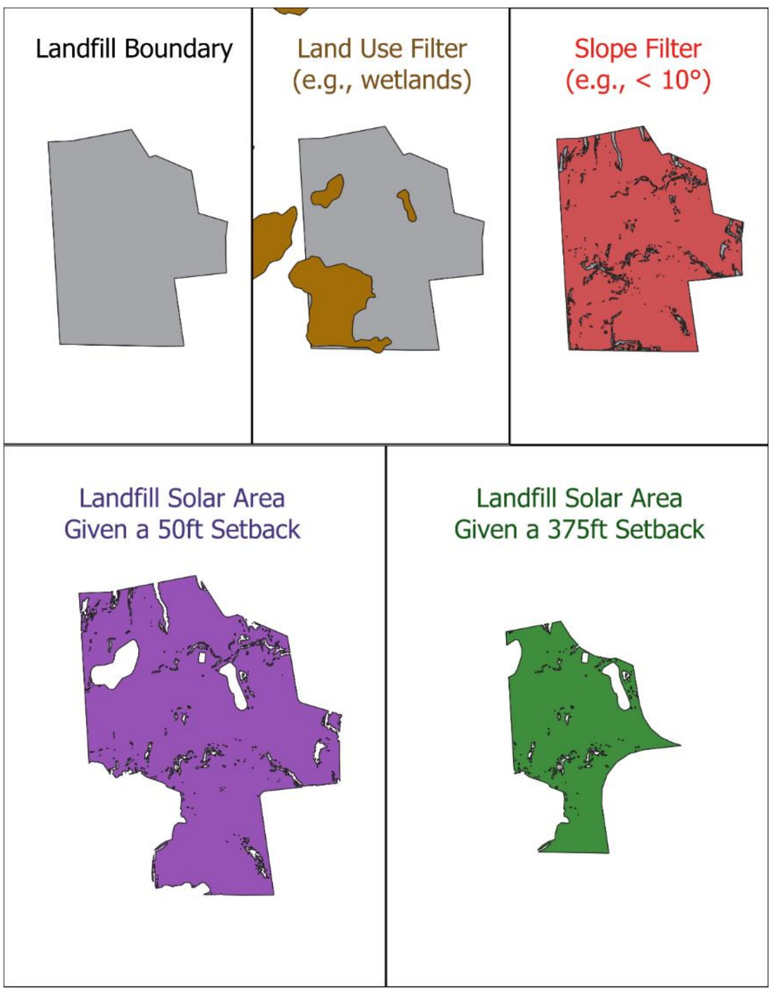
[27] This threshold was selected based on conversations with solar developers in Rhode Island. For the purposes of defining technical potential, the practicality of building on steeper slopes is based on expense. Surveys of solar developers suggested that their projects were unlikely to see cost increases or changes to feasibility as long as land slopes were lower than 10 percent. However, construction on steeper land may be possible at higher costs, meaning that this technical potential may be an underestimate.

Due range in likely property setbacks across Rhode Island's municipalities, we calculated two technical potentials for landfills—a low technical potential area (using the 375ft setback) and a high technical potential value area (using the 50ft setback).

Findings

Figure 13 illustrates the order in which the technical restrictions were applied to the original landfill data, as follows: property and building setbacks, land-use restrictions, and slope. The technical filters reduce the statewide solar PV analysis to a range of 70 to 260 MW. Richmond—the municipality with the largest landfills by area—has the highest technical potential at 20 to 40 MW.

Figure 13. Schematic of the approach to calculating area for landfill solar technical potential



Caveats and data limitations

The following caveats apply to the landfill analysis:

First, the original landfill dataset and polygon shapefile from URI is from 2005 and has not been updated. As such, there may be some newer landfills (or expansions of current landfills) that are excluded from our analysis. Further, some of the re-use information may be out of date (e.g., whether the landfill is currently being used for athletic fields, parks, transfer stations).

Second, we assume the URI polygons of Rhode Island landfills accurately represent the entire property of each landfill; therefore, we made no changes to those boundaries. Given the large number of landfills (over 60), we were unable to manually check the accuracy of the available metadata and polygon shapes.

Third, we consider all landfills to be suitable for solar development, regardless of their capping status. Landfills must be capped before solar PV can be installed; therefore, already capped landfills are likely to be better suited for PV than uncapped landfills, or represent sites with lower development costs, all else being equal.

Fourth, only landfill area that is less than 10 degrees sloped is considered to be feasible for solar under our definition of technical potential. Solar installations may be possible at locations with steeper slopes, which means that our technical potential would be an underestimate.

Finally, there are currently installed solar facilities at landfills in Rhode Island, as well as solar facilities that are currently being installed at landfills at the time of this report's publication. However, data provided from RI Commerce Corporation and National Grid does not identify which of the thousands of facilities are sited on landfills. Using satellite data from Google Maps, we removed areas that clearly feature solar facilities; however, this satellite data was last updated 2018 and may be outdated. For this reason, our derived values for potential are likely to be an overestimate for landfill locations that presently have installed solar.

3.2. Brownfield solar potential

According to the Rhode Island Department of Environmental Management (RI DEM), brownfields are properties where expansion, redevelopment, or reuse might be complicated by the presence (or potential presence) of a hazardous substance, pollutant, or contaminant.[28] Statewide, we estimate the technical potential for solar on remediated brownfields to be 260 to 650 MW (see Figure 14, Table 11, and Figure 15).

[28] *Reinvesting in Rhode Island's Brownfields*. Rhode Island Department of Environmental Management. 2018. http://www.dem.ri.gov/brownfields/.

Figure 14. Number of brownfields in Rhode Island by municipality

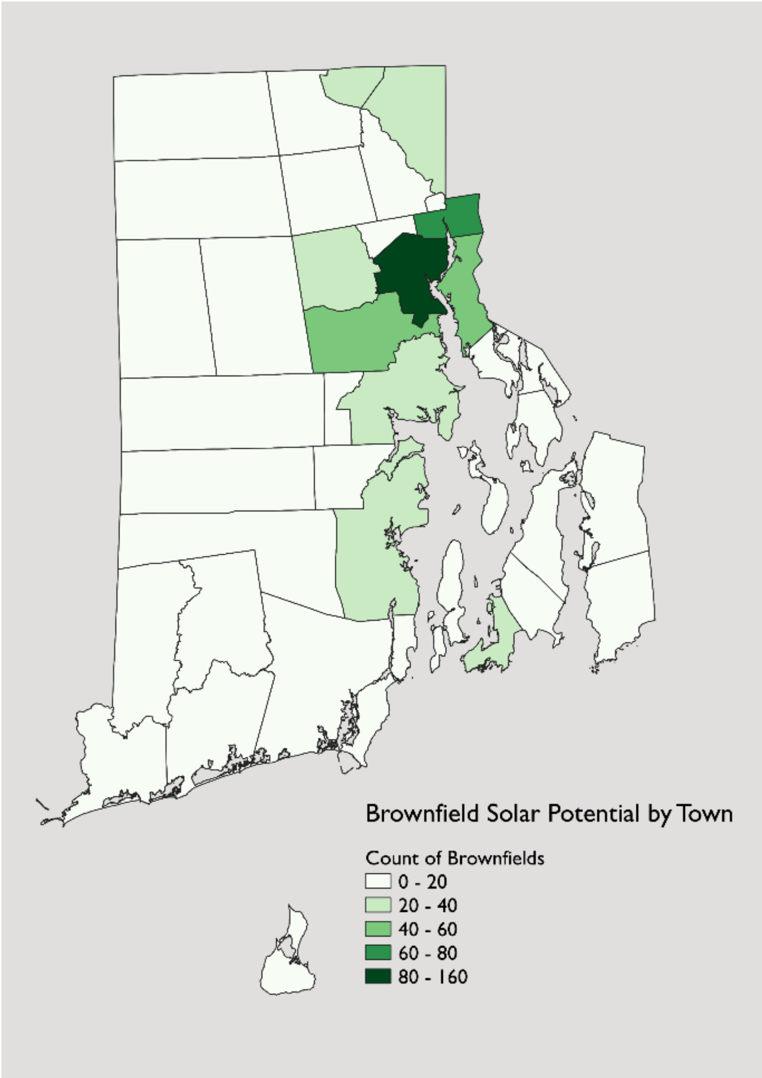
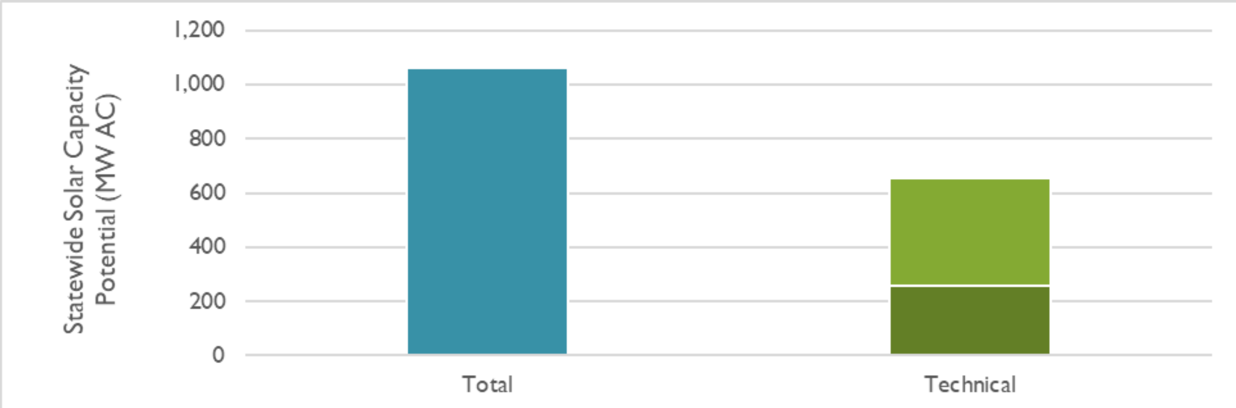


Table 11. Summary of brownfield solar potential

Subcategory	Total potential (MW)	Technical potential (MW)	Avoided GHG emissions (MT CO2)
Brownfields	1,060	260 – 650	273,000 – 686,000

Figure 15. Brownfield solar PV total and technical potentials (MW)



Total potential

Total potential refers to the entire quantity of solar possible, less the solar capacity currently installed through Fall 2019.

Data and methods

First, RI DEM provided a dataset listing over 700 known remediated brownfield sites in the state of Rhode Island. This dataset includes the brownfield name, address, municipality name, and area.[29] We cleaned this address data and successfully matched about one-third of all brownfields to parcels in the town/city geospatial data. Using the addresses in the supplied DEM dataset, along with addresses in parcel data provided by cities and towns, we were able to match over 230 of those sites to known parcels.[30] For those brownfields that didn't match to an address, we manually reviewed satellite and parcel data and created additional polygons for the 14 largest brownfields. To estimate total potential, we multiplied the total area of brownfield sites from the DEM dataset by the ground-mount installation MW-per-square-kilometer value used in the landfill analysis. Then, we subtracted the MW capacity of existing solar facilities sited at brownfields.

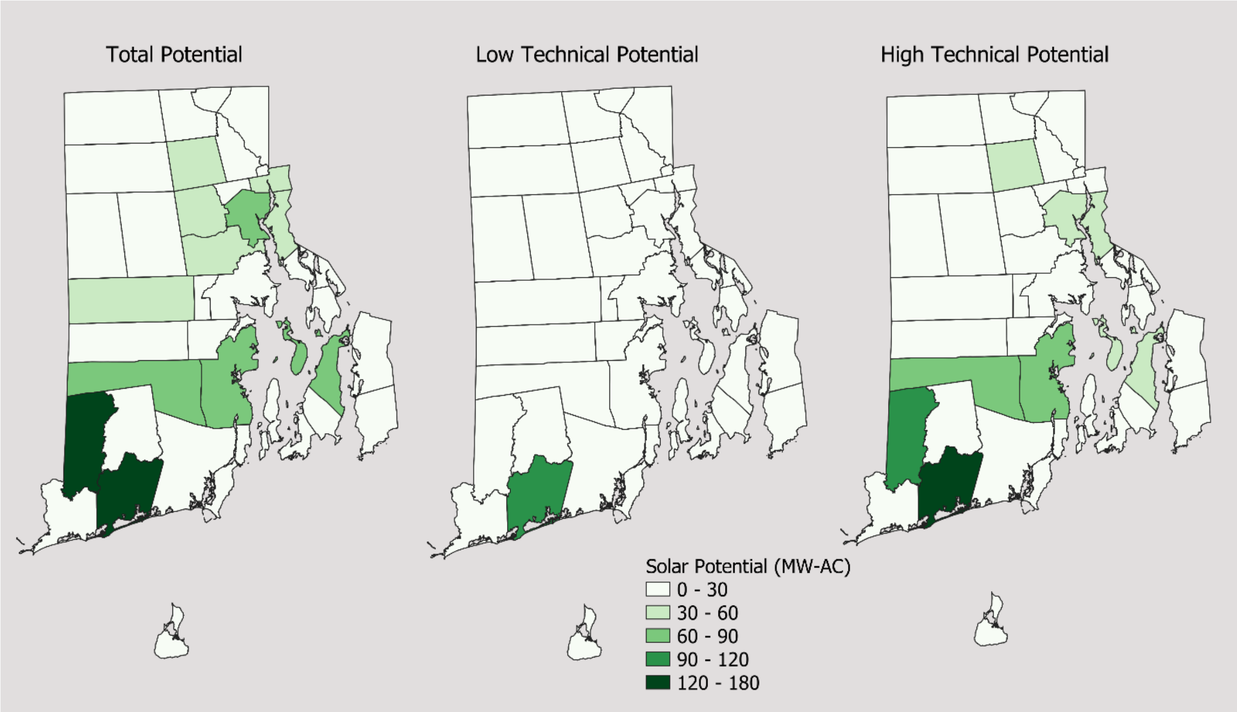
Findings

Across the state, there is approximately 1,060 MW of solar PV total potential in Rhode Island (Figure 16). The Town of Charleston has the highest total brownfield potential at 182 MW.

[29] RI DEM. (2019, September 16). *Remediated Sites – Potential Solar*. Available at http://www.dem.ri.gov/programs/wastemanagement/inventories.php.

[30] The remaining 500 sites had generic, unspecific addresses that did not match to a parcel (i.e., addresses without a street number). We also attempted to manually match the largest 15 remaining unmatched brownfield sites. However, we were only able to manually code four sites, which were then added to the GIS analysis.

Figure 16. Map of brownfield solar total, low technical, and high technical potential by municipality (MW)



Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

We then analyzed these parcels in GIS. We applied most of the same technical potential filters that were applied to landfills: setbacks from the edge of the landfill property (50 and 375 ft), a setback from any buildings on the property (50 ft), and land-use restrictions.[31] As with landfills, this process yielded both a low end and a high end for technical area. Because of discrepancies in the area value described by DEM and the values for matched parcels using data provided by towns and cities, and because the matched parcels analyzed in GIS comprised only a third of total brownfields across the state, the ratio of technical area (high and low) was converted into a statewide scalar and multiplied by each municipality's aggregate brownfield area. These resulting high and low technical potential areas were then multiplied by the same ground-mount installation MW-per-square-kilometer value used in the total potential calculation to produce a range of technical potential MW.

[31] We did not analyze land slope for brownfields due to computational barriers in estimating slope for over 230 discrete parcels. Many brownfield sites are small or were previously the site of economic activity. As a result, they are less likely to feature extreme topological variations that could prohibit solar installations.

Findings

The technical filters reduced the total potential to a range of 260 to 650 MW. The Town of Charleston retains the highest brownfield solar potential even after the technical filters, with a technical potential range of 120 to 170 MW (Figure 16).

Caveats and data limitations

There are several caveats associated with the original dataset obtained from DEM:

- This dataset only contains information on remediated brownfields, rather than all brownfields.
- The dataset is likely not up to date. Because of the large number of brownfield sites, each parcel was not manually analyzed. As a result, our analysis likely includes some sites that have already been repurposed or are planned for redevelopment for some other purpose.
- Only some of the brownfield addresses identified by DEM were able to be mapped. To estimate the total area of all brownfields (including both mapped and unmapped parcels), we relied on DEM's estimates of total area. We then reduced this total area proportional to the areas determined to be technical feasible using GIS software (i.e., total area, reduced to account for account for setbacks and inappropriate land uses). However, this this is only an estimation, and may overestimate the overall area suitable for solar development. For the brownfields that were able to be analyzed using GIS software, we estimated that DEM areas were, on average, 1.4 times larger than the same parcel areas mapped using GIS.

As with all ground-mounted solar estimates, the range of technical potential hinges on the assumed setbacks. See the "Estimating Setbacks" sidebar for more information on how different assumptions for this category could produce changes in technical potential.

We removed any existing solar capacity identified as being installed on a brownfield. However, it is possible that there are other existing solar facilities that are located on a brownfield but are not identified as such. As a result, our analysis may over-estimate solar potential.

3.3. Gravel pit solar potential

A third category of ground-mounted encompasses solar built on sand, stone, and gravel pits in Rhode Island. According to the United States Geological Survey (USGS), there are 13 known such locations in Rhode Island (see Figure 17). Only nine towns and cities have a gravel pit: Coventry, Cranston, Cumberland, Exeter, North Smithfield, Richmond, South Kingstown, Tiverton, and Westerly. In aggregate, we estimate the gravel pit technical potential to be 30-90 MW (see Table 12 and Figure 18).

Figure 17. Map of gravel pits counts by municipality

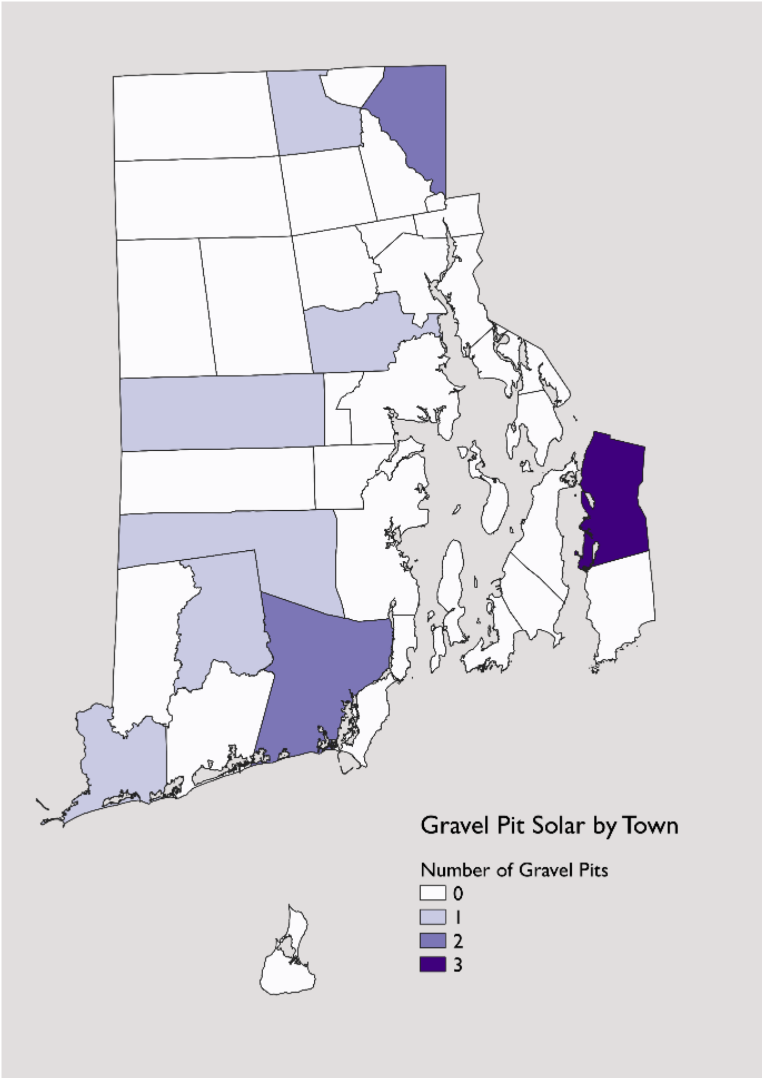
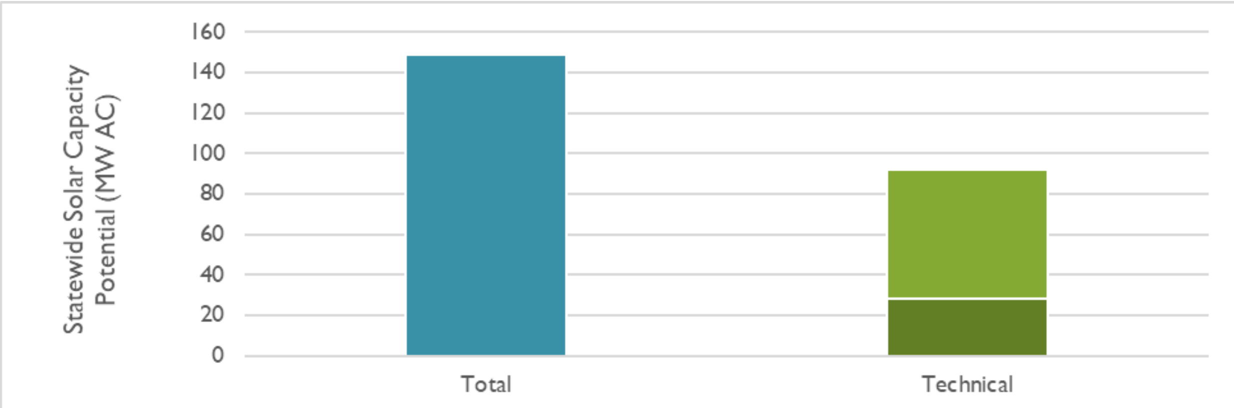


Table 12. Summary of gravel pit solar potential

Subcategory	Total potential (MW)	Technical potential (MW)	Avoided GHG emissions (MT CO2)
Gravel pits	150	30 – 90	29,300 – 96,300

Figure 18. Gravel pit total and technical potentials (MW)



Total potential

Total potential refers to the entire quantity of solar possible, less the solar capacity currently installed through Fall 2019.

Data and methods

A polygon shapefile for gravel pits in Rhode Island does not already exist; therefore, we utilized a point-based shapefile from USGS as a starting point for this analysis.[32] Because of the small number of gravel pits in the point-based shapefile, we were able to create our own polygon-based shapefile. To do so, we used satellite imagery to assist in drawing a polygon around the extent of each gravel pit or mine in the state. As a second step, we merged each of those custom-drawn polygons to any intersecting parcel polygons. The resulting polygons reflect the shape of all parcels within which a gravel pit or mine is located (Figure 19). Total potential (in MW) was then calculated by multiplying the total area of all gravel pits with the NREL-derived value representing the number of MW that can be built per square kilometer.

[32] United States Geological Survey. 2003. Active mines and mineral plants in the US. Available at: https://mrdata.usgs.gov/catalog/cite-view.php?cite=17.

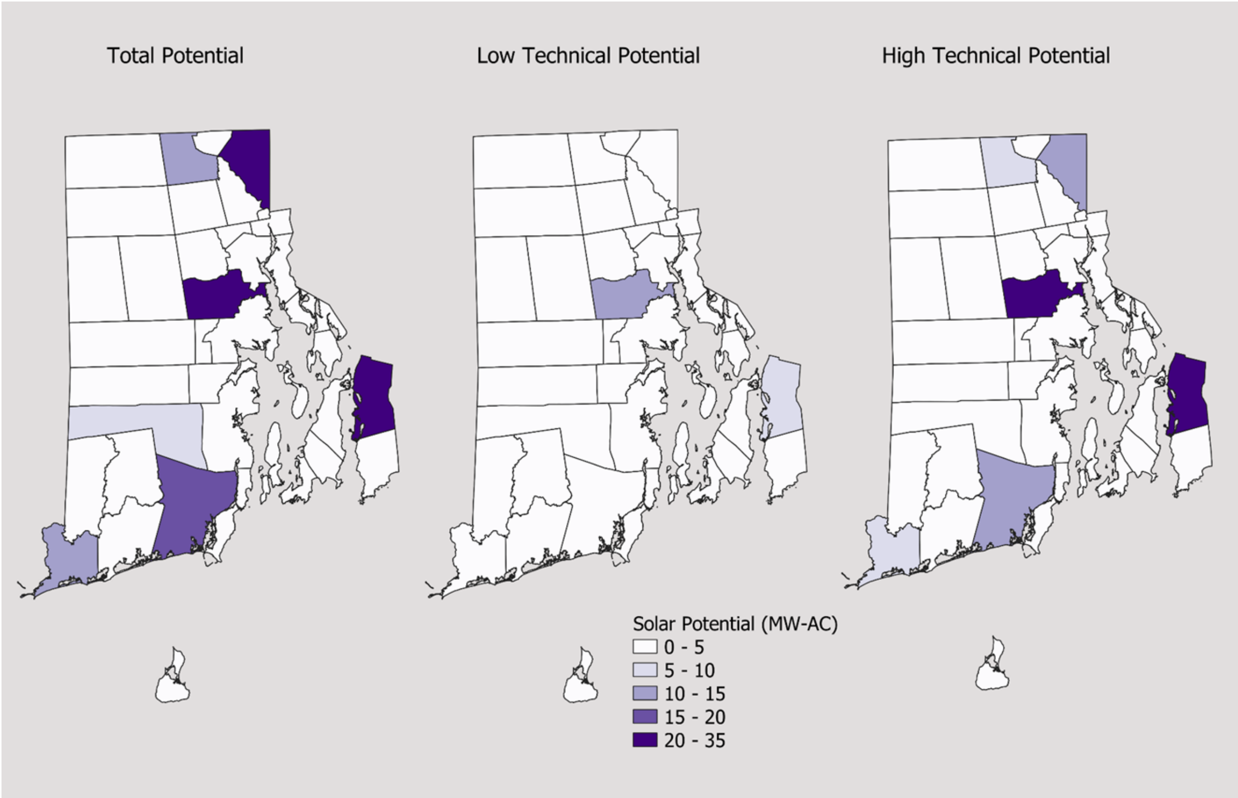
Figure 19. Example gravel pit polygons, after the merge with parcel polygons

Note: Municipality names for each gravel pit are located in the bottom corner of the images.

Findings

We calculate the total solar PV potential of Rhode Island is 150 MW. The City of Cranston has the highest total potential, at 40 MW (see Figure 20).

Figure 20. Maps of gravel pit total, low technical, and high technical solar potentials by municipality (MW)



Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

The process for calculating technical potential for solar at gravel pits followed the same process as landfills. After identifying each of the polygons, we applied the same technical potential filters that were applied to landfills: setbacks from the edge of the landfill property (50 and 375 ft), a setback from any buildings on the property (50 ft), land-use restrictions, and land slope.

As in our landfill analysis, we calculated two technical potential areas for gravel pits—a low technical potential area (using the 375 ft setback) and a high technical potential value area (using the 50 ft setback). The low and high technical potential areas were multiplied by the same MW-per-square-kilometer value used in the total potential analysis, yielding a low and high technical potential estimate for solar PV capacity on gravel pits.

Findings

This process yielded a statewide low technical potential of 30 MW and a statewide high technical potential of 90 MW. The City of Cranston, which had the highest total potential, also had the highest technical potential, with a range of 10 to 20 MW (Figure 20).

Caveats and data limitations

The following caveats apply to the gravel pit analysis:

First, because the original point-based shapefile only included active mines (as categorized by the US Geological Survey in 2003), there might be other inactive gravel pits in Rhode Island not included in this assessment. Because these locations are defined as "active," solar installations may not be possible at some or all parts of the site at this point in time.

Second, because the gravel pit boundary polygons were merged with the boundaries of intersecting parcels, there is a possibility that our resulting polygons over-estimate the geographic area of the gravel pits.

Third, because the LIDAR data used to calculate slope was collected in 2011, there is a possibility that the slope analysis unnecessarily removes parts of gravel pits that have been smoothed. Alternatively, the slope analysis may neglect to filter out steep slopes from pits that have had additional topographical changes since 2011.

Fourth, only gravel pit area that is less than 10 degrees sloped is considered to be feasible for solar under our definition of technical potential. Solar installations may be possible at locations with steeper slopes, which means that our technical potential would be an underestimate.

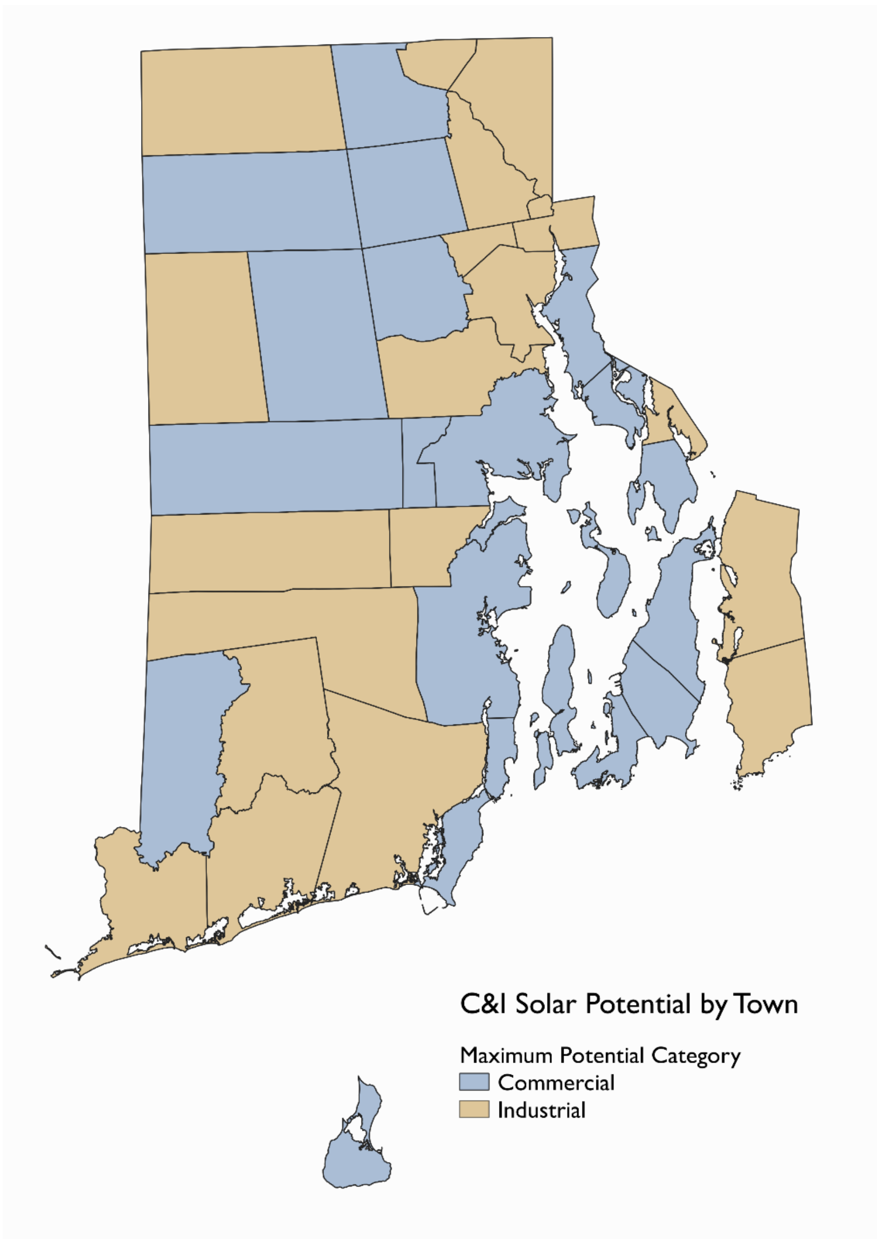
As with all ground-mounted solar estimates, the range of technical potential hinges on the assumed setbacks. See the "Estimating Setbacks" sidebar for more information on how different assumptions for this category could produce changes in technical potential.

3.4. Solar potential at developed and undeveloped commercial and industrial parcels

Commercial and industrial developed and undeveloped parcels (referred to in this report as "C&I parcels") are plots of land that are zoned for commercial or industrial use, or both. By joining zoning and parcel data from each of the towns and cities in Rhode Island, we were able to determine whether each parcel could be categorized as commercial or industrial. Note that this section is only concerned with ground-mounted solar potential on C&I sites and does not include rooftop solar on commercial or industrial sites. Rooftop solar on commercial and industrial buildings is discussed above in Chapter 2. This analysis includes parcels that are both completely undeveloped (e.g., devoid of any existing buildings), as well as parcels that currently have existing buildings in place. For this latter type of parcel, we examined the available area after removing any area associated with building footprints or existing solar installations.

We estimate the aggregate technical potential of ground-mounted solar on C&I parcels to be 1,200 to 4,600 MW (see Table 13 and Figure 22). Figure 21 illustrates whether each municipality has a predominance of commercial or industrial parcels with potential for solar PV. About half of Rhode Island municipalities have a majority of total potential located on commercial buildings, with the other half on industrial buildings. The same is true of the statewide C&I technical potential values: about half of Rhode Island municipalities have a majority of technical potential located on commercial buildings, with the other half on industrial buildings.

Figure 21. Maximum potential category in C&I parcels by municipality



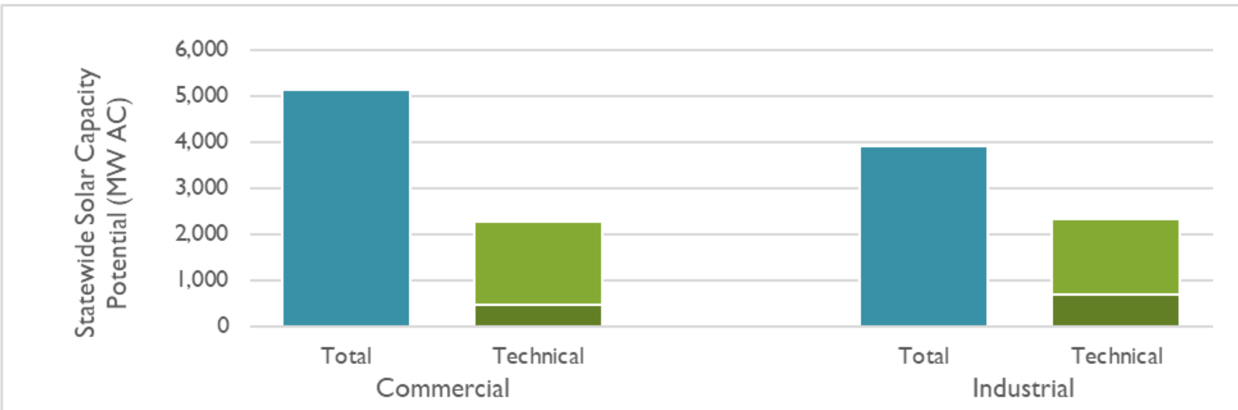
Note: Data described in this figure refers only to ground-mounted commercial and industrial solar facilities. Rooftop-mounted potentials are described above in Chapter 2.

Table 13. Summary of commercial and industrial parcel solar potential

Subcategory	Total potential (MW)	Technical potential (MW)	Avoided GHG emissions (MT CO2)
Commercial	5,120	470 – 2,300	5,372,500 – 2,398,500
Industrial	3,920	680 – 2,300	715,500 – 2,435,300
Total	**9,040**	**1,160 – 4,600**	**1,213,300 – 4,833,800**

Note: Data described in this table refers only to ground-mounted commercial and industrial solar facilities. Rooftop-mounted potentials are described above in Chapter 2.

Figure 22. Commercial and industrial total and technical potentials (MW)



Note: Data described in this figure refers only to ground-mounted commercial and industrial solar facilities. Rooftop-mounted potentials are described above in Chapter 2.

Total potential

Total potential refers to the entire quantity of solar possible, less the solar capacity currently installed through Fall 2019.

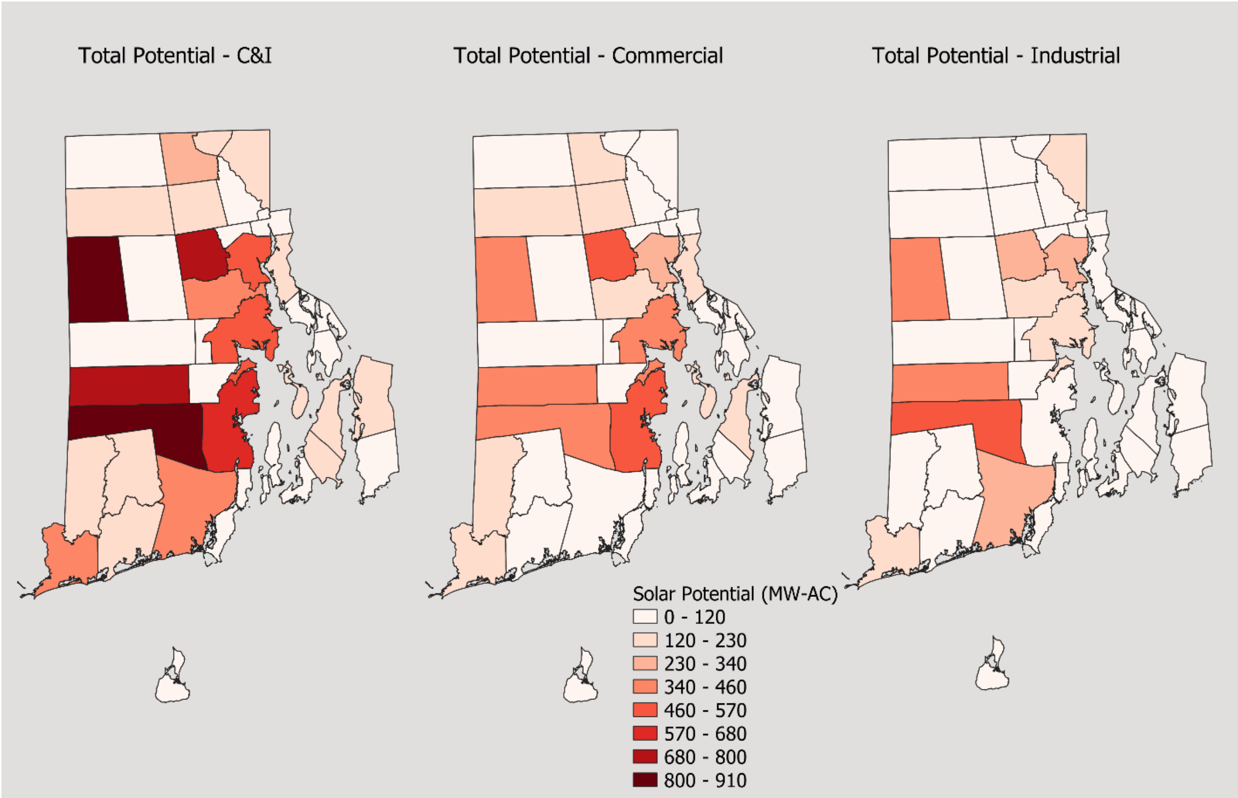
Data and methods

Using zoning and parcel data provided by most cities and towns in Rhode Island, we identified each parcel as being industrial or commercial. The areas of these parcels were then aggregated by municipality and multiplied by an NREL-derived factor describing the quantity of ground-mounted solar able to be installed per square kilometer (see section on Landfill Total potential, above).

Findings

The statewide total potential on C&I parcels is estimated to be 9,000 MW (see Figure 23).

Figure 23. Map of total potential for C&I parcels by building type (MW)



Note: Data described in this figure refers only to ground-mounted commercial and industrial solar facilities. Rooftop-mounted potentials are described above in Chapter 2.

Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

For each commercial and industrial parcel, we applied most of the same technical potential filters that were applied to landfills: setbacks from the edge of the landfill property (50 and 375 ft), a setback from any buildings on the property (50 ft), and land-use restrictions.[33] As with landfills, this process yielded both a low end and a high end for technical area. These resulting high and low technical potential areas were then multiplied by the ground-mount installation MW-per-square-kilometer value used in the total potential calculation to produce a range of technical potential MW.

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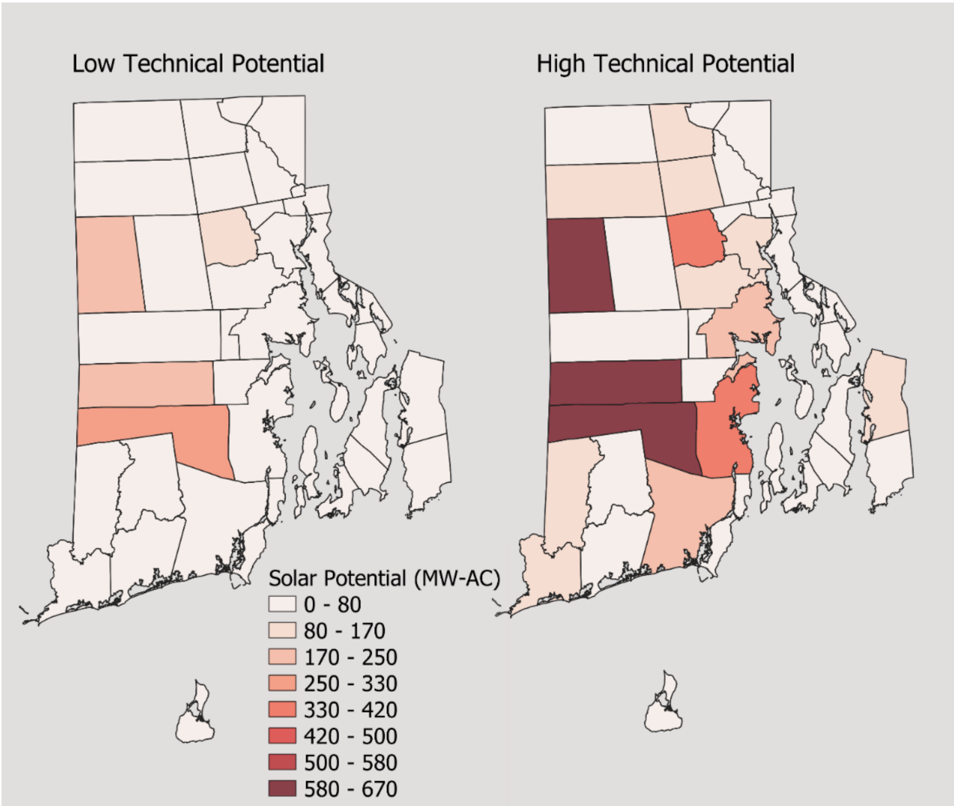
[33] We did not analyze land slope for commercial and industrial parcels due to computational barriers in estimating slope for thousands of discrete parcels.

Findings

The technical potential filters reduce the C&I potential to between 1,200 to 4,600 MW (see Figure 24).

Figure 24. C&I low and high technical potential (MW)



Note: Data described in this figure refers only to ground-mounted commercial and industrial solar facilities. Rooftop-mounted potentials are described above in Chapter 2.

Caveats and data limitations

Commercial and industrial parcels were identified using zoning and parcel data provided by the municipalities. Municipalities' individual zoning data are of different vintages and have different characteristics influencing the results for this category. Out of the 39 municipalities in Rhode Island, Synapse received zoning and parcel data from 34 of the municipalities (see Appendix B for more information). For the municipalities from which we did not receive zoning and parcel data, we used census data to find a similar municipality (based on data on housing density, median income, and population) and used that municipality's C&I parcels per square mile. We then applied this ratio to the municipality without data using that municipality's square mile data. This may mean that potentials for these municipalities may be under- or over-estimated, depending on how similar or different they are to the proxy municipality in terms of zoned area.

We were only able to include one-third of existing brownfield sites in the state using GIS mapping, and were thus able to only remove the brownfields from the C&I category that were correctly coded. This means that there is still some overlap between the C&I parcels we have identified here and other existing brownfields. As a result, we are likely overcounting some amount of existing solar in this category that is actually built on brownfields, and double-counting some amount of total and technical potential that is already counted with brownfields.

Finally, some municipalities may currently have zoning ordinances that govern where ground-mounted solar may be installed. Because of the challenges in comprehensively analyzing all 39 municipalities' most-up-to-date zoning ordinances, these special cases were not considered in our analysis. As a result, technical potentials for municipalities with such ordinances maybe lower than the values estimated in this report.

3.5. Estimated annual generation

The estimated annual generation (measured in GWh) for total and technical potential on ground-mounted solar sites was calculated using an NREL-derived capacity factor of 20 percent for solar facilities in Rhode Island.[34] Capacity factors for ground-mounted facilities are typically higher than rooftop-mounted facilities as it is easier to site ground-mounted facilities for maximum solar output. The aggregated technical potential across all ground-mounted categories totals 2,610 to 9,650 GWh. As a point of reference, according to ISO New England, wholesale electricity load for Rhode Island in 2020 totaled 7,826 GWh.[35] Although the high end of this range exceeds the current electricity load for Rhode Island, the ability for solar to completely meet in-state electricity demand is limited by timing of generation and demand, hosting availability (see Chapter 5), and other factors.

Table 14. Estimated annual ground-mounted generation (GWh)

Subcategory	Total potential	Technical potential
Landfills	730	120 – 450
Brownfields	1,830	450 – 1,120
Gravel pits	260	50 – 160
Commercial and Industrial	15,500	1,990 – 7,920
Commercial	8,800	820 – 3,930
Industrial	6,700	1,170 – 3,990
Total	**18,320**	**2,610 – 9,650**

[34] Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf. .

[35] ISO New England's 2020 CELT Forecast, available at https://www.iso-ne.com/static-assets/documents/2020/04/forecast_data_2020.xlsx. Note that this number refers to net demand, after taking into account the impact of existing energy efficiency and distributed PV resources.

3.6. Costs

Table 15 summarizes the estimated historical costs of ground-mounted solar. As with rooftop solar, costs are presented using two different metrics:

- Dollars per Watt, direct current ($\$/W_{DC}$)—a metric commonly used in the solar industry to compare the installed costs of solar across different facilities
- Dollars per megawatt-hour, alternating current ($\$/MWh_{AC}$), a metric that is commonly used to compare the lifetime, levelized costs of different types of generating facilities (e.g., solar, wind, and natural gas combined cycle).[36]

For example, the median cost of ground-mounted solar installations is $\$3.21/W_{DC}$, or $\$122/MWh_{AC}$. In addition to median values, we also report the following percentiles—5th, 20th, 80th, and 95th—in order to indicate the range of solar costs reported by the REF and REG programs. All costs are presented in 2018 dollars.

Table 15. Costs of ground-mounted solar

Cost type	Minimum (5%)	Low (20%)	Mid (50%)	High (80%)	Maximum (95%)
$\$/W_{DC}$	\$1.21	\$1.71	\$3.21	\$4.04	\$5.52
$\$/MWh_{AC}$	\$53	\$70	\$122	\$151	\$203

For ground-mounted solar categories, robust cost data for each category was not available, and a typical cost for ground-mounted solar is shown instead. Calculation of a $\$/MWh_{AC}$ cost requires assumptions about capacity factors, DC-to-AC conversion ratios, operating and maintenance costs, and financing costs which may vary in reality for each solar installation.[37]

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[36] Data on REF costs provided by Rhode Island Commerce Corporation in Fall 2019; data on REG costs provided by National Grid in Spring 2020. All other costs are based on REG data provided by National Grid.

[37] For ground-mounted solar, we assume a 20 percent capacity factor (based on data from Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf), an 87 percent DC-to-AC conversion rate, based on data provided to Synapse by National Grid, a fixed operating and maintenance cost of \$20/kW (based on data from NREL's 2019 "Alternative Technology Baseline" study), a variable operating and maintenance cost of \$0/kWh (based on data from NREL's 2019 "Alternative Technology Baseline" study), and a financing cost of 5 percent (based on data from NREL's 2019 "Alternative Technology Baseline" study).

Case Study: Incremental Costs of Ground-Mounted Solar on a Non-Conventional Site

The cost of installing ground-mounted solar on sites like brownfields, landfills, and gravel pits may be higher than similar installations on conventional ground-mounted sites, due to additional permitting and site remediation costs prior to installing the solar panels. To better understand these costs, we used a survey to elicit feedback from solar developers. Revity Energy LLC provided detailed information for one landfill/brownfield combination solar installation.

Table 16 illustrates the estimated incremental costs for several cost categories for the 6.3 MW_{DC} installation at Kilvert Street in Warwick. At this site, incremental costs were estimated to be approximately $0.13 per W_{DC} above comparable conventional ground-mounted installations. Relative to the Mid (50th percentile) cost estimates described in Table 15, this represents an increase of 4 percent. According to this particular developer, the incremental installation costs are primarily due to additional construction expenses required to prepare the land for the installation of the panels. In addition, this site also has a less ideal slope than other comparable installations. This inhibits optimum solar production, reducing the site's capacity factor by an average of 2 percentage points, relative to comparable conventional sites.

Note that this case study is included in order to provide context on possible incremental costs at non-conventional ground-mounted sites. These costs may not necessarily be representative of all installations at brownfields, landfills, or gravel pits. In addition, solar installations on developed and undeveloped commercial and industrial parcels may not be substantially different or more costly than solar developed on conventional ground-mounted sites.

Table 16. Estimates of incremental costs for brownfield solar installations

Cost Category	Incremental Costs ($/$W_{DC}$)
Permitting/ Professional Fees	**$0.03**
Legal	$0.01
Civil engineering	$0.01
Environmental engineering	$0.01
Survey	<$0.01
Miscellaneous permits	<$0.01
Site Remediation	**$0.03**
Removal of electrical debris	$0.01
Solid waste excavation	$0.02
Landfill cap repair	$0.01
Construction	**$0.05**
Drainage work	$0.02
Ballasted block for cap	$0.02
Cable tray system for cap	$0.01
Developer Burden	**$0.01**
Oversight/ coordination	$0.01
Total	**$0.13**

Source: Revity Energy
Note: Totals may not equal the sum of numbers due to rounding.

3.7. Avoided emissions

To calculate the avoided emissions associated with each category of solar PV, we used U.S. EPA's AVERT model. We utilized distributed solar PV CO_2 emissions factors from AVERT's Northeast region to calculate the avoided emissions associated with rooftop solar PV in Rhode Island. In total, we estimate that the 1,480-5,430 MW ground-mounted technical potential is capable of avoiding between 1.6 and 5.9 million metric tons of CO_2 ($MMTCO_2$).

Table 17. Avoided emissions, all ground-mounted technical potential (metric tons CO_2)

Subcategory	Avoided GHG emissions
Landfills	74,600 – 273,500
Brownfields	272,600 – 685,600
Gravel pits	29,300 – 96,300
Commercial and Industrial	1,213,300 – 4,833,800
Commercial	497,800 – 2,398,500
Industrial	715,500 – 2,435,300
Total	**1,589,800 – 5,889,200**

4. PARKING LOTS

At the time of this report's publication, deployment of solar on parking lots was limited in Rhode Island. Yet it is an area of increasing interest. Parking lot solar is typically mounted on independent raised structures, also known as carports, and is in some ways a hybridization of rooftop solar and ground-mounted solar. By using crowdsourced data as a foundation for this analysis, we were able to develop estimates of total and technical potential for each municipality in the state. In aggregate, we estimate the technical potential of carport solar to be 1,060 MW (see Figure 26, Table 18 and Figure 26).

Figure 25. Map of parking lot quantity by municipality

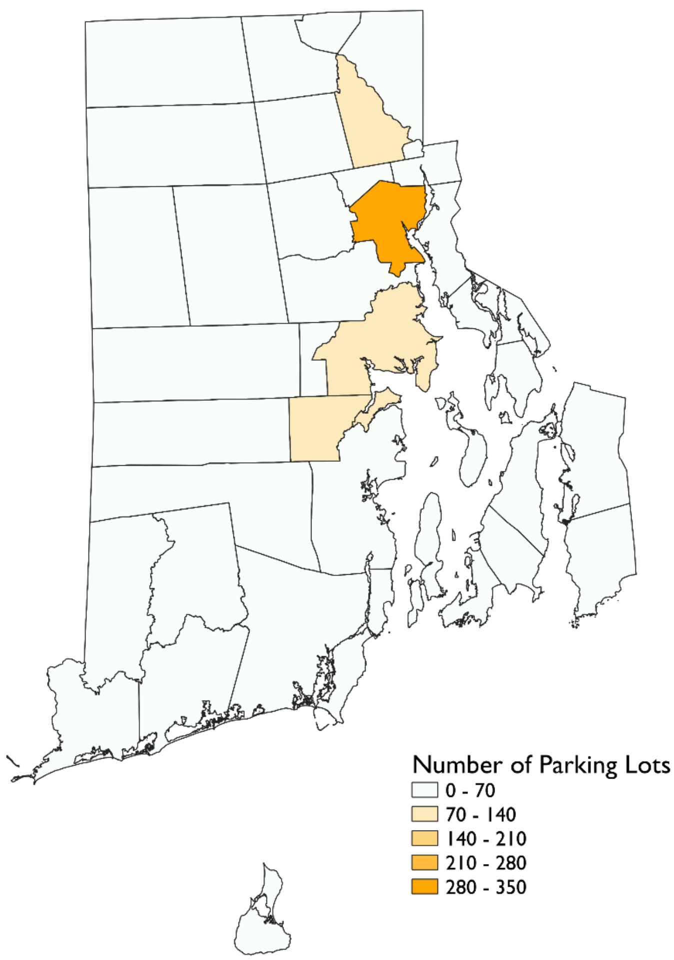
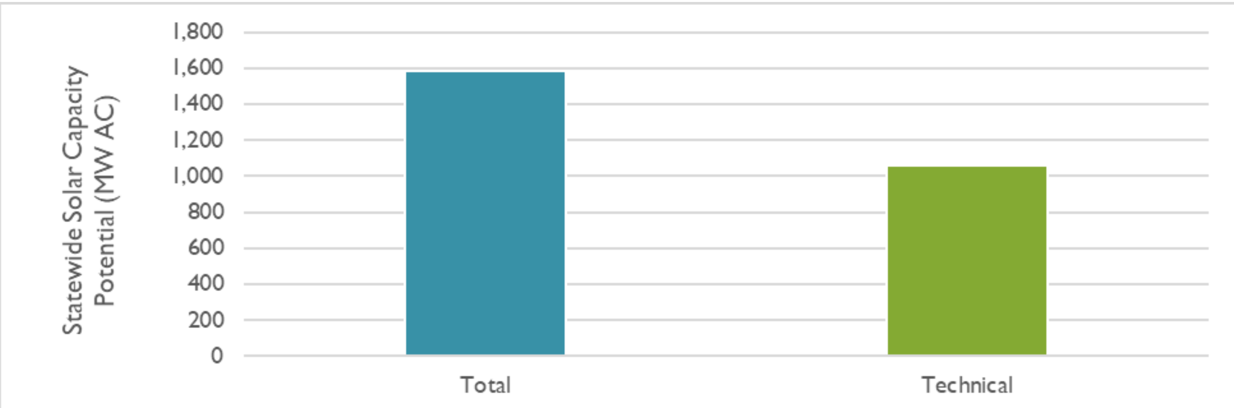


Table 18. Summary of parking lot solar potential

Subcategory	Total potential (MW)	Technical potential (MW)	Technical potential (GWh)	Avoided GHG emissions (MT CO2)
Parking lots	1,590	1,060	1,820	1,191,400

Figure 26. Parking lot total and technical solar PV potential (MW)



4.1. Parking lot solar potential

For the calculation of total and technical potentials in this study, we primarily relied on GIS data from OpenStreetMaps.com[38] and population data from the U.S. Census.[39]

Total potential

Total potential refers to the entire quantity of parking lot solar possible.

Data and methods

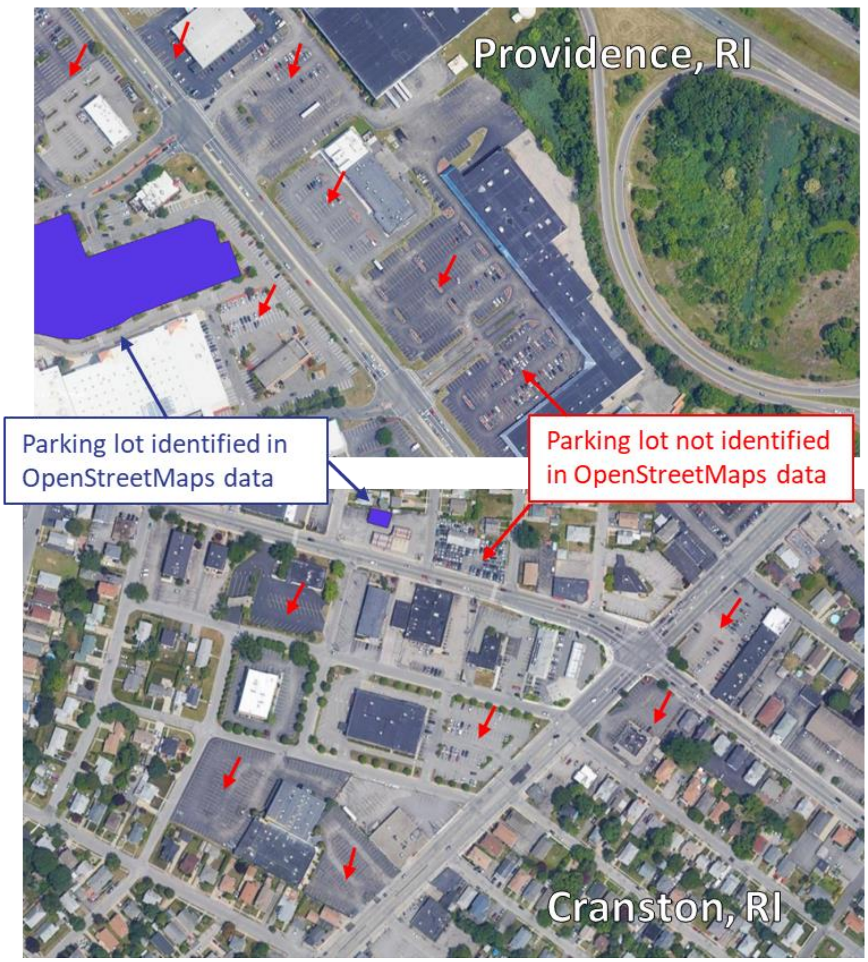
First, we used a crowdsource-generated shapefile obtained from OpenStreetMaps.com to identify a subset of the parking lots throughout Rhode Island. While in many situations, users have developed polygons that accurately represent the dimensions of parking lots across the state, this dataset is far from comprehensive. Generally, parking lot data tends to be more complete in more populated areas while some cities and towns lack any parking lot data whatsoever.

[38] Data downloaded from http://download.geofabrik.de/north-america/us/rhode-island.html, accessed October 2019.

[39] U.S. Census data obtained from RI GIS clearinghouse at http://www.rigis.org/datasets/us-census-2000-summary-file-3-population-and-statewide-housing.

As a result, we performed a series of spot checks for different-sized municipalities (by population) to estimate the number of parking lots not included in the OpenStreetMaps.com dataset. For eight locations across Rhode Island, we analyzed small, medium, and large municipalities and estimated the number of parking lots not mapped in the OpenStreetMaps.com dataset. Figure 27 demonstrates how parking lots were identified as included in the dataset or missing for two example locations. Table 19 describes the results of this calibration step. Each city and town was then classified as small, medium, or large using population data from the U.S. Census and the number of parking lots within that municipality was then scaled up according to the factors described in Table 19.[40] The resulting parking lot areas were then multiplied by the same NREL-derived factor describing the quantity of ground-mounted solar able to be installed per square kilometer used in the ground-mounted solar analysis. This capacity factor was based on discussions with solar developers, who indicated that siting parking lot solar for maximum solar output was more akin to ground-mounted solar than rooftop-mounted solar.

Figure 27. Example of parking lot calibration step using OpenStreetMaps.com dataset



[40] For municipalities that did not have any parking lots mapped in the OpenStreetMaps.com dataset, we applied a number derived from the statewide average.

Table 19. Estimate of parking lots missing from OpenStreetMaps.com dataset by municipality population

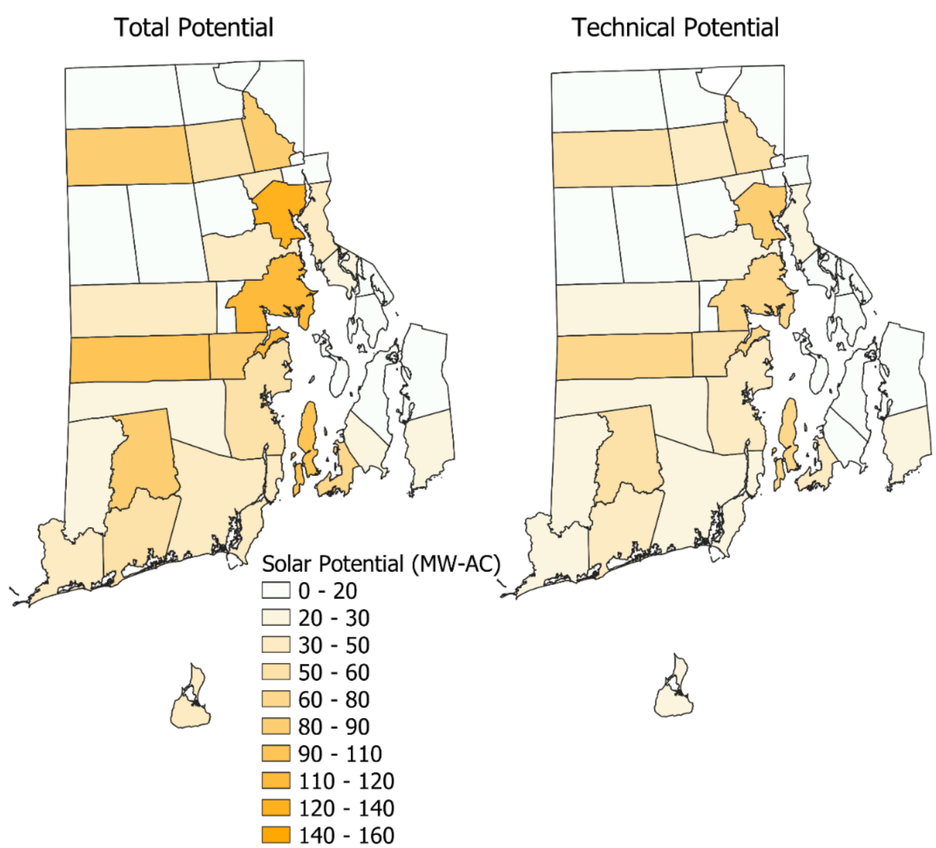
City size	Definition by population	% of parking lots estimated missing from OpenStreetMaps.com dataset
Small	<10,000	97.5%
Medium	10,000 to 100,000	85%
Large	>100,000	60%

Findings

We calculate the total potential of parking lot solar at approximately 1,590 MW. Providence has the highest total potential, at 130 MW.

Given the limitations of the geospatial parking lot data (crowd-sourced and focused on only certain parts of the state), these potential estimates likely have a high level of uncertainty. Furthermore, because there is limited literature available on land use dedicated to parking lots in Rhode Island, validation of the OpenStreetMaps data and the resulting estimates of parking lot solar potential is challenging.

Figure 28. Maps of total and technical parking lot solar potential (MW)



Technical potential

Technical potential is a subset of total potential that includes only areas that are suitable for solar development.

Data and methods

To estimate technical potential, we applied a building setback to the GIS data obtained from OpenStreetMaps.com. Using the building footprint shapefile from RI GIS (described above in Chapter 2. Rooftops), we removed any areas that were within 50 feet of a building in order to avoid impacts of shading (see "Estimating setbacks" sidebar in Section 3.1).[41] As with total potential, these technical potentials were then adjusted to reflect the number and area of parking lots likely to be missing from the OpenStreetMaps.com dataset. Our analysis does not take into account any reductions reflecting owners' possible preferences for avoiding siting solar along main road frontage in order to maintain business visibility.

Findings

The statewide technical potential is calculated to be 1,060 MW, with the highest potential located in Providence (80 MW).

4.2. Estimated annual generation

The estimated annual generation (measured in GWh) for total and technical potential on carport solar sites was calculated using an NREL-derived capacity factor of 20 percent for solar facilities in Rhode Island.[42] The technical potential for parking lot solar totals 1,820 GWh. As a point of reference, according to ISO New England, wholesale electricity load for Rhode Island in 2020 totaled 7,826 GWh.[43] Although this technical potential represents 23 percent of the current electricity load for Rhode Island, the ability for solar to completely meet in-state electricity demand is limited by timing of generation and demand, hosting availability (see Chapter 5), and other factors.

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[41] A single setback number was used for purposes of simplicity. Each of the 39 towns and cities in Rhode Island has its own zoning ordinance, which may contain different rules governing setbacks on different parcel types (dense commercial, low-rise industrial, downtown area, etc.). The actual required setback at each parking lot may differ based on these zoning ordinances, as well as physical features at the site (e.g., height of nearby buildings or trees).

[42] Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf.

[43] ISO New England's 2020 CELT Forecast, available at https://www.iso-ne.com/static-assets/documents/2020/04/forecast_data_2020.xlsx. Note that this number refers to net demand, after taking into account the impact of existing energy efficiency and distributed PV resources.

Table 20. Estimated annual carport-mounted generation (GWh)

	Total potential	Technical potential
Carports	2,730	1,820

Costs

Based on limited data from two existing parking lot solar facilities installed under the REF program through Fall 2019, we estimate that solar installed on carports costs \$5.09/W_{DC} (see Table 21).[44] This is about \$2/W_{DC} higher than the estimated cost of ground-mounted solar or solar installed on non-residential rooftops, and about \$1/W_{DC} higher than the estimated cost of solar installed on non-residential rooftops. This in line with estimates described by two different solar developers (described via survey and phone conversations), who estimate a cost adder of \$1.00 to 1.50 per W_{DC}, relative to rooftop solar. According to discussions with solar developers, these incremental costs are often due to more complexities relating to engineering and permitting, as well as additional costs related to building the carport structure itself. All costs are presented in 2018 dollars.

Table 21. Costs of carport-mounted solar

Cost type	Middle estimate
\$/W_{DC}	\$5.09
\$/MWh_{AC}	\$222

As with other solar categories, the calculation of a \$/MWh_{AC} cost for parking lot solar requires assumptions about capacity factors, DC-to-AC conversion ratios, operating and maintenance costs, and financing costs which may vary in reality for each solar installation.[45]

Avoided emissions

To calculate the avoided emissions associated with each category of solar PV, we used U.S. EPA's AVERT model. We utilized distributed solar PV CO_2 emissions factors from AVERT's Northeast region to calculate the avoided emissions associated with rooftop solar PV in Rhode Island. In total, we estimate

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[44] Parking lot solar installations in Rhode Island remain limited. At the time this report was published, there were known to be fewer than six such installations.

[45] For parking lot solar, we relied the same assumptions as ground-mounted solar: we assume a 20 percent capacity factor (based on data from Brown, A., P. Beiter, D. Heimiller, C. Davidson, P. Denholm, J. Melius, A. Lopez, D. Hettinger, D. Mulcahy, and G. Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy15osti/64503.pdf), an 87 percent DC-to-AC conversion rate, based on data provided to Synapse by National Grid, a fixed operating and maintenance cost of \$20/kW (based on data from NREL's 2019 "Alternative Technology Baseline" study), a variable operating and maintenance cost of \$0/kWh (based on data from NREL's 2019 "Alternative Technology Baseline" study), and a financing cost of 5 percent (based on data from NREL's 2019 "Alternative Technology Baseline" study).

that the 1,060 MW carport technical potential is capable of avoiding about 1,191,400 metric tons of CO_2, or 1.2 million metric tons ($MMTCO_2$) (see Table 22).

Table 22. Avoided emissions, carport technical potential (metric tons CO_2)

	Avoided GHG emissions
Carports	1,191,400

Caveats and data limitations

We relied on crowdsourced geospatial data from OpenStreetMaps.com, a tool for creating and sharing map information, to estimate the number and area of parking lots in Rhode Island. Although this dataset does provide accurate polygons for many parking lots throughout the state, it is largely incomplete. While data created in this dataset relies on local knowledge, anyone can contribute to it and the ultimately quality of the data depends on the input of the contributors. Based on spot checks, parking lot polygons appear to be accurate at a high level, but data quality is typically better in urban areas (especially downtown Providence) as opposed to rural areas. In addition, there is limited literature available on land use dedicated to parking lots in Rhode Island which makes validation of OpenStreetMaps data challenging. As a result, our total and technical potential estimates are uncertain.

Existing data on carport solar is currently very limited. For this analysis, we had access to cost data at two installations that existed as of Fall 2019. By Summer 2020, there were roughly half-dozen installations in Rhode Island. Because of the limited number of in-state installations, assumptions on capacity factor and kilowatts-per-square-kilometer were instead based on conventional ground-mounted solar installations solar data. Actual values for parking lot solar installations may be different.

Our analysis does not take into account that buildings adjacent to parking lots may be taller or shorter than assumed here. This could impact the necessary setback and affect the overall technical potential. Likewise, our analysis does not take into account any setback requirements due to zoning or owners' preferences (e.g., avoiding siting solar along main road frontage in order to maintain business visibility).

Finally, our analysis also does not include any estimates of solar that could be installed on parking garages or other existing parking structures. Including carport solar sited at these facilities could increase the overall technical potential estimated here.

5. SOLAR POTENTIAL FROM ALL CATEGORIES

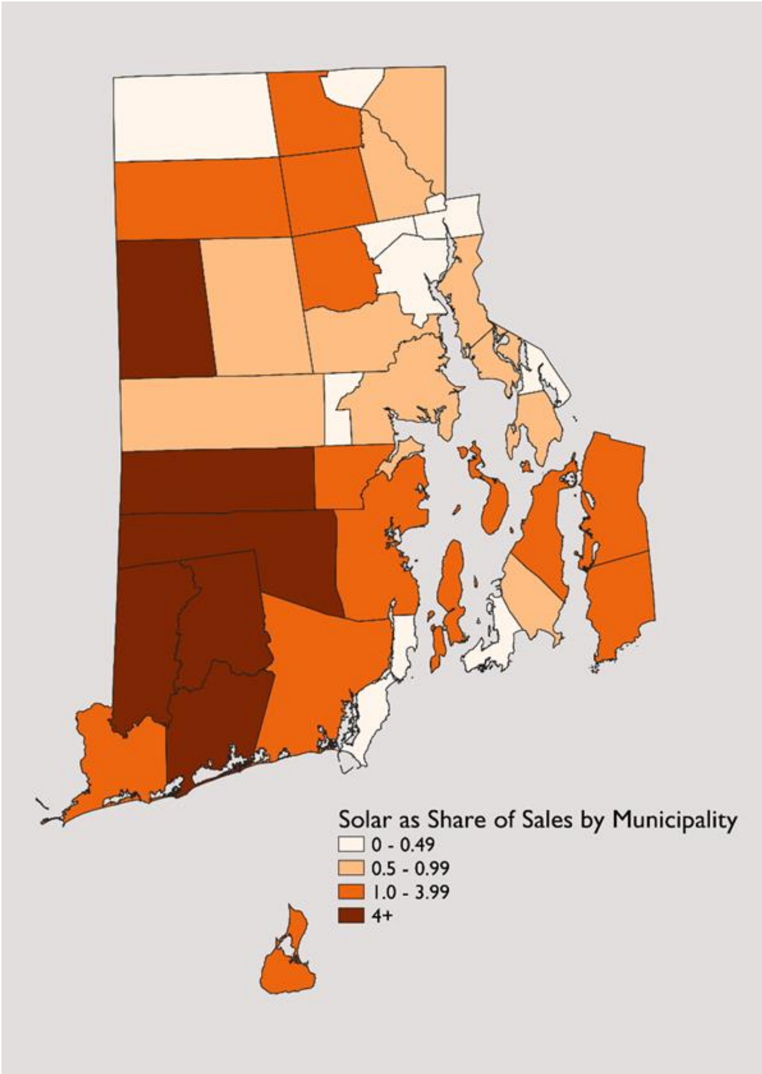
The preceding sections of the report analyze the total, technical, and economic potentials of solar within each category independently. However, some constraints that potentially impact the overall buildout of solar in Rhode Island may restrict the quantity of solar in aggregate. For example, solar of all categories contribute to a single hosting capacity—the amount of distributed energy resources that can be accommodated on the distribution system without adversely impacting power quality or reliability—for a given area. The following section discuss the aggregate impacts of solar by municipality (supplemented by data in Appendix E) and is followed by a section that discusses the impact of hosting capacity on municipality-wide solar potential.

5.1. Aggregate impacts by municipality

For purposes of comparison, we illustrate how these solar technical potentials compare to each municipality's annual retail sales. Figure 29 compares the average technical potential generation (estimated by averaging the "low" end and "high" end estimates for each municipality's technical potential) with retail electricity sales in each municipality.[46] For purposes of comparison, 20 of 39 municipalities—or roughly half—are estimated to have solar technical potentials that are smaller than that municipality's annual electricity sales. 19 municipalities have potentials that range from roughly equal to the municipality's electricity sales, to some multiple of that municipality's electricity sales.

[46] Retail electricity sales are calculated for each municipality using 2018 data from EIA's Form 861 (available at https://www.eia.gov/electricity/data/eia861/), but split out the total by town based on the town-specific sales provided by National Grid. EIA Form 861 reports statewide data for National Grid, Block Island Electric Co, and Pascoag Utility District. We assume that 100 percent of Block Island Electric Co's retail sales are in New Shoreham, and that 100 percent of Pascoag Utility District's retail sales are in Burrillville. We also assume that the retail sales for Pascoag Utility District comprise 50 percent of Burrillville's total electricity sales. We then allocate the remaining National Grid sales to each municipality based on population data obtained from U.S. Census.

Figure 29. Map of aggregate technical potential relative to retail electricity sales



Caveats

This analysis compares annual solar generation to annual retail electricity sales. These values may not be comparable on a daily or hour-by-hour basis, as solar generation does not perfectly match electricity consumption. For example, in summer months, solar output often peaks around noon, whereas the demand for electricity may not peak until later in the evening. Other technologies and practices, such as demand response and energy storage, may be able to better match electricity supply with electricity demand and more easily allow solar to provide a larger share of Rhode Island's electricity.

5.2. Impacts of hosting capacity

Hosting capacity is defined as the amount of distributed energy resources that can be accommodated on the distribution system without adversely impacting power quality or reliability. Unlike many other constraints assessed in this analysis (e.g., setbacks, land-use type) hosting capacities are physical constraints that can be overcome with infrastructure upgrades. In other words, though hosting capacities of a distribution system may be limited now, they can be mitigated through some amount of capital expenditure.

These capital expenditures can—in certain cases—be expensive relative to the size of the project. In other cases, these capital expenditures could potentially be reduced as a result of distributed storage to limit export to the grid, mitigating system upgrade needs and/or costs.

Case Study: Hosting Capacity Upgrade Costs

The cost to upgrade a distribution system in order to expand its hosting capacity may be high. To assist with understanding these costs, Revity Energy, a solar installer in Rhode Island, provided information on several projects that were not ultimately pursued because of hosting capacity costs.

Revity's team members note that in situations that require line upgrades, on average over the last 2 years, they have observed costs of $1.5 million per mile in line upgrades. In one instance, Revity noted that given the distance of the proposed solar installation from the closest substation, Revity estimated the total line upgrade could cost $13.5 million (compared to an estimated upfront cost of a $16 million for a 5 MW installation built at the median price of $3.21 described in Table 15). In addition, Revity has observed that in situations where substation upgrades are required, additional transformer banks may be needed, doubling total interconnection costs.

Note that this case study is included in order to provide context on possible costs associated with expanding hosting capacity. These costs to upgrade the distribution system are not necessarily unique to solar proposed on brownfield, landfill, or gravel pit sites, and may be a consideration at any proposed solar facility. However, the costs cited in this case study may not necessarily be representative of all installations or situations.

Data provided

Synapse received feeder hosting capacity data and shapefiles from National Grid, which contain information on the hosting capacity for 3-Phase lines throughout Rhode Island (Figure 30).[47] National Grid also provided shapefiles for 1- and 2-phase lines, but these lines do not have any numerical data about hosting capacity.

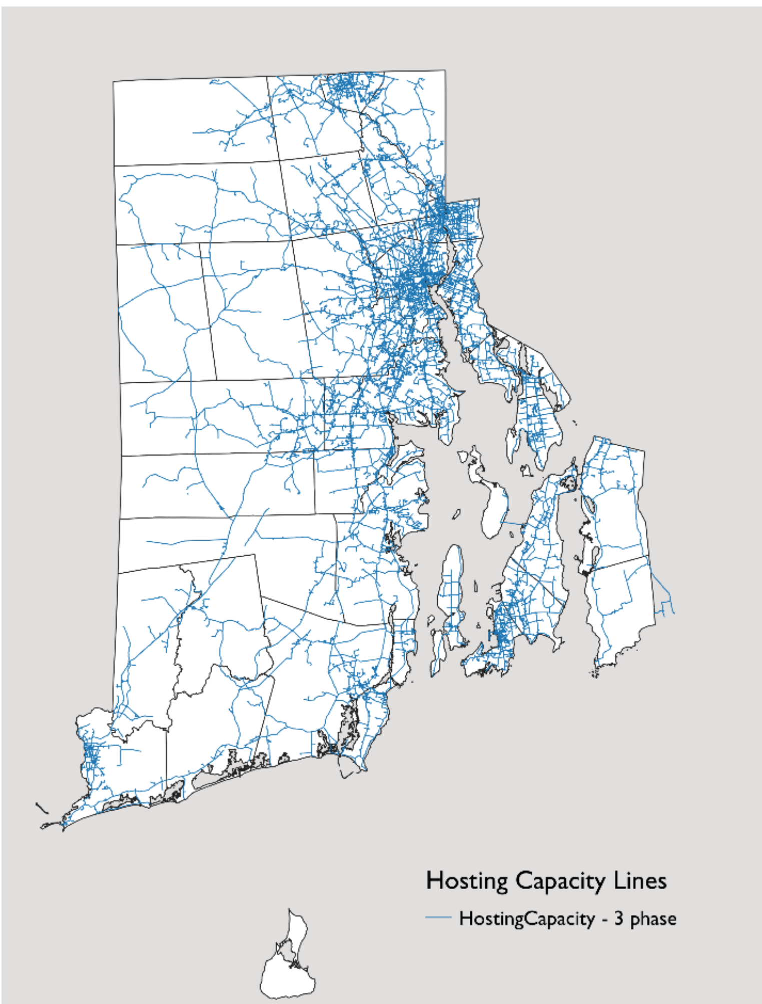
For each 3-phase line, we have several datapoints. These include the amount of distributed generation (DG) capacity currently connected to the line and the amount of DG capacity that is pending. The 3-phase lines are often very large and frequently span across municipalities. In many situations, the lines have forks or loops, which means that they are difficult, and usually impossible, to assign to a single municipality.

[47] A non-downloadable version of this data is also available at: https://www.arcgis.com/apps/MapSeries/index.html?appid=36c3c4ba3f92493a8d81aea4fae22d9d. Data used in this analysis was last updated November 12, 2019.

This 3-phase data also includes two types of information about available hosting capacity:

- The data points identified by National Grid as "Min Hosting Capacity" state that for any single 3-phase line, there is a segment of it that is limited in hosting capacity. For example, if this listed number were 150 kW, it might mean that for a 10-mile line, there could be a segment ¼ mile long that has a maximum hosting capacity of 150 kW. These numbers do not take into account any installed or pending DG capacity (i.e., if this limiting segment had 150 kW of DG currently installed, this number will still read as 150 kW).
- Meanwhile, the data points identified as "Max Hosting Capacity" also apply to only a single segment of the 3-phase line. But these refer to the maximum available capacity that is available for some segment of that line. For our 10-mile line example, this might mean that there is a 1-mile segment where there is 800 kW of capacity available. Unlike "Min Hosting Capacity," this second capacity number is reported *in addition* to existing DG.

Figure 30. 3-phase feeder lines in Rhode Island



The data received from National Grid represents the hosting capacity at a certain point in time (e.g., as of November 12, 2019). This hosting capacity evolves as the distribution grid changes. Because we cannot discern what the hosting capacities are at the sub-line resolution, and because we cannot assign lines to specific municipalities, it is impossible to identify the actual hosting capacity with any certainty. Given this limitation, we have performed a series of analyses that help to compare certain hosting capacity datapoints to aggregate technical capacity.

Approach

We divided our hosting capacity approach into two analyses: a project perspective analysis and a policy perspective analysis. The project perspective considers the hosting capacity issue from the perspective of a single installation: Where can a solar PV installation currently be hosted given capacity constraints? The policy perspective considers the hosting capacity issue from the perspective of multiple solar installations: What is the gap between solar PV potential and hosting capacity across the state, and where are the biggest gaps?

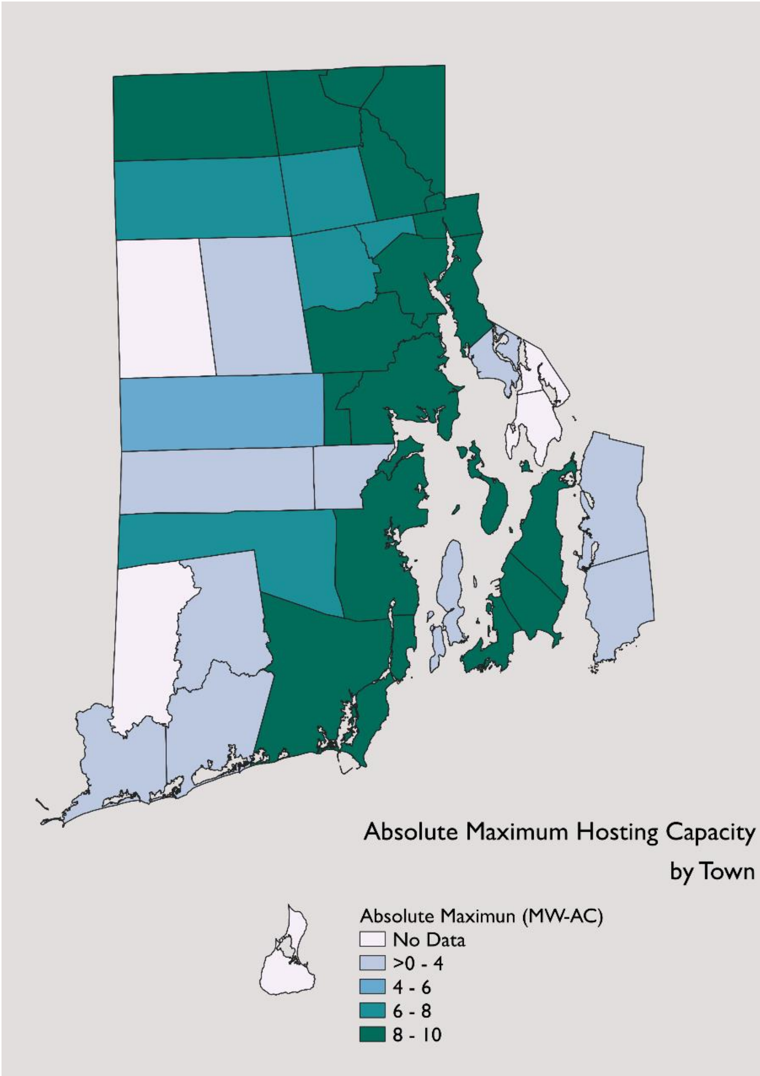
Project Perspective

For the project perspective analysis, we first identified all 3-phase feeder lines that go through each of the 39 municipalities. For each municipality, we examined the maximum incremental hosting capacity for any one of the lines that crosses the municipality boundaries. Figure 31 identifies the maximum hosting capacity currently allowable for each municipality on any one line.

Because lines cross municipal boundaries, and because we do not have data on where the maximum capacity is located on the line, it is possible that some of the observed maximum quantities are appropriate for certain municipalities, but not others.

According to this figure, 21 municipalities have a maximum available hosting capacity of 8 to 10 MW on at least one line. 15 towns have a maximum available hosting capacity of 0-8 MW on at least one line. Three municipalities do not have any 3-phase feeder lines or have missing data for the lines that do cross town boundaries. Municipalities in eastern parts of the state tend to have higher maximum incremental hosting capacities than municipalities in western parts of the state. This may be because these towns are more densely populated and therefore have a larger electric grid infrastructure.

Figure 31. Maximum incremental hosting capacity by municipality (project perspective)



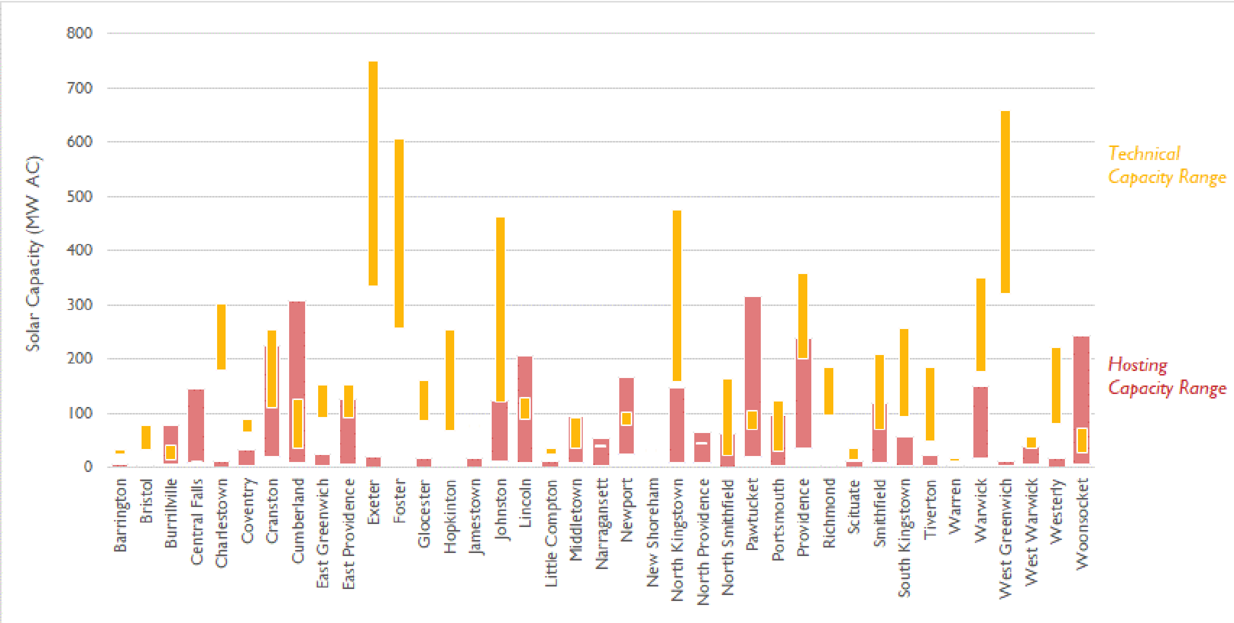
Policy Perspective

For the policy perspective, we compared the range of aggregate technical capacities (rooftops, landfills, gravel pits, C&I parcels, parking lots, and brownfields) with the range of hosting capacities (see Figure 32). The "low" end of each hosting capacity is calculated by summing the minimum hosting capacities for each of the lines within each municipality.[48] The "high" end of each hosting capacity is calculated by summing the maximum hosting capacities for each of the lines within each municipality. Because lines cross municipal boundaries, and because we do not have data on where the specific maximums or minimums are located, it is possible that some of the stated quantities are appropriate for certain municipalities, but not others. Using this approach, we find that the towns of Exeter, Foster, and West

[48] The actual minimum hosting capacity at certain points of the line may in fact be smaller, as the reported minimum hosting capacity does not account for any existing distributed resources.

Greenwich have the largest hosting capacity "gaps" in the state—each in excess of 430 MW. These towns have very high solar technical capacities and therefore may be priority towns for distribution system upgrades in the near future.

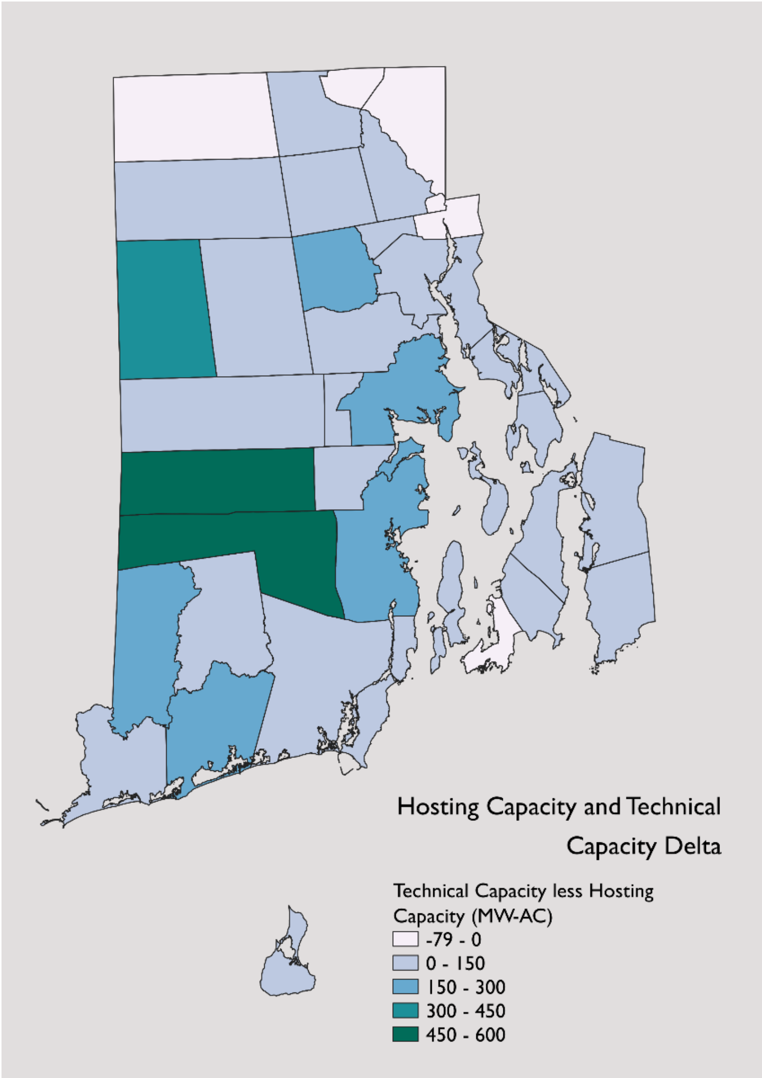
Figure 32. Technical solar capacity and hosting capacity ranges for each municipality in Rhode Island



This concept can be illustrated another way in map format. Subtracting the average hosting capacity from the average technical capacity in each municipality demonstrates the approximate hosting capacity "gap" for each municipality (see Figure 33). Looking at the entire state, about 85 percent of municipalities have a hosting capacity gap, meaning that 85 percent of municipalities have technical potentials that exceed their hosting capacities.

In summary, there is justification for a more thorough hosting capacity analysis for the state of Rhode Island using more granular geospatial data, if available. Such a study would provide more precise insights into which towns, and which distribution feeders, could benefit most from hosting capacity upgrades to support the adoption of solar.

Figure 33. Hosting capacity gap for each municipality in Rhode Island (policy perspective)



Note: Positive numbers indicate municipalities where the estimated technical potential exceeds the estimated hosting capacity. In contrast, negative numbers indicate municipalities that have larger hosting capacities than technical potentials.

6. CONCLUSION

Synapse's granular bottom-up geospatial analysis of Rhode Island's solar potential demonstrates that the state is host to between 3.4 and 7.3 GW of solar technical potential, with commercial and industrial developed and undeveloped parcels representing the largest category—up to 4.6 GW (Table 25). Parking lots represent the second-largest category, though the state has seen only very limited parking lot solar installations (e.g., fewer than ten) to date.

Within the residential category, single family rooftops have a higher economic potential than multifamily rooftops, with a potential up to 220 MW (Table 24), concentrated in the eastern portion of the state.

Table 23. Summary of potentials and costs, rooftops

Subcategory	Technical potential (MW)	Technical potential (GWh)	Estimated cost ($/Watt-DC)	Estimated cost ($/MWh-AC)	Potential avoided GHG emissions (MMTCO2)
Rooftop	850	1,130	$3.07 – $4.15	$153 – $208	0.74
Landfills	70 – 260	120 – 450	$3.21	$122	0.07 – 0.27
Brownfields	260 – 650	450 – 1,120	$3.21	$122	0.27 – 0.69
Gravel pits	30 – 90	50 – 160	$3.21	$122	0.03 – 0.10
Commercial and industrial parcels	1,160 – 4,600	1,990 – 7,920	$3.21	$122	1.21 – 4.83
Parking lots	1,060	1,820	$5.09	$188	1.19
Total	**3,390 – 7,340**	**5,560 – 12,600**	**-**	**-**	**3.47 – 7.65**

Table 24. Summary of total, technical, and economic potentials for residential rooftop solar

Subcategory	Total potential (MW)	Technical potential (MW)	High Economic Potential (MW)	Low Economic Potential (MW)
Residential Single Family	2,100	440	220	90
Residential Multifamily	480	100	40	20
Total	**2,580**	**540**	**260**	**110**

Though Rhode Island is host up to 4,680 MW of solar potential on rooftops, brownfields, landfills, gravel pits, and parking lots, the cost of developing these sites may be higher than equivalent installations on conventional ground-mounted sites due to additional permitting, construction, and site remediation costs. These incremental costs are likely to be site-specific and vary across sites with different characteristics. Though siting solar on these types of sites may address siting or environmental concerns, there are potential tradeoffs given potentials for additional costs and lower-than-average annual generation. Furthermore, hosting capacity limitations may also pose a tradeoff when deciding where to site solar projects. Our analysis indicates there are many towns across the state where distribution hosting capacity upgrades may be advantageous for interconnecting the state's future solar potential.

APPENDIX A. EXISTING SOLAR

Table 25. Existing solar installations and capacity by program and installation type

Program	Subprogram	Type	Total Installations	Total MW_{AC}	Range MW_{AC}
REF	Brownfield Solar PV Program	Roof	-	-	-
REF	Brownfield Solar PV Program	Ground	-	-	-
REF	Commercial Scale Program	Roof	108	14	0.009 - 5.692
REF	Commercial Scale Program	Ground	18	21	0.009 - 4.630
REF	Commercial Scale Program	Carport	2	0.4	0.048 - 0.174
REF	Commercial Scale Program	Unknown	1	0.2	0.217 - 0.217
REF	Commercial Scale Program	Roof/Ground Combination	2	0.4	-
REF	Commercial Scale Program	Roof/Ground/Carport Combination	-	-	0.118 - 0.169
REF	Small Scale Program	Roof	1,123	8	0.000 - 0.000
REF	Small Scale Program	Ground	60	0.5	0.001 - 0.022
REF	Small Scale Program	Roof/Ground Combination	1	0.01	0.001 - 0.024
REG, Small Scale	Commercial	-	13	0.1	0.006 - 0.015
REG, Small Scale	Individual	-	3,375	20	0.002 - 0.016
REG, Small Scale	Third-party owned	-	98	0.5	0.002 - 0.022
REG, Large Scale	Commercial-Scale Solar	Ground	9	7.1	0.434 - 0.868
REG, Large Scale	Commercial-Scale Solar	Rooftop	2	1.7	0.868 - 0.868
REG, Large Scale	Large-Scale Solar	Ground	4	9.3	1.364 - 3.520
REG, Large Scale	Medium-Scale Solar	Unknown	27	5.5	0.036 - 0.217
REG, Large Scale	Medium-Scale Solar	Rooftop	9	0.9	0.036 - 0.216
REG, Large Scale	Medium-Scale Solar	Ground	1	0.2	0.217 - 0.217
VNM	Unknown	-	20	52	0.060 - 7.387
DG Contracts		-	27	18	0.039 - 2.607
Community Solar Virtual Net Metering Pilot Program		-	1	2.5	2.5
Total			**7,711**	**186**	**-**
All Net Metering	Residential	-	7,341	44	-
All Net Metering	Commercial	-	208	21	-

Note: The data above comes from the following programs: REF, REG (Small), REG (Medium, Large, and Commercial), VNM, DG Contracts Program, the 30 MW pilot, and earlier non-programmatic net-metering. Values of "-" are shown for categories that have MW that have had incentives awarded, but are not existing as of Fall 2019. MW ranges highlight the minimum and maximum values reported for each subprogram. This does not include solar installed between fall 2019 and March 2020, which is estimated to total around 53 MW.
Source: RI Commerce Corporation and National Grid.

APPENDIX B. GEOSPATIAL SOURCES

Table 26. Geospatial data (parcels, addresses, and zoning) provided by municipality

Municipality	Parcels?	Addresses?	Zoning?	Notes
Barrington	Yes	Yes	Yes	
Bristol	Yes	Yes	Yes	
Burrillville	Yes	Yes	Yes	
Central Falls	Yes	Yes	Yes	
Charlestown	Yes	Yes	Yes	
Coventry	Yes	-	Yes	
Cranston	Yes	Yes	Yes	
Cumberland	Yes	-	Yes	
East Greenwich	Yes	-	Yes	
East Providence	Yes	-	-	
Exeter	Yes	-	Yes	
Foster	-	-	-	No digital geospatial data was provided
Glocester	Yes	Yes	Yes	
Hopkinton	Yes	Yes	Yes	
Jamestown	Yes	Yes	Yes	
Johnston	Yes	Yes	Yes	
Lincoln	Yes	Yes	Yes	
Little Compton	-	-	-	No digital geospatial data was provided
Middletown	Yes	Yes	Yes	
Narragansett	Yes	-	Yes	
Newport	Yes	-	Yes	
New Shoreham	Yes	Yes	Yes	
North Kingstown	Yes	-	Yes	
North Providence	Yes	Yes	Yes	
North Smithfield	Yes	Yes	Yes	
Pawtucket	Yes	-	Yes	
Portsmouth	Yes	Yes	Yes	
Providence	Yes	Yes	Yes	
Richmond	Yes	-	Yes	
Scituate	Yes	Yes	Yes	
Smithfield	-	-	-	No digital geospatial data was provided
South Kingstown	Yes	Yes	Yes	
Tiverton	Yes	Yes	Yes	
Warren	Yes	Yes	Yes	
Warwick	Yes	Yes	Yes	
West Greenwich	-	-	-	No digital geospatial data was provided
West Warwick	Yes	-	Yes	Digital geospatial data was provided, but files were corrupted and unusable for this analysis
Westerly	Yes	Yes	Yes	
Woonsocket	Yes	Yes	Yes	

Note: Full geospatial analysis was possible for municipalities that provided both parcel and zoning data. For municipalities that did not provide zoning data, we assumed that similar zoning from municipalities defined as "similar" based on U.S Census data on population, median income, and housing density. Address data was used to identify parcels as brownfields.

Table 27. Other geospatial sources

Data	Description	Source	Link
Building Footprints	Building area shapefile	RIGIS	http://www.rigis.org/datasets/building-footprints?geometry=-71.615%2C41.673%2C-71.533%2C41.685
Median Income	GIS data from the 2010 US Census for RI	RIGIS	http://www.rigis.org/datasets/us-census-2000-summary-file-3-population-and-statewide-housing
Local Permitting	Data on zoning district, including historical districts	Municipalities	See Table 26
Landfills	GIS shapefile from landfill solar potential study	URI	Data provided by Chris Damon, University of Rhode Island Environmental Data Center
Gravel Pits	GIS shapefile for mine plants and operations	USGS	https://mrdata.usgs.gov/catalog/cite-view.php?cite=17
Brownfields	List of brownfields in Rhode Island provided by DEM via OER	DEM	RI DEM. (2019, September 16). *Remediated Sites – Potential Solar*. Available at http://www.dem.ri.gov/programs/wastemanagement/inventories.php.
Land Use	GIS shapefile including the land cover/land use for the State of RI	RIGIS	http://www.rigis.org/datasets/land-use-and-land-cover-2011
Carports	GIS shapefile for publicly sourced parking lot data accessed October 2019	OpenStreetMaps	http://download.geofabrik.de/north-america/us/rhode-island.html
Land Slope	2011 RI LIDAR data	RIGIS	http://www.rigis.org/pages/2011-statewide-lidar
Feeder line Hosting Capacity	Maps of distribution system hosting capacity	National Grid	https://ngrid.apps.esri.com/NGSysDataPortal/RI/index.html

APPENDIX C. CURRENT SOLAR POLICIES IN RHODE ISLAND

Over the years, Rhode Island has supported distributed solar through a number of different mechanisms. Table 28 summarizes these mechanisms, which are detailed in the following paragraphs. As elsewhere, all capacity values in this section are quoted in MW_{AC}.

Table 28. Summary of Rhode Island's distributed solar incentive programs

Program	History	Incentive	Eligibility	Size of the program (MW_{AC})	Administration and subcategorization
Net Metering	Current law passed in 2011; cap of 3% of utility's peak load removed in 2014; currently no cap.	Generation exported to the grid offsets cost of electricity consumed	Customer-sited generation sized to meet on-site loads and based on historical kWh consumption	68 MW of solar as of Fall 2019	Administered by National Grid
Virtual net metering	Enacted in 2011 with net metering; cap on project size raised from 5 MW to 10 MW in 2016	Generation exported to the grid offsets cost of electricity consumed	Public and non-profit entities (including schools and hospitals); up to 10 MW per site	52 MW of solar as of Fall 2019	Administered by National Grid
Community Solar Virtual Net Metering Pilot Program	Legislation passed in 2016 created the set-aside	Generation exported to the grid offsets cost of electricity consumed	Residential customers and affordable housing units	30 MW pilot (2.54 MW installed as of Fall 2019)	Subset of virtual net metering
Renewable Energy Fund	Regulations establishing the program were adopted in 2014	$0.85/kW for residential; $0.70/kW for commercial for the first 50 kW, drops for later blocks (as of Summer 2020)	Solar PV and solar domestic hot water that is net metered and owned by the electricity customer	7 MW small scale and 36 MW commercial installed as of Fall 2019	Divided into small scale, commercial scale, brownfields, and community solar; managed by RI Commerce
Renewable Energy Growth	Originally authorized by law in 2014; successor to the DG contracts program	Long-term fixed price contract; small-scale systems receive pre-determined payment; large scale projects competitively bid	Generation cannot be net metered; res. systems must be sized ≤ historical consumption levels	20 MW small-scale and 25 MW large-scale installed as of Fall 2019	Small scale (solar) and large scale (solar larger than 25 kW, wind, hydro, and anaerobic digesters)
DG standard contracts	Program was available 2011-2014	15-year contracts with projects selected through a competitive procurement based on price and economic factors	Private landowners, businesses, and municipalities with solar PV, wind, and anaerobic digester facilities	18 MW operational as of Fall 2019 (no additional projects pending)	National Grid required to sign 15-year contracts with DG

C.1 Net metering

Rhode Island requires National Grid to offer a net metering tariff for customers with DG. The current implementing law was passed in 2011, and as of 2014 there is no cap on the total amount of renewable capacity that can participate. When a customer enrolls in net metering, any generation exported to the grid offsets an equivalent amount of electricity consumed from the grid and reduces the customer's electric bill. Excess generation beyond a customer's total consumption within a given billing period is compensated at the utility's avoided cost rate up to an additional 25 percent of a customer's consumption for the billing period. DG must be connected to the grid at the same place as the customer's load to be eligible for net metering, though there are exceptions through virtual net metering and the community solar pilot. As of December 2, 2019, a total of 68 MW of solar was net metered in Rhode Island (not including virtual net metering or community solar).[49]

C.2 Virtual net metering

Virtual net metering is a subset of net metering that applies the same incentive mechanism to DG installations that are not located at the site of a customer's load. It was enacted in 2011 with the current implementation of net metering. The virtual net metering option is available to public and non-profit entities, state agencies, quasi-state agencies, municipalities, public housing authorities, public schools, private schools, non-profits, federal government, and hospitals.[50] In 2016, the maximum project size was raised from 5 MW to 10 MW.[51] As of Fall 2020, 52 MW of DG was virtually net metered.[52]

C.3 Community Solar Virtual Net Metering Pilot Program

The Community Solar Virtual Net Metering Pilot Program allows residential electric customers to take advantage of net metered distributed renewable generation without needing to site the resource at the point of the load. Through the program, residential customers can benefit from participation in a community solar project from which they receive net metering credits. Customers pay the third-party developers for their share of a community solar project's output. In 2016, the state legislature passed a law authorizing 30 MW of community solar. Six projects will provide the full 30 MW, with the latest

[49] Rhode Island Office of Energy Resources. December 5, 2019. *Rhode Island Distributed Generation Solar Updates*. Available at: https://www.iso-ne.com/static-assets/documents/2019/12/p2_dgfwg_ri2019.pdf.

[50] Rhode Island Office of Energy Resources. Accessed April 27, 2020. "Net Metering and Virtual Net Metering Overview." Available at: http://www.energy.ri.gov/policies-programs/programs-incentives/net-metering.php.

[51] National Renewable Energy Laboratory. Accessed April 27, 2020. "Midmarket Solar Policies in the United States: Rhode Island." Available at: https://www.nrel.gov/solar/rps/ri.html.

[52] Rhode Island Office of Energy Resources. December 5, 2019. *Rhode Island Distributed Generation Solar Updates*. Available at: https://www.iso-ne.com/static-assets/documents/2019/12/p2_dgfwg_ri2019.pdf.

project breaking ground in November 2019.[53] According to National Grid, 26.621 MW of solar have been reserved and another 3.379 MW remain available to potential subscribers as of February 2020.[54]

C.4 Renewable Energy Fund

The REF program, managed by RI Commerce, provides grants for individuals and businesses who install DG and participate in net metering. Regulations establishing the program were adopted in 2014.[55] The program is divided into four separate categories: small scale (including residential), commercial scale, brownfields, and community solar. Small-scale projects can be either solar PV generation or solar domestic hot water and must have high quality access to the sun.[56]

REF rebates are distributed on a per-kW basis. As of Summer 2020, the incentive for residential customers is $0.85/kW (for up to 8.235 kW.)[57] Commercial customers can receive $0.70/kW for the first 50 kW of a project, and declining amounts for subsequent 50-kW blocks (maximum of $75,000/project.)[58] As of Fall 2019, the REF program had awarded 10 MW of small-scale projects, 54 MW of commercial-scale projects, and 11 MW of brownfields projects.[59]

C.5 Renewable Energy Growth

The REG program offers pre-determined per-kWh payments for renewable generation through a buy-all/sell-all contract. For small-scale solar installations to be eligible for the program, systems must be sized at or smaller than historical electricity consumption levels and cannot be net metered. Under the program's buy-all/sell-all structure, DG is metered separately from customer load. The customer is compensated at the fixed incentive level for the duration of the REG contract (either 15 or 20 years.) The REG program was established in 2014 as the successor to the Distributed Generation Standard Contracts program, and unlike the Standard Contracts program, REG incorporates small-scale solar in addition to larger projects. The original goal of the REG program was to incentivize 160 MW of renewable

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[53] ecoRI News. November 14, 2019. "Ground Broken on Largest Community Solar Project." Available at: https://www.ecori.org/renewable-energy/2019/11/14/d4vcl1zd7zmqrjpdcbi75vpceyvnol.

[54] National Grid. March 2, 2020. "RI – Net Metering." Available at: https://ngus.force.com/s/article/Net-Metering-in-Rhode-Island.

[55] Rhode Island Department of State. Accessed April 27, 2020. "2014-2016 Rules and Regulations for the Renewable Energy Development Fund Programs." Available at: https://rules.sos.ri.gov/regulations/part/870-20-00-1/7592.

[56] Rhode Island Commerce. December 30, 2019. *Small-Scale Program Request for Proposals*. Available at: https://commerceri.com/wp-content/uploads/2019/05/Small-Scale-Solar-Requests-for-Projects-12.30.19.pdf.

[57] Rhode Island Commerce. December 30, 2019. *Small-Scale Program Request for Proposals*. Available at: https://commerceri.com/wp-content/uploads/2019/05/Small-Scale-Solar-Requests-for-Projects-12.30.19.pdf.

[58] Rhode Island Commerce. December 30, 2019. *Commercial-Scale Program Request for Proposals*. Available at: https://commerceri.com/wp-content/uploads/2019/05/Commercial-General-Requests-12.30.19.pdf.

[59] Rhode Island Office of Energy Resources. December 5, 2019. *Rhode Island Distributed Generation Solar Updates*. Available at: https://www.iso-ne.com/static-assets/documents/2019/12/p2_dgfwg_ri2019.pdf.

generation between 2015 and 2019.[60] This program has since been extended from 2020 to 2029, with a goal of installing 40 MW per year.[61]

REG has two approaches for incentives. First, the small-scale component incorporates solar projects that are smaller than 25 kW. These projects are paid pre-determined fixed incentive payments. As of April 1, 2020, projects sized 1–10 kW receive $296.50/MWh for 15 years, while projects that are between 11 kW and 25 kW receive $234.50/MWh for a period of 20 years.[62] Second, large-scale projects in the REG program compete for contracts, so the resulting compensation depends on the bids. This category of REG is for solar projects that are larger than 25 kW as well as wind, hydroelectric, and anaerobic digester projects. As of Fall 2019, 43 MW of large-scale projects was operational.[63]

C.6 Distributed Generation Standard Contracts

The Distributed Generation Standard Contracts program existed between 2011 and 2014 to procure distributed solar PV, wind, and anaerobic digester-based generation. The program required National Grid to enter into 15-year contracts, which were awarded based on both price and economic factors. Private landowners, businesses, and municipalities were all eligible to participate in the program. As of Fall 2019, 18 MW of generation awarded contracts through the program was operational with no additional projects pending.[64]

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[60] Rhode Island Office of Energy Resources. Accessed April 27, 2020. “Renewable Energy Growth Program (2014.)” Available at: http://www.energy.ri.gov/policies-programs/ri-energy-laws/renewable-energy-growth-program-2014.php

[61] National Grid. April 3, 2018. “Renewable Energy Growth Program: Expanding Renewable Distributed Generation in Rhode Island.” Available at https://www9.nationalgridus.com/non_html/CM6021RenewableDistribution3_18.pdf.

[62] National Grid. April 27, 2020. “Rhode Island Renewable Energy Growth Program.” Available at: https://ngus.force.com/s/article/Rhode-Island-Renewable-Energy-Growth-Program.

[63] Rhode Island Office of Energy Resources. December 5, 2019. *Rhode Island Distributed Generation Solar Updates*. Available at: https://www.iso-ne.com/static-assets/documents/2019/12/p2_dgfwg_ri2019.pdf.

[64] Rhode Island Office of Energy Resources. December 5, 2019. *Rhode Island Distributed Generation Solar Updates*. Available at: https://www.iso-ne.com/static-assets/documents/2019/12/p2_dgfwg_ri2019.pdf.

APPENDIX D. POLICES IN OTHER STATES INCENTIVIZING NON-CONVENTIONAL GROUND-MOUNTED SOLAR

In recent years, neighboring states have begun to implement policies that provide incentives for ground-mounted solar that is not located on conventional sites. Neighboring states have also implemented incentives that are available to solar units that are installed on parking canopies. This appendix describes the overall structure of these policies, along with detail on the incentive levels currently provided.

Note that other states throughout New England and the mid-Atlantic region were also examined for this appendix; these states do not appear to currently have policies incentivizing non-conventional ground-mounted solar.[65]

D.1 Massachusetts

The Solar Massachusetts Renewable Target (SMART) program was established to incentivize statewide use and development of solar PV generating units by residential, commercial, governmental, and industrial electricity customers throughout the Commonwealth.[66] It is a tariff-based incentive program intended to offer longer-term incentives to solar generation units. As part of this program, all solar tariff generation units that are larger than 25 kW_{AC} are eligible to receive incentive payments for 20 years and systems below 25 kW_{AC} receive payments for 10 years. The program is a declining block program with the incentive payment decreasing as the capacity block is filled. All units are eligible for a base compensation rate which varies by service territory and size of the system, with smaller systems receiving higher rates.

For example, the base compensation rates for National Grid's Massachusetts territory are $0.31126 per kWh for units that are less than or equal to 25 kW_{AC} and $0.15563 per kWh for units greater than 1 MW (see Table 29).[67] In addition to this base compensation rate, certain units are eligible for an adder known as the compensation rate adder. The compensation adder for solar that is sited on brownfields and eligible landfills are at $0.03 per kWh and $0.04 per kWh, respectively. In addition, any solar generating units that are located on a greenfield are subject to a subtractor between $0.0005 per kWh to $0.0025 per kWh per acre occupied by the solar development depending on the land-use classification and the

[65] Note that these states—which include Connecticut, New Hampshire, Maine, New Jersey, and Pennsylvania—may have solar installed on non-conventional sites such as landfills, but do not appear to have specific programs incentivizing solar development at these sites.

[66] For more information on the SMART program, see https://www.mass.gov/doc/225-cmr-2000-solar-massachusetts-renewable-target-smart-program/download. Synapse's December 2018 overview of the SMART program, *Getting SMART*, can be found at https://www.synapse-energy.com/sites/default/files/Getting-SMART-16-069.pdf.

[67] Massachusetts SMART Solar Program Base Compensation Rates, http://masmartsolar.com/_/documents/Base-Compensation-Rates.pdf and https://www.mass.gov/doc/capacity-block-base-compensation-rate-and-compensation-rate-adder-guideline-041520.

date on which the land-use classification occurred. The SMART program also established an incentive for canopy solar generation and sites conducive to pollinators.[68] The compensation adder for canopy solar is $0.06 per kWh.

On April 16, 2020, Massachusetts Department of Energy Resources (DOER) issued an emergency rulemaking amending the SMART program.[69] A major part of this emergency rulemaking includes clarifying the land-use categories for which SMART-eligible projects can qualify.[70] These include:

- **Category 1**: This category is itself subdivided into two sub-categories: agricultural and non-agricultural land use. Agricultural land must be land that is currently enrolled in Massachusetts' Chapter 61A tax benefit program. Only certain types of SMART facilities are eligible in this subcategory, including building-mounted and canopy-mounted facilities. All facilities must be sized to be no greater than 200 percent of the annual load of the facility. Facilities that receive the agricultural adder (not necessarily all facilities built on agricultural land) must also meet additional siting criteria.[71]

  Facilities sited on non-agricultural land in this category may be building- or canopy-mounted, sited on brownfields or landfills, or be owned by a public entity. Any facility may be ≤ 500 kW_{AC}. Facilities may be up to 4,999 kW_{AC} if they are sited on land that has been previously developed.

- **Category 2**: This category applies to facilities that are greater than 500 kW_{AC} and less than 5,000 kW_{AC} that are sited on land that has not been previously developed and is zoned for commercial or industrial use. This category also applies to solar of this size that is cited within a zoning overlay district that explicitly allows for this type of solar.

- **Category 3:** This category applies to facilities that are greater than 500 kW_{AC} and less than 5,000 kW_{AC} that do not fall into either Category 1 or Category 2.

Importantly, new ground-mounted facilities are ineligible to receive incentives of any kind under the SMART program if they are sited on permanently protected open space or lands designated as Priority Habitats, Core Habitats, or Critical Natural Lands (provided that these lands do not fall under Category 1). Priority Habitats, Core Habitats, or Critical Natural Lands are all land designations defined by Massachusetts Division of Fisheries and Wildlife BioMap2 framework within the Natural Heritage and Endangered Species Program.[72]

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[68] A canopy solar tariff generation unit is defined as a Solar Tariff Generation Unit with 100 percent of the nameplate capacity of the solar PV modules used for generating power installed on top of a parking surface, pedestrian walkway, or canal in a manner that maintains the function of the area beneath the canopy.

[69] See https://www.mass.gov/info-details/smart-emergency-rulemaking for more information.

[70] See https://www.mass.gov/doc/land-use-and-siting-guideline/download.

[71] This criteria includes not interfering with ongoing use of the land for agricultural purposes. See https://www.mass.gov/doc/225-cmr-2000-smart-clean/download, Section 20.06(1)(d) for more information.

[72] Geospatial data on these designations can be found at http://maps.massgis.state.ma.us/dfg/biomap2.htm.

Table 29. SMART program compensation rates by block, National Grid Massachusetts (nominal $/kWh)

Base compensation rate	
Low income less than or equal to 25 kW AC	$0.35795
Less than or equal to 25 kW AC	$0.31126
Greater than 25 kW AC to 250 kW AC	$0.23345
Greater than 250 kW AC to 500 kW AC	$0.19454
Greater than 500 kW AC to 1,000 kW AC	$0.17119
Greater than 1,000 kW AC to 5,000 kW AC	$0.15563
Location-based adders	
Building mounted	$0.01920
Floating solar	$0.03000
Brownfields	$0.03000
Landfills	$0.04000
Canopy solar	$0.06000
Agricultural	$0.06000
Location-based subtractors	
Greenfield (Category 2)	-$0.00050 per kWh per acre
Greenfield (Category 3)	-$0.00050 per kWh per acre

Notes: All values shown are for the National Grid (non-Nantucket) service territory only. Base compensation rates change with each block. For National Grid Massachusetts' service territory, each block is about 90 MW. For the first 8 blocks, base compensation rates fall by 4 percent per block; after that, they fall by 4 percent per block for standalone systems and 2 percent per block for behind-the-meter systems. Data represents rates and adders as they existed in April 2020. All data obtained from https://www.mass.gov/doc/capacity-block-base-compensation-rate-and-compensation-rate-adder-guideline-041520 and https://www.mass.gov/files/documents/2018/04/26/SMART%20Program%20Overview%20042618.pdf.

D.2 New York

NY-Sun offers financial incentives to install solar panels for residential, non-residential, and large commercial and industrial projects. Incentives are available of a dollar-per-watt basis.[73] Incentives are paid after the photovoltaic system has been connected to the grid. Small commercial projects have the option to receive the incentive payments in two increments based on installation milestones (e.g., a first incentive payment when all system components are delivered to a customer's site and a second incentive payment after a PV system has been connected to the utility grid and inspected by NYSERDA or its representatives).[74] Each of the three regions, Con Edison, Upstate, and Long Island are designated an allocation of megawatts that are eligible for NY-Sun incentives and the incentives remain applicable until the region is fully subscribed. To encourage development on brownfields and landfills, additional $/W incentives are available for ground-mounted solar electric systems. These projects are eligible for an incentive of $0.10 per Watt in addition to the standard nonresidential incentives. For example, for

[73] See https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Contractors/Dashboards-and-incentives.

[74] See DSIRE, https://programs.dsireusa.org/system/program/detail/701.

Con Edison, the standard nonresidential incentives range between $0.60 to $1.00 per Watt for the first 50 kW (with additional $0.40 to $0.60 per Watt up to 200 kW total) for certain blocks and $0.15 to $0.60 per Watt up to 7.5 MW for certain blocks.

In addition, incentives may be available for newly constructed solar parking canopies.[75] These incentives are available in addition to standard nonresidential incentives. For example, Con Edison parking canopy incentive adder ranges from $0.20 to $0.30 per Watt depending on the block. This incentive does not appear to be offered by the Upstate and Long Island regions.[76]

D.3 Vermont

In July 2017, the Vermont PUC established rules pertaining to construction and operation of net metering system which set specific incentives for net metering projects on preferred sites.[77] A "preferred site" includes but is not limited to sites certified to be brownfield sites, sanitary landfills, parking lot canopies and the disturbed portion of gravel pits, quarries or similar sites used for extraction of a mineral resources.[78] The incentivized rates are paid on a per kWh basis. The incentives vary based on the size of the installation, and are paid on a net metering basis where the payment rate is equal to the incentives described in Table 30, rather than a retail rate. In 2019, installations on preferred sites received a greater $-per-kWh incentive than similarly sized projects on non-preferred sites ($0.174 per kWh in Category II vs $0.134 in Category IV—an increase of 30 percent). Grants, loans, and in some cases, local tax incentives are available for site assessment, cleanup, and redevelopment or reuse projects on contaminated sites.

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[75] Con Edison defines parking solar canopies as elevated above parking lots or added to an open-top deck of a parking garage structure to provide both shade and energy production. See NY-Sun Con Edison Program Manual, page 10. https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Contractors/Resources-for-Contractors.

[76] See https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Contractors/Dashboards-and-incentives/ConEd-Dashboard.

[77] See https://puc.vermont.gov/sites/psbnew/files/doc_library/5100-PUC-nm-effective-07-01-2017_0.pdf and http://www.newmoa.org/events/docs/311_272/VT_PreferredSitesJune2018.pdf.

[78] A "sanitary landfill "means a land disposal site employing an engineered method of disposing of solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the solid waste to the smallest practical volume, and applying and compacting cover material at the end of each operating day.

Table 30. Incentive rates for net-metering projects ($/kWh)

	2017	2018	2019
Category I (up to 15 kW)	$0.189	$0.184	$0.174
Category II (> 15 kW to 150 kW on preferred site)	$0.189	$0.184	$0.174
Category III (> 150 kW to 500 kW on preferred site)	$0.167	$0.154	$0.144
Category IV (> 15 kW to 150 kW on non-preferred site)	$0.149	$0.144	$0.134

Source: Table reproduced from http://www.newmoa.org/events/docs/311_272/VT_PreferredSitesJune2018.pdf, page 5.

D.4 Maryland

The Maryland Energy Administration (MEA) provides grants to install parking lot solar PV canopies with electric vehicle chargers over parking lots. The MEA offers up to $400 per kW (DC) of canopy-mounted solar PV per project with a maximum cap of $200,000 per project.[79] To qualify, the project must consist of at least 7 kW of solar PV panels and consist of at minimum four Level II or Level III charging stations located in the same parking lot. The program is available to businesses, government agencies, and non-profits in Maryland.

[79] Maryland Energy Administration, Parking Lot Solar PV Canopy with EV Charger Grant Program. https://energy.maryland.gov/Business/Documents/Notice%20of%20Grant%20Availability%20Solar%20Canopy%20FY20.pdf.

APPENDIX E. MUNICIPALITY-SPECIFIC DATA

Data in this appendix is provided at a greater level of precision than in preceding sections in order to illustrate the differences among municipalities

Table 31. Detailed results for each municipality, rooftop solar

Municipality	Number of rooftops	Total potential (MW)	Technical potential (MW)	Low economic potential (MW)	High economic potential (MW)
Barrington	6,700	58.1	12.6	3.4	8.2
Bristol	7,800	72.2	18.1	2.5	6.1
Burrillville	6,400	51.5	10.4	2.0	4.8
Central Falls	3,000	31.3	9.2	0.4	1.0
Charlestown	5,700	42.7	6.6	1.1	2.7
Coventry	14,100	115.5	23.2	4.0	10.2
Cranston	27,100	260.4	68.7	7.8	17.1
Cumberland	11,800	110.6	27.6	3.8	8.4
East Greenwich	5,100	60.7	15.6	3.5	9.3
East Providence	16,500	149.4	41.0	5.8	13.6
Exeter	3,200	27.5	4.8	0.6	1.8
Foster	2,900	21.0	3.2	0.5	1.3
Glocester	4,900	38.7	7.1	1.1	2.6
Hopkinton	4,200	33.2	6.2	0.9	2.3
Jamestown	3,300	27.4	5.3	1.1	2.6
Johnston	11,000	106.4	25.6	2.8	6.2
Lincoln	7,200	87.1	26.5	3.9	9.3
Little Compton	3,300	25.7	3.7	0.6	1.7
Middletown	6,700	71.3	19.1	2.6	5.8
Narragansett	9,200	72.5	16.1	2.8	7.9
Newport	8,300	81.6	21.8	2.1	5.0
New Shoreham	1,900	12.9	3.3	0.6	1.7
North Kingstown	11,200	124.2	37.4	4.4	9.8
North Providence	10,000	95.3	21.8	2.6	6.2
North Smithfield	4,900	49.0	13.0	1.6	4.5
Pawtucket	19,300	172.1	48.5	3.4	7.6
Portsmouth	8,300	76.3	17.1	3.3	8.2
Providence	36,200	355.7	103.1	5.6	12.2
Richmond	3,700	25.9	4.7	1.4	3.2
Scituate	5,000	43.4	7.7	1.3	3.5
Smithfield	7,000	81.5	24.5	4.8	11.0
South Kingstown	13,300	110.4	18.2	3.1	7.4
Tiverton	7,500	62.0	10.1	1.7	3.9
Warren	4,200	38.5	9.9	1.4	3.4
Warwick	32,200	299.7	85.5	10.2	22.8
West Greenwich	2,700	27.0	6.6	1.3	3.7
West Warwick	8,900	77.2	19.5	2.9	6.4
Westerly	11,900	108.0	21.1	2.7	6.4
Woonsocket	10,300	96.6	27.4	1.4	3.2
Total	**366,900**	**3,400.7**	**852.1**	**107.2**	**253.1**

Table 32. Detailed results for each municipality, landfills

Municipality	Number of landfills	Total potential (MW)	Low technical potential (MW)	High technical potential (MW)
Barrington	4	4.5	0.0	2.2
Bristol	2	14.3	3.4	10.2
Burrillville	2	16.4	0.4	7.6
Central Falls	0	0.0	0.0	0.0
Charlestown	2	12.1	2.1	7.5
Coventry	3	17.1	4.0	11.8
Cranston	1	6.5	1.1	3.7
Cumberland	1	5.4	0.2	2.6
East Greenwich	1	2.3	0.0	0.0
East Providence	5	42.9	12.4	32.8
Exeter	0	0.0	0.0	0.0
Foster	1	13.7	3.1	11.7
Glocester	2	13.1	1.2	8.2
Hopkinton	1	13.1	2.7	9.0
Jamestown	1	2.6	0.0	1.7
Johnston	1	2.8	0.0	1.5
Lincoln	3	9.2	0.0	2.3
Little Compton	1	3.4	0.0	2.3
Middletown	0	0.0	0.0	0.0
Narragansett	0	0.0	0.0	0.0
Newport	1	3.0	0.0	2.2
New Shoreham	1	1.3	0.0	0.6
North Kingstown	4	27.3	4.4	17.4
North Providence	0	0.0	0.0	0.0
North Smithfield	3	20.4	2.9	12.2
Pawtucket	1	2.9	0.1	1.6
Portsmouth	1	6.6	0.3	3.1
Providence	1	3.7	0.1	2.3
Richmond	2	55.8	18.7	35.5
Scituate	1	4.6	0.2	2.2
Smithfield	3	16.2	0.1	9.8
South Kingstown	2	34.8	8.4	26.5
Tiverton	3	22.7	2.8	13.5
Warren	3	5.6	0.0	0.9
Warwick	3	19.4	1.9	10.0
West Greenwich	0	0.0	0.0	0.0
West Warwick	1	4.0	0.0	0.4
Westerly	1	10.5	0.4	6.6
Woonsocket	1	6.9	0.0	0.6
Total	**63**	**425.1**	**71.0**	**260.4**

Table 33. Detailed results for each municipality, brownfields

Municipality	Number of brownfields	Total potential (MW)	Low technical potential (MW)	High technical potential (MW)
Barrington	4	1.3	0.0	0.1
Bristol	17	6.9	0.0	0.9
Burrillville	8	1.9	0.0	0.0
Central Falls	11	3.4	0.0	0.5
Charlestown	5	181.6	118.8	168.6
Coventry	16	30.2	11.7	21.8
Cranston	48	38.4	0.0	8.4
Cumberland	25	12.8	5.0	9.3
East Greenwich	7	26.9	10.4	19.4
East Providence	50	40.2	15.6	29.1
Exeter	3	75.4	29.2	54.5
Foster	0	0.0	0.0	0.0
Glocester	2	3.9	1.5	2.8
Hopkinton	4	122.2	13.2	87.3
Jamestown	7	2.6	0.0	0.4
Johnston	22	33.2	0.5	21.9
Lincoln	12	21.7	0.0	7.9
Little Compton	2	0.8	0.3	0.6
Middletown	12	14.6	0.0	3.2
Narragansett	8	1.7	0.6	1.2
Newport	27	22.2	8.6	16.0
New Shoreham	0	0.0	0.0	0.0
North Kingstown	22	67.7	26.2	48.9
North Providence	13	3.0	1.1	2.1
North Smithfield	6	29.6	0.0	9.3
Pawtucket	70	32.2	12.5	23.3
Portsmouth	16	67.2	0.0	29.2
Providence	164	79.8	0.0	22.9
Richmond	3	0.4	0.1	0.3
Scituate	4	1.2	0.0	0.5
Smithfield	19	55.9	0.0	33.0
South Kingstown	15	0.5	0.0	0.0
Tiverton	6	20.0	0.0	8.9
Warren	12	8.9	0.0	2.0
Warwick	35	25.7	0.0	6.0
West Greenwich	1	0.0	0.0	0.0
West Warwick	19	11.0	4.3	8.0
Westerly	11	3.1	0.0	0.2
Woonsocket	32	12.5	0.0	4.5
Total	**738**	**1,060.8**	**259.6**	**653.0**

Table 34. Detailed results for each municipality, gravel pits

Municipality	Number of gravel pits	Total potential (MW)	Low technical potential (MW)	High technical potential (MW)
Barrington	0	0.0	0.0	0.0
Bristol	0	0.0	0.0	0.0
Burrillville	0	0.0	0.0	0.0
Central Falls	0	0.0	0.0	0.0
Charlestown	0	0.0	0.0	0.0
Coventry	1	0.6	0.0	0.1
Cranston	1	59.5	11.2	22.4
Cumberland	2	45.3	2.8	13.1
East Greenwich	0	0.0	0.0	0.0
East Providence	0	0.0	0.0	0.0
Exeter	1	12.6	0.9	4.7
Foster	0	0.0	0.0	0.0
Glocester	0	0.0	0.0	0.0
Hopkinton	0	0.0	0.0	0.0
Jamestown	0	0.0	0.0	0.0
Johnston	0	0.0	0.0	0.0
Lincoln	0	0.0	0.0	0.0
Little Compton	0	0.0	0.0	0.0
Middletown	0	0.0	0.0	0.0
Narragansett	0	0.0	0.0	0.0
Newport	0	0.0	0.0	0.0
New Shoreham	0	0.0	0.0	0.0
North Kingstown	0	0.0	0.0	0.0
North Providence	0	0.0	0.0	0.0
North Smithfield	1	19.7	2.3	7.6
Pawtucket	0	0.0	0.0	0.0
Portsmouth	0	0.0	0.0	0.0
Providence	0	0.0	0.0	0.0
Richmond	1	8.1	0.6	3.4
Scituate	0	0.0	0.0	0.0
Smithfield	0	0.0	0.0	0.0
South Kingstown	2	32.3	2.8	12.1
Tiverton	3	52.5	5.7	20.6
Warren	0	0.0	0.0	0.0
Warwick	0	0.0	0.0	0.0
West Greenwich	0	0.0	0.0	0.0
West Warwick	0	0.0	0.0	0.0
Westerly	1	25.1	1.6	7.8
Woonsocket	0	0.0	0.0	0.0
Total	**13**	**255.6**	**27.9**	**91.7**

Table 35. Detailed results for each municipality, developed and undeveloped commercial and industrial parcels

Municipality	Number of parcels	Total potential (MW)	Low technical potential (MW)	High technical potential (MW)
Barrington	145	41.9	1.4	8.4
Bristol	533	87.5	4.6	41.3
Burrillville	102	42.2	0.7	22.1
Central Falls	274	13.7	0.0	1.2
Charlestown	152	157.0	12.4	79.7
Coventry	326	53.4	0.0	7.9
Cranston	2,240	373.1	1.1	122.5
Cumberland	833	185.0	0.4	73.4
East Greenwich	318	119.5	10.2	63.2
East Providence	583	123.2	0.0	26.8
Exeter	224	909.5	279.8	664.9
Foster	198	803.7	247.7	587.7
Glocester	107	143.7	18.1	84.1
Hopkinton	155	226.7	26.6	132.0
Jamestown	61	4.5	0.0	0.6
Johnston	2,013	780.5	84.4	403.5
Lincoln	265	92.0	0.0	31.1
Little Compton	38	16.6	0.6	9.1
Middletown	487	156.7	7.0	57.3
Narragansett	128	11.1	0.0	1.5
Newport	337	75.0	3.3	19.2
New Shoreham	102	4.6	0.0	0.2
North Kingstown	753	594.7	53.7	332.1
North Providence	703	32.9	0.0	1.3
North Smithfield	565	293.9	1.8	118.7
Pawtucket	981	89.9	0.4	20.6
Portsmouth	430	201.0	10.2	69.2
Providence	6,826	553.2	14.6	145.2
Richmond	130	122.3	9.9	79.5
Scituate	144	45.0	0.0	18.7
Smithfield	272	184.1	6.3	100.4
South Kingstown	523	359.5	36.4	171.7
Tiverton	258	212.6	29.0	131.1
Warren	428	18.4	0.0	2.1
Warwick	2,587	540.3	15.7	174.4
West Greenwich	196	795.3	244.4	581.3
West Warwick	341	75.9	3.2	19.4
Westerly	559	341.6	31.6	159.4
Woonsocket	692	155.1	0.1	41.3
Total	**26,008**	**9,036.9**	**1,155.5**	**4,603.7**

Table 36. Detailed results for each municipality, parking lot parcels

Municipality	Estimated number of parking lots	Total potential (MW)	Technical potential (MW)
Barrington	120	17.5	11.7
Bristol	87	12.7	8.4
Burrillville	27	3.9	2.6
Central Falls	13	1.8	1.2
Charlestown	400	58.5	39.0
Coventry	267	39.0	26.0
Cranston	307	44.8	29.9
Cumberland	20	2.9	1.9
East Greenwich	567	82.8	55.2
East Providence	253	36.8	24.5
Exeter	200	29.2	19.5
Foster	40	5.8	3.9
Glocester	600	87.7	58.4
Hopkinton	200	29.2	19.5
Jamestown	720	105.2	70.1
Johnston	107	15.6	10.4
Lincoln	640	93.5	62.3
Little Compton	216	31.5	21.0
Middletown	120	17.5	11.7
Narragansett	227	33.1	22.1
Newport	453	66.2	44.1
New Shoreham	280	40.9	27.3
North Kingstown	393	57.5	38.3
North Providence	227	33.1	22.1
North Smithfield	40	5.8	3.9
Pawtucket	107	15.6	10.4
Portsmouth	47	6.8	4.5
Providence	870	127.1	84.7
Richmond	640	93.5	62.3
Scituate	67	9.7	6.5
Smithfield	420	61.4	40.9
South Kingstown	287	41.9	27.9
Tiverton	20	2.9	1.9
Warren	20	2.9	1.9
Warwick	760	110.8	73.8
West Greenwich	720	105.2	70.1
West Warwick	107	15.6	10.4
Westerly	273	39.9	26.6
Woonsocket	13	1.9	1.3
Total	**10,872**	**1,588.3**	**1,058.3**

Table 37. Non-rooftop solar potentials: total, low technical, and high technical (MW)

Municipality	Total potential (MW)	Low technical potential (MW)	High technical potential (MW)
Barrington	65.3	13.1	22.4
Bristol	121.3	16.5	61.0
Burrillville	64.5	3.7	32.3
Central Falls	18.9	1.2	3.0
Charlestown	409.1	172.2	294.8
Coventry	140.1	41.7	67.7
Cranston	497.4	43.2	186.9
Cumberland	232.4	10.3	100.3
East Greenwich	231.5	75.8	137.8
East Providence	243.2	52.5	113.2
Exeter	1,021.5	329.4	743.5
Foster	823.2	254.7	603.3
Glocester	248.3	79.3	153.5
Hopkinton	391.2	62.0	247.7
Jamestown	114.9	70.1	72.7
Johnston	832.1	95.3	437.3
Lincoln	216.4	62.3	103.5
Little Compton	52.4	21.9	33.0
Middletown	188.9	18.7	72.2
Narragansett	45.9	22.7	24.8
Newport	166.4	56.0	81.6
New Shoreham	46.8	27.3	28.0
North Kingstown	747.2	122.6	436.6
North Providence	68.9	23.2	25.5
North Smithfield	361.2	10.9	151.8
Pawtucket	140.7	23.3	55.9
Portsmouth	281.7	15.0	106.0
Providence	763.9	99.5	255.1
Richmond	276.7	91.6	181.0
Scituate	60.6	6.7	27.8
Smithfield	317.6	47.3	184.1
South Kingstown	455.4	75.5	238.2
Tiverton	288.7	39.5	176.0
Warren	35.9	1.9	6.9
Warwick	696.2	91.4	264.2
West Greenwich	900.5	314.5	651.4
West Warwick	106.5	17.9	38.1
Westerly	409.8	60.2	200.6
Woonsocket	176.5	1.4	47.7
Total	**12,259.7**	**2,572.4**	**6,667.2**

Table 38. Residential buildings that cannot host solar PV

Municipality	Total number of residential rooftops (thousands)	Fraction of buildings with no buildable area	Number of rooftops with no buildable area	Economic potential (MW)
Barrington	6.4	3%	222	1.3
Bristol	7.0	3%	243	1.5
Burrillville	6.3	5%	300	1.8
Central Falls	2.7	3%	95	0.6
Charlestown	5.2	5%	250	1.5
Coventry	13.6	5%	654	3.9
Cranston	24.8	3%	862	5.2
Cumberland	9.8	3%	340	2.0
East Greenwich	4.6	3%	161	1.0
East Providence	14.3	3%	496	3.0
Exeter	2.3	5%	112	0.7
Foster	2.1	5%	102	0.6
Glocester	3.7	5%	175	1.1
Hopkinton	3.6	5%	170	1.0
Jamestown	2.7	3%	93	0.6
Johnston	9.0	3%	314	1.9
Lincoln	7.0	3%	243	1.5
Little Compton	2.9	5%	141	0.8
Middletown	5.6	3%	195	1.2
Narragansett	8.8	3%	307	1.8
Newport	7.2	3%	251	1.5
New Shoreham	1.7	3%	46	0.3
North Kingstown	9.9	3%	345	2.1
North Providence	9.2	3%	320	1.9
North Smithfield	4.3	3%	148	0.9
Pawtucket	17.5	3%	608	3.7
Portsmouth	7.7	3%	267	1.6
Providence	30.7	3%	926	5.6
Richmond	3.4	5%	163	1.0
Scituate	4.4	5%	213	1.3
Smithfield	6.7	3%	231	1.4
South Kingstown	12.2	5%	586	3.5
Tiverton	6.7	5%	323	1.9
Warren	3.8	3%	133	0.8
Warwick	29.0	3%	741	4.4
West Greenwich	2.0	5%	95	0.6
West Warwick	8.0	3%	277	1.7
Westerly	10.9	5%	522	3.1
Woonsocket	8.5	3%	296	1.8
Total	**326.4**	**-**	**11,965**	**71.8**

Note: This table is intended to facilitate discussion of community solar development, in response to a request from Rhode Island Office of Energy Resources.