Massachusetts Technical Potential of Solar

An analysis of solar potential and siting suitability in the Commonwealth

Prepared for Massachusetts Department of Energy Resources (DOER)

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EXECUTIVE SUMMARY

This report presents the results of an analysis conducted by Synapse Energy Economics (Synapse) to determine the total technical potential and suitability for solar construction across Massachusetts. This work was funded by the Massachusetts Department of Energy Resources (DOER).

Overview

Solar photovoltaic (PV) systems are a major component in Massachusetts' expanding energy sector and plans to meet its climate goals. In 2022, the State released the *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (CECP) and the *Massachusetts Clean Energy and Climate Plan for 2050* (2050 CECP); these publications outline comprehensive plans to achieve statewide emissions limits and sector-specific sublimits.[1] The CECP estimates that approximately 27 to 34 gigawatts (GW) of solar would be required in 2050 to reach these limits. This is over 10 times the 3 GW of solar currently installed in Massachusetts.[2] Reaching this level of solar by 2050 would require the state to triple or quadruple its current annual rate of solar installations (about 0.3 GW per year according to SMART program data).

As Massachusetts seeks to meet the limits outlined in the CECP, DOER identified the need for a technical potential of solar study to quantify the technical potential for solar development in Massachusetts, or an estimate of the total amount of solar that could physically be built, thematically ranked for suitability based on natural resource impacts and economic factors. DOER engaged Synapse to work with interested parties to determine categories upon which to base this suitability ranking. Based on these suitability categories, Synapse conducted a geospatial analysis to estimate the statewide technical potential for solar in light of Massachusetts's climate goals. The full results of this geospatial analysis are hosted online at https://TechnicalPotentialOfSolar-MA-synapse.hub.arcgis.com/.

This is a screening-level analysis intended as a preliminary consideration of locations that may be suitable for solar. The numbers calculated are estimates and are not intended to provide exact amounts of solar that can be built in a specific location. The purpose of this analysis is to be a source of information for policymakers, developers, communities, and other stakeholders; readers should not interpret it as instruction or recommendations about specific locations where solar should be built or what kind of solar should be built at those locations.

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[1] Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA). 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2025-and-2030; MA EEA. 2022. *Massachusetts Clean Energy and Climate Plan for 2050*. Available at https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050.

[2] Throughout this analysis, all capacity values for kilowatts (kW), megawatts (MW), and gigawatts (GW) are given in terms of alternating current (AC) capacity, unless otherwise stated.

The technical potential and suitability analysis presented here do not account for all practical and economic decision points necessary prior to developing solar, including but not limited to the full cost of installation and interconnection, competing development pressures, potential new land-use restrictions, and site conditions (e.g., roof age and condition). Instead, this study provides a general estimate of technical solar potential and a framework for ranking different sites' suitability. Section 3, Policy Considerations, provides further discussion of these and other solar development considerations that were not included in the spatial analysis.

Stakeholder and Public Outreach

To solicit input on preferred areas for solar development, Synapse partnered with Climable, a non-profit organization that specializes in climate communication and stakeholder outreach. Synapse and Climable gathered stakeholder feedback through several avenues: a focus group, a statewide survey, public outreach meetings, and Technical Advisory Committee meetings.

At the beginning of the project, Climable convened a virtual focus group for guidance on the creation of a survey to collect opinions from stakeholders around the state about solar siting. Synapse and Climable identified focus group attendees in collaboration with the DOER. Using feedback from the focus group, Climable, Synapse, and DOER designed a survey to solicit public opinions about priorities and concerns around the siting of large-scale solar projects. The survey was open to anyone in Massachusetts for a 60-day period in 2022 from September 19th to November 18th. See Appendix A, Description of Survey, for further details on survey questions and results.

In parallel with the survey period, Climable, Synapse, and DOER convened five statewide stakeholder meetings. These meetings were open to all interested members of the public and served to solicit additional, detailed feedback from Massachusetts residents and other interested parties on concerns and preferences related to solar siting. Three stakeholder meetings were held virtually via Zoom, with one focused on specific regional considerations and priorities. The team also conducted two stakeholder meetings in person in Buzzards Bay and Pittsfield.

Throughout the project, Synapse and DOER solicited feedback from the Technical Advisory Committee. The Technical Advisory Committee consisted of a wide array of stakeholders including from environmental groups, planning commissions, utilities, government agencies, and solar developers.[3] The purpose of this group was to provide insight and feedback throughout the project that would help Synapse and DOER shape the methodology and criteria for identifying suitable sites for solar. Synapse and DOER met with the Technical Advisory Committee six times at different project milestones between August 2022 and March 2023.

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[3] Please see the Acknowledgements section at the beginning of this document for a complete list of Technical Advisory Committee members.

Geospatial Analysis

Using stakeholder feedback, Synapse conducted geospatial analysis using ArcGIS software to (a) estimate the technical potential for solar at each individual land parcel in Massachusetts and (b) thematically rank each parcel for its suitability for different types of solar. A property tax parcel (“parcel”) is a spatial object representing property lot boundaries from property tax assessor maps. Parcel information is publicly accessible across Massachusetts in the online Massachusetts Interactive Property Map.[4]

For this study, we analyzed three main types of solar installations:

- **Rooftop**: Solar installed on the roof of buildings. This includes residential rooftops as well as commercial or industrial buildings, and any other building surface in the Commonwealth.

- **Ground-mounted**: Solar installed directly on the ground. Most large-scale solar is ground-mounted.

- **Canopy**: Solar installed above parking lots that still allows cars to drive and park below, acting as a shading structure (i.e., a “canopy”).

After identifying the types of solar most likely to be hosted on each parcel, we analyzed each parcel’s ability to host solar based on physical and legal considerations, which produced the estimated technical solar potential.

Once we determined the quantity of technical solar potential likely at each parcel, we then assessed that parcel’s suitability for solar. We assessed suitability across six categories relating to land use or land development considerations. Synapse used geospatial data in ArcGIS to give every parcel a grade in each suitability category. For each category, we gave each parcel a score of A, B, or C, which corresponded to how well-suited that parcel is to build solar.

For some suitability categories, we implemented a minimum capacity threshold below which an “object” (i.e., a trimmed part of a parcel) is graded according to whether any part of the object intersects a particular land-use layer. We used a threshold of 1.3 acres and smaller, which can support about 1 MW of ground-mounted solar. Objects less than 1.3 acres that span more than one suitability score received the lowest score across the entire object. For an illustrative example of how we applied this scoring threshold, please see Figure 3 in Section 1.3, Suitability.

The six suitability categories Synapse analyzed were:

- **Agriculture**: Does the land contain important farmland or agricultural soil?

[4] *MassGIS Data: Property Tax Parcels*. MassGIS (Bureau of Geographic Information). Accessed July 2022. Available at https://www.mass.gov/info-details/massgis-data-property-tax-parcels.

- **Biodiversity**: Does the land contain areas important for conserving biological diversity?
- **Other Ecosystem Services**: Is the land in a wellhead protection area or area of critical environmental concern?
- **Embedded Carbon Dioxide (CO_2e)**: How much carbon dioxide equivalent would be emitted by building solar on the land, and how much future sequestration of carbon dioxide equivalent would be foregone?
- **Electric Infrastructure**: How close is the land to the electric infrastructure required to support renewable generation?
- **Slope and Aspect**: Is the terrain well-shaped and is the land oriented for solar development?

Suitability categories used in this analysis do not necessarily reflect current Massachusetts policy or incentives. While existing solar policy may include elements of the suitability categories, the suitability categories used in this analysis were developed independently of any existing solar policy. Instead, the above suitability categories reflect land-use considerations that may be used in the development of future policy.

Solar siting may be subject to regulations of state agencies such as the Department of Energy Resources, the Department of Environmental Protection, and the Department of Fish and Game. The results of this geospatial analysis do not account for all potential regulations, and developers should comply with any relevant regulations for a proposed solar site and consult with the regulating agency as needed.

Through this methodology, Synapse estimated the technical potential for each parcel to host solar. For those parcels capable of hosting solar, we also assessed the parcels' relative suitability to host solar according to the six suitability categories. Additionally, Synapse identified the amount of solar already hosted by each parcel and the zoning designation of that parcel.

StoryMap

Synapse created a web application, called a StoryMap, that allows users to explore solar suitability across Massachusetts. The online platform summarizes the results of Synapse's geospatial analyses to determine the technical potential and suitability for solar construction across Massachusetts. Users of the StoryMap can fully interact with parcel-level data from this analysis, clicking on a parcel to learn about its technical solar potential and suitability scores. The StoryMap is available at https://TechnicalPotentialOfSolar-MA-synapse.hub.arcgis.com.

Findings

Synapse estimated that Massachusetts' technical solar potential is 506 GW_{AC}, 15 to 18 times greater than the amount required by the CECP (27 to 34 GW). After applying the suitability criteria, the technical potential that scored a C ("less suitable") in at least one suitability category makes up 353 GW of the 506

GW total, or about 70 percent of all technical potential. Approximately 30 percent, or 152 GW, of the technical potential is identified as being "highly suitable" (scored only A's and B's) for solar (see Table 1).

Table 1. Technical potential for solar in Massachusetts

Type of Mount	Number of Scored Parcels	Total Technical Potential (GW)	Total Highly Suitable Potential (GW)
Ground (Small, <1 MW)	767,338	91	39
Ground (Large, ≥1 MW) [(a)]	70,425	359	60
Rooftop	1,878,188	40	40
Canopy	83,335	14	14
All	**2,190,306**[(b)]	**506**	**152**

Notes: (a) Our analysis assumes that 1 MW of ground-mounted solar requires approximately 1.3 acres of land. (b) This value is not a sum of the above rows. Instead, it reflects the total number of parcels analyzed, some of which may have technical potential for multiple types of solar and are therefore listed more than once. In this table, "Highly Suitable" potential is that technical potential that does not receive any C suitability grades in any of the six analyzed categories as described in Table 2 and Table 3 below.

To see how the different suitability categories affected overall score for the estimated capacity, we broke out each category by score. Table 2 shows estimated solar capacity for each suitability category by score, while Table 3 describes these capacities as a share of estimated technical potential. For categories such as Electric Infrastructure and Agriculture, very little capacity falls into the "Less Suitable" score. For other categories, like embedded CO_2e, technical potential is more evenly distributed among suitability scores. Each column represents the consideration of total technical potential on the basis of an individual suitability category (e.g., considering only electric infrastructure, 242 GW_{AC} received a "Most Suitable" score, and 48 percent of all parcels scored a "Most Suitable" score for electric infrastructure). Section 2 of this report provides more detailed results.

Table 2. Solar potential by suitability category and score (GW_{AC})

Suitability Score	Agriculture	Biodiversity	Other Ecosystem Services	Embedded CO_2e	Electric Infrastructure	Slope and Aspect
(A) Most Suitable	292	200	448	156	242	328
(B) More Suitable	173	59	37	129	211	84
(C) Less Suitable	39	245	19	218	52	92

Note: Columns may not sum exactly to 506 GW_{AC} due to rounding.

Table 3. Solar potential by suitability category as a share of total technical potential

Suitability Score	Agriculture	Biodiversity	Other Ecosystem Services	Embedded CO_2e	Electric Infrastructure	Slope and Aspect
(A) Most Suitable	58%	40%	89%	31%	48%	65%
(B) More Suitable	34%	12%	7%	26%	42%	17%
(C) Less Suitable	8%	49%	4%	43%	10%	18%

1. METHODS AND SOURCES

We worked with stakeholders to determine the categories and criteria of suitable sites for solar in Massachusetts. Based on these suitability categories, we conducted an analysis of land area to estimate the statewide technical potential for solar development. We calculated estimates of both the technical potential (how much land is available and technically possible for solar construction) and the suitability of these technically possible areas for solar across six different categories.

To calculate the technical potential, we screened out land area based on feasibility and permissibility constraints:

- Feasibility: What are the physical limitations to building solar at this location? This includes applying zoning setbacks and buffers around buildings, as well as smoothing to remove sharp angles or irregular shapes that are unlikely to support solar construction.
- Permissibility: Can solar be built at this location within existing physical or policy constraints? This includes removing impermissible areas such as wetlands and surface water, protected open space, and roads and other non-buildable surfaces.[5] For the purposes of this analysis, we assume there is no technical solar potential at these locations, although there may be exceptions.

We used MassGIS's publicly available property tax parcel data to assess the total area and technical potential for solar in Massachusetts.[6] A property tax parcel ("parcel") is a spatial object representing property lot boundaries from property tax assessor maps. After calculating each parcel's technical potential for the three types of solar (rooftop, ground-mounted, and canopy), we scored each potential area across six different suitability categories. For each category, the parcel received a score of A, B, or C, which correspond to how well-suited that area is to build solar. The six suitability categories analyzed in this study are:

- **Agriculture**: Does the land contain important farmland or agricultural soil?
- **Biodiversity**: Does the land contain areas important for conserving biological diversity?
- **Other Ecosystem Services**: Is the land in a wellhead protection area or area of critical environmental concern?
- **Embedded Carbon Dioxide (CO_2e)**: How much carbon dioxide equivalent would be emitted by building solar on the land, and how much future sequestration of carbon dioxide equivalent would be foregone?

[5] "Protected open space" includes areas such as playgrounds, playing fields, wilderness areas, conservation areas, golf courses, cemeteries, and many other land-use types. See the Feasibility and Permissibility subsection on page 13 for more.

[6] *MassGIS Data: Property Tax Parcels*. MassGIS (Bureau of Geographic Information). Accessed July 2022. Available at https://www.mass.gov/info-details/massgis-data-property-tax-parcels.

- **Electric Infrastructure**: How close is the land to the electric infrastructure required to support renewable generation?
- **Slope and Aspect**: Is the terrain and land well-shaped and oriented for solar development?

1.1. Data Sources

Table 4 summarizes the data sources we used in our analysis of technical potential and suitability of solar in Massachusetts. Most data sources came from MassGIS (Bureau of Geographic Information), which provides many publicly available geospatial data layers of Massachusetts data points. Where necessary, we supplemented this data with other publicly available datasets, as well as proprietary data sources obtained from stakeholders involved in this project.

Table 4. Data sources used to analyze technical potential and suitability

Data Source	Data Type	Analysis Step
2016 Land Cover/Land Use *Version updated May 2019* This statewide dataset contains a combination of land cover mapping from 2016 aerial imagery and land use derived from standardized assessor parcel information for Massachusetts. Link: https://www.mass.gov/info-details/massgis-data-2016-land-coverland use	ArcGIS Layers	Technical potential
Areas of Critical Environmental Concern *Version updated April 2009* This layer represents Areas of Critical Environmental Concern, which are places in Massachusetts that receive special recognition because of the quality, uniqueness, and significance of their natural and cultural resources. Link: https://www.mass.gov/info-details/massgis-data-areas-of-critical-environmental-concern	ArcGIS Layers	Suitability
BioMap *Version updated November 2022* The BioMap dataset contains shapefiles with the different elements of BioMap. BioMap guides strategic protection and stewardship of lands and waters that are most important for conserving biological diversity in Massachusetts. Link: https://www.mass.gov/info-details/massgis-data-biomap-the-future-of-conservation	ArcGIS Layers	Suitability
Building Structures (2-D) *Version updated July 2021* This dataset consists of 2-dimensional roof outlines ("roofprints") for all buildings larger than 150 square feet for all of Massachusetts. Link: https://www.mass.gov/info-details/massgis-data-building-structures-2-d	ArcGIS Layers	Technical potential

Data Source	Data Type	Analysis Step
Eversource Substation Data *Provided via email to Synapse February 2023* Eversource provides publicly available data of substation locations, which are important for considering the costs of a solar facility's interconnection. Link: https://www.eversource.com/content/nh/business/about/doing-business-with-us/builders-contractors/interconnections/massachusetts/hosting-capacity-map	ArcGIS Layers	Suitability
Homeland Infrastructure Foundation-Level Data (HIFLD) *Version updated December 2022* This Department of Homeland Security shapefile represents electric power substations primarily associated with electric power transmission. In this layer, substations are considered facilities and equipment that switch, transform, or regulate electric power at voltages equal to, or greater than, 69 kilovolts. Substations with a maximum operating voltage less than 69 kilovolts may be included, depending on the availability of authoritative sources, but coverage of these features should not be considered complete. Link: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::substations/about	ArcGIS Layers	Suitability
Massachusetts Brownfield Tracking Spreadsheet *Version updated December 2018* This spreadsheet contains a list of reported releases at properties that meet the unofficial definition of a Brownfield site in Massachusetts, described as follows: A real property whose redevelopment may be complicated by actual or perceived contamination by oil or hazardous materials. These properties are typically abandoned or for sale or lease and have been used for commercial or industrial purposes. Link: https://www.mass.gov/service-details/find-brownfields-sites	Excel Spreadsheet	Technical potential
Massachusetts Department of Transportation (MassDOT) Airports *Version updated March 2021* This layer is the official state-maintained dataset containing the location of all airport facilities in Massachusetts, available from MassGIS. Link: https://www.mass.gov/info-details/massgis-data-layers-from-massdot-0	ArcGIS Layers	Technical potential
Massachusetts Department of Transportation (MassDOT) Roads *Version updated May 2022* This layer is the official state-maintained street transportation dataset available from MassGIS. It represents all the public and many of the private roadways in Massachusetts and includes designations for interstate, U.S., and state routes. Link: https://www.mass.gov/info-details/massgis-data-massachusetts-department-of-transportation-massdot-roads	ArcGIS Layers	Technical potential

Data Source	Data Type	Analysis Step
MassDEP Solid Waste Diversion and Disposal *Version updated January 2016* The Solid Waste Diversion and Disposal Datalayer was compiled by the Department of Environmental Protection (MassDEP) to track the locations of land disposal of solid waste. Link: https://www.mass.gov/info-details/massgis-data-massdep-solid-waste-diversion-and-disposal.	ArcGIS Layers	Technical potential
National Grid Substation Data *Provided via email to Synapse January 2023* National Grid provides publicly available data of substation locations, which are important for considering the costs of a solar facility's interconnection. Link: https://systemdataportal.nationalgrid.com/MA/?_gl=1*1u2gwxg*_ga*MTc0Mjg5MTcwNi4xNjgwMjI2NDc3*_ga_FH50R0D4B4*MTY4MDIyNjQ3Ni4xLjAuMTY4MDIyNjQ3Ni42MC4wLjA.	ArcGIS Layers	Suitability
Property Tax Parcels *Version updated June 2022* MassGIS' standardized assessors' parcel mapping data set contains property (land lot) boundaries and database information from each community's assessor. Link: https://www.mass.gov/info-details/massgis-data-property-tax-parcels	ArcGIS Layers	Technical potential, suitability
Protected and Recreational OpenSpace *Version updated April 2022* The protected and recreational open space datalayer contains the boundaries of conservation lands and outdoor recreational facilities in Massachusetts. Link: https://www.mass.gov/info-details/massgis-data-protected-and-recreational-openspace	ArcGIS Layers	Technical potential
Slope and Aspect *Provided via email to Synapse January 2022* Data layers of slope and aspect created by MassGIS in 2017 using LiDAR data. Created by P. John at MassGIS using Sandy, 2015 and 2021 USGS LiDAR and Nantucket LiDAR	ArcGIS Layers	Suitability
Soils SSURGO-Certified NRCS *Version updated November 2021* The Soils datalayer has been automated from published soils surveys as provided on various media by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). All soils data released by MassGIS have been "SSURGO-certified," which means they have been reviewed and approved by the NRCS and meet all standards and requirements for inclusion in the national SSURGO (Soil Survey Geographic database) release of county-level digital soils data. Soil survey areas are roughly based on county boundaries. Link: https://www.mass.gov/info-details/massgis-data-soils-ssurgo-certified-nrcs	ArcGIS Layers	Suitability

Data Source	Data Type	Analysis Step
U.S. Department of Transportation (US DOT) Runway Lines *Version updated July 2020* This source contains runways throughout the U.S. and U.S. territories, compiled by the Federal Aviation Administration and is part of the US DOT Bureau of Transportation Statistics National Transportation Atlas Database. Link: https://data-usdot.opendata.arcgis.com/datasets/usdot::runway-lines/about	ArcGIS Layers	Technical potential
Unitil Substation Data *Provided via email to Synapse January 2023* Unitil provides publicly available data of substation locations, which are important for considering the costs of a solar facility's interconnection. Link: https://unitil.com/ways-to-save/solar-private-generation/interconnection-hosting-capacity-map.	ArcGIS Layers	Suitability
Wellhead Protection Areas *Version updated November 2022* Wellhead protection areas are important for protecting the recharge area around public water supply (PWS) groundwater sources. This data source contains layers for Zone I, Zone II, and Interim Wellhead Protection Areas (IWPAs). Link: https://www.mass.gov/info-details/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa	ArcGIS Layers	Suitability

1.2. Calculating Technical Potential: Categorization, Feasibility, and Permissibility

Prior to assessing suitability of solar at any one location, we performed a set of steps to estimate how much of each type of solar may be buildable in each parcel.

Categorization

Using ArcGIS, we divided parcels into "objects" representing the areas of each parcel occupied by buildings (ideal for building-mounted solar), parking lots (ideal for canopy-mounted solar), and other surfaces (ideal for ground-mounted solar).

We also categorized each of these objects by property type classification codes, as defined by the Massachusetts Bureau of Local Assessment.[7] Each parcel in the Massachusetts property tax assessor maps has a use code based on its detailed land-use or zoning classification. We simplified these

[7] Bureau of Local Assessment. Revised April 2019. *Property Type Classification Codes: Non-arm's Length Codes and Sales Report Spreadsheet Specifications*. Available at https://www.mass.gov/doc/property-type-classification-codes-non-arms-length-codes-and-sales-report-spreadsheet/download.

classification codes into 10 land type categories: Agricultural, Commercial, Industrial, Recreation and Open Space, Forest, Single-family Residential, Other Residential, Multi-use, Government, and Other.

We also categorized parcels by the type of development on each parcel. If a parcel intersected the site of a landfill designated by MassDEP or the U.S. Environmental Protection Agency's Facility Registry System, we classified the parcel as a landfill site.[8,9] If a parcel intersected a brownfield site designated by MassDEP, defined as "a real property whose redevelopment may be complicated by actual or perceived contamination by oil or hazardous materials," we classified the parcel as a brownfield site.[10] For the purposes of this analysis, landfills are defined as operations established with a valid Massachusetts site assignment for the disposal of solid waste into or onto land. If a parcel contained a building or parking lot with enough area to build solar, we classified the parcel as "other partially developed." If a parcel did not contain a landfill, brownfield, building, or parking lot, we classified it as "other." Parcels can fall into multiple development categories; some parcels can be a landfill, brownfield, and/or other partially developed.

Existing solar

We also identified parcels that had existing solar currently built on the site. We compiled records of solar installations in Massachusetts from the SMART program, Massachusetts Clean Energy Center's Production Tracking System (PTS) Solar Renewable Energy Certificate program data, and data from the Municipal Light Plant Solar Rebate program, as provided by Massachusetts Department of Energy Resources (see Table 5). Solar installation data included the site address and capacity. We categorized the existing solar data by solar type (rooftop, ground-mounted, or canopy) and removed duplicate records across different datasets. Using the installation site addresses, we matched the existing solar to the parcel addresses in the tax parcel dataset. We successfully matched 85 percent of solar installation addresses to addresses in this analysis' parcel dataset, representing 67 percent of existing solar capacity (1.86 GW out of 2.78 GW). Unmatched existing installations were primarily due to data quality issues within the street addresses. For example, some parcels do not have an address, or the address may be written differently than in the solar site record. This may be the case for larger-scale solar installations which do not have a typical street address (as is typical with large parcels that have not historically been developed), as well as smaller, residential rooftop solar installations in apartment buildings or condos which could have additional location details (for example "123 Main Street, Unit #2").

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8 Massachusetts Department of Environmental Protection. Updated January 2016. *MassGIS Data: MassDEP Solid Waste Diversion and Disposal*. Accessed March 2023. Available at: https://www.mass.gov/info-details/massgis-data-massdep-solid-waste-diversion-and-disposal.

9 Homeland Infrastructure Foundation-Level Data (HIFLD) database. Accessed March 2023. *Solid Waste Landfill Facilities.* Available at: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::solid-waste-landfill-facilities/about.

10 Massachusetts Department of Environmental Protection. Updated December 2018. *Massachusetts Brownfield Tracking Spreadsheet*. Available at https://www.mass.gov/service-details/find-brownfields-sites.

Table 5. List of sources for existing solar data

Solar Program Data Source	Date updated	Number of installation records
Existing Solar Data for Massachusetts *Provided by email to Synapse August 2022* Contains solar installation data for three statewide programs: Solar Renewable Energy Certificate (SREC), Solar Massachusetts Renewable Target (SMART), and the Renewable Portfolio Standard (RPS), including installer, installation date, site address, and system capacity.	August 2022	RPS: 1,063 SREC: 99,777 SMART: 52,625
SMART Solar Tariff Generation Units *Massachusetts Department of Energy Resources* Dataset identifies Solar Tariff Generation Units status as Approved, Qualified, Waitlist, or Under Review. For the purposes of this analysis, we only included SMART installations with an "Approved" status. We used this dataset to fill in data gaps and identify installations as rooftop, ground-mounted, or canopy solar. Link: https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program	August 2022	52,738
Production Tracking System Solar PV Report *Massachusetts Clean Energy Center* Dataset includes all solar PV systems fully registered in PTS. We used this dataset to fill in data gaps and identify installations as rooftop, ground-mounted, or canopy solar. Link: https://www.masscec.com/production-tracking-system-pts#data	February 2022	121,592
Municipal Light Plant Solar Rebate Program Completed Solar Projects *Provided by email to Synapse September 2022*	September 2022	198
Residential Municipal Solar Program (Energy New England) *Provided by email to Synapse September 2022*	September 2022	335

Table 6 describes how much solar had been installed in Massachusetts through August 2022. It also estimates the recent installation rate of solar based on facilities built since January 2018. In the past five years, Massachusetts has seen a rate of solar installations of about 0.3 GW_{AC} per year. To reach the emissions limits established in the 2050 CECP, Massachusetts will need to triple or quadruple the rate of annual solar installations to 1 to 1.3 GW_{AC} installed per year. Figure 1 shows the total number of solar installations from all programs since the mid-2000s.

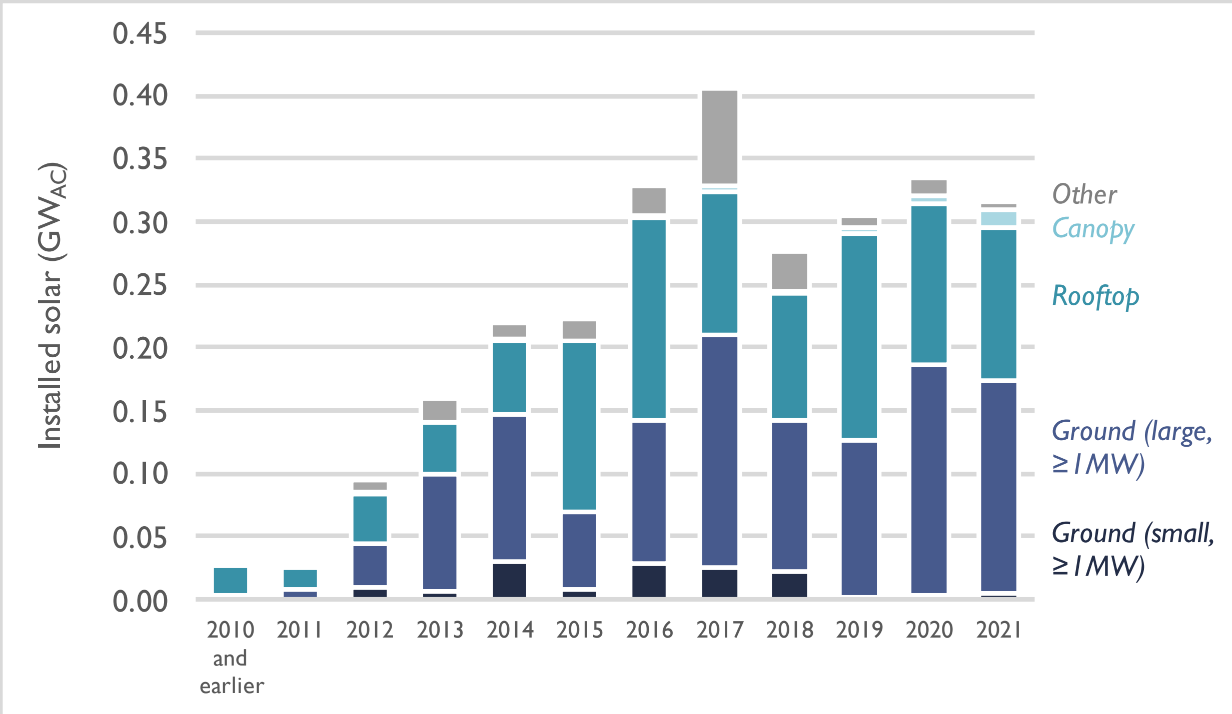
Table 6. Recent rate of solar installations in Massachusetts

Solar type	Total installed solar, Aug 2005 to Aug 2022 (GW_{AC})	Total installed solar, Jan 2018 to Aug 2022 (GW_{AC})	Capacity installed per year, Jan 2018 to Aug 2022 (GW_{AC} per year)
Ground-mounted (small, <1MW)	0.148	0.034	0.009
Ground-mounted (large, ≥1MW)	1.228	0.618	0.155
Rooftop	1.137	0.541	0.135
Canopy	0.038	0.028	0.007
Other	0.229	0.061	0.015
Total	**2.779**	**1.283**	**0.321**

Note: The solar type marked as "other" refers to solar installations that are not obviously identifiable as one of the other four categories. These 401 installations range from 25 kW_{AC} to 1 MW_{AC} in size; they may represent installations where the category cannot be derived from the existing information, or situations where there may be more than one type of solar installed on a parcel.

We identified the type of existing solar for each installation record. Some datasets had locational or other information (like SMART adders) that identified the installation as building-mounted, ground-mounted, or canopy solar. We categorized the remainder of the existing solar using two methods. First, we categorized all solar less than 25 kW in size as building-mounted, and all solar greater than 1 MW as ground-mounted. After screening those datapoints out, we used address data and aerial imagery to manually identify the remaining solar installations as ground-mounted, building-mounted, or canopy solar. Any solar unable to be identified after these three steps was labeled "Other."

Figure 1. Solar installations in Massachusetts by year



Note: The solar type marked as "other" refers to solar installations that are not obviously identifiable as one of the other four categories. This chart only displays solar built through 2021; however, the data used in our analysis included 0.05 GW of solar installed as of August 2022. At the time of this report, the most recent SMART dataset includes an additional 0.12 GW of solar built in 2022 and 2023 beyond what is included in this study. Additionally, as municipal light plant (MLP) projects do not qualify for the SMART program, an additional 3.3.MW, or about 0.003 GW, has been developed under MLP rebate programs, but was unable to be included in this figure as the data were undated.

Feasibility and Permissibility

Once we categorized parcels into areas for building-mounted, canopy-mounted, and ground-mounted solar, we applied a series of screens in ArcGIS to remove land from parcels that are unlikely to be used for solar due to physical, financial, or policy reasons. Figure 2 illustrates how we applied these screens.

During the feasibility screening step, we removed:

- Wetlands and surface water, due to the infeasibility of building solar on these ecosystems
- Protected and recreational open space as defined in MassGIS's protected open space dataset[11]

[11] MassGIS (Bureau of Geographic Information). Accessed July 2022. *MassGIS Data: Protected and Recreational OpenSpace*. Available at https://www.mass.gov/info-details/massgis-data-protected-and-recreational-openspace. This includes areas such as playgrounds, playing fields, wilderness areas, conservation areas, golf courses, cemeteries, and many other land-use types.

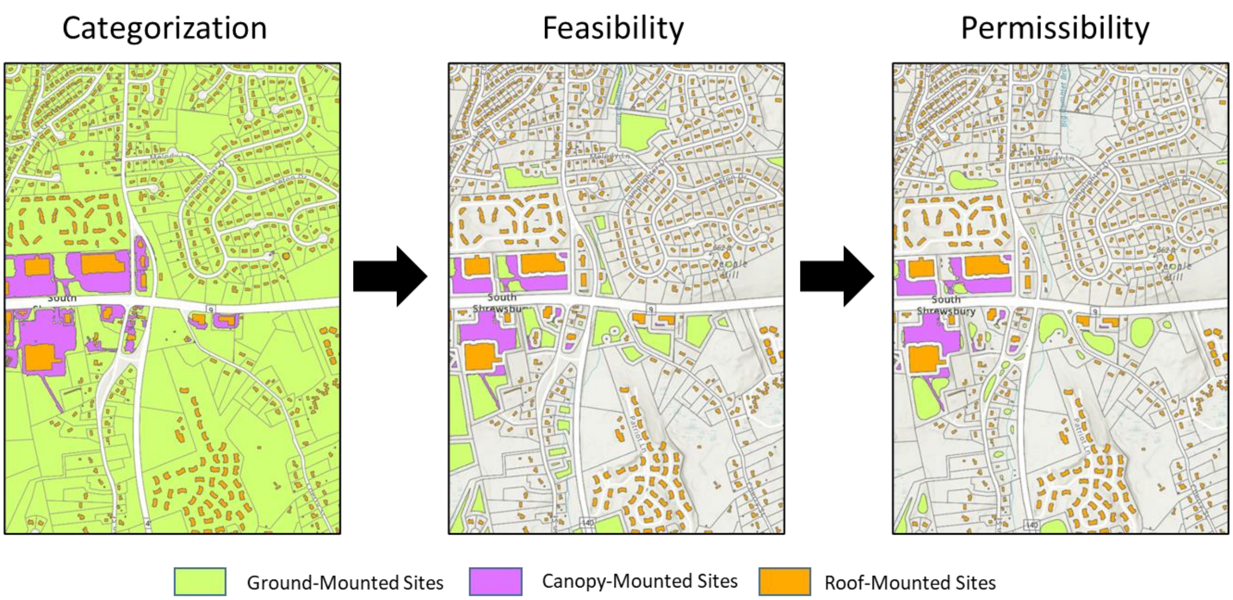
- Ground and parking lot area at airports, due to difficulty in identifying if land at airports is buildable for solar or necessary to exclude
- Objects classified as ground- and canopy-mounted areas with areas less than 1,560 sq feet (about 10 kW_{AC}, which represents the smallest ground- or canopy-mounted parcels we see installed historically)

During the permissibility screening step, we also applied the following screens:

- Added a setbacks buffer around all buildings and edges of parcels of 25 feet, based on input from members of the Technical Advisory Committee [12]
- Smoothed parcels to remove irregular edges that would be unlikely to support solar

Once we had applied all feasibility and permissibility screens, we were left with the area available to build solar, or the total area of technical solar potential.

Figure 2. Illustrative example of screening parcels for feasibility and permissibility



[12] Members of the Technical Advisory Committee provided detail on a set of recent historical solar installations featuring average setbacks of about 60 feet from buildings and property lines, as well as a summary of setbacks of installations on Cape Cod ranging from 10 to 100 feet. In addition, an ongoing study being performed by Eversource uses a setback assumption of 25 feet for all solar installations (*Testimony of Digaunto Chatterjee et al. on behalf of NSTAR Electric Company d/b/a Eversource Energy. Exhibit ES-Engineering Panel-1 (Marion-Fairhaven)(Revised)*. D.P.U. 22-47. April 15, 2022. Available at https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14906016). To be consistent with this other statewide study, and because this assumption is reasonably similar to setback ranges identified by other members of the Technical Advisory Committee, we assumed a 25-foot setback for all solar.

Technical Potential

To convert from total *area* of technical solar potential to total *capacity* of technical solar potential, we applied “packing factors” (i.e., the amount of solar capacity that can be installed in a particular area, expressed in megawatts per square kilometer) based on previous analyses from the National Renewable Energy Laboratory (NREL) and Lawrence Berkeley National Laboratory, respectively.[13,14]

- For ground-mounted and canopy solar we applied a packing factor of 69 MW_{AC} per square kilometer.
- For rooftop solar, we applied packing factors ranging from 80 to 92 MW_{AC} per square kilometer, or about 6.5 to 7.5 kW_{AC} per house, depending on rooftop size. Rooftops have no feasibility or permissibility screening applied. Instead, the packing factors used are inclusive of obstacles, which ultimately reduce the amount of buildable solar that could be sited. This and certain other factors (e.g., building or fire code requirements that limit solar on rooftops) were not accounted for in calculating the technical potential for rooftops. For more information on barriers to rooftop solar, see Section 3.4, Rooftop and Canopy Solar.

This analysis also calculates the total generation potential (measured in terawatt-hours or TWh) and emissions abatement potential (measured in avoided carbon dioxide) possible from potential solar capacity. See Section 2.3., Converting Capacity into Generation and Emissions Benefits, for more.

1.3. Suitability

Once we determined the total area where it is possible to build solar, we determined the suitability of these areas across six suitability categories. Within each category, we determined if a parcel is (A) Most Suitable, (B) More Suitable, and (C) Less Suitable. Each category has its own set of criteria about what constitutes suitability.

Agriculture

We ranked suitability under the Agriculture suitability category based on whether we identified parcels as "farmland" and based on the estimated amount of prime agricultural soil within the buildable solar area on the parcel. Under this suitability category, we identify ground-mounted parcels that are not located on farmland or prime agricultural soils as being most suitable for solar development.

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[13] National Renewable Energy Laboratory. *Rooftop Solar Photovoltaic Technical Potential in the United States*. 2016. Available at https://www.nrel.gov/docs/fy16osti/65298.pdf.

[14] Bolinger, M., and G. Bolinger. 2022. "Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density," in IEEE Journal of Photovoltaics, vol. 12, no. 2, pp. 589-594, doi: 10.1109/JPHOTOV.2021.3136805. See Figure 3 and Section IV.

Scoring

We analyzed each parcel area classified as ground-mounted to determine if it was designated as farmland and based on whether it contained prime agricultural soil. We designated objects as farmland if they are classified as agricultural or horticultural land under M.G.L. Chapter 61A, as listed in MassGIS' property tax parcel database.[15] We determined an object contained prime agricultural soil if it is designated as containing "Prime Farmland," "Farmland of Statewide Importance," and "Farmland of Unique Importance," in the National Cooperative Soil Survey.[16] This is the same definition for prime agricultural soil currently used in the SMART program as of spring 2023.[17] In Massachusetts, only 6 percent of the land is designated as farmland, but a significantly higher portion of the land contains prime agricultural soils. Approximately 25 percent of land is classified as prime agricultural soil in Massachusetts.

Based on these criteria, we assigned objects a suitability score of A, B, or C (see table below).

Table 7. Suitability grades for the Agriculture category

Suitability Score	Criteria
(A) Most Suitable	Prime agricultural soil area covers less than 25% of the object area and parcel is not designated as farmland
(B) More Suitable	Prime agricultural soil area covers greater than or equal to 25% of the object area and parcel is not designated as farmland
(C) Less Suitable	Parcel is coded as farmland

We apply the above criteria to all objects greater than 1.3 acres in size. For all objects 1.3 acres or smaller, we assign objects the least favorable suitability score if the object spans more than one suitability score. For example, if a ground-mounted object is 1.3 acres or smaller, and it intersects prime agricultural soil, it will be given a C grade under Agriculture.

We automatically assigned all objects identified as buildings and parking lots a suitability score of A for this category. We then aggregated all objects within a given parcel area to create separate suitability scores for rooftops, parking lots, and other surfaces for each parcel as whole.

It is important to note that the data used to identify prime agricultural soils in Massachusetts originates from soil mapping done in the 1970s through the 1980s. Some survey areas have been updated in more recent years. The earliest soil data for Massachusetts is from 1978, and the most recent update was in

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15 MassGIS (Bureau of Geographic Information). Accessed July 2022. *MassGIS Data: Property Tax Parcels*. Available at https://www.mass.gov/info-details/massgis-data-property-tax-parcels.

16 MassGIS (Bureau of Geographic Information). Accessed August 2022. *MassGIS Data: Soils SSURGO-Certified NRCS*. Available at https://www.mass.gov/info-details/massgis-data-soils-ssurgo-certified-nrcs.

17 Massachusetts Department of Energy Resources. Accessed March 30, 2023. *SMART Guideline Regarding the Definition of ASTGU*. Available at https://www.mass.gov/info-details/smart-guideline-regarding-the-definition-of-astgu.

2011. While this dataset is dated for the purposes of this study, this is the most up to date and readily used data available for determining soil conditions

It is also important to note that, while this analysis scored parcels coded as farmland as "Less Suitable," dual-use agrivoltaic projects sited on farmland are currently supported by the Commonwealth's solar energy policy. Dual-use projects can receive an increased incentive rate under the Commonwealth's current SMART solar incentive program through a collaborative qualification process with the Massachusetts Department of Agricultural Resources (MDAR) and the University of Massachusetts Clean Energy Extension (UMass CEE).[18] The qualification of dual-use solar projects is still in its nascency, and Massachusetts' current goal of 80 MW of dual-use solar makes up a negligible portion of the Commonwealth's renewable energy mandates. However, this analysis should not be interpreted to indicate that dual-use solar does not have a role to play in Massachusetts' emissions reduction strategy; rather, the methodology does not allow for the nuances of farmland conversion for solar development versus dual-use solar that maintains existing farmlands. See Section 3.3, Agriculture and Solar, for more on this topic.

Biodiversity

We ranked suitability under the Biodiversity suitability category based on whether parcels overlapped with Core Habitats, Critical Natural Landscapes, or Local BioMap Areas, per the 2022 BioMap tool.[19] We identify ground-mounted parcels that are not located within these areas as being most suitable for solar development.

Scoring

We analyzed each parcel area classified as ground-mounted to determine if it overlapped BioMap data layers including Core Habitats, Critical Natural Landscapes, or Local BioMap Areas. BioMap is a web-based tool created by MassWildlife and The Nature Conservancy that identifies land that is most important for preserving biodiversity and habitats across Massachusetts.

BioMap groups land that is important for conservation into two elements: Core Habitat and Critical Natural Landscape. Core Habitats are areas identified as critical for the long-term persistence of rare species, natural communities, and resilient ecosystems. Core Habitat consists of 1.5 million acres across the state, 49 percent of which is permanently protected. We screened out any land identified as permanently protected in the permissibility step in the analysis; as a result, this land is not identified as being buildable for solar in this step of the analysis.

Critical Natural Landscapes are large land areas that are minimally impacted by development, along with buffering areas around Core Habitats and coastal areas. Critical Natural Landscape consists of 2.1 million

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[18] Ibid.

[19] MassGIS (Bureau of Geographic Information). Accessed November 2022. *MassGIS Data: BioMap: The Future of Conservation*. Available at https://www.mass.gov/info-details/massgis-data-biomap-the-future-of-conservation.

acres, 46 percent of which is permanently protected. Critical Natural Landscape and Core Habitat overlap significantly. The total footprint of Core Habitat and Critical Natural Landscape is 2.4 million acres, 44 percent of which is permanently protected. We screened out any land identified as permanently protected in the permissibility step in the analysis; as a result, this land is not identified as being buildable for solar in this step of the analysis.

Additionally, BioMap includes local components, which are local habitats that are analogous to Core Habitat or Critical Natural Landscapes, assessed from the perspective of each city and town. This is land that may not be characterized as BioMap area at the state level but is important conservation land specific to each town. Local BioMap Area consists of over 1.1 million acres, the majority of which overlaps with statewide Core Habitat and/or Critical Natural Landscapes.

Based on the portion of land within each parcel that is comprised of BioMap lands, we assigned objects a suitability score of A, B, or C, as shown in Table 8.

Table 8. Suitability grades for the Biodiversity category

Suitability Score	Criteria
(A) Most Suitable	Total footprint of Local BioMap Area, Core Habitat, and Critical Natural Landscape area within the object is less than 25% of the object area
(B) More Suitable	Total footprint of Local BioMap Area, Core Habitat, and Critical Natural Landscape area within object is greater than or equal to 25% of the object area
(C) Less Suitable	Total footprint of Core Habitat and Critical Natural Landscape area within object is greater than or equal to 25% of the object area

We apply the above criteria to all objects greater than 1.3 acres in size. For all objects 1.3 acres or smaller, we assign objects the least favorable suitability score if the object spans more than one suitability score. For example, if a ground-mounted object is 1.3 acres or smaller, and it intersects Core Habitat, it will be given a C grade under Biodiversity.

We automatically assign all objects identified as buildings and parking lots a suitability score of A for this category. We then aggregate all objects within a given parcel area to create separate suitability scores for rooftops, parking lots, and other surfaces for each parcel as whole.

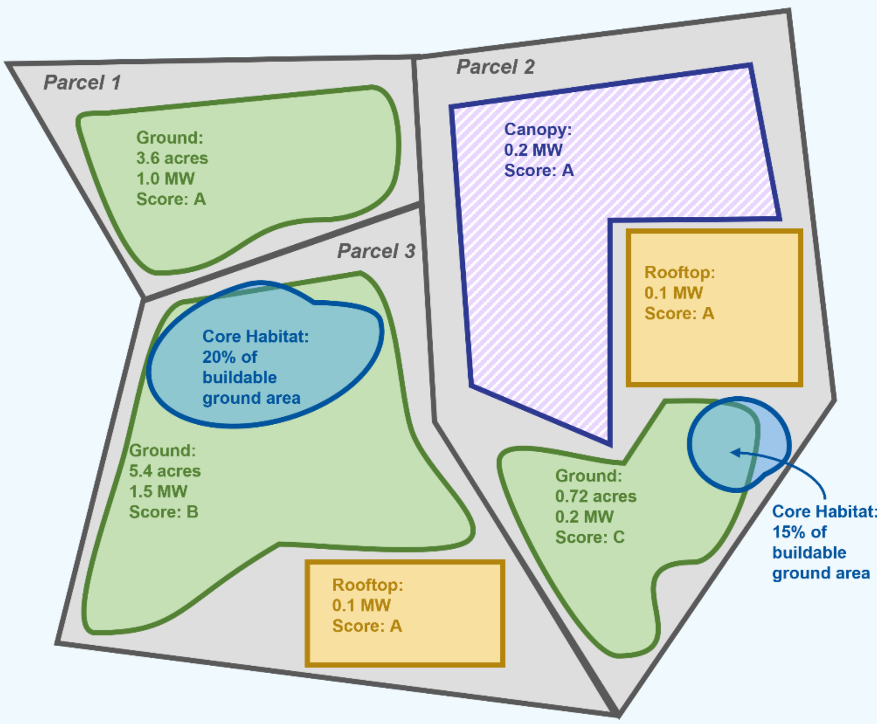
Figure 3. Illustrative example of suitability rules

This example illustrates how we applied suitability criteria for the biodiversity category. In general, we applied these criteria similarly for all other suitability categories.

Parcel 1 has **no Local BioMap Area, Core Habitat, or Critical Natural Landscape** area within the area that is buildable for ground-mounted solar. The 1.0 MW of technical ground-mounted solar potential receives an **A score** under the biodiversity category. It has no buildings or parking lots to score.

Parcel 2 has **BioMap Core Habitat covering 15 percent of the buildable ground area** within the parcel. Because the available ground area in this parcel is **less than 1.3 acres**, the 0.2 MW of technical ground-mounted solar potential receives a **C score**, even though less than 25 percent of the buildable area is covered by BioMap Core habitat. The 0.1 MW of technical rooftop solar potential and 0.2 MW of technical canopy solar potential within the parcel are automatically assigned a score of A.

Parcel 3 has **BioMap Core Habitat covering less than 25 percent of the buildable ground area** within the parcel. Therefore, the 1.5 MW of technical ground-mounted solar potential in that parcel is given a suitability **score of A**. The 0.1 MW in technical rooftop solar potential within the parcel is automatically assigned a score of A.



Other Ecosystem Services

We ranked suitability under the Other Ecosystem Services category based on whether or not a parcel overlapped with Massachusetts-designated Areas of Critical Environmental Concern (ACEC) or wellhead protection areas.[20, 21] Under this suitability category, we identify ground-mounted parcels that are not located within these areas as being most suitable for solar development.

Scoring

We analyzed each part of a parcel classified as ground-mounted to determine whether it overlapped with ACECs or wellhead protection areas. Areas of Critical Environmental Concern are places that receive special recognition because of the quality, uniqueness, and significance of their natural and cultural resources. Thirty areas covering approximately 268,000 acres across Massachusetts are currently designated as ACECs.

Wellhead protection areas are important for protecting the area around public water supply groundwater sources. A well's water supply is replenished when precipitation or stormwater seeps through the ground and reaches the water table. Wellhead protection areas are the surface and subsurface land areas from which a well draws water. Wellhead protection areas are categorized as either Zone 1 areas, Zone 2 areas, or as Interim Wellhead Protection Areas. Zone 1 wellhead protection areas are the required protective area closest to a public water supply well. The radius of this protected area must be at least 100 feet from the water supply, up to 400 feet. Typically, only land uses and activities directly related to the water supply are allowed in Zone 1 areas, however DEP has released guidance indicating that some solar development in Zone 1 areas may be permissible on case-by-case basis.[22] Zone 2 wellhead protection areas are areas surrounding a water supply well that contribute water to that well under the most severe pumping and recharge conditions anticipated. Zone 2 areas must include the entire Zone 1 area. Interim Wellhead Protection Areas are for wells that lack an approved Zone 2 protection area and are established by the Department of Environmental Protection. The radius of an Interim Wellhead Protection Area ranges from at least 400 feet from the well up to half a mile.

We assigned parcels a suitability score of A, B, or C based on the overlap of an object with ACECs or wellhead protection areas, as shown in Table 9. ACECs and wellhead protection areas cover only 15 percent of Massachusetts. Wellhead protection areas in particular are primarily located in eastern Massachusetts.

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[20] Department of Conservation and Recreation. Accessed July 2022. *ACEC Designations*. Available at https://www.mass.gov/lists/acec-designations.

[21] MassGIS (Bureau of Geographic Information). Accessed November 2022. *MassGIS Data: MassDEP Wellhead Protection Areas (Zone II, Zone I, IWPA)*. Available at https://www.mass.gov/info-details/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa.

[22] Department of Environmental Protection. Accessed May 2023. *Water and Solar Energy Projects Proposed in Zone 1.* Available at https://www.mass.gov/files/documents/2016/08/ua/1101_1.pdf.

Table 9. Suitability grades for the Other Ecosystem Services category

Suitability Score	Criteria
(A) Most Suitable	Sum of area covered by Interim Wellhead Protection Area, Zone 2 wellhead protection area, ACECs, and Zone 1 wellhead protection area is less than 25% of the object area
(B) More Suitable	Sum of area covered by Interim Wellhead Protection Area, Zone 2 wellhead protection area, ACECs, and Zone 1 wellhead protection area is greater than or equal to 25% of the object area
(C) Less Suitable	Sum of area covered by ACECs and Zone 1 wellhead protection area is greater than or equal to 25% of the object area

We apply the above criteria to all objects greater than 1.3 acres in size. For all objects 1.3 acres or smaller, we assign objects the least favorable suitability score if the object spans more than one suitability score. For example, if a ground-mounted object is 1.3 acres or smaller, and if it intersects ACECs or Zone 1 wellhead protection areas, it will be given a C grade under Other Ecosystem Services.

We automatically assign all objects identified as buildings and parking lots a suitability score of A for this category. We then aggregate all objects within a given parcel area to create separate suitability scores for rooftops, parking lots, and other surfaces for each parcel as whole.

Embedded CO_2e

This suitability category ranked parcels based on estimated embedded carbon and forgone carbon sequestration within parcels, per a 2021 Clark University study.[23] We identify parcels that have lower levels of embedded and foregone CO_2e as being most suitable for solar development.

Scoring

Building solar on land that sequesters carbon dioxide may lead to foregone carbon sequestration as well as the release of currently sequestered carbon. We analyzed each part of a parcel classified as ground-mounted to determine the amount of embedded and foregone carbon dioxide in the area of interest if ground-mounted solar panels were placed upon it. Embedded CO_2e refers to the greenhouse gases that are currently sequestered in forests or other biomass in an identified area. For the purpose of this study, we use the term “embedded CO_2e” to encompass both embedded carbon-dioxide-equivalent emissions and potential foregone sequestration of greenhouse gases. The potential foregone carbon sequestration quantifies the lost, or “foregone,” amount of CO_2e that could be sequestered by forests over the next 40 years if forests continue to grow and are not converted to non-forest land. The thresholds chosen divided the total area of the state into roughly three tranches of equal area, prior to any feasibility or permissibility screening. As a parcel-based analysis, our methodology did not include an analysis of potential avoided greenhouse gas emissions from solar development displacing fossil fuel generation.

[23] Williams CA, Hasler N, Xi L. 2021. “Avoided Deforestation: A Climate Mitigation Opportunity in New England and New York,” a report prepared for the United States Climate Alliance Natural and Working Lands Research Program, pp. 1 – 42. Available at https://www.nature.org/content/dam/tnc/nature/en/photos/Avoided-Deforestation-Report-NE-NY.pdf.

Because solar generation in one location may offset fossil fuel generation in another, this nuance was not able to be captured in this parcel-level analysis.

To assess the potential for solar siting to release or forgo potential carbon sequestration, we assigned parcels a suitability score of A, B, or C based on estimated embedded carbon, as shown in Table 10.

Table 10. Suitability grades for the Embedded CO_2e category

Suitability Score	Criteria
(A) Most Suitable	No embedded CO2e, as estimated in Clark University study, or contains up to 225 MT CO_2e/acre embedded and foregone CO_2e
(B) More Suitable	Embedded and foregone CO2e ranges from 226-275 MT CO_2e/acre
(C) Less Suitable	Embedded and foregone CO2e ranges from 276-363 MT CO_2e/acre

Unlike many other suitability categories, the grade for this category is based on "majority rules"—each object is assigned the grade that covers the majority of that object. We automatically assign all objects identified as buildings and parking lots a suitability score of A for this category. We then aggregate all objects within a given parcel area to create separate suitability scores for rooftops, parking lots, and other surfaces for each parcel as whole.

Areas with high levels of embedded CO_2e closely overlap with land classified as Core Habitat and Critical Natural Landscape within BioMap. Many of the most biodiverse areas have high levels of embedded carbon because of the natural landscape in those areas. Because of this, a parcel's suitability score for Embedded CO_2e is often the same as its suitability score for Biodiversity.

Electric Infrastructure

We ranked parcels under the Electric Infrastructure suitability category based on their proximity to electric substations. Under this suitability category, we identify ground-mounted parcels that are closest to electric substations as being most suitable for solar development. While this suitability category focuses on the proximity of parcels to electric substations, it does not incorporate the current hosting capacity of substations, which is a key factor in the cost of interconnection. Please refer to the hosting capacity maps published by electric distribution companies for more information.[24]

Scoring

Substations are high-voltage electric system facilities. The main role of a substation is to convert electricity to different voltages so that it can be transmitted from electric generation plants to

[24] Massachusetts Department of Energy Resources. Accessed June 1, 2023. *Utility Interconnection in Massachusetts*. Available at https://www.mass.gov/info-details/utility-interconnection-in-massachusetts#hosting-capacity-maps-.

consumers. Proximity to substations is an important consideration when siting solar because there are often lower costs associated with interconnecting solar facilities that are closer to electric substations, compared to facilities that are further away. Distances to substations selected for analysis in this study were developed based on discussion with the Technical Advisory Committee.

We analyzed each object to determine how close it was to electric substations. Based on this criterion, objects were assigned a suitability score of A, B, or C, as shown in Table 11.

Table 11. Suitability grades for the Electric Infrastructure category

Suitability Score	Criteria
(A) Most Suitable	Parcel is within 2 miles of a substation
(B) More Suitable	Parcel is within 2 to 5 miles of a substation
(C) Less Suitable	Parcel is more than 5 miles from a substation

Unlike all other suitability categories, all objects (buildings, parking lots, and other surfaces) were evaluated under this category. All objects within a given parcel are then aggregated to create separate suitability scores for rooftops, parking lots, and other surfaces for each parcel as whole.

For this analysis, proximity to substations acts as a proxy for the additional cost of solar development for any one parcel. To develop the quantity of solar and meet electrification needs estimated under the CECP for 2050, upgrades are likely to be necessary at many or most substations throughout the Commonwealth, and in many cases, new substations altogether will need to be constructed. This suitability category is intended to identify the parcels that are closest to substations that exist today and thus least likely to incur additional costs related to interconnection. Proximity to a substation is just one consideration related to grid infrastructure, and one that may vary by substation or by nearby land use (e.g., the cost to interconnect a solar facility that is 2 miles from a substation in an urban environment may be more than the cost to interconnect a solar facility that is a similar distance from a substation in a rural environment). It is important to note that, while a given parcel may be graded as "Most Suitable" based on proximity to a substation, that substation may not have capacity to host new solar without upgrades, which may vary in cost.[25] At the same time, it is not a wholly limiting factor against solar construction given that grid infrastructure upgrades, including the use of grid modernization and DER technologies to maximize virtual power plants, are ongoing and likely to continue. As a result, this suitability category (as with all other suitability categories) should be regarded on a relative basis and used to compare more suitable solar siting locations with less suitable locations.

[25] For more information on current substation hosting capacity, please refer to the hosting capacity maps available at https://www.mass.gov/info-details/utility-interconnection-in-massachusetts#hosting-capacity-maps-.

Slope and Aspect

We ranked parcels under the Slope and Aspect suitability category based on how steep the land was at a particular parcel and in which direction the land was facing, using data layers of slope and aspect created by MassGIS using LiDAR data.[26] Under this suitability category, we identify parcels that are south-facing and on relatively flat land as most suitable for solar development.

Scoring

We define slope as the grade of an area, measured in percent. A 0-degree grade represents perfectly flat land. A 90-degree grade represents land that is perfectly vertical. Based on conversations with solar developers, we identified land with grades less than 10 degrees as being roughly equivalent (for ease-of-building purposes) with perfectly flat land, while grades between 10 degrees and 20 degrees were buildable for solar—albeit with increased costs. Grades larger than 20 degrees are viewed as not generally buildable for solar.

We define aspect as the direction an area is tilted towards, measured in degrees. Degrees are expressed in terms of a compass rose, where 0 degrees represents land facing north, 90 degrees represents land facing east, and so on. For this analysis, solar sited on land with a slope greater than 10 degrees is better suited to be facing away from north, or roughly north-by-east through south to north-by-west. This is because south-facing land receives more direct sunlight.

We analyzed each object to determine its steepness (measured in percent grade) and aspect (measured in degrees, with 0 degrees facing north, 90 degrees facing east, and so on). Based on these criteria, objects were assigned a suitability score of A, B, or C, as shown in Table 12. Although some parts of Massachusetts are hilly, particularly in Worcester, Franklin, Hampden, Hampshire, and Berkshire counties, most of the state is relatively flat or has south-facing hilly areas.

Table 12. Suitability grades for the Slope and Aspect category

Suitability Score	Categorization
(A) Most Suitable	Parcel has less than or equal to a 10-degree grade, facing any direction[(a)]
(B) More Suitable	Parcel has a grade greater than 10 degrees and less than or equal to 20 degrees facing south, where “south” is defined as between 45° and 315°
(C) Less Suitable	Parcel has a grade greater than 10 degrees and less than or equal to 20 degrees facing north, or greater than a 20-degree grade facing south

Note: The “Most Suitable” slope criteria of 10 degrees or less was determined based on feedback from the Technical Advisory Committee pertaining to relative ease and cost of building solar on parcels of various grades. However, solar siting decisions should account for potential environmental impacts on adjacent or nearby parcels due to erosion and sedimentation as a result of building solar at a grade of 10 degree or higher. For more information on best practices for solar siting in accordance with the Wetlands Protection Act, please see https://www.mass.gov/info-details/massdep-wetlands-program-policy-17-1-photovoltaic-system-solar-array-review.

[26] MassGIS (Bureau of Geographic Information). Slope and Aspect Data. Provided via email to Synapse January 2022.

2. RESULTS

This chapter summarizes our statewide findings with respect to technical potential and suitability grades. For detailed information on capacity and suitability for individual parcels, see this report's accompanying StoryMap at https://TechnicalPotentialOfSolar-MA-synapse.hub.arcgis.com.

The technical potential and suitability analysis presented here do not account for all practical and economic decision points necessary prior to developing solar, including but not limited to the full cost of installation and interconnection, competing development pressures, potential new land-use restrictions, and site conditions (e.g., roof age and condition). Instead, this study to provide a general estimate of technical solar potential and a framework for ranking different sites' suitability. Further discussion of these and other solar development considerations that were not included in the spatial analysis can be found in Section 3, Policy Considerations.

2.1. Technical Potential

Table 13 shows our results for the total amount of land in Massachusetts where it is possible to build solar. We found that Massachusetts has the technical potential to site 506 GW_{AC} of solar prior to applying any suitability criteria and identifying the most suitable parcels. Synapse estimated that Massachusetts' technical solar potential is 15 to 18 times greater than the amount required by the CECP (27 to 34 GW_{AC}).[27] Most of the technical potential (over 90 percent) is ground-mounted solar, the majority of which is large ground-mounted (greater than 1 MW_{AC}). The total technical potential estimated in this study spans nearly 7,200 square kilometers or nearly 1.78 million acres, of which 91 percent is ground-mounted technical solar potential.[28]

[27] This range is based on values estimated in Figure A.11 of Appendix A to the Mass CECP (see Massachusetts Executive Office of Energy and Environmental Affairs. June 2022. *Appendices to the Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at https://www.mass.gov/doc/appendices-to-the-clean-energy-and-climate-plan-for-2025-and-2030/download). The lower 27 GW value is an average of the capacity built in Massachusetts in the five scenarios considered in this study. The higher 34 GW value is an average of the capacity built in all of New England in the five scenarios, derated to reflect Massachusetts current share of regional electricity demand (45 percent), which hold constant through this estimate for purposes of simplification.

[28] As a point of reference this is equivalent to about one-third of Massachusetts' total land area.

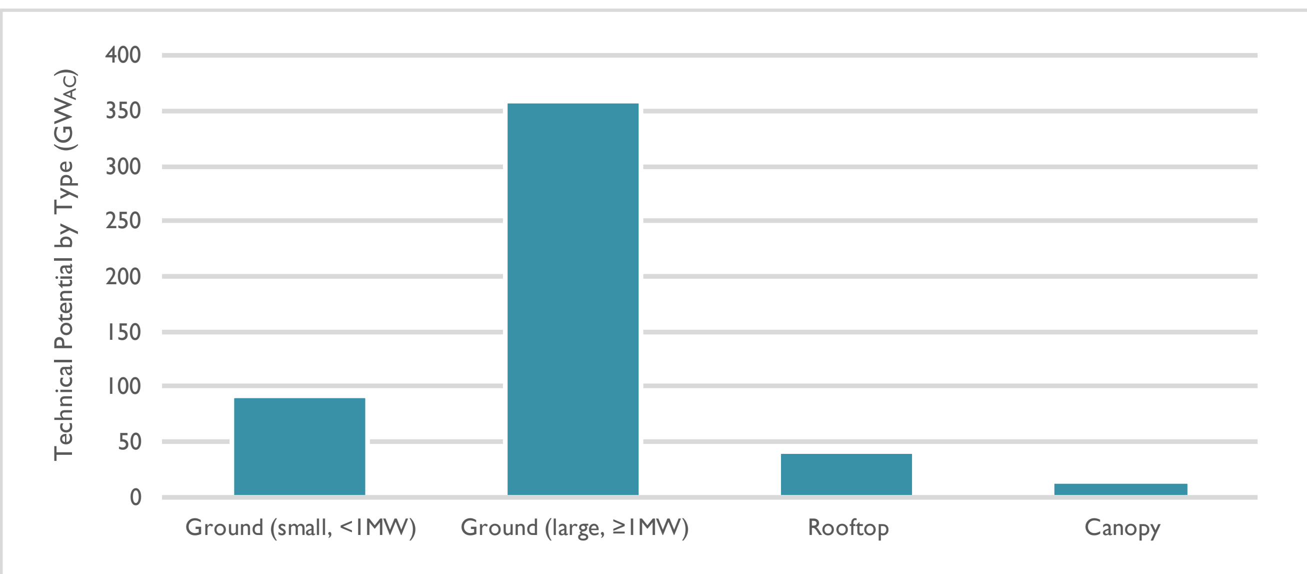
Table 13. Technical potential for solar in Massachusetts

Type of Solar	Number of Scored Parcels	Total Technical Potential (GW)	Median Capacity (kW_{AC})[a]	Middle 50% Capacity (kW_{AC})[a]	Historical Costs (2021 $/$W_{DC}$)
Ground (Small, <1MW)	767,338	91	38	19 – 94	$2.95 *($2.02 – $3.15)*[b]
Ground (Large, ≥1MW)	70,425	359	2,146	1,503 – 3,652	$2.31 *($1.74 – $2.76)*[b]
Rooftop	1,878,188	40	15	11 – 20	$3.46 *($3.31 – $4.05)* [d]
Canopy	83,335	14	44	19 – 122	$3.31 *($2.71 – $4.06)*
All	**2,190,306**[c]	**506**	-	-	-

Notes: (a) Median and middle 50 percent statistics are only shown for all solar installations that did not get a single C grade in any suitability category. This is 97–98 percent of the rooftop and canopy technical potentials, but just 23–54 percent of the ground-mounted technical potentials.
(b) Costs in parentheses represent the middle 50 percent of costs. All costs are based on approved projects under the SMART program, installed from 2018–2022. For more on costs, see "Existing solar" section on page 12.
(c) This is not a sum of the above rows. Instead, it reflects the total number of parcels analyzed, some of which may have multiple different technical solar potentials
(d) The median rooftop cost includes both residential and commercial rooftops, which have different average costs due to their respective scales.

Figure 4 illustrates the technical potential for each type of solar. Of all technical solar potential estimated, 89 percent is either small or large ground-mounted; 71 percent of all technical solar potential estimated is large ground-mounted solar.

Figure 4. Estimated technical potential by type of solar



2.2. Suitable Potential

Figure 5 shows the technical potential of solar broken out by type of solar and suitability score. This figure does not include any technical potential scored with a C (less suitable) in any category. The technical potential that did score at least one C makes up 353 GW of the 506 GW total, or about 70 percent of all technical potential. Non-ground-mounted solar that scores a C makes up less than 0.2 percent of all technical potential. Figure 6 highlights just the ground-mounted solar, which makes up almost 90 percent of the estimated technical potential, and almost two-thirds of all technical potential earning at least a B grade in each category.

10 percent of all technical potential (52 GW) scores an A (most suitable) in every category.

152 GW of technical potential receives either an A or B grade in every category.

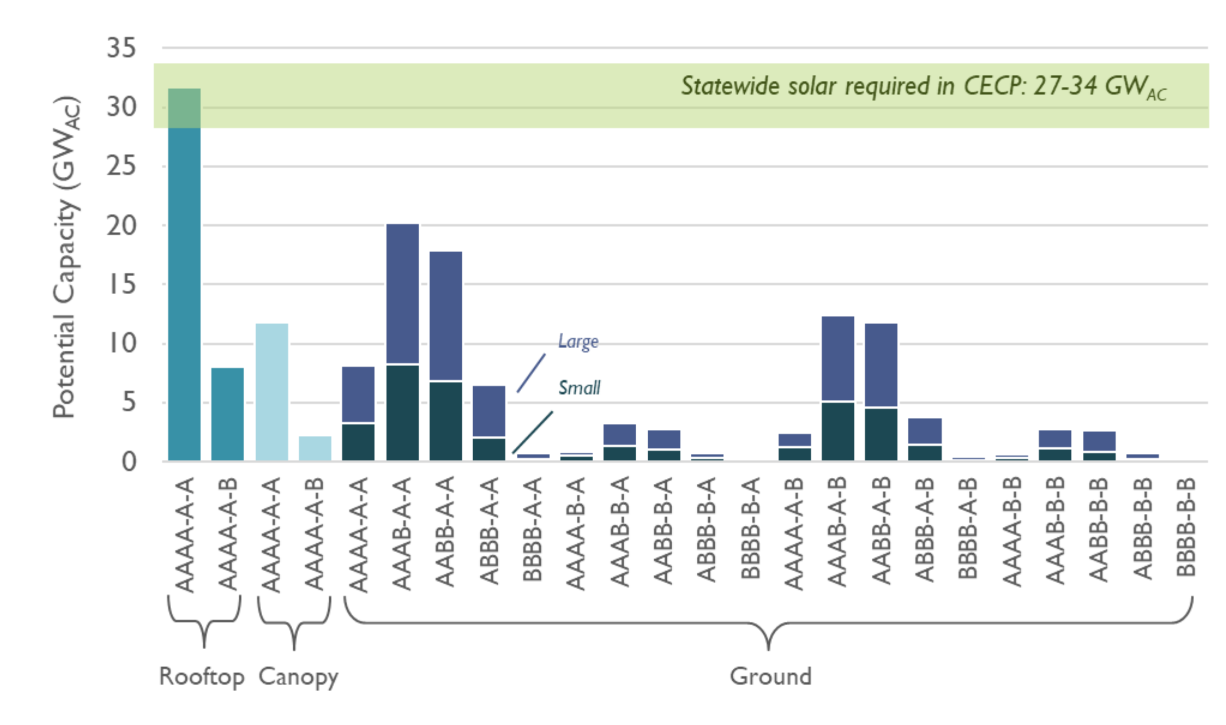
In total, 10 percent of all technical solar potential (52 GW) scores an A (most suitable) in every category. Because Massachusetts will need 27 to 34 GW_{AC} of solar to meet CECP limits by 2050, 100 percent of needed solar could in theory be sited in the most suitable (all A's) parcels. In aggregate, the 152 GW_{AC} of solar potential shown in Figure 5 receives either an A or B grade in every category. We refer to this quantity of solar as "highly suitable."

The total highly suitable potential in the first eight columns of Figure 5 is equal to 3-4 times the solar requirement implied by the CECP, indicating that Massachusetts has a significant amount of land that is highly suitable for solar.

Rooftop And Canopy Solar Caveats

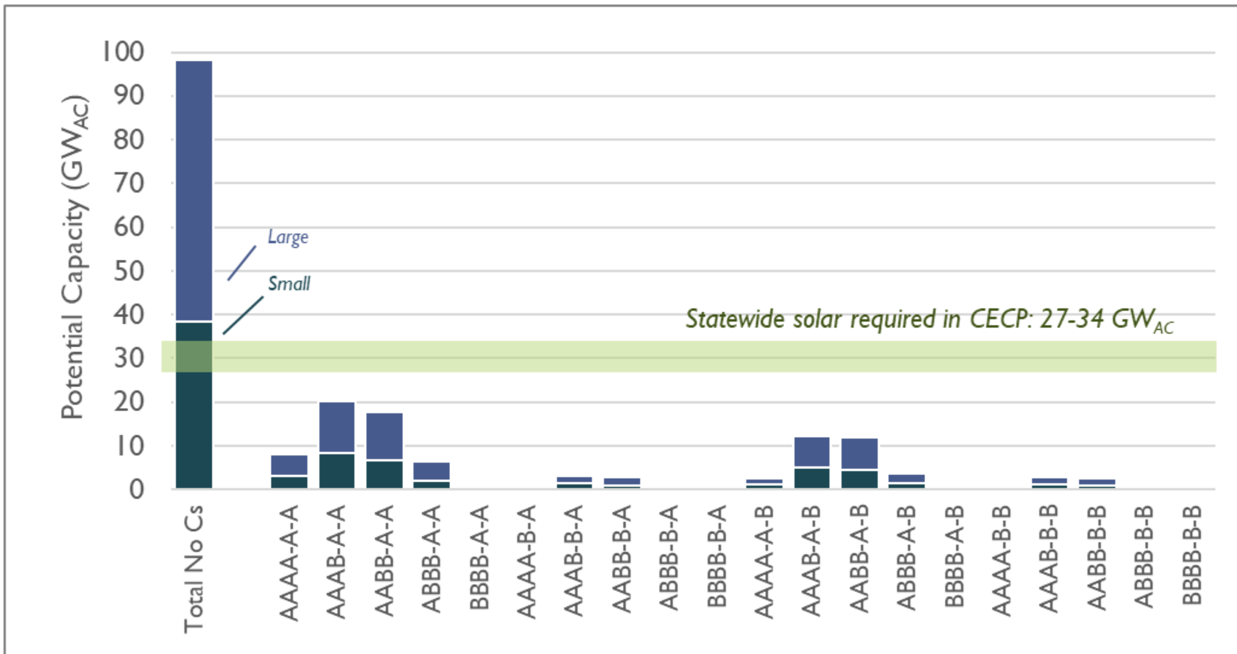
It is important to note that the only suitability criterion applied to rooftop and canopy solar was electric infrastructure. There are several other key barriers to rooftop and canopy solar development that were not included in this analysis. Therefore, the estimated highly suitable potential of rooftop and canopy solar development is likely to be overestimated. Please see Section 3.4. Rooftop and Canopy Solar, for more details on barriers to rooftop and canopy solar. The bars marked "Ground" in Figure 5 (e.g., the first column of Figure 6) shows that even without rooftop and canopy solar, ground-mounted solar provides 3–4 times the requirement implied by the CECP.

Figure 5. Solar potential by combined suitability score, all types, no C grades



Note: This figure does not account for existing solar installations. Existing solar is small compared to the potentials estimated here (about 3 GW).

Figure 6. Solar potential by combined suitability score, ground-mounted solar only, no C grades



Given the importance of proximity to existing grid infrastructure in terms of reducing costs of new solar installations, we examined how much solar is graded as highly suitable in the Grid Infrastructure category, relative to all other categories. We found that 21 percent of solar (104 GW) scores an A or B (More Suitable) in the first five categories (Agriculture, Biodiversity, Other Ecosystem Services, Embedded CO_2e, and Slope and Aspect) and is also located within 2 miles of a substation (an A in the last category). Of this amount, 37 GW is "Large" ground-mounted solar (greater than 1 MW). We found that 9 percent of capacity (48 GW) scores an A or B in the first five categories and is also located 2 to 5 miles from a substation (a B in the last category). Of this, 23 GW is "Large" ground-mounted solar (greater than 1 MW).[29]

21 percent of solar (104 GW) scores an A or B (more suitable) in the first five categories and is also located within 2 miles of a substation.

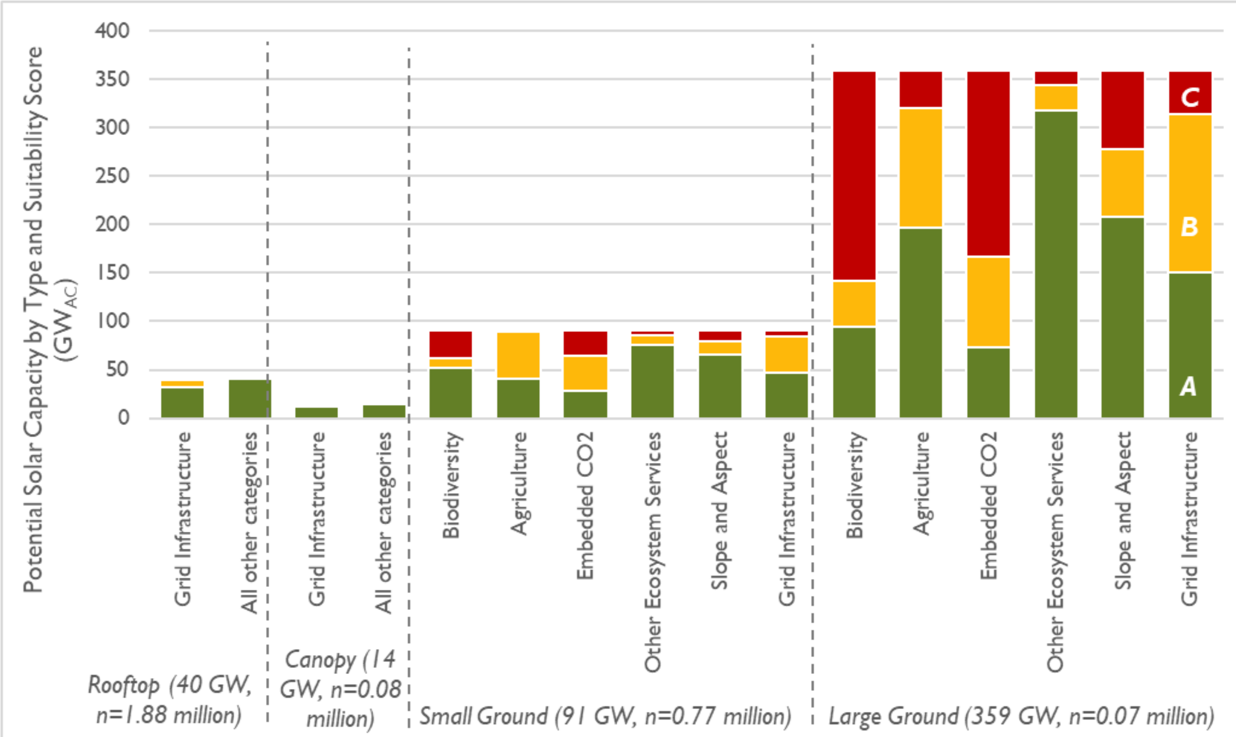
9 percent of capacity (48 GW) scores an A or B in the first five categories and is also located 2 to 5 miles from a substation.

Suitable Potential by Category

Figure 7 shows the share of technical potential for each type of solar within each suitability category. The applied suitability categories affect different types of solar in different ways, as described below.

[29] As the Electric Infrastructure suitability category did not account for current hosting capacity, this is likely an overestimation of the current suitable solar potential based on electric infrastructure. Hosting capacity is essential to the ability to interconnect solar generation with the grid as well as the associated cost of development and plays a key role in specific solar siting decisions. For more information on current substation hosting capacity, please refer to the hosting capacity maps available at https://www.mass.gov/info-details/utility-interconnection-in-massachusetts#hosting-capacity-maps-.

Figure 7. Share of technical potential by solar type and suitability score



Rooftop and Canopy

Within parcels that can site solar on rooftops or above parking lots, **Grid Infrastructure** is the only category where these parcels may have a score other than A. However, we only scored a small fraction of these potential sites (2 percent) with a C score for Grid Infrastructure. We gave 78 percent of rooftop capacity and 83 percent of canopy capacity a suitability score of A. In essence, there are many substations throughout Massachusetts, and 2- and 5-mile circles surrounding all of the substations covers a substantial amount of land statewide. For more information on additional considerations related to suitability of solar on rooftops, see Section 3.4, Rooftop and Canopy Solar.

Ground-mounted

A relatively small share (9 percent) of statewide capacity received a suitability score of C for **Agriculture**. Only 6 percent of the land in Massachusetts is designated as farmland, but a significantly higher portion of the land contains prime agricultural soils. Approximately 25 percent of land is classified as prime agricultural soil in Massachusetts. Over half of the statewide technical potential (53 percent) received a suitability score of A.

Ground-mounted solar, Agriculture category: *Over half of the statewide technical potential (53 percent) received a suitability score of A.*

Within parcels that can host ground-mounted solar, we only rank about 46 percent of ground-mounted technical solar potential in the **Biodiversity** category with an A or B. BioMap-designated land spans a large share of the state, resulting in many parcels receiving a C score for Biodiversity. In total, BioMap identifies 1.3 million acres of Core Habitat or Critical Natural Landscape across Massachusetts that is not permanently protected, covering approximately one-quarter of Massachusetts' land area.

Ground-mounted solar, Biodiversity category: *BioMap-designated land spans a large share of the state, resulting in many parcels receiving a C score.*

Similarly, suitability results under **Embedded CO_2e** resemble those for Biodiversity. Many of the most biodiverse areas have high levels of embedded carbon because of the natural landscape in those areas. Capacity scores for Embedded CO_2e are relatively well-distributed across the three grades. Each of the three category thresholds contains roughly one-third of Massachusetts' land area.

In the **Other Ecosystem Services** category, most technical potential received a high score, and few parcels are scored a C. In this category, C scores cover land types that are relatively rare or small or both: ACECs and wellhead protection areas cover only 15 percent of Massachusetts. Wellhead protection areas in particular are primarily located in eastern Massachusetts. As a result, the majority (88 percent) of statewide capacity receives a suitability score of A.

Grid Infrastructure has similarly small impacts on ground-mounted solar, with most technical potential (88 percent) scoring an A or B. Simply put, there are many substations distributed throughout the state and drawing a 2- to 5-mile radius around all of them reaches the majority of potential ground-mounted solar sites.

Ground-mounted solar, Grid Infrastructure category: *There are many substations distributed throughout the state and drawing a 2- to 5-mile radius around all of them reaches the majority of potential ground-mounted solar sites.*

Under **Slope and Aspect,** 80 percent of land scores A or B. Although some parts of Massachusetts are hilly, most of the state is relatively flat; or where land is hilly, it is facing the right direction to take advantage of solar rays.

Suitable Potential by Land-Use Type

Table 14 summarizes solar potential by land-use type for solar potential scored with no C's in any suitability category (i.e., the "highly suitable" quantity of solar). We group land use in two ways: by zoning and by development. Group I breaks out solar potential by major property type classification codes, as defined by the Massachusetts Bureau of Local Assessment.[30] Group II breaks out solar potential by the type of development on a parcel, as defined in Section 1.2 of this report. Values tallied under Grouping I will not match the values tallied under Grouping II because some parcels can be a landfill, brownfield, and/or other partially developed. We note that some of the definitions used in Massachusetts Bureau of Local Assessment's classification may not match conventional definitions or definitions used elsewhere in this analysis. For example, "Forest" refers to a limited set of lands meeting a specific set of conditions and is not inclusive of all forested land. In addition, "Agriculture" refers to lands that are identified by Massachusetts Bureau of Local Assessment as agricultural, but the term does not necessarily encompass all farmland or lands with prime agricultural soils.

In Table 14, "0.0" values are less than 0.1 GW. Within Grouping I, most potential is in land designated as "Residential – Single Family." This is in part because this is the land use that is most prevalent in Massachusetts. In many municipalities, it is the "default" land-use type according to municipal zoning. This should not be read that there are necessarily existing residential buildings on these parcels, but rather, they are zoned residential and may or may not have existing buildings. Within Grouping II, most potential solar (87 percent) can be sited on land that is developed, either as a brownfield, landfill, or other development.

[30] Massachusetts Bureau of Local Assessment. Revised April 2019. *Property Type Classification Codes: Non-arm's Length Codes and Sales Report Spreadsheet Specifications*. Available at https://www.mass.gov/doc/property-type-classification-codes-non-arms-length-codes-and-sales-report-spreadsheet/download.

Table 14. Solar potential by land use type (GW_{AC})

	Land Use Type	Rooftop	Canopy	Ground (Small)	Ground (Large)	Total
Grouping I	Agriculture	0.1	0.1	0.0	0.0	0.1
	Forest	0.0	0.0	0.1	1.7	1.8
	Commercial	4.5	5.2	1.5	3.3	14.5
	Industrial	3.0	2.9	1.3	6.2	13.4
	Government	1.7	2.2	1.5	6.0	11.5
	Residential - Single Family	21.6	0.0	25.4	10.4	57.4
	Residential - Other	5.9	1.3	6.3	12.6	26.1
	Multi-use	1.2	0.7	0.7	12.3	14.9
	Recreation and Open Space	0.0	0.0	0.2	1.4	1.6
	Other	1.7	1.5	1.6	6.0	10.7
Total		**39.7**	**14.0**	**38.5**	**59.9**	**152.1**
Grouping II	Landfill	0.1	0.3	0.0	1.1	1.6
	Brownfield	0.3	0.4	0.1	0.6	1.4
	Other partially developed	39.7	14.0	32.1	43.5	129.4
	Other	0.0	0.0	6.4	16.2	22.5

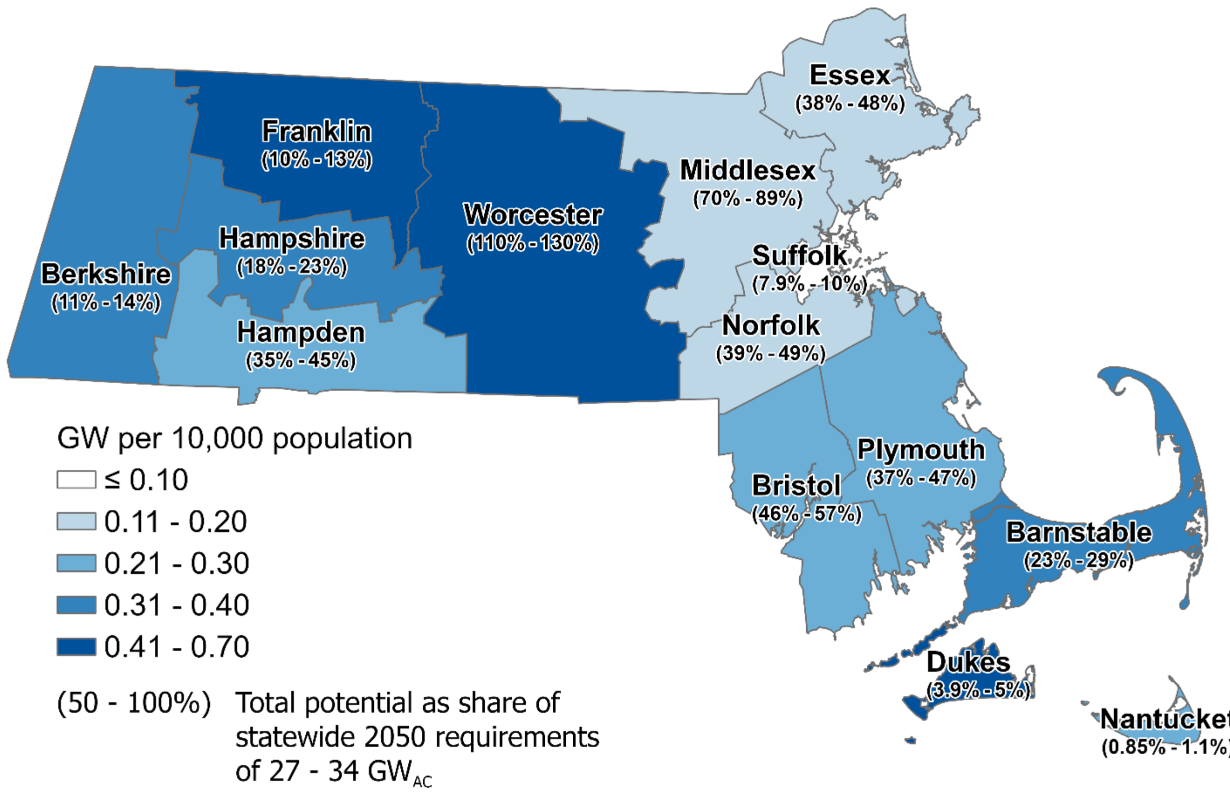
Note: This table only includes solar potential that does not receive a C grade in any category.

Distribution of Suitable Potential

Figure 8 maps suitable (no C's) solar potential for each county in Massachusetts, with results normalized according to population (per 10,000 people). Historically there has been a disparity between what areas in the Commonwealth have hosted energy infrastructure to support other populations in Massachusetts. Using population as a proxy for energy consumption, dividing solar potential by 10,000 population allows us to assess if the demand for solar per county can be met with the county's own solar potential.

Suitable solar potential in GW per 10,000 people ranges from 0.03 in Suffolk County to 0.65 in Dukes County. Generally, the western part of the state has both more potential and fewer people than the eastern part of the state. However, every county in Massachusetts has the potential to build its own share of the CECP-required solar allocated by population except for Suffolk County, which only has 70–90 percent of its allocated requirement. All other counties have suitable potential equal to 3–17 times their requirement, and 8 of 14 counties could each host more than one-fifth of Massachusetts' required solar. This analysis of the distribution of suitable potential does not account for network distribution systems in many dense urban areas, which may further limit solar development in these areas. More detail on this is provided in Section 3.4, Rooftop and Canopy Solar.

Figure 8. Highly suitable solar potential across Massachusetts, normalized by population[(a)]



Note: This map only includes suitable solar potential, or solar potential that did not receive any C's in the suitability analysis.

2.3. Converting Capacity into Generation and Emissions Benefits

The previous steps entail calculating the potential capacity associated with solar in Massachusetts. As such, these values relate to the amount of land that would be required to host solar facilities. However, capacity values do not describe the amount of electricity that solar panels could generate, nor do they describe the amount of emissions avoidable from this electricity.

Using information from DOER's published SREC dataset on capacity factors, and U.S. Environmental Protection Agency's Avoided Emissions and Generation Tool (AVERT) model on emission rates, we estimated the total generation and avoided emissions associated with the estimated technical solar potential (see Table 15).[31,32] Across all estimated types and grades of solar, if the 506 GW_{AC} of technical potential were built, it would generate 576 TWh. This is equal to about 13 times the current demand for electricity in Massachusetts. Table 16 translates this quantity of generation into avoided emissions, based on the marginal emissions rate estimate for 2021 for New England. We estimate the technical solar potential derived in this study from all types and grades would avoid over 500 million short tons of carbon dioxide per year, and thousands of short tons of other pollutants that have detrimental impacts on human health. Importantly, this number represents an upper ceiling on avoidable emissions for two reasons: first, it is highly unlikely that the full quantity of 506 GW_{AC} will be built. Second, the marginal emissions rates used in Table 16 represent the rate at which solar displaces emissions today. Over time, we would expect the grid to become cleaner and for this rate to decrease. Eventually, if the entire grid were made up of zero-emitting generation, the marginal emissions rate for any pollutant would be 0 lb per MWh.

Table 15. Capacity factors and estimated generation

Type of Solar	Assumed Capacity Factor	Technical Potential (GW_{AC})	Technical Potential Generation (TWh_{AC})
Ground (Small, <1MW)	13%	91	104
Ground (Large, ≥1MW)	13%	359	409
Rooftop[(a)]	13%	40	46
Canopy[(a)]	13%	14	16
Total	**-**	**506**	**576**

Notes: All capacity factors are estimated based on MWh_{AC} output per MW_{AC}.

31 MassCEC. *SREC Capacity Factor Analysis*. August 2022. Available at https://www.masscec.com/sites/default/files/documents/SREC%20Capacity%20Factor%20Analysis%202010%20thru%202021_FINAL_2022.08.30.xlsx.

32 U.S. Environmental Protection Agency. March 2022. *Avoided Emission Rates Generated from AVERT, v3.2*. Available at https://www.epa.gov/avert/avoided-emission-rates-generated-avert. We note that emission rates generated with AVERT assume solar resources that operate with capacity factors that are 5 to 10 percentage points higher than observed in MassCEC's SREC Capacity Factor Analysis. However, this change in capacity factor is unlikely to substantially alter the marginal emissions rate, based on our review of published emission rates for different resource types in the AVERT dataset.

Table 16. Emission factors and avoided emissions for a single year

Type of Solar	Assumed emission rates (lb/MWh)				Estimated avoided emissions (thousand short tons)			
	CO_2	NO_X	SO_2	$PM_{2.5}$	CO_2	NO_X	SO_2	$PM_{2.5}$
Ground (Small)	1,010	0.19	0.10	0.03	52,604	10	5	2
Ground (Large)	1,010	0.19	0.10	0.03	206,601	39	20	7
Rooftop[(a)]	1,095	0.20	0.10	0.03	25,230	5	2	1
Canopy[(a)]	1,095	0.20	0.10	0.03	8,851	2	1	<1
Total	-	-	-	-	**293,286**	**55**	**28**	**9**

Notes: (a) Emission factors shown for these types of solar are inclusive of transmission and distribution losses.

3. POLICY CONSIDERATIONS

While the above suitability analysis grades the technical solar potential for six suitability categories, there are other factors we did not analyze quantitatively that impact a specific site's suitability for solar. In addition, our analysis is a high-level screening analysis and within each suitability category, there are additional factors that we did not consider for suitability. This chapter provides additional detail and sources on solar siting, beyond the considerations reflected in our quantitative geospatial analysis. These factors need consideration alongside our quantitative analysis when developing future policy in order to ensure positive outcomes for solar development and land use. We based many of these considerations on discussions with members of the public and the study's Technical Advisory Committee.

3.1. Aligning Solar Siting Considerations with the Commonwealth's Land-Use Priorities

Massachusetts' solar siting policies should align with the Commonwealth's existing goals and strategies with regards to land use and natural resource management.

The CECP establishes specific goals for managing natural and working lands, defined in Chapter 8 of the Acts of 2021 as "lands within the commonwealth that: (i) are actively used by an agricultural owner or operator for an agricultural operation that includes, but is not limited to, active engagement in farming or ranching; (ii) produce forest products; (iii) consist of forests, grasslands, freshwater and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands or wildlife habitats; or (iv) are used for recreational purposes, including parks, urban and community forests, trails or other similar open space land."[33] The CECP establishes a goal of permanently conserving 40 percent of natural and working lands by 2050 and calls on the Commonwealth to develop solar siting policies in a manner that is consistent with the protection of critical habitats, as well as to develop regulatory pathways to limit forest clearing.[34]

The Resilient Lands Initiative was developed by the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) in part "as a companion to the CECP and Roadmap focused on a vision of climate resilience that keeps the ecosystems of the Commonwealth intact and uses nature for the benefit of the residents."[35] The practices and policies outlined in the Resilient Lands Initiative around

[33] *An Act Creating A Next Generation Roadmap for Massachusetts Climate Policy*. 2021. Available at https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8.

[34] Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA). 2022. *Massachusetts Clean Energy and Climate Plan for 2050*. Available at https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050.

[35] MA EEA. 2023. *Resilient Lands Initiative*. Available at https://www.mass.gov/doc/the-resilient-lands-initiative-2023/download.

land use, conservation, and protection of water resources may provide guidance to policymakers to ensure solar siting policies are aligned with statewide goals.

The stakeholder engagement process for this study included a public survey to learn about Massachusetts residents' priorities and concerns around the siting of large-scale solar projects. The survey was open to anyone in Massachusetts for a 60-day period in 2022 from September 19th to November 18th. See Appendix A, Description of Survey, for further details on survey questions and results.

Feedback from the public survey demonstrated consensus from the public in support of solar siting policies that are aligned with the state's land-use and natural resource management priorities described above. The theme that appeared most often in responses to the survey was a general opposition to clearing forests, wetlands, and vegetated areas to make way for solar installations. Respondents were opposed to removing these carbon sinks and felt that it was counterproductive to clear forests. Respondents also noted the ecosystem services that these types of areas provide, including water purification, erosion control, air filtration, local cooling, hillside stability, critical roles in the water cycle and nitrogen cycle, and maintaining microclimates. In addition, respondents noted that these areas provide valuable habitats for wildlife and pollinators. Furthermore, there was concern over drought, noise pollution, and drainage issues from the removal of these ecosystems. To a lesser extent, respondents were receptive to solar projects replacing forests in situations where the forests had lower levels of carbon sequestration ability, such as new growth forests or small wooded areas on parcel edges. Some respondents felt positively about siting on wooded and vegetated areas because they believed that Massachusetts should be doing everything it could to move away from fossil fuel use.

3.2. Current Solar Policy and Land Use

In Massachusetts, several types of policy impact solar siting, including the Solar Massachusetts Renewable Target (SMART), net metering, Solar Renewable Energy Certificates (SRECs), State Tax Credits and Payments in Lieu of Taxes (PILOTs), and zoning and property laws. We did not take these policies into account when assessing technical potential and relative suitability of solar, but these policies may impact the financial or legal feasibility of building solar on a specific parcel of land. Broadening our suitability categories to include these policies may make some parcels more financially attractive for development and some less financially attractive; but the adjustment would not likely change our overall estimates of potential.

Solar Massachusetts Renewable Target (SMART): Initiated in 2018, participants in the SMART program receive fixed per-kilowatt-hour (kWh) incentive compensation for 10 or 20 years. The incentive for new participants is set to decline in steps as deployment proceeds through 3,200 MW_{AC} of solar.[36] Any solar

[36] Solar Massachusetts Renewable Target Program (SMART) 225 CMR 20.00: Guideline Regarding Land Use, Siting, and Project Segmentation. Revised October 8, 2020. Available at https://www.mass.gov/doc/land use-and-siting-guideline-october-2020/download.

PV resource with a capacity less than or equal to 5 MW_{AC} can potentially qualify. So far, SMART has contributed to the development of over 1 GW of new operational solar generation across approximately 45,000 separate installations since 2018.[37] Small rooftop projects make up the majority of currently operating units (approximately 97 percent), but large ground-mounted projects make up the majority of the currently operating capacity (approximately 70 percent).[38] In order to qualify for the SMART program, solar tariff generating units (STGU) must meet certain land-use requirements including criteria for zoning; existing use and development; and site characteristics related to natural resources, endangered species, and topography. For example:

- Projects qualifying for capacity must consider whether they are being sited on land with a BioMap designation. To give one example, in the second 1,600 MW of the program, certain types of solar cannot be sited on land designated as Core Habitat or Critical Natural Landscape, or on parcels where at least 50 percent of the parcel's area is designated as Core Habitat or Critical Natural Landscape.
- Certain generators cannot be located on "Land in Agricultural Use" or "Important Agricultural Farmland."
- Some generators sited on land identified as "greenfields" may have a "greenfield subtractor" applied, wherein the incentive they receive under the SMART program is reduced.
- No more than 5 MW_{AC} can be installed on a single tax parcel, however, some exceptions do apply.

Net Metering: Net metering allows customers to offset their energy usage with solar energy they generate. Customers are able to sell their generated energy back to their electric companies in exchange for credits. Eligible facilities include private facilities that are 2 MW or smaller and public facilities that are 10 MW or smaller.[39] Facilities can generate net metering credits for 25 years from the date of interconnection. Massachusetts' net metering policy does not include any land-use provisions but does limit the amount of capacity that can be installed on a single tax parcel to 2 MW_{AC} (for private facilities) or 10 MW_{AC} (for public facilities). It is also generally not permissible to site more than one net-metered facility on a single parcel, although some exceptions do apply.

Solar Renewable Energy Certificates (SRECs): In Massachusetts, Solar Carve-out (original SREC) and Solar Carve-out II (SREC II) Programs allowed owners of renewable resources to generate "renewable energy credits" (RECs). A REC is created every time a renewable resource generates a MWh of energy.

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[37] Our analysis included over 850 MW of SMART solar generation across approximately 38,000 units, as reflected in the August 2022 SMART dataset.

[38] Massachusetts Department of Energy Resources. April 5, 2023 Update. *SMART Qualified Units List*. Available at https://www.mass.gov/doc/smart-solar-tariff-generation-units.

[39] Massachusetts Department of Public Utilities, Electric Power Division. Accessed April 2023. *Net Metering Guide*. Available at https://www.mass.gov/guides/net-metering-guide.

RECs can be sold to utilities or end-use customers, allowing them to prove they purchased a quantity of renewable energy. SRECs are a specific type of REC in Massachusetts produced by small, in-state solar resources. Prices for SRECs are typically higher than for RECs. While the SREC program did modify the number of SRECs available to qualified systems based on various factors (including some related to siting such as those located on landfills or brownfields) the program did not include the scope of land-use provisions seen in current solar policies, such as the SMART program.

The original SREC program (SREC-I) had capacity for 400 MW_{DC} of eligible resources but was extended and ended up qualifying over 650 MW_{DC} of operational capacity; the program closed in April 2014. The state opened a second version of the program (SREC-II) for approximately 1,200 MW_{DC} and eventually extended it until the start of the SMART program in 2018, ultimately qualifying over 1,750 MW_{DC} of operational capacity. Customers who installed solar before November 2018 may sell SRECs and are eligible to receive them for 10 years. After that, they produce only RECs. Because this program no longer accepts new projects and only applies to existing projects, it will not impact future solar siting. Both programs limited the amount of capacity that could be sited on a single tax parcel to 5 MW_{DC}.

State Tax Credits and Payments in Lieu of Taxes (PILOTs): Under Massachusetts law, a variety of tax benefits are provided to different types of solar facilities:

- Owners of residential solar installations located on their primary residence are eligible to receive a tax credit equal to 15 percent of the net solar expenditures for the year their project began construction. This tax credit is capped at $1,000.[40]
- Additionally, equipment directly related to solar is fully exempt from the Massachusetts sales tax, provided it is being utilized as a primary or auxiliary source of energy for an individual's principal residence.[41]
- Provided that the facility does not produce more than 125 percent of the annual electricity needs of the property on which it is located, the owner does not have to pay property taxes on the installation for 20 years. All facilities sized 25 kW or less are also exempt from property taxes for a period of 20 years, regardless of how much electricity they produce relative to the annual electricity needs of the property on which they are located. [42]

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[40] Massachusetts General Laws Part I, Title IX, Chapter 62, Section 6(d). Available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIX/Chapter62/Section6.

[41] Massachusetts General Laws Part I, Title IX, Chapter 64H, Section 6(dd). Available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIX/Chapter64H/Section6.

[42] Massachusetts General Laws Part I, Title IX, Chapter 59, Section 5(45). Available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIX/Chapter59/Section5.

- According to a study by the Massachusetts Office of the State Auditor, PILOT agreements are a key tool for developers of larger, standalone, projects seeking to establish predictable tax rates for their facilities.[43]
- Land classified as being in primarily agricultural or horticultural use under M.G.L. Chapter 61A may also be used to site solar and receive Chapter 61A property tax benefits, provided that the solar "does not impede the continued use of the land for agricultural or horticultural purposes."[44]

Zoning and Property Laws: Massachusetts has state-level zoning and property laws to facilitate solar development. These include provisions that no zoning ordinance or by-law shall prohibit or unreasonably regulate the installation of solar energy systems, as well as provisions that exempt solar installations from setback, building height, and roof and lot coverage restrictions.[45]Property laws relating to solar siting ensure that no provision forbids or unreasonably restricts the installation of solar energy systems, and they allow easements of direct sunlight over land of another to be acquired.[46,47]

Municipalities in Massachusetts often have their own zoning laws relating to solar siting. For example, Belchertown does not allow commercial solar installations that are larger than 20 acres, require forest clearing greater than 10 acres, on slopes of 8 percent or greater, or have inadequate frontage.[48] Shutesbury requires developers that will convert forestland to ground-mounted solar to designate an area of land at least four times as large as the installation to remain in its natural condition without alteration in order to mitigate the loss of carbon sequestration and forest habitat. Developers must also create a wildflower meadow habitat within and around the solar system and a successional forest habitat in the surrounding areas.[49] Note that municipal-level regulations such as these were not included in our analysis and would likely decrease the potential estimated in municipalities where such regulations apply.

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[43] Massachusetts Office of the State Auditor Division of Local Mandates. December 10, 2020. *The Impact of the State-Owned Land PILOT and Solar Taxation Policies on Municipalities*. Available at https://www.mass.gov/report/the-impact-of-the-state-owned-land-pilot-and-solar-taxation-policies-on-municipalities.

[44] Massachusetts General Laws Part I, Title IX, Chapter 61A, Section 2A. Available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIX/Chapter61A/Section2A.

[45] Massachusetts General Laws Part I, Title VII, Chapter 40A, Section 3. Available at: https://www.mass.gov/info-details/mass-general-laws-c40a-ss-3.

[46] Massachusetts General Laws Part II, Title I, Chapter 184, Section 23C. Available at: https://malegislature.gov/Laws/GeneralLaws/PartII/TitleI/Chapter184/Section23C.

[47] Massachusetts General Laws Part II, Title I, Chapter 187, Section 1A. Available at: https://malegislature.gov/Laws/GeneralLaws/PartII/TitleI/Chapter187/Section1A#:~:text=Section%201A.,B%20of%20chapter%20forty%20A.

[48] Town of Belchertown. Part I: Bylaws, Zoning. Section 145-28 Commercial solar photovoltaic installations. Available at https://ecode360.com/9051481.

[49] Town of Shutesbury Zoning Bylaw. Amended June 12, 2021. Available at https://www.shutesbury.org/sites/default/files/files-and-images/Bylaws/ZoningBylaw_amended2021.pdf.

In addition, in order to achieve a Massachusetts Green Community designation and be eligible for state and technical assistance and funding to promote clean energy adoption, municipalities are required to adopt zoning in designated locations for the as-of-right siting of renewable or alternative energy generation, research and development, or manufacturing facilities.[50] As of spring 2023, 290 municipalities across Massachusetts had been designated as Green Communities.[51]

3.3. Agriculture and Solar

Agricultural land is often attractive for large-scale solar development due to large parcel sizes and relatively flat, open terrain.[52] As a result, solar can typically be developed on agricultural land less expensively than previously developed land or brownfields.[53] As of 2023, current solar policy in Massachusetts incentivizes agricultural solar, including ground-mounted solar, as long as some portion of the land in question continues to be utilized for agricultural purposes (i.e., "dual-use solar" or "agrivoltaics").[54]

Agrivoltaic solar siting is an evolving topic in Massachusetts. There are important tradeoffs to consider when it comes to potential solar development on farmland regarding competing land uses, impacts to local farmers, and aesthetics:

Land Use. Large-scale solar sited on agricultural land can cover large areas otherwise used for crop production or grazing. In some situations, siting solar takes farmland out of production, resulting in a competition for land between food production and energy production.[55] As both food production and clean energy production are essential for Massachusetts, it is important to carefully consider policies that reduce land competition between the two. Dual-use solar is one potential way to site solar on agricultural land while still allowing agricultural production. Dual-use solar allows crop or livestock

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[50] Massachusetts Department of Energy Resources, Green Communities Division. 2022. *Becoming a Designated Green Community*. Available at https://www.mass.gov/guides/becoming-a-designated-green-community#-green-communities-division-overview-.

[51] Ibid.

[52] Daniels, Thomas L. and Hannah Wagner. *Regulating Utility-Scale Solar Projects on Agricultural Land*. Kleinman Center for Energy Policy, University of Pennsylvania. August 2022. Available at https://kleinmanenergy.upenn.edu/wp-content/uploads/2022/08/KCEP-Regulating-Utility-Scale-Solar-Projects.pdf.

[53] Hall, Peggy Kirk et al. 2022. *Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses and Agriculture Uses*. The National Agricultural Law Center. Available at https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1104&context=law_faculty.

[54] Massachusetts Department of Energy Resources. Accessed March 30, 2023. *SMART Guideline Regarding the Definition of ASTGU*. Available at https://www.mass.gov/info-details/smart-guideline-regarding-the-definition-of-astgu.

[55] Daniels, Thomas L. and Hannah Wagner. 2022. *Regulating Utility-Scale Solar Projects on Agricultural Land*. Kleinman Center for Energy Policy, University of Pennsylvania. Available at https://kleinmanenergy.upenn.edu/wp-content/uploads/2022/08/KCEP-Regulating-Utility-Scale-Solar-Projects.pdf.

production or pollinator habitats to occur beneath or adjacent to solar panels.[56] When siting dual-use solar, it is important to consider the relative compatibility of certain crops and livestock with solar. For example, most large-scale solar panel heights are compatible with sheep grazing underneath, while other livestock may require panels to be higher.[57] Solar panels can also be sited on unutilized land or rooftops on farms, mitigating the solar facility's impacts on food production while providing energy savings to agricultural operations.[58]

Impacts on Local Farmers. Solar sited on agricultural land can provide additional revenue to farmland owners. By co-locating solar with existing agricultural operations, solar development can bring additional income to farmers and diversify their revenue streams for low-crop-production years. This may help keep agricultural land in production when farm owners may face financial pressure to sell farmland for other uses.[59] Solar can also provide opportunities for farmers and landowners to reduce energy bills.[60] However, demand for agricultural land for solar siting can increase land rents and prices. For farmers that rent farmland, this demand can increase the risk that they lose their land to solar development or see increases in rental costs.[61] For farmers that own land, this increase in land prices increases their wealth, but increased prices may lead to the land being sold for development rather than being retained as farmland.

During the public stakeholder process, farmers and agrivoltaic developers identified barriers to developing dual-use solar projects under the SMART program's current rules, such as restrictions on the types of crops that qualify under the program and system design requirements. Continued engagement with agrivoltaic stakeholders to learn more about these barriers may help identify ways to promote further agrivoltaic adoption in Massachusetts.

Aesthetics. Common concerns with solar development in rural areas are visual impacts and disruption of natural landscapes. Placing solar over farmland can interfere with scenic views. However, several methods exist for mitigating the visual impact of large-scale solar. Developers can conduct viewshed analyses to evaluate the visual impact of solar projects on nearby properties and roadways. To reduce

[56] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Solar Energy Technologies Office. Accessed March 30, 2023. *Solar and Agriculture Co-Location*. Available at https://www.energy.gov/eere/solar/solar-and-agriculture-co-location#:~:text=Co%2Dlocation%2C%20also%20known%20as,or%20adjacent%20to%20solar%20panels.

[57] National Renewable Energy Laboratory. *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons From the InSPIRE Research Study*. 2022. Available at https://www.nrel.gov/docs/fy22osti/83566.pdf.

[58] Macknick, Jordan et al. 2013. *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy14osti/60240.pdf.

[59] Ibid.

[60] Brunswick, Sarah and Danika Marzillier. March 2023. "The New Solar Farms: Growing a Fertile Policy Environment for Agrivoltaics." *Minnesota Journal of Law, Science & Technology*. Available at https://scholarship.law.umn.edu/cgi/viewcontent.cgi?article=1532&context=mjlst.

[61] Hall, Peggy Kirk et al. 2022. *Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses and Agriculture Uses*. The National Agricultural Law Center. Available at https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1104&context=law_faculty.

visual impact, developers can use setbacks to site solar projects a certain distance from the property edge. They can also install vegetative buffers that obscure solar panels.[62]

Alternatives to Solar Development. One concept raised in several public stakeholder meetings is that solar is just one possible development that may take place on farmland or other types of scenic or informal recreational land. Farmlands are increasingly being converted into residential development and commercial and industrial sites, with solar introducing another competing land use. These other land uses convert agricultural land to non-farmland, and unlike solar, often do not allow for dual use of the land.[63] It is important to consider the specific needs of the community in which development is proposed to identify which type of development and agricultural land use will provide the most benefits.

In our analysis, we identify 441 GW of highly suitable statewide potential for solar in the agricultural suitability category (e.g., scoring an A or B in this category, across all solar types). We categorized parcels as less suitable (scoring a C in this category) if they are classified as agricultural or horticultural land under M.G.L. Chapter 61A. Broadening our suitability categories to include portions of parcels designated as farmland to accommodate dual-use solar would increase potential, but this increase would be relatively small as only 1 percent of potential is currently scored as a C in the agricultural suitability category.

3.4. Rooftop and Canopy Solar

In our analysis, we identify 40 GW of statewide potential for rooftop solar. In this analysis, the only suitability factor we analyzed for rooftop solar is Grid Infrastructure.[64] In addition, this analysis uses simplified packing factors for rooftop solar derived from NREL that consider roof size, shading and orientation, tilt, and rooftop obstructions. However, various factors that we did not consider in our analysis may impact the ability of a specific rooftop to support solar and broadening our suitability categories to include these factors may reduce overall rooftop solar potential.

Rooftop Age. Rooftop age can be a barrier to installing solar. Solar panels have a lifetime of 25 to 30 years, and rooftops have a lifetime of 20 to 50 years. The U.S. Department of Energy estimates that nationwide, the average cost of installing a residential rooftop solar array is $19,000, and the average

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62 Daniels, Thomas L. and Hannah Wagner. 2022. *Regulating Utility-Scale Solar Projects on Agricultural Land*. Kleinman Center for Energy Policy, University of Pennsylvania. Available at https://kleinmanenergy.upenn.edu/wp-content/uploads/2022/08/KCEP-Regulating-Utility-Scale-Solar-Projects.pdf

63 Freedgood, Julia, et al. 2020. *Farms Under Threat: The State of the States*. American Farmland Trust. Available at https://farmlandinfo.org/wp-content/uploads/sites/2/2020/09/AFT_FUT_StateoftheStates_rev.pdf.

64 As previously mentioned, the Grid Infrastructure suitability category only considered proximity to substations and did not account for current hosting capacity. Therefore, the estimate of highly suitable rooftop solar potential is likely to be an overestimate based on current hosting capacity. For more information on current substation hosting capacity, please refer to the hosting capacity maps available at https://www.mass.gov/info-details/utility-interconnection-in-massachusetts#hosting-capacity-maps-.

cost to replace a roof is about $10,000.[65] If a building's rooftop needs to be replaced before solar is installed, this could increase the cost by 50 percent. If a building's roof reaches the end of its lifetime before the end of the lifetime of installed solar panels, building owners will need to remove, store, and reinstall solar panels to replace the roof, which can be expensive.[66]

Building Age. According to feedback from members of our Technical Advisory Committee and public meetings (including but not limited to solar developers), building age and associated structural concerns can influence the feasibility of installing solar. Snow loads within Massachusetts building codes have increased over time, which means that older buildings do not necessarily have the capacity to support the same weight as newer buildings.[67, 68] Adding solar to a building adds weight that older buildings may not have the additional capacity needed to support, and whose owners may not be able to afford a major retrofit.

Building Tenure. According to NREL, residential rooftop solar is currently concentrated among high-income households and single-family owner-occupied homes.[69] Solar has been adopted at a low rate on renter-occupied buildings.[70] Rental property owners have little reason to invest in solar because most tenants pay directly for their own utilities rather than landlords paying utilities. Because of this, there is reduced incentive for building owners to invest in solar as the renter, rather than the building owner, sees the cost savings.[71] Multi-family buildings face logistical challenges in installing rooftop solar because multiple owners may need to coordinate, or because multi-family buildings owned by one owner are typically occupied by renters.[72]

Similarly, for canopy solar, the owner of the parking lot may not be the same as the owner of the nearby buildings who may derive the benefits of solar. Based on discussions with solar developers, commercial buildings often face similar challenges because most commercial buildings are leased and are rarely

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65 U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Solar Energy Technologies Office. Accessed March 30, 2023. *Replacing Your Roof? It's a Great Time to Add Solar*. Available at https://www.energy.gov/eere/solar/articles/replacing-your-roof-its-great-time-add-solar.

66 Hurtibise, Ron. 2022. "You'll have to wait to install solar panels if you're going to need a new roof." *South Florida Sun Sentinel*. September 25. Available at https://www.sun-sentinel.com/business/fl-bz-dont-install-solar-if-new-roof-needed-20220925-scyov2ddqbbi7lupndermmwcv4-story.html.

67 780 CMR Ninth Edition. Chapter 16 – Structural Design – Amendments. Posted January 1, 2018. Available at https://www.mass.gov/doc/780-cmr-ninth-edition-chapter-16-structural-design-amendments/download.

68 780 CMR State Board of Building Regulations and Standards. Massachusetts Amendments to the International Building Code 2009. Available at https://www.mass.gov/doc/780-cmr-state-board-of-building-regulations-and-standards-massachusetts-amendments-to-the-0/download.

69 Sigrin, Benjamin and Meghan Moody. 2018. *Rooftop Solar Technical Potential for Low-to-Moderate Income Households in the United States*. National Renewable Energy Laboratory NREL/TP-6A20-70901. Available at https://www.nrel.gov/docs/fy18osti/70901.pdf.

70 Ibid.

71 Ibid.

72 Ibid.

owner-occupied. However, tenants of commercial buildings can sometimes enter into arrangements with amenable property owners if they have a long-term lease. In addition, during public meetings participants identified yet another obstacle to this type of solar: some owners of parking lots or the business located adjacent to parking lots may find canopy solar objectionable as it may obstruct business signage.

Owner Priorities. Many building owners have competing investments that they are looking to make into their property and/or business. As such, they may simply just not be interested in installing solar. It is also the case that many property owners decide not to move forward with solar because it may limit the redevelopment options for their property (e.g., a parking lot owner who may want to preserve their option to sell the lot to a housing or commercial property development). The addition of new structures, such as solar canopies, may also increase maintenance costs for property owners (e.g., costs associated with plowing and de-icing).

Rooftop Material. Certain types of rooftop materials can make solar installation cost-prohibitive. Based on our conversations with solar developers, installing solar arrays on slate rooftops is costly and impacts the feasibility of rooftop solar.

Rooftop Shading. Information provided by solar developers suggested that about half of all single-family homes and one-quarter of all multifamily structures do not face shading challenges (from existing buildings or tree canopy) that would render them unsuitable for solar development. The NREL-derived packing factors used in this analysis for all types of rooftop solar incorporate the impacts of shading from nearby structures, including trees. In other words, the amount of solar estimated to be buildable on any one rooftop in Massachusetts has been de-rated to reflect the fact that some of this solar would be shaded by nearby buildings or trees some or most of the day. However, if this shading was not being taken into account, and rooftop and canopy solar were further de-rated to reflect shading, we would find that our estimate of high-scoring rooftop and canopy solar potential described in Table 14 would shrink from 54 GW_{AC} to 35 GW_{AC}.

Competition for Roof Space. As Massachusetts moves towards increased electrification of the building sector, solar will likely need to compete with other technologies, such as heat pump equipment which may require roof space for the siting of air compressors or other outdoor HVAC equipment. Additionally, the fire code includes setback requirements which limit the amount of roof space that can be used for solar panels, thereby reducing the amount of roof space available to host solar.[73]

Rooftop Solar in Dense Urban Areas. It can be challenging to interconnect solar with the grid in dense urban areas which typically have network distribution systems. While these areas may appear suitable for rooftop solar, it is more complex to interconnect generation that feeds back onto the distribution

[73] 527 CMR 1.00: Massachusetts Comprehensive Fire Safety Code. Available at https://www.mass.gov/doc/massachusetts-527-cmr-100-2021-edition-effective-february-3-2023/download.

system in those locations. Therefore, the actual potential for rooftop solar in areas with network distribution may be lower than this analysis estimates.

3.5. Landfills and Solar

Massachusetts is the national leader among all U.S. states in developing solar on landfills. Approximately one-third of all solar projects installed on landfills in the United States are located in the Commonwealth, resulting in Massachusetts having more installed capacity on landfills than any other state.[74,75] In our suitability analysis, we determined that there is 2 GW of highly suitable potential for solar on landfills. In addition, we identify 0.07 GW of existing solar present on parcels identified as landfills. However, this may be an underestimate of the actual existing solar installed on landfills in Massachusetts. According to MassDEP permits, there may be as much as 0.3 GW of solar capacity currently installed on landfills.[76] This figure aligns reasonably closely with DOER's records of landfill solar projects, which indicate that approximately 249 MW of landfill-sited projects are collectively operating under the SREC, SREC II, and SMART programs.[77] Data availability and data quality might explain the discrepancy between solar we matched to landfills and total existing solar on landfills. To identify which parcels with existing solar are landfills, we matched existing solar to parcels using address data, and then intersected our parcel layer with the MassDEP Solid Waste Diversion and Disposal layer in ArcGIS. Within our overall dataset of existing solar, we were unable to match 33 percent of all existing solar capacity due to data quality issues within the street addresses. Landfills are likely disproportionately represented in this category, as many do not have traditional addresses. For example, in the MassDEP Master List of Solid Waste Facilities in Massachusetts dataset, many landfills have a street address with no street number, or their addresses are given as cross streets.[78] Without street numbers, we were not able to match solar at these sites to specific parcels.

For parcels matched to existing solar, we identified 1.1 GW of very suitable solar potential on those same parcels, compared to 0.07 GW of actual installed capacity. This implies that there is 1.03 GW of remaining land that could be developed for solar on these parcels. However, several factors make landfills more or less feasible for solar development and may impact the decision of how much solar to install on a landfill.

[74] U.S. Environmental Protection Agency. November 2022, RE-Powering Tracking Matrix. Available at: https://www.epa.gov/system/files/documents/2022-06/epa-re-powering-profiles-state-programs-may-2022%20508.pdf.

[75] According to U.S. EPA, Massachusetts has approximately 229 MW of solar installed on landfills, which is 60 MW more than the next state (New Jersey), and nearly 160 MW more than the third ranked state (New York).

[76] Massachusetts Department of Environmental Protection. 2023. *Closed Landfills with Permits for Renewable Energy*. Available at https://www.mass.gov/lists/closed-landfills-with-permits-for-renewable-energy#communities-v-z-

[77] Massachusetts Department of Energy Resources. 2023. *Lists of Qualified Units*. Available at https://www.mass.gov/service-details/lists-of-qualified-generation-units.

[78] Massachusetts Department of Environmental Protection, May 2022. *Master List of Solid Waste Facilities in Massachusetts*. *Available at* https://www.mass.gov/lists/massachusetts-landfills-transfer-stations-compost-sites-recycling-facilities.

Land Use. Even closed and capped landfills are typically unusable for most types of development due to environmental conditions and substantial clean-up costs. Siting solar on landfills provides an economically viable use for these sites.[79] Closed landfills may have use restrictions, height restrictions, monitoring requirements, and post-closure compliance plans that must be followed, which can mean additional permitting requirements or costs associated with solar development.[80]

Access to Infrastructure. Landfills are typically located in developed areas near electric distribution infrastructure and access roads. Building solar on landfills with good access to this type of infrastructure reduces the need to build additional infrastructure for construction and interconnection.[81]

Sun Exposure. Landfills typically lack shading and are large areas of open space; this provides solar panels with a considerable amount of sun exposure, making them ideal sites for electricity generation from solar.[82] Not all portions of a landfill will have the optimal slope orientations for sun exposure, however, and regrading the ground to adjust solar orientation is typically not permitted on solid waste landfills.[83] Sloped areas that do not have the ideal orientation range for sun exposure are often excluded from the area of a landfill that can be developed for solar.[84]

Landfill Age. As landfills close and are capped, building solar on those landfills may not be immediately feasible. Over time, the surface of a landfill can lower in a process called landfill settlement. Rates of landfill settlement are higher in newly capped landfills. Landfill solar developers generally avoid projects on landfills that have been capped for less than 2–3 years due to potential for high settlement rates.[85]

Slope and Instability. Because landfills experience landfill settlement, there is a risk of instability that may deter solar development. Additionally, designing solar panel systems for landfills requires more complex considerations to ensure the liner of a capped landfill will not be broken. Ballasted systems, systems that rest on top of, but are not affixed to the ground below, are commonly used to support landfill solar but can be difficult to install on sloped landfill surfaces.[86]

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[79] U.S. Environmental Protection Agency and National Renewable Energy Laboratory. May 2022. *Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills*. Available at https://www.epa.gov/system/files/documents/2022-05/best-practices-siting-solar-photovoltaics-municipal-solid-waste-landfills_051722-pub.pdf.

[80] Ibid.

[81] Popkin, Matthew and Akshay Krishnan. *The Future of Landfills is Bright*. 2021. Available at https://rmi.org/insight/the-future-of-landfills-is-bright/.

[82] Ibid.

[83] U.S. Environmental Protection Agency and National Renewable Energy Laboratory. May 2022. *Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills*. Available at https://www.epa.gov/system/files/documents/2022-05/best-practices-siting-solar-photovoltaics-municipal-solid-waste-landfills_051722-pub.pdf.

[84] Ibid.

[85] Ibid.

[86] Ibid.

Incentives. Incentives for landfill solar at the federal and state levels can improve the economics of siting solar on landfills. As of spring 2023, the SMART program has adders for landfill solar projects to incentivize their development.[87]

3.6. Environmental Justice

In Massachusetts, environmental justice principles are defined as "principles that support protection from environmental pollution and the ability to live in and enjoy a clean and healthy environment, regardless of race, color, income, class, handicap, gender identity, sexual orientation, national origin, ethnicity or ancestry, religious belief or English language proficiency, which includes: (i) the meaningful involvement of all people with respect to the development, implementation and enforcement of environmental laws, regulations and policies, including climate change policies; and (ii) the equitable distribution of energy and environmental benefits and environmental burdens."[88]

Massachusetts defines environmental justice populations as "the segments of the population that EEA has determined to be most at risk of being unaware of or unable to participate in environmental decision-making or to gain access to state environmental resources, or are especially vulnerable."[89] Massachusetts identifies a neighborhood as an environmental justice population if it meets one or more of the following criteria:

- the annual median household income is 65 percent or less of the statewide annual median household income;
- minorities make up 40 percent or more of the population;
- 25 percent or more of households identify as speaking English less than "very well";
- minorities make up 25 percent or more of the population and the annual median household income of the municipality in which the neighborhood is located does not exceed 150 percent of the statewide annual median household income.[90]

In our analysis, we did not include a suitability criterion related to environmental justice. The relationship between solar siting and environmental justice impacts is nuanced. Solar can reduce health impacts from fossil fuel emissions if it displaces existing fossil fuel generation in environmental justice communities, for example. However, it is not easily determined whether the production of electricity from any one solar facility will displace emissions at any one other emitting facility.

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[87] 225 CMR 20.00 Solar Massachusetts Renewable Target (SMART) Program. Available at https://www.mass.gov/doc/225-cmr-2000-final-071020-clean/download.

[88] Massachusetts General Laws Part I, Title III, Chapter 30, Section 62. Available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIII/Chapter30/Section62

[89] Massachusetts Executive Office of Energy and Environmental Affairs. Updated June 24, 2021. *Environmental Justice Policy of the Executive Office of Energy and Environmental Affairs*. Available at https://www.mass.gov/doc/environmental-justice-policy6242021-update/download..

[90] Ibid.

In addition, the deployment of solar can add to increased energy infrastructure in a community already overburdened by energy infrastructure. Some environmental justice communities might see benefits from solar sited in their communities (for example, with the redevelopment of brownfields or the deployment of community solar), while others might not (for example, with the conversion of existing green spaces that provide other community benefits). Because of this, we could not make a suitability metric that incorporated all the nuance associated with environmental justice.

It is important to recognize that many environmental justice communities may face barriers to effective community planning for solar. For example, environmental justice communities may face capacity challenges to engage in proactive planning for solar projects with community benefits, such as community solar projects to serve renters and low-income residents. Additionally, municipal governments in small rural communities may face capacity challenges to engage in planning, update local land-use policies, and engage with developers of large-scale, well-funded projects. Environmental justice communities are one of many stakeholders that are encouraged to use the interactive StoryMap to support community planning for solar. Communities interested in learning more about solar potential in their neighborhoods can use the StoryMap to identify the relative suitability of different parcels according to the suitability categories that are most important to them. Additional state guidance and tools for community-based clean energy planning may increase local capacity and support equitable siting of solar and distribution of its benefits.

We encourage policymakers to take environmental justice into account when designing policies for siting solar. On an individual project basis, solar siting discussions should engage members of the community in which a project is proposed early in the planning process, and community members should be provided with a clear picture of potential costs and benefits of solar development in their community.

One tool to facilitate this consideration is the Solar Climate Justice Scorecard (developed by Community Climate Collaborative, or C3). This is a tool for assessing how large-scale, solar projects affect environmental justice communities. This scorecard can provide a guide to evaluating the environmental justice impacts of a solar project and ensuring that a solar project is developed in a way that enhances equity and distributes benefits to environmental justice communities.[91] Criteria evaluated by the scorecard include:

- **Procedural justice**: the extent to which the public is informed, engaged, and listened to in environmental decision-making;
- **Distributional justice**: how the harms and benefits of the project are felt throughout the community, ensuring that no group is overburdened by negative impacts;
- **Restorative justice:** the extent to which the project redistributes benefits to those who have been disadvantaged and closes fossil fuel-powered power plants, which have historically been located in environmental justice communities;

[91] Community Climate Collaborative. Accessed March 30, 2023. *Solar Climate Justice Scorecard*. Available at https://theclimatecollaborative.org/solar-climate-justice-scorecard.

- **Environmental and human health:** how the solar development in question improves or degrades the environment of the site based on the existing or otherwise expected use; and
- **Economic impact:** the overall change in in local economic conditions as a result of the project.

3.7. Relative Costs of Different Types of Solar Development

In addition to considerations related to land use, there are cost considerations associated with siting different types of solar. Using data on solar projects installed through the SMART program from 2018 through August 2022, we estimated the range of costs associated with installing each of the types of solar analyzed in this study (see Table 17).[92] In general, large ground-mounted projects are the least expensive type of solar at \$2.95 per $W_{DC.}$ They are about three-quarters the price of small ground-mounted projects (on a per-Watt bass), one-third less expensive than canopy solar projects, and 40 percent less expensive than rooftop solar. However, there is a wide spread of costs, even when focusing on the middle 50 percent of projects (sorted by cost): in at least some cases, it is possible for small ground-mounted projects and canopy projects to approach the median cost of large, ground-mounted solar. Even within rooftop projects there is wide variation, when the sample of nearly 38,000 projects is subdivided by size (see Table 18). As with ground-mounted projects, larger rooftop projects are cheaper than smaller projects due to economies of scale. Medium-sized rooftop projects (defined as between 25 and 100 kW_{DC} in size) feature median costs that approach large, ground-mounted projects, with costs of \$3.13 per WDC. The largest rooftop projects (those greater than 100 kW_{DC}) have median costs below the median large ground-mounted project.

Costs are an important factor in developing solar siting policy as a significant portion of the costs of deploying solar are borne by taxpayers and ratepayers through incentives. To the extent that policy heavily favors siting projects in the built environment, it will have the effect of reducing local, state, and federal tax revenues (e.g., higher value tax credits reducing state and federal income tax revenue, more property and sales tax-exempt facilities, etc.) and likely increasing ratepayer costs (e.g., higher incentive requirements that are ultimately passed onto electric ratepayers) relative to a scenario where more ground-mounted solar is deployed.

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[92] For projects listed in the SMART dataset, we used locational or other information (like SMART adders) to help identify installations as building-mounted, ground-mounted, or canopy solar. We categorized the remainder of the existing solar using two methods. First, we categorized all solar less than 25 kW in size as building-mounted, and all solar greater than 1 MW as ground-mounted. After screening those datapoints out, we used address data and aerial imagery to manually identify the remaining solar installations as ground-mounted, building-mounted, or canopy solar. Any solar unable to be identified after these three steps was labeled "Other."

Table 17. Relative costs of solar development under the SMART program (2021 $ per $Watt_{DC}$)

	Count in sample	Median cost	Range of costs in middle 50%
Ground (Small, <1 MW)	22	$2.95	$2.02 to $3.15
Ground (Large, ≥1 MW)	114	$2.31	$1.74 to $2.76
Rooftop	37,957	$3.46	$3.31 to $4.05
Canopy	50	$3.31	$2.71 to $4.06

Table 18. Relative costs of solar development under the SMART program, rooftop detail (2021 $ per $Watt_{DC}$)

	Count in sample	Median cost	Range of costs in middle 50%
Rooftop projects ≤25 kW_{DC}	37,288	$3.92	$3.65 to $4.48
Rooftop projects >25 kW_{DC} and ≤100 kW_{DC}	298	$3.13	$2.15 to $3.62
Rooftop projects >100 kW_{DC}	371	$2.63	$1.34 to $2.99
All rooftop projects	37,957	$3.46	$3.31 to $4.05

Note that the solar projects described in the above tables do not include solar projects installed outside of the SMART program, which are likely to be skewed towards larger ground-mounted projects (but are not necessarily any more or less expensive than the projects in the above dataset). These costs do not account for recent trends in solar costs related to supply chain constraints or federal incentives available under the *Inflation Reduction Act* or *Infrastructure Investment and Jobs Act*.

3.8. Electric Infrastructure Capacity

Limited electric infrastructure capacity and interconnection timelines are currently one of the biggest barriers to solar development. This analysis did not incorporate the current hosting capacity of substations which is a key factor in the cost of interconnection. Please refer to the hosting capacity maps published by electric distribution companies for more information.[93]

As of March 2023, large projects (≥1 MW) in the SMART program are currently experiencing over two-year interconnection timelines on average, which does not include work performed prior to submitting

[93] Massachusetts Department of Energy Resources. Accessed June 1, 2023. *Utility Interconnection in Massachusetts*. Available at https://www.mass.gov/info-details/utility-interconnection-in-massachusetts#hosting-capacity-maps-.

applications to DOER.[94] Given that projects cannot apply until they have a signed interconnection services agreement with the utility, this could mean that their development cycle is four to five years, with some projects expecting to be in the queue for up to 10 years. While grid infrastructure upgrades are ongoing and planned to continue, promoting solar development in areas with available capacity and electricity demand may help mitigate costs and achieve renewable goals in the short term.

[94] Based on an internal DOER analysis of SMART timelines.

Appendix A. DESCRIPTION OF SURVEY

Between September 19th to November 18th, 2022, DOER hosted a survey on its website aimed at collecting feedback on preferred types of solar development and land-use priorities from Massachusetts residents. The survey focused on collecting attitudes towards locating solar on small, residential rooftops; large rooftops; roadsides; undeveloped land; previously or partially developed land; brownfields and capped landfills; parking lot canopies; and agricultural land throughout Massachusetts. Respondents were welcome to elaborate on their attitudes toward siting solar on each location. Synapse categorized each respondent elaboration into reoccurring themes.[95] The survey also asked respondents to indicate their topics of interest regarding the tradeoffs in siting solar projects.

Although the survey was open to all residents of Massachusetts, the results of the survey are not scientific or representative of all residents. Instead, it is likely that the responses came from people interested in the development and siting of solar. The results described below are most representative of the responses provided.

Responses Collected

In the two months it was open, the survey collected 3,033 responses, with respondents representing 77 percent of Massachusetts's cities and towns. Of those responses, 53 percent of respondents hailed from suburban areas, while Boston was the municipality with the most respondents (106). In addition to collecting attitudes towards siting solar at various locations, the survey asked respondents to self-identify from a list of categories. Respondents could select multiple options. Results show that 58 percent of respondents identified as a community member, 50 percent as a ratepayer or electric customer, 35 percent as an environmentalist, and 15 percent as an environmental justice advocate.[96]

The survey also asked respondents about their attitudes towards climate change and solar development, and their familiarity with solar. Respondents who were extremely concerned about climate change comprised 89 percent of responses; 79 percent at least somewhat agreed that Massachusetts should be aggressively pursuing solar development to increase electricity generation from a clean source. Most respondents (79 percent) felt that they knew at least a fair amount when it comes to solar energy in Massachusetts.

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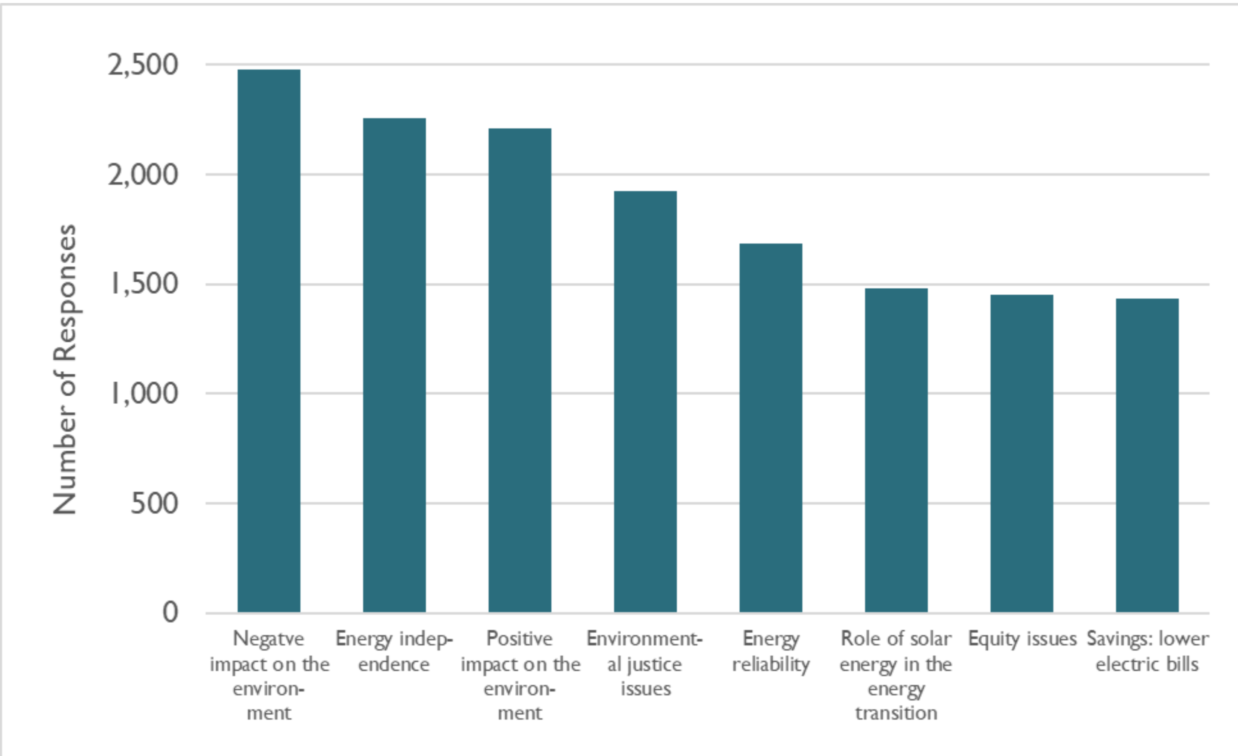
[95] Elaborations that applied to solar at all locations, (e.g., the lifecycle of materials, how solar should be built, and concerns over fire risk) were not considered as the survey was looking at different land-use priorities.

[96] Other self-identifiers with fewer than 15 percent of responses included academic, nonprofit employee, environmental justice community member, municipal-level policymaker, clean energy economy worker, energy expert, state-level policymaker, fossil fuel industry worker, electric utility representative, and First Nation member.

The tradeoff when considering solar siting that respondents selected the most was a negative impact on the environment at 82 percent (see Figure 9). Other important tradeoffs noted included energy independence (selected by 74 percent of respondents), positive impacts on the environment (selected by 73 percent of respondents), environmental justice issues (selected by 64 percent of respondents, and energy reliability (selected by 56 percent of respondents). Other categories that were selected by fewer than half of all respondents include role of solar energy in the energy transition, equity issues, bill savings (lower electric bill), tax savings (tax rebates and deductions), aesthetics and/or glare, jobs in my community, and temporary construction impacts. Except for the last category (temporary construction impacts) all categories were selected by at least 29 percent of all respondents.

Figure 9. Tradeoffs identified as most important by respondents



Notes: Each respondent could select any number of tradeoffs (from zero to all). Other tradeoffs not shown on this chart include savings: tax rebates and deductions (1,078 selections), aesthetics and/or glare (1,075 selections), jobs in my community (894 selections), and temporary construction impacts (212 selections).

Observed Themes

The theme that appeared most often in responses to the survey was a general opposition to clearing forests, wetlands, and vegetated areas to make way for solar installations. Respondents were opposed to removing these carbon sinks and felt that it was counterproductive to clear forests, which could increase carbon dioxide in the atmosphere (since reducing carbon dioxide is partly the intention of building more solar facilities). Respondents also noted the ecosystem services that these types of areas provide, including water purification, erosion control, air filtration, local cooling, hillside stability, critical roles in the water cycle and nitrogen cycle, and maintaining microclimates. In addition, respondents noted that these areas provide valuable habitats for wildlife and pollinators. Furthermore, there was concern over drought, noise pollution, and drainage issues from the removal of these ecosystems. To a lesser extent, respondents were receptive to solar projects replacing forests in situations where the forests had lower levels of carbon sequestration ability. Some respondents felt positively about siting on wooded and vegetated areas because they believed that Massachusetts should be doing everything it could to move away from fossil fuel use.

In contrast, respondents identified existing developed land as the most preferred location for siting solar. People felt that siting on existing developed land would be minimally disruptive to the environment because developing of the land wouldn't be necessary and it would be unlikely that wildlife habitats exist on these lands. These locations include small, residential rooftops; large rooftops; and parking lot canopies. Generally, the less developed the land, the less preferred siting solar would be at that location.

Respondents identified existing developed land as the most preferred location for siting solar.

These locations include small, residential rooftops; large rooftops; and parking lot canopies. Generally, the less developed the land, the less preferred siting solar would be at that location.

Location-Specific Attitudes

In addition to the opposition of clearing forested and vegetated land at all locations, respondents provided insights towards preference or opposition to siting solar at each location. For example, respondents were concerned about the construction and maintenance of solar panels and the impact on wildlife and natural habitats. Respondents also felt positively towards solar sited close to energy demand and the efficiency provided by large-scale solar (see Table 19). The survey showed that respondents preferred siting solar on undeveloped lands the least, and on developed lands (i.e., small residential rooftops, parking lot canopies, and large rooftops) the most (see Figure 10).

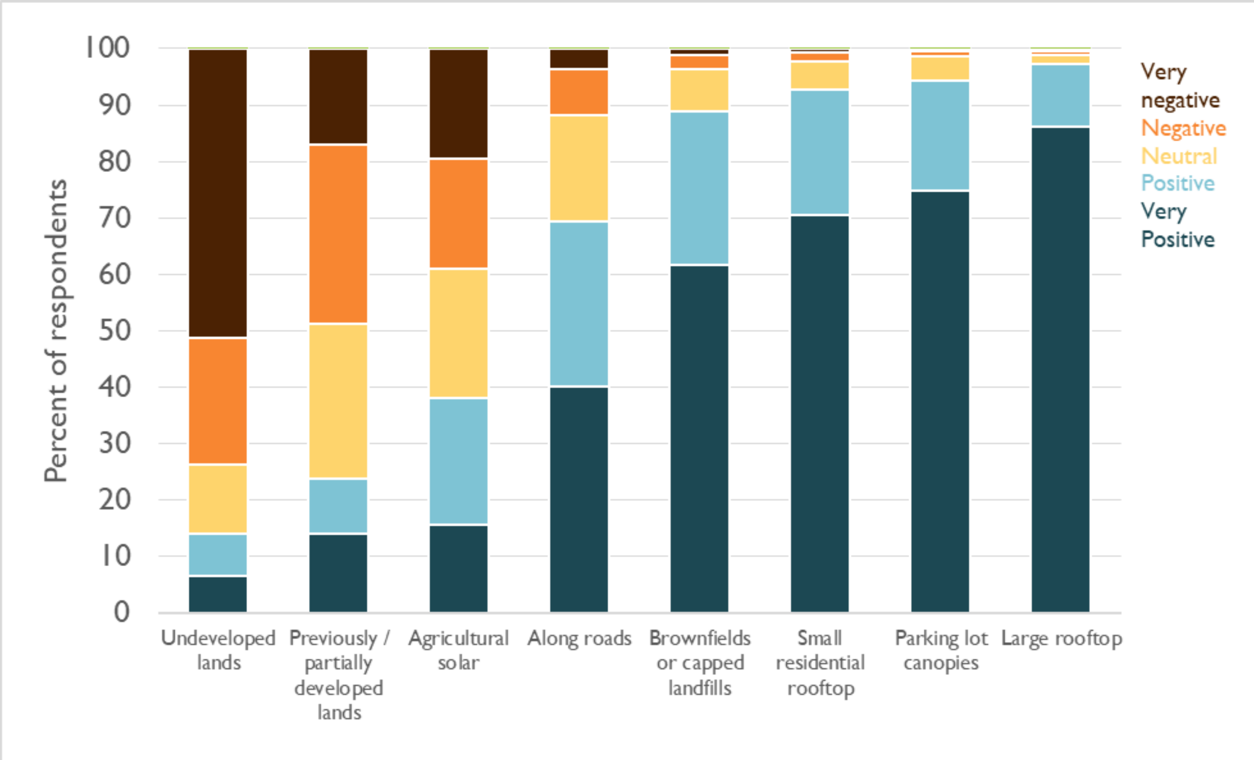
The following sections elaborate on preferences for siting solar at each location, ranked in order of most preferred to least preferred.

Table 19. Common reasons of support and concern towards siting solar at each location

	Large rooftops	Canopies above parking lots	Small residential rooftops	Brownfields & capped landfills	Along roads	Agricultural land	Previously & partially developed land	Undevelop-ed land
Reasons to site solar								
Land is already clear & cannot otherwise be used	+ + + +	+ +	+ + +	+ + +	+ + +		+ + + (for partially developed part of land)	
Panels provide multiple uses or benefits		+ + + +		+		+ + + (regarding dual-use solar projects)		
Large-scale efficiency	+ +							
Close to load	+	+	+ +					
Concerns with siting solar								
Construction & maintenance concerns			+		+	+		
Panels are unsightly			+		+ + +			
Impact on wildlife and natural habitats					+ + +	+ + + +	+ +	+ + + +
Prefer other use for the land				+ +			+ + +	
Impacts intended use of land						+ + + +		+ + + +

Notes: ++++ indicates that theme appeared at least in 400 elaborations, +++ in at least in 200 elaborations, ++ in at least in 100 elaborations, + in at least in 40 elaborations. On average, there were 1,338 elaborations for each question regarding siting solar at each of these locations.

Figure 10. Attitudes towards siting solar at each location



Large Rooftops

> *Respondents identified large rooftops as the most preferred location for siting solar.*

Large rooftop solar projects are built on the roof of a large building, such as one used by a school or public building. Respondents identified large rooftops as the most preferred location for siting solar. Respondents noted that siting on large rooftops would use "otherwise wasted space" and that it seemed like it would be the least intrusive of all the locations. Respondents also noted that, because larger rooftops can host larger solar installations than smaller rooftops, they can take advantage of economies of scale and would presumably be less expensive on a per-kWh basis. Furthermore, respondents observed that placing solar on rooftops would provide distributed energy benefits such as on-site generation, reduced transmission losses, lower costs, and resiliency for the building owners. In addition, these roofs "are typically flat or have low pitches, which will making servicing the panels easier and safer." However, there was also concern over needing to retrofit (for high wind and excessive rain weather occurrences) or eventually replace the roof.

Parking Lot Canopies

> *Respondents liked that canopies could potentially protect their car from heat, rain, and snow, which would help them save fuel (from reduced air conditioner and heat use) and time (from no longer needing to sand, salt, and shovel the ground.*

Solar projects built on parking lot canopies allow the parking lot to maintain its function while providing cars with protection from heat, rain, and snow. Historically, the cost per kilowatt of building solar on parking lot canopies has been about 1.4 times more than what a typical, ground-mounted solar project might cost because of the need to build the canopies and other infrastructure. Respondents identified solar sited on parking lot canopies as a close second to large rooftops for being the most preferred location. About 40 percent of respondents who provided elaborations for their attitudes toward siting solar on parking lot canopies noted the shading and shelter benefits that canopies could provide. Respondents liked that canopies could potentially protect their car from heat, rain, and snow, which would help them save fuel (from reduced air conditioner and heat use) and time (from no longer needing to sand, salt, and shovel the ground). Another benefit that respondents appreciated was that this type of land has already been developed and paved, which reduces construction and thus disruption to wildlife, habitats, and forests on other undeveloped land.

Small Residential Rooftops

> *However, there was concern over implementation barriers to homeowners…the payback period could be too long, seniors do not have the income or time to amortize the costs, or the cost is prohibitive especially for low- and moderate-income households.*

Small, residential solar projects are usually built on the roof of a house. Similar to responses regarding large rooftops, respondents that noted a preference for siting solar on small residential rooftops did so because it uses existing land and provides distributed generation benefits and financial benefits to homeowners. However, there was concern over implementation barriers to homeowners. For example, respondents felt that the payback period could be too long, that seniors do not have the income or time to amortize the costs, or that the cost is prohibitive especially for low- and moderate-income households. There was also distrust in solar contractors (e.g., some respondents worried that contractors would "skirt building codes and town rules"). Respondents also felt that the difficulty of the general process of installing and maintaining was preventing them from adding solar to their roofs. For example, they mentioned that it was difficult to make an informed decision on a solar installation, that lease deals are difficult to evaluate, that the installation process would require a lot of due diligence, that working with a contractor would be time consuming, and that it would make selling a house more difficult.

Brownfield and Capped Landfills

Solar projects built on brownfields (former industrial sites with environmental contamination) and capped landfills can meet the electricity needs of a few dozen homes to hundreds of homes. This type of project may be less expensive than other ground-mounted projects because it can take advantage of the cheaper cost of land; but it could also be more expensive due to environmental remediation or increased engineering costs. The respondents who expressed preferences for developing solar on brownfields and capped landfills did so because those land types have already been impacted, degraded, labeled a problem site, contaminated, or could not be sufficiently remediated, and that the land had no better use otherwise. There were also respondents that preferred other uses for the brownfields and capped landfills such as parks, recreation sites, open space wildlands, conservation land, tree or vegetation cover, affordable housing, industrial development, golf courses, dog parks, etc. In situations where these areas could not be restored for other uses, respondents felt that solar would then be appropriate for the land. Another benefit that respondents felt siting solar on these fields provided was the improvement of the land and environment. They felt that this was an opportunity to make a polluted area safer or "a potentially hazardous property productive."

Along Roads

The most frequently mentioned theme when considering siting solar along roads was an opposition toward clearing trees. Respondents appreciated that trees located along roadways absorb sounds, provide shade, mitigate stormwater runoff, and sequester carbon. There was also concern that clearing trees for solar would expand further, causing future deforestation adjacent to the area. The next greatest concern was the aesthetics of solar panels along roads; respondents expressed preferences for greenery and foliage, which they felt were important for stress reduction and for tourism. Respondents also pointed out that roadsides are habitats and corridors for plants and animals, and that solar could negatively impact wildlife and natural habitats. Some respondents opined that glare and reflectivity of solar panels might be distracting to drivers, that solar stations could take up room needed for disabled cars and emergency vehicles, that heat that radiated off of panels would be dangerous, or that it would make roadsides monotonous.[97]

The most frequently mentioned theme when considering siting solar along roads was an opposition toward clearing trees. Respondents appreciated that trees located along roadways absorb sounds, provide shade, mitigate stormwater runoff, and sequester carbon.

[97] We note that these are opinions noted by respondents of the survey and may not be factual statements. Massachusetts DOER and other state agencies have published a document addressing the reality of some of these concerns (see Massachusetts Department of Energy Resources, Massachusetts Department of Environmental Protection, Massachusetts Clean Energy Center. *Clean Energy Results: Questions & Answers Ground Mounted Solar Photovoltaic Systems*. June 2015. Available at https://www.mass.gov/doc/ground-mounted-solar-pv-guide/download.) For example, solar panels are designed to absorb solar energy, reflecting only a small amount of incoming light, making glare minimal (see page 22). This document also notes that, "All available evidence indicates that there is no solar "heat island" effect caused by the functioning of solar arrays" with more on this topic available on this document's page 9.

Agricultural Land

Agricultural solar projects may be built on part of a farm (for example, cropland or pasture) or may replace current farmland. Depending on the size, these projects may meet some or all the electricity needs of a farm or may provide enough power to meet the electricity needs of dozens or hundreds of homes. Current policies allow for dual-use solar projects on agricultural land, where solar projects can be built on productive farmland if the agricultural activities on that land are not interrupted. With regards to siting solar on agricultural land, respondents were opposed to displacing farmland and disrupting food production. Respondents expressed preferences for food security and felt that locally grown food had benefits in emitting less carbon during its transportation process. There was support for dual-use solar projects with caveats that dual-use does not detract from farmland activities, but rather enhances them; that agricultural use of the land be continued; that operation and output of the farm is not impacted; and that it does not change the productivity or use type of the land. However, there were respondents who expressed skepticism in the intentions and feasibility of dual-use agricultural solar. For example, there was apprehension over the viability of dual-use agricultural solar in conjunction with crops, that dual-use leaves crops energy poor, and that dual-use requires clearing a portion of the land, which constitutes disturbing agricultural activities.[98] There was also mention that solar placed on agricultural land should solely provide electricity for the farm, and that large-scale solar should not be placed there. Those respondents wanted the solar installation to be able to provide cost savings and benefits for the farmers.

Previously, Partially, and Undeveloped Land

Solar projects built on typical ground-mounted locations including undeveloped land (forests) and previously or partially developed land (vacant lots, suburban parks) can meet the electricity needs of anywhere from a few dozen homes to hundreds or thousands of homes. Respondents wanted to site solar on existing developed land, which they identified as previously developed land, or the developed portion of partially developed land. However, there was also preference that the land be used elsewise such as community gardens, new parks, affordable housing, green spaces, productive agriculture, and in reforestation. As mentioned earlier, respondents were the most opposed to using undeveloped land for solar, including the undeveloped portion of partially developed land.

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[98] We note that a team at the UMass Clean Energy is currently studying the effects of dual-use solar on crop productivity and economic impacts. For more, see UMass Clean Energy Extension. *Researching the Agricultural and Economic Impacts of Agrivoltaics (Dual-Use Solar).* Available at https://ag.umass.edu/clean-energy/research-initiatives/solar-agriculture/researching-agricultural-economic-impacts-of-agrivoltaics-dual-use-solar.