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November 2, 2023

Sherborn Zoning Board of Appeals
Sherborn Town Hall
19 Washington Street
Sherborn, MA 01770

Re: Additional Comments on Farm Road Homes -
Evaluation of Solar Portion of Development Plan
Farm Road Homes Project
55-65 Farm Road
Sherborn, MA

Chair Novack and Board Members:

Mary and I have composed this additional letter as a follow-up to our other letters raising concerns about the Farm Road Homes project being proposed by Fenix Partners Farm Road, LLC (Fenix) at the abutting 53-55-65 Farm Road property.

This letter is focused on the application's lack of clarity on its use of solar panel arrays as part of the development project. We are extremely concerned that the applicant is not fully considering the implications of their intentions to install solar arrays on the job site and the resulting negative long-term impacts of such work.

Concerns Related to Ground-Mounted Solar Arrays

Although no final plans are available depicting the location and arrangement of the arrays of solar panels planned for this project, the applicant has not fully vetted the location, arrangement, layout, and potential negative impacts of the arrays such as those identified by Massachusetts Audubon and Harvard Forest in *Growing Solar, Protecting Nature* (Attachment A).

According to these authorities, since 2010 clearing for ground-mounted solar projects has become a leading driver for land-use change in Massachusetts. The current landscape and setting of the area of the subject project should be considered a carbon-rich landscape, the loss of which may further exacerbate and/or magnify the detrimental aspects of the overly dense, 40B Farm Road Homes development. In fact, nowhere does the applicant address in narrative form or in their plans the following issues and concerns ground-mounted solar arrays will bring with this project:

1. Loss and Fragmentation of Forrest Land;
2. Implications on nearby Wetland Habitats;
3. Biodiversity Impacts;
4. Erosion and Flooding Concerns; and
5. Financial implications of Solar Array on HOA and/or Owners.

We view the fact that this project includes consideration and provisions related to installation and reliance on solar energy as a positive, but we disagree with using stand-alone ground-mounted installations. It begs the question (again) as to who within the development is responsible for management and maintenance of the ground-mounted arrays? It also raises the questions about ownership of the arrays themselves – is Fenix planning on maintaining ownership of the arrays? Are they seeking any tax credits for their installation? Will tax credits benefit the future residents of Farm Road Homes, or contribute to the affordability of these dwellings? What financial assurance mechanism exists to ensure that funding for maintenance, repair, and inevitable replacement of the solar arrays for this project?

All these questions are applicable at this point based on the lack of clarity provided in the applicant filings with the ZBA.

Recommendations and Requests

1. We remain very, very concerned that the Town of Sherborn ZBA, as well as other Town Boards and Commissions, are still having to review and critique the comprehensive permit application for Farm Road Homes which have been arriving in piecemeal form – despite the fact that the applicant has been working on this development for the last two (2) + years.

2. We also still believe that the common-scheme restriction remains a "threshold" consideration and should continue to be evaluated considering the potential implications on this total project.

3. And finally, we believe that, just as the wetlands and their ecosystems are essential components of our environment, the carbon-rich landscape of currently undeveloped portions of 53-55-65 Farm Road serves as a valuable carbon sink and continues to off-set greenhouse gas emissions. Recent publications of authorities such as Mass Audubon and Hartford Forests clearly state that " . . . **forests and natural ecosystems provide valuable, irreplaceable public goods: biodiversity, drinking water filtration, wildlife habitat, recreation, and resilience to impacts of climate change such as flooding and extreme heat.**"

Based on these concerns, we request the Zoning Board of Appeals instruct their third-party expert to review the solar components to the applicant's project plans – specifically requesting information and responses related to the stated impacts and concerns as put forth here.

This development does not consider any replacement or consideration for damage to the itemized "public goods" during the applicant's project. In fact, a basic review of the plans as they currently stand indicate more the 68,000 square feet of natural forested hillside land will need to be cleared, stumped, grubbed, prepped, and re-graded to allow for the installation of the solar arrays and associated cart paths – and this does not event take into account any additional clearing will be undertaken to maximize sun exposures for the arrays once installed.

When you combine this 68,000 square foot area with the **more than 40,000 square feet** of land to be cleared, stumped, grubbed, graded, and modified to accommodate the combined septic system, **the more than 20,000 square feet** of land to be cleared, stumped, grubbed, graded, and modified to accommodate the stormwater detection basins, and **the more than 110,000 square**

feet of land to be converted from its natural state into impermeable surface, we are now **approaching 240,000 square feet (6 acres)** of carbon-rich landscape to be cleared, graded, modified, and/or paved as part of this project. **This area is more than twice the size of a Manhattan city block** – a dense and concentrated area of damage and loss outrageously disproportionate to the over-exaggerated gains to our stock of affordable housing!

To put this loss into perspective, each of these 6 acres likely stores more than 20 tons of sequesterd carbon and is capable of sequestering at least 0.5 more tons of carbon each year – that is 120 tons of carbon with 3+ tons being added each year. By removing these 6 acres of sequestering forest from the landscape, it will take the remaining 8 acres of the parcel approximately 30 years to re-sequester the carbon lost during the project development. Accounting for the changes to this carbon-rich landscape and the reduced rate of carbon sequestration caused by this project, the loss of previously-sequestered carbon **will ultimately not be rectified until calendar year 2143,** and the parcel will **forever sequester carbon at a rate of 57% of its current capacity**.

All of this loss and damage is being inflicted at the expense of the area between Mount Misery and Pine Hill - two (2) valuable reaches of Town Forest that serve as valuable rechange areas for the private water supplies that serve our neighborhood, contribute to the Zone II/groundwater resource for Town wells, and represent an important biological habitat and corridor.

We also feel the need to reiterate our position that the Town should be entitled to an extension of the 180-day Public Hearing timeline for reviewing this project as more than half of the allotted time has passed and complete plans have yet to be presented for either the on-site solar panel systems or septic systems/leach fields.

Thank you very much for your attention in these matters. We appreciate having this opportunity to table more of our concerns and look forward to your deliberations on this project.

Most respectfully,

Brian D. Moore
Mary O. Moore
49 Farm Road
Sherborn, MA 01770

Attachment A

Mass Audubon and Harvard Forests Report dated October 23, 2022

Growing Solar, Protecting Nature

Building the solar Massachusetts needs while protecting the nature we have

Mass Audubon and Harvard Forest | October 2023

Preferred Citation:
Michelle Manion, Jonathan R. Thompson, Katie Pickrell, Lucy Lee, Heidi Ricci, Jeff Collins, Joshua Plisinski, Ryan Jones, Gabe Kwok, Drew Powell, & Will Rhatigan (2023). *Growing Solar, Protecting Nature.* Mass Audubon and Harvard Forest. DOI:10.5281/zenodo.8403839

Transitioning to clean electric power in less than three decades is an absolute imperative for decarbonizing our economy, and a massive challenge. Massachusetts has made great initial strides in reducing greenhouse gas (GHG) emissions from electricity production, and has ambitious interim goals in place to complete the transition to nearly carbon-free electric power by 2050. Getting there will require a significant increase in the pace of clean energy deployment, including a growing role for solar of all types, and an unprecedented level of investment in electricity grid upgrades and transmission infrastructure.

Urgency on climate action, however, does not justify the haphazard approach to solar deployment witnessed in the Commonwealth over the past decade. The current trajectory of deployment of large ground-mount solar is coming at too high a cost to nature. Concerns about impacts to nature are partly responsible for erosion of public support for solar, with many communities now seeking to slow or entirely stop new ground-mount solar systems.

Growing Solar, Protecting Nature explores a different path forward for scaling up solar energy resources in the Commonwealth. In this vision, solar plays an essential and growing role in cleaning our power grid, while nature is also left intact to continue its irreplaceable role combating climate change, supporting biodiversity, and providing resilience to climate change's worst impacts. This analysis shows that achieving the vision of growing solar while protecting nature is fully within our grasp. But, doing so requires a quick and intentional pivot from current siting practices, with immediate and purposeful changes to energy incentives and programs, enhanced and coordinated state and local planning efforts, and stronger incentives for keeping natural and working lands intact.

Motivation for *Growing Solar, Protecting Nature*

Massachusetts is one of a handful of U.S. states with ambitious laws for tackling the risks of unchecked climate change. Under the *Next-Generation Roadmap for Massachusetts Climate Policy*, passed into law in 2021, the Commonwealth must reach net-zero greenhouse gas (GHG) emissions by 2050.

The challenge is formidable. By 2030, climate-polluting emissions in Massachusetts must be reduced by 50 percent relative to 1990 levels, and by 75 percent by 2040, on the way to net-zero emissions by 2050. Because it is not feasible to eliminate fossil fuel use across the entire economy by 2050, reaching our net-zero goal will also require *removing* carbon from the atmosphere, to counteract our remaining GHG emissions. Massachusetts' forests are our primary and only means of carbon removal.[1] As of yet, no other technology exists that can perform this function affordably.[2] Ensuring that nature continues this carbon removal service is among our lowest-cost strategies for meeting the net-zero goal.

But forests can't do it alone. Clean energy is foundational to unlocking reductions in GHG emissions needed across the economy. Massachusetts needs a massive build-out of clean electricity to support the electrification of the building and transportation sectors. In the *Clean Energy and Climate Plan for 2050*, the state estimates that the clean energy generation mix needed in Massachusetts could be 8 gigawatts (GW) of solar and 4 GW of wind (onshore and offshore) by 2030, and at least 27 GW of solar and 24 GW of wind by 2050.[3] Other New England states also need to expand clean power resources: estimates are that the capacity of the New England electric grid will need to expand by 2 to 2.5 times by 2050, and more transmission must also be built to move clean power to where it's needed.

The New England grid will need to expand in size by **2.5 times.**

Fortunately, Massachusetts and the New England region have abundant solar and wind resources. Massachusetts alone is planning for an estimated 5,600 megawatts (MW) of offshore wind energy by 2027. Both renewable technologies have recently undergone a massive market transformation. The National Renewable Energy Lab (NREL) estimates that, over the last decade, the price of solar photovoltaic modules has declined by 85 percent.[4]

Mass Audubon and Harvard Forest believe that scaling up solar and other clean energy resources is an absolute imperative to meeting the state's climate targets for 2030, 2040, and 2050. All types of solar will be needed, including ground-mount systems as well as "distributed" solar, i.e., rooftop solar that connects into the electricity distribution system, and solar on canopies erected on top of parking lots.

As we scale up our deployment of solar, **we must also recognize the instrumental role that natural and working lands play in stabilizing our climate system**. More than 60 percent of Massachusetts is covered by diverse forests, which are storehouses of carbon. Our trees alone contain the equivalent amount of carbon as in five years' of statewide fossil fuel emissions.[5] Forest soils contain a similar amount.[6] Beyond storage, forests are also actively capturing carbon from the atmosphere at a rate equivalent to 10 percent of our current GHG emissions.[7] **In addition, forests and natural ecosystems provide valuable, irreplaceable public goods: biodiversity, drinking water filtration, wildlife habitat, recreation, and resilience to impacts of climate change such as flooding and extreme heat.**

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1 Massachusetts Executive Office of Energy and Environmental Affairs, "Massachusetts Forest Carbon Study: Workshop 1 (June 2023)."

2 Boston Consulting Group (BCG). "Shifting the Direct Air Capture Paradigm." *BCG Global*, June 1, 2023. https://www.bcg.com/publications/2023/solving-direct-air-carbon-capture-challenge.
Technical carbon removal technologies under development such as Direct Air Capture (DAC) are currently very costly, ranging at about $600 to $1,000 per ton of CO_2 removed; if DAC becomes commercially viable, BCG predicts that costs of DAC could drop to $100 per ton by 2050.

3 Massachusetts Executive Office of Energy and Environmental Affairs, "Massachusetts Clean Energy and Climate Plan 2025 and 2030," June 30, 2022. These goals for clean energy are inclusive of solar and wind capacity already installed, not in addition to today's capacity.

4 David Feldman et al., "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark (Q1 2020)" (National Renewable Energy Laboratory (NREL), January, 2021), https://doi.org/10.2172/1764908.

5 Thompson J.R. et al. "Land Sector Report, Massachusetts 2050 Decarbonization Roadmap." 2020. 62 pp.

6 Adrien C. Finzi et al., "Carbon Budget of the Harvard Forest Long-Term Ecological Research Site: Pattern, Process, and Response to Global Change," *Ecological Monographs* 90, no. 4 (November 2020): e01423, https://doi.org/10.1002/ecm.1423.

7 Massachusetts Executive Office of Energy and Environmental Affairs, "Massachusetts Forest Carbon Study: Workshop 1 (June 2023). Note that 10 percent of today's yearly GHG emissions in Massachusetts is equivalent to 7 percent of 1990's yearly GHG emissions, which were nearly 100 $MMTCO_2e$.

Solar Deployment at Mass Audubon

Solar energy is essential to Mass Audubon's plans to reach net-zero GHG emissions across our properties and operations. We've been committed to solar energy since the early 2000s, when we established a goal to install solar at every staffed sanctuary. Today Mass Audubon owns a total of 45 solar arrays spread across 21 sanctuaries. At a total capacity of 621 kW, our solar systems produced nearly 50 percent of our total electric consumption last year. While most of the arrays are rooftop systems, about a third of our solar generation comes from our 14 ground-mount systems. Solar will certainly play a large role in our future plans: new buildings at Mass Audubon must be net-zero or better, so solar will be part of any new construction.

Mass Audubon's
solar systems produced
NEARLY 50%
of our total electric consumption
last year.

Incentives under the Solar Massachusetts Renewable Target (SMART) program (and its predecessor programs for solar) have been very effective at driving development of ground-mount solar systems onto already-developed lands such as landfills and brownfields. As of 2020, over 50 percent of all landfills in the U.S. with large ground-mount solar projects were located in Massachusetts.[8] Massachusetts is also among the top 10 states in the U.S. in community and rooftop solar placed on buildings and parking lot canopies on a per capita basis.[9]

However, our clean energy and land policies are still not doing enough to safeguard natural ecosystems and working lands. Under current siting practices, thousands of acres of forests, farms, and other carbon-rich landscapes are being converted to host large-scale solar. Mass Audubon's 2020 *Losing Ground* analysis showed this recent shift: starting around 2010, clearing for ground-mount solar became one of the leading drivers of land-use change in Massachusetts.[10] A loophole in SMART provides state funding to ground-mount projects on high biodiversity lands as long as they are community solar. And with the state's 2030 climate goals only seven years away, combined with new federal incentives for solar provided by the Biden Administration's groundbreaking *Inflation Reduction Act* (IRA), the pace of ground-mount solar development is poised to accelerate.

> *According to a recent state survey of public attitudes towards solar, over 85 percent of surveyed residents in Massachusetts believe that solar should be built on rooftops, parking lots, landfills, and other developed areas, rather than on cleared forests and on top of productive farmland.*

By 2020,
OVER 50% **OF ALL LANDFILLS IN THE U.S.**
with large ground-mount solar projects were located in Massachusetts.

Massachusetts citizens strongly support expansion of solar and other clean energy resources. But local opposition to large ground-mount solar projects is growing, especially in places where the pace and scale of development has been significant, or done without sufficient input from communities. Public opinion is clear: Massachusetts residents expect a solar build-out that is balanced as much as possible with nature and agriculture. In fact, a recent Massachusetts Division of Energy Resources

(DOER)[11] survey found overwhelming support from the public for a more balanced approach to solar siting:

- Over 85 percent of surveyed residents in Massachusetts believe that solar should be built on rooftops, parking lots, landfills, and other developed areas, rather than on cleared forests and on top of productive farmland.
- Over 70 percent of residents believe environmental impact is the most important trade-off to consider when siting new solar.

8 Matthew Popkin and Akshay Krishnan, "The Future of Landfills Is Bright" (Rocky Mountain Institute (RMI), October 2021), https://rmi.org/insight/the-future-of-landfills-is-bright/.
9 U.S. Energy Information Administration, "Massachusetts State Energy Profile," October 2022, https://www.eia.gov/state/print.php?sid=MA.
10 Heidi Ricci et al., "Losing Ground: Nature's Value in a Changing Climate" (Mass Audubon, 2020).
11 Pat Knight et al., "Massachusetts Technical Potential of Solar" (Synapse Energy Economics, Inc, July 6, 2023), https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download.

Research Questions

Growing Solar, Protecting Nature explores pathways for deploying solar energy at levels aligned with the state's decarbonization goals and timelines, while minimizing impacts on natural and working lands.

Our hypothesis is that there is ample space in Massachusetts to build economically viable solar on already-developed lands, buildings, and parking lots while minimizing solar that drives losses of terrestrial carbon, biodiversity, prime farmland, and lands that provide resilience to flooding, heat waves, and other climate impacts.

We also believe that public opposition to ground-mount solar could grow unless policies are designed to ensure the best possible balance among clean energy, nature, and working lands. This will require adjustments to the status quo—that is, changing our current siting practices and incentives for large ground-mount solar projects, and deploying even more solar on our buildings and already-developed lands.

In *Growing Solar, Protecting Nature*, researchers from Mass Audubon, Harvard Forest, and Evolved Energy Research used the best geospatial data and energy-economic modeling available to answer the following questions:

- How have large ground-mount solar systems affected Massachusetts' forests, habitats, and farms thus far? What would impacts be if roughly ten times as much ground-mount solar is sited in a similar way?
- Can Massachusetts deploy enough solar to meet the GHG emission reduction goals of the state's *Clean Energy and Climate Plan for 2050* while minimizing impacts on lands with the highest value for carbon, biodiversity, and food production, and reducing the impacts of climate change?
- Which sites for ground-mount solar avoid additional losses to nature and farmlands? How much solar can be economically

sited in the built environment?

- What are the cost implications of deploying more solar with minimal impacts on highest value natural landscapes and farms? What is the cost of siting ground-mount solar on natural and working lands when the true value of carbon removal is included?
- What changes to policy and programs are needed to achieve better balance between ground-mount solar, nature, and working lands?

Profiles of Solar Impacts

Solar installations in Massachusetts range from exemplary, nation-leading projects on landfills and brownfields to poorly designed and executed projects that harm unique ecosystems and natural assets. These Profiles of actual projects illuminate both the challenges and opportunities for all types of solar projects as we scale up this essential clean energy resource over the next few decades.

Challenges

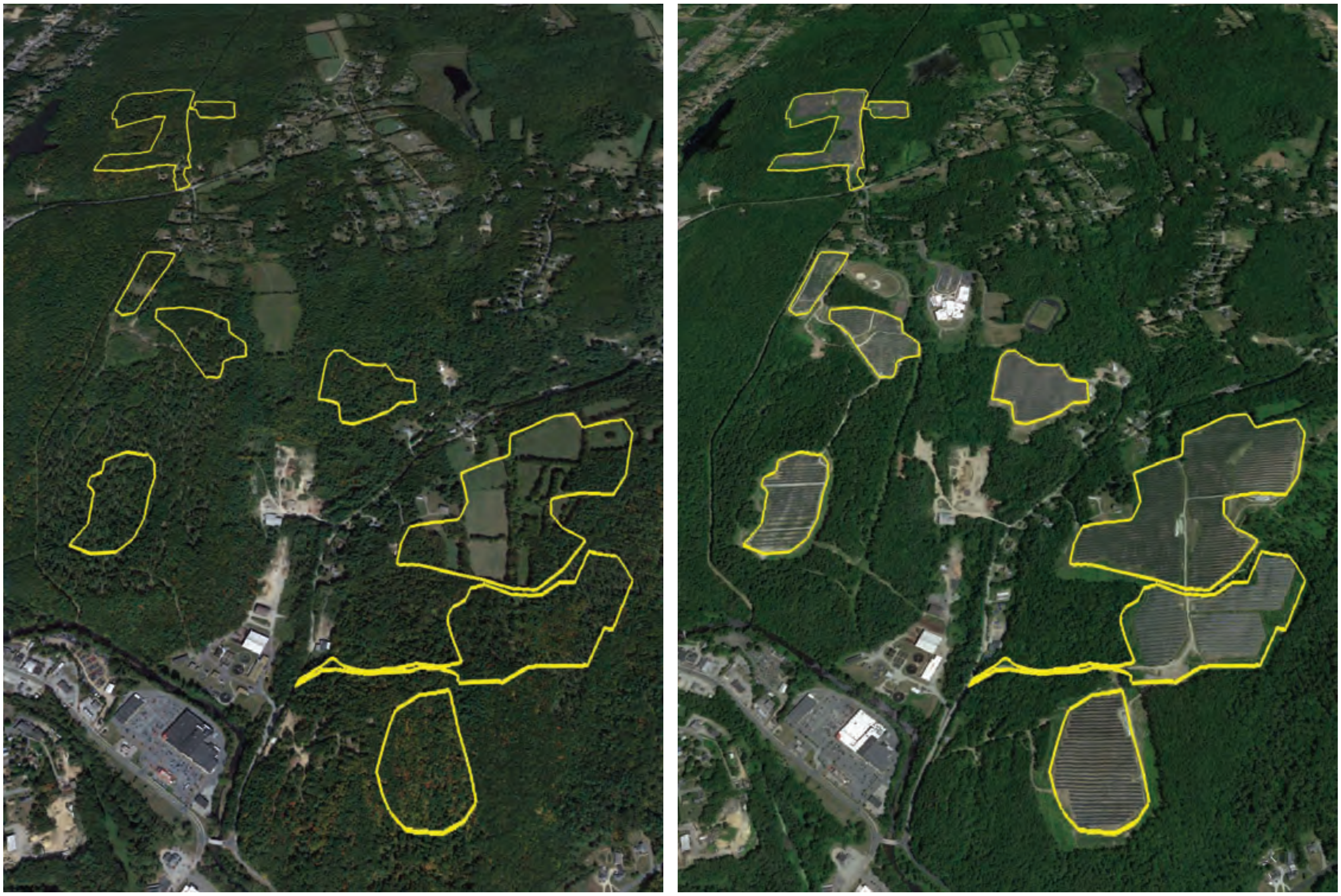
- Forest Loss and Fragmentation
- Conversion of Prime Farmland to Solar
- Biodiversity Impacts
- Erosion and Runoff

Solutions

- Landfills and Brownfields
- Solar Deployment on Commercial Rooftops and Parking Lots
- Redevelopment Opportunities for Solar
- Public Agencies and Non-Profit Institutions

Proceed with Caution

- Agrivoltaics



Challenge: Forest Loss and Fragmentation

Forests not only remove carbon from the atmosphere, they also filter drinking water, provide flood control, cooling and shade, wildlife habitat, and areas for outdoor recreation. However, some solar siting practices are putting Massachusetts' forests at serious risk.

From 2010-2020, nearly half of ground mount arrays (3,753 of 7,900 acres) were sited in forested areas. This resulted in a loss of over 500,000 metric tons of CO_2, equivalent to the annual emissions of more than 110,000 passenger cars. South-central Massachusetts is home to most of these projects, accounting for 37 percent of overall forest loss in the State.

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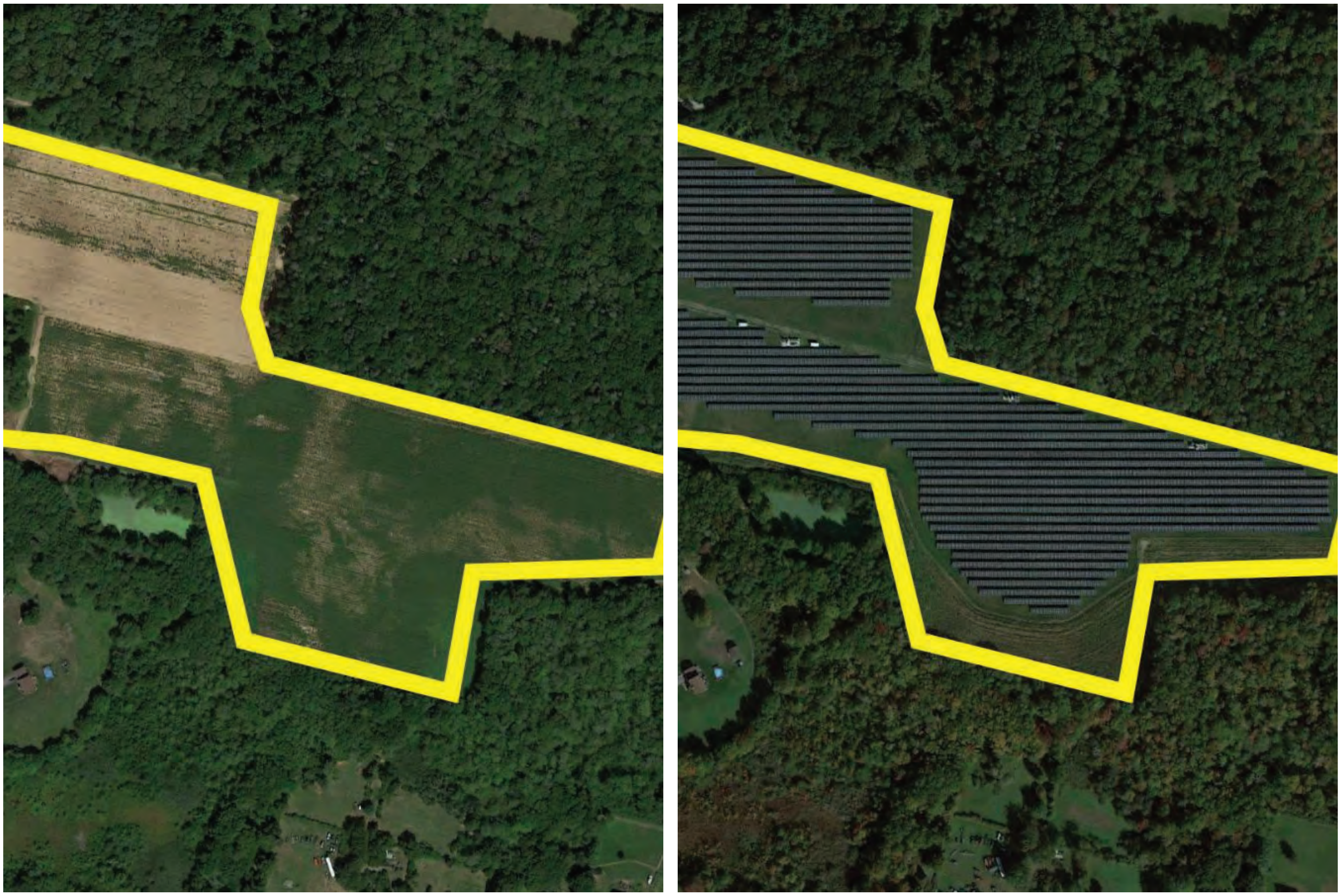

Challenge: Conversion of Prime Farmland to Solar

To date, nearly 1,600 acres of Massachusetts prime farmland has been converted to host ground-mount solar arrays. These lands are attractive for ground-mount development because they're flat and have workable soils. Construction of large ground-mount arrays directly on productive agricultural land reduces the state's capacity for producing locally-grown food.

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Challenge: Biodiversity Impacts

The Southeast region contains the second largest area of coastal pine barrens in the U.S., supporting more than 200 state-listed species, including globally rare species and habitats.

More than 190 ground mount solar arrays have been built in Plymouth and Bristol Counties across 2,322 acres, resulting in destruction and fragmentation of some of these rare ecosystems. Many more ground-mount projects are planned for this region. Indigenous leaders are concerned about the loss of forests and important cultural sites from ground-mount solar.

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Challenge: Erosion and Runoff

Removing forest on steep slopes to site solar arrays can lead to serious erosion and sedimentation into sensitive wetlands and streams. In Williamsburg, a solar project sited on a steep slope was assessed over $1 million in penalties for damage to Mill River, a cold-water fishery, due to erosion. Massachusetts Department of Environmental Protection's guidance for stormwater management on solar arrays encourages avoidance of steep slopes but it does not require the same level of treatment as other impervious surfaces. This policy should be revised.

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Solution: Landfills and Brownfields

Closed landfills have grassy open areas where trees are not allowed to grow in order to protect the landfill cap, and thus can be excellent sites for ground-mounted solar. Due in part to strong state incentives, Massachusetts is a national leader in building solar arrays on closed landfills. As of 2019, 65 utility-scale projects (>1MW) had been built, over half of all such projects nationwide. Many of the best opportunities on landfills have been done, but there is still potential for more. Rocky Mountain Institute estimates that Massachusetts has landfills offering more than 2.5 GW capacity if fully built out. Not all of these sites will be suitable due to slope and soil characteristics, but significant opportunities remain.

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Solution: Solar Deployment on Commercial Rooftops and Parking Lots

Densely developed commercial properties offer many opportunities to install solar systems. These are often located close to load centers, which can help avoid electricity distribution costs in many instances.

Rooftop solar has been widely deployed on commercial buildings such as in the Natick Mall, but many commercial buildings are not built to accommodate the weight of solar systems. Codes for new commercial buildings should require load-bearing capacity for rooftop solar.

With many vacant or uneconomic properties around the state including malls, strip malls, and underutilized parking lots, redevelopment of these sites to mixed-use, i.e., housing plus commercial zones, is an opportunity to integrate new solar onto rooftops and parking lots while also addressing needs for new affordable housing.

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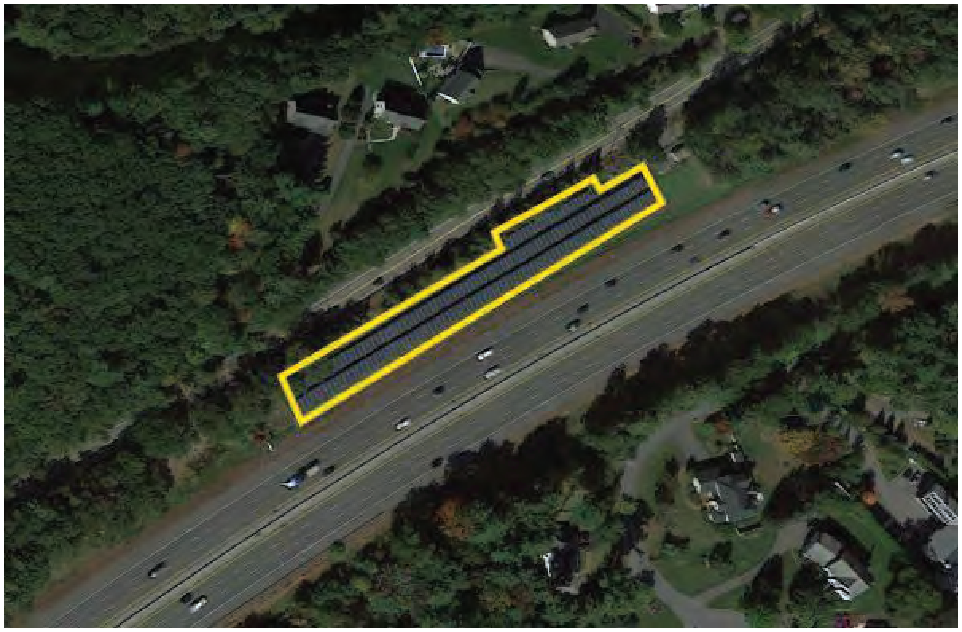

Solar installation, Natick, MA

Solution: Redevelopment Opportunities for Solar

Developed lands that are no longer economically viable for their original use offer opportunities for redevelopment, which can be a great opportunity to include new ground-mount solar. The former Shirley airport, for example, has been converted to a large ground-mount array on 34 acres of former runway and adjoining land. Closed shopping malls like Eastfield have large paved areas that could host solar.

Of the more than 280 golf courses in Massachusetts, some are no longer viable businesses. Several of these have already been converted to hosting solar, including private clubs in Warren (54 ac), Hardwick (19 ac), and a public driving range in Lancaster (25 ac). While some golf courses and former airfields are strong candidates for ecological restoration and habitat (e.g., Pine Grove Golf Course in Northampton), others with lower ecological value are excellent candidates for new ground-mount systems.

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Solution: Public Agencies and Non-Profit Institutions

State agencies, cities and towns, and public and private non-profit institutions often invest in solar on their developed sites and buildings even when the return on investment timeframes are relatively long, reflecting strong commitments to net-zero climate goals.

Colleges, schools, and many other institutions receiving state funding are leaders on installing canopy solar, including UMass Amherst, Roxbury and Bristol community colleges, and MBTA stations. With an estimated 35,000 acres of parking lots available for hosting solar across the Commonwealth, the potential canopy solar capacity is nearly 10 GW. Canopies are also popular with the public as they shield from sun, rain, and snow. However, most canopy projects require direct funding or higher program incentives to overcome higher costs relative to rooftop and ground-mount systems.

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Proceed with Caution: Agrivoltaics

Agrivoltaic solar projects involve integrating solar arrays into agricultural fields, using panel spacing and heights that can allow farming to continue underneath. By creating a new source of revenues from energy markets, they may help maintain marginally viable farms from converting to other forms of development.

DOER's SMART includes incentives for 80MW for development of agrivoltaic solar projects. As of June 2023, 44 projects totaling 63MW AC capacity have been approved or are in review under SMART's agrivoltaics incentives. Planned crops include squash, leafy greens, apples, cranberries, hay, cattle, and sheep.

Agrivoltaics are relatively new to Massachusetts. More information is needed on farm viability, crop selection, changes in food production, soil impacts, and costs before any scale-up of agrivoltaics. Studies underway by UMass Extension and other research should inform program review of incentives and possible future adjustments.

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Methods

This *Growing Solar, Protecting Nature* analysis examines three scenarios depicting Massachusetts solar build-out from now until 2050.

> *Importantly, each of these scenarios is projected to reach the GHG emissions targets set out in Massachusetts'* Clean Energy and Climate Plan for 2050,

though they may employ different levels of clean energy resources like solar, wind, and clean energy imports.[12]

Our analysis relies on the best available geospatial data, maps, and best-in-class energy modeling tools. This analytic approach involved three main steps, described below. More detailed descriptions of our methods, data and assumptions, and modeling tools are available in Appendix A.

Step 1. Estimate technical potential of solar in Massachusetts, using different estimates of lands available for ground-mount solar.

We created three scenarios of *technical* solar potential, defined as where solar can be deployed based on technical and legal considerations only, from now until 2050. Estimates of technical potential do not include any economic considerations. All three scenarios use the same estimate of technical potential for solar on building rooftops and parking lot canopies. Of the ~119,160 acres[13] of available rooftops in the Commonwealth, NREL estimates that 40,772 acres are currently viable for hosting rooftop, with a technical solar potential of 20.6 GW. With over 55,000 acres of parking lots in the Commonwealth, we estimate that with set-backs, over 35,000 acres of these could viably host solar now, with technical solar potential of 9.9 GW. Combined together, the best rooftop and parking lot spaces in Massachusetts have over 30 GW of technical solar potential.

The key difference among the three scenarios is in how we depict the *lands available to host ground-mount solar projects*. This difference is created in order to estimate the range of impacts that ground-mount solar could have on natural and working lands over the next few decades, in particular to levels of forest carbon removal, biodiversity, climate resilience, and productive farmland. Specific assumptions used for the three scenarios are described below.

- The ***Current Siting* scenario** approximates the status quo in siting practices for ground-mount solar. In this scenario, ground-mount solar projects comply with existing legal and physical requirements for solar (e.g., relatively low slopes), but otherwise are not constrained by environmental or social goals or considerations.

> Under the **Current Siting scenario,** over 1 million acres of lands in Massachusetts have the technical potential for ground-mount solar.

In contrast with the *Current Siting* scenario, two *Protecting Nature* scenarios estimate the technical potential of solar if it is primarily limited to sites on already-developed lands, buildings, and parking lots in order to be highly protective of natural and working lands. By design, the supply of sites for ground-mount solar from now until 2050 is restricted in these scenarios as follows:

- The ***Protecting Nature—Mid-Impact* scenario** protects the majority of lands featuring high-carbon natural ecosystems, biodiversity, high climate resiliency, and productive farmland from the supply of sites modeled for hosting ground-mount solar.

> Under the **Protecting Nature—Mid-Impact scenario,** 94,000 acres have the technical potential for ground-mount solar, which is less than one-tenth of the lands under the Current Siting scenario.

- The ***Protecting Nature—Low-Impact* scenario** is even more protective of nature, farmlands, and other environmental attributes than the Mid-Impact scenario above.

The **Protecting Nature—Low-Impact scenario** identifies only 38,000 acres with the technical potential for ground-mount solar.

Step 2. Estimate how much technical potential for solar is most economically attractive.

As noted above, technical potential for solar only indicates where solar meets minimal legal and technical requirements (e.g., low slope). There is a subset of sites with technical potential that are the most economically attractive—these are the land parcels, buildings, and parking lots that are most likely to be first developed for solar, because they have lower costs compared to other sites. We refer to this portion of technical solar potential with lower relative costs as 'economic' or 'economically attractive' solar. Using a best-in-class energy-economic model, we evaluated the technical solar potential for each scenario to identify the portion of land parcels, rooftops, and parking lots of the technical potential that are the most economically attractive for hosting solar systems.

> *Many projects that rank as higher cost will still be developed by homeowners and business owners because of state policy incentives, preferences, and other reasons for installing solar.*

Our economic analysis takes into account the effect of federal renewable energy incentives created by the *Inflation Reduction Act* on future solar capacity. Importantly, it does not include existing state-level incentives that impact the relative cost-effectiveness of solar. State incentives are a key policy tool available to encourage the types of renewable energy development that align with state priorities. By leaving the state-level incentives for solar out of the economic analysis, we are able to understand how changing them would impact future solar capacity. It is important to note that the solar identified as the most economic in our least-cost energy model is not a limit to how much solar can get built. Many projects that rank as higher cost will still be developed by homeowners and business owners because of state policy incentives, preferences, and other reasons for installing solar.

Step 3. Estimate impacts of economic ground-mount solar on natural and working lands.

For each scenario, parcels identified as most economically attractive for ground-mount solar were then evaluated for the environmental impacts of converting the parcel for development, including changes in forest carbon, biodiversity, climate resiliency, and prime farmland. We used a statistical technique (i.e., Monte Carlo resampling; see Appendix A) to account for the uncertainty in exactly which sites are most likely to get built, then calculated differences among the scenarios to estimate the net impacts to nature and working lands.

12 Massachusetts Executive Office of Energy and Environmental Affairs, "Massachusetts Clean Energy and Climate Plan 2025 and 2030" (Massachusetts Executive Office of Energy and Environmental Affairs, June 30, 2022).
13 Pieter Gagnon et al., "Rooftop Solar Photovoltaic Technical Potential in the United States. A Detailed Assessment," January 1, 2016, https://doi.org/10.2172/1236153.

Key Findings

KEY FINDING #1

Ground-mount solar systems installed in Massachusetts since 2010 have caused significant losses to forest carbon, biodiversity, and productive farmland. State goals for carbon removal, biodiversity, and climate resilience will be at high risk unless siting of ground-mount solar changes, and quickly.

As of 2023, Massachusetts has an estimated 4.2 GW of solar energy capacity, currently among the top 15 states in the U.S.[14] Most of this capacity—roughly 2.8 GW—is distributed solar on rooftops and canopies over parking lots. The remaining roughly

1.4 GW is estimated to be ground-mount solar. Starting around 2010, the build-out of ground-mount solar began to have a major impact on the state’s natural lands.

Figure 1:
Ground-Mounted Solar Systems in Massachusetts, 2010–2021

This map reflects the location and size of hundreds of ground-mount solar projects which were built between 2010 and 2020, covering more than 8,000 acres in Massachusetts. Nearly 2,000 additional acres have been converted since 2020. Large ground-mount solar projects are highly concentrated in south-central and southeastern Massachusetts, where solar energy and transmission infrastructure are most abundant. Just four counties—Worcester, Hampden, Plymouth, and Bristol—account for 75 percent of the total ground-mount solar capacity, with Worcester County accounting for most of this.

The impacts of over hundreds of ground-mount solar projects on our natural and working lands over the last decade have been broad and deep. Before these sites hosted ground-mount solar, 60 percent of the land was forested. We estimate that conversion of forests resulted in emissions of more than 500,000 metric tons of CO_2—equivalent to the annual GHG emissions from 112,000 passenger cars.

Ground-mount solar has resulted in losses to more than forest carbon. Sixteen percent of these sites were previously agricultural land. Almost 10 percent of solar acres built during this decade overlap with core wildlife habitat, and 11 percent overlap with critical natural landscapes identified by the state's map of lands supporting high levels of biodiversity, called BioMap.[15] Moreover, approximately 15 percent of the affected areas are designated as "above average" for providing resilience to impacts of climate change, according to The Nature Conservancy.[16]

If current trends of ground-mount solar construction continue, we stand to lose more than 20,000 additional acres of the most valuable wildlife habitat in the state, including 9,000 acres in the globally rare pine barrens habitat of southeastern Massachusetts and another 9,000 acres in largely forested areas of central and western Massachusetts. When left intact and connected, these areas are habitat for most of the Commonwealth's 432 endangered, threatened, and special concern species such as Blue-spotted Salamander, Northern Long-eared Bat, and Eastern Whip-poor-will. Connected forests also support our more common species and provide critical movement corridors for wide-ranging species such as bobcat, fisher, and black bear. Conversion to ground-mount solar, like other forms of development, drastically alters these natural communities, fragments the landscape, and interrupts wildlife movement patterns. These new forest openings also serve as entry points for invasive plants and provide favorable conditions for increased white-tailed deer density which has further negative impacts on the surrounding forest.

Examples of valuable forests that were cleared for solar installations. From left to right: Oxford, Shirley, Southbridge, MA. Click each image to enlarge.

Beyond the direct impacts to wildlife, a fragmented landscape is a less resilient landscape, one that is less able to adapt as the climate continues to change. In Massachusetts, more than a quarter of the forest area is within 65 feet of a non-forest edge,[17] so it's imperative that we keep our remaining forests intact. Connected and resilient landscapes allow for the slow range shifts of plants and animals in response to shifting temperature and precipitation patterns. They are better able to support our communities by absorbing and filtering stormwater, reducing flooding and protecting our rivers and drinking water supplies. By breaking up the landscape, we reduce resilience and put these precious ecosystem services at risk.

14 Solar Energy Industries Association, "Massachusetts Solar | SEIA," accessed September 5, 2023. https://www.seia.org/state-solar-policy/massachusetts-solar.
Pat Knight et al., 2023. "Massachusetts Technical Potential of Solar."
15 MassGIS. "BioMap: The Future of Conservation," [Dataset]. November 2022.
16 The Nature Conservancy, "Resilient Lands Mapping Tool," [Mapping Tool], 2016, https://maps.tnc.org/resilientland/.
17 Reinmann, Andrew B., Ian A. Smith, Jonathan R. Thompson, and Lucy R. Hutyra. "Urbanization and Fragmentation Mediate Temperate Forest Carbon Cycle Response to Climate." *Environmental Research Letters* 15, no. 11 (November 2020): 114036. https://doi.org/10.1088/1748-9326/abbf16.

KEY FINDING #2

Massachusetts has ample sites for solar to reach the state's GHG emission reduction goals without further sacrifices of natural and working lands.

Results for the *Protecting Nature* scenarios show that Massachusetts has ample locations to site economically attractive solar, meeting the Commonwealth's GHG emissions targets while being highly protective of nature. Under the first of these scenarios—the *Protecting Nature—Mid-Impact* scenario—solar deployment is at nearly 80 percent of the levels called for by the *Clean Energy and Climate Plan for 2050*. Reaching the solar levels described in the *Clean Energy and Climate Plan* can be achieved while protecting nature and working lands, but will require a shift in current state incentives to bring in even more distributed (i.e., rooftop and canopy) solar while also changing the type and location of new ground-mount solar.

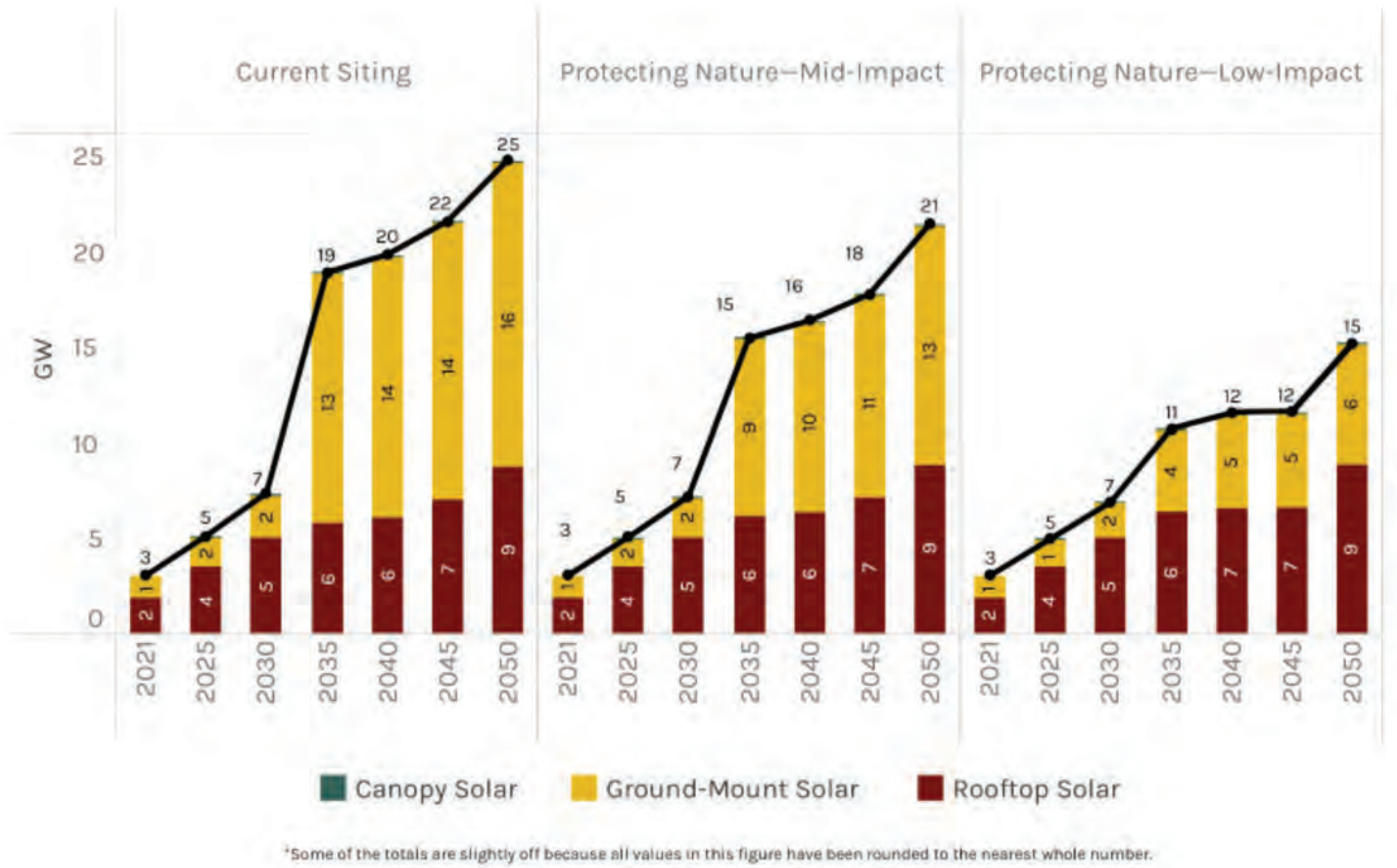

Figure 2:

Estimated Economic Solar Capacity to 2050

The Massachusetts electric portfolio reflected in the *Clean Energy and Climate Plan* includes a total of 8 GW of solar by 2030, and 27 GW by 2050. With just over 4 GW of solar capacity already in Massachusetts, this means an additional ~4 GW could be needed by 2030, and an additional 23 GW by 2050.[18] Least-cost modeling of the *Current Siting* scenario results in total economic solar capacity of 7 GW by 2030 and 25 GW by 2050. Under the *Protecting Nature—Mid-Impact* scenario, total potential for the most economic solar nearly reaches this level, with 7 GW of solar by 2030 and 21 GW by 2050. Under the *Protecting Nature—Low-Impact* scenario, which is more protective of nature when siting ground-mount projects, solar capacity is projected to be 10 GW lower than *Current Siting* in 2050. To meet our 2050 renewable energy goals, adding state-level incentives will be necessary to locate these 10 GW of solar somewhere other than on the ground.

Because canopy solar on parking lots is more expensive than most rooftop and ground-mount systems, it is not chosen at all using least-cost economic modeling. So it it will likely need more incentives to further take advantage of its nearly 10 GW of statewide capacity.

18 Modeling for Massachusetts *Clean Energy and Climate Plan for 2050* estimates New England-wide renewable electricity capacity in 2050 to include 74 GW of solar PV (including both ground-mount and rooftop) and 51 GW of wind (including both onshore and offshore wind).

KEY FINDING #3

Massachusetts has over 30 GW of solar potential on buildings and parking lots alone. Maximizing solar in the built environment would unlock a better balance between clean energy and natural and working lands.

Ground-mount solar systems generally enjoy economies of scale over rooftop solar systems, which on average are smaller, and involve higher ‘soft costs’ (e.g., permitting, marketing).[19] Placing solar canopy systems over parking lots is very popular with the public, and the Commonwealth has supported deployment of many successful canopy systems on state-owned parking lots, state universities, and community colleges. However, canopies have higher average costs than most ground-mount and rooftop projects due to the additional materials and labor needed to elevate solar panels. These systems would benefit from additional incentives to be more attractive for developers.

If soft costs of rooftop and canopy systems can be reduced relative to the cost of ground-mount solar over the next few decades, the financial edge that large ground-mount systems currently have will be even lower. And our results project that solar will remain competitive with all other forms of electricity generation over the full timeframe to 2050.

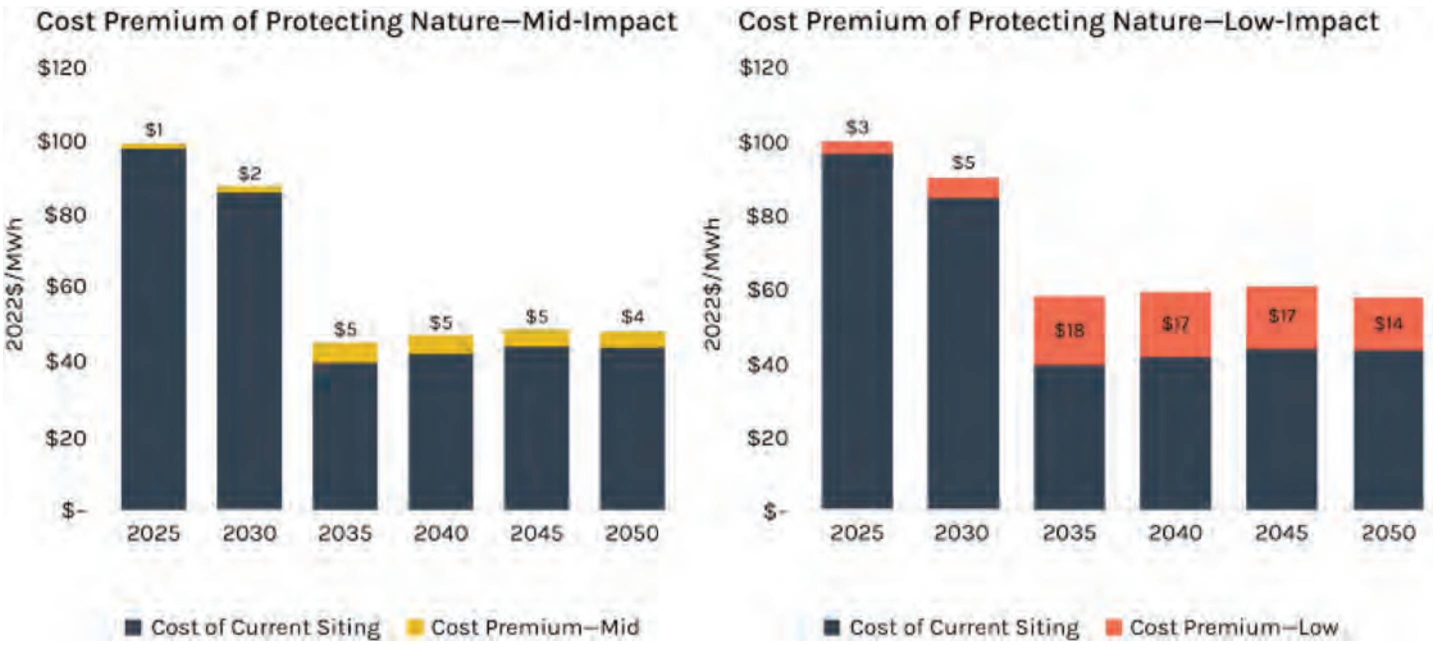

Figure 3:
Projected Costs of Solar to 2050

On average, the cost of solar in the *Protecting Nature—Mid-Impact* scenario is 2.6 percent higher per MWh than in the *Current Siting* scenario in 2030, and 10 percent higher in 2050. In all scenarios, the average cost of solar in Massachusetts declines dramatically from 2030 to 2035: this is because IRA incentives, combined with gradually declining solar costs over time,[20] make it economic to add a large quantity of new solar in 2035 before incentives expire. The higher average costs of solar in the *Protecting Nature* scenarios result from shifting large ground-mount solar projects to small ground-mount installations and rooftop projects. When aggregating the total costs of achieving Massachusetts' GHG emissions targets through 2050, the *Protecting Nature—Mid-Impact* scenario costs $900 million more than the *Current Siting* scenario in present value terms. In relative terms, this is a very small fraction of the aggregate cost of the energy system in Massachusetts over multiple decades.

Soft costs like permitting and marketing make up a large portion of rooftop solar costs. We see an opportunity to reduce those costs via policy interventions, which has been achieved in some international markets like Australia. To evaluate the impact of reducing soft costs for rooftops, we modeled potential reductions in these costs of 30 percent.[21]

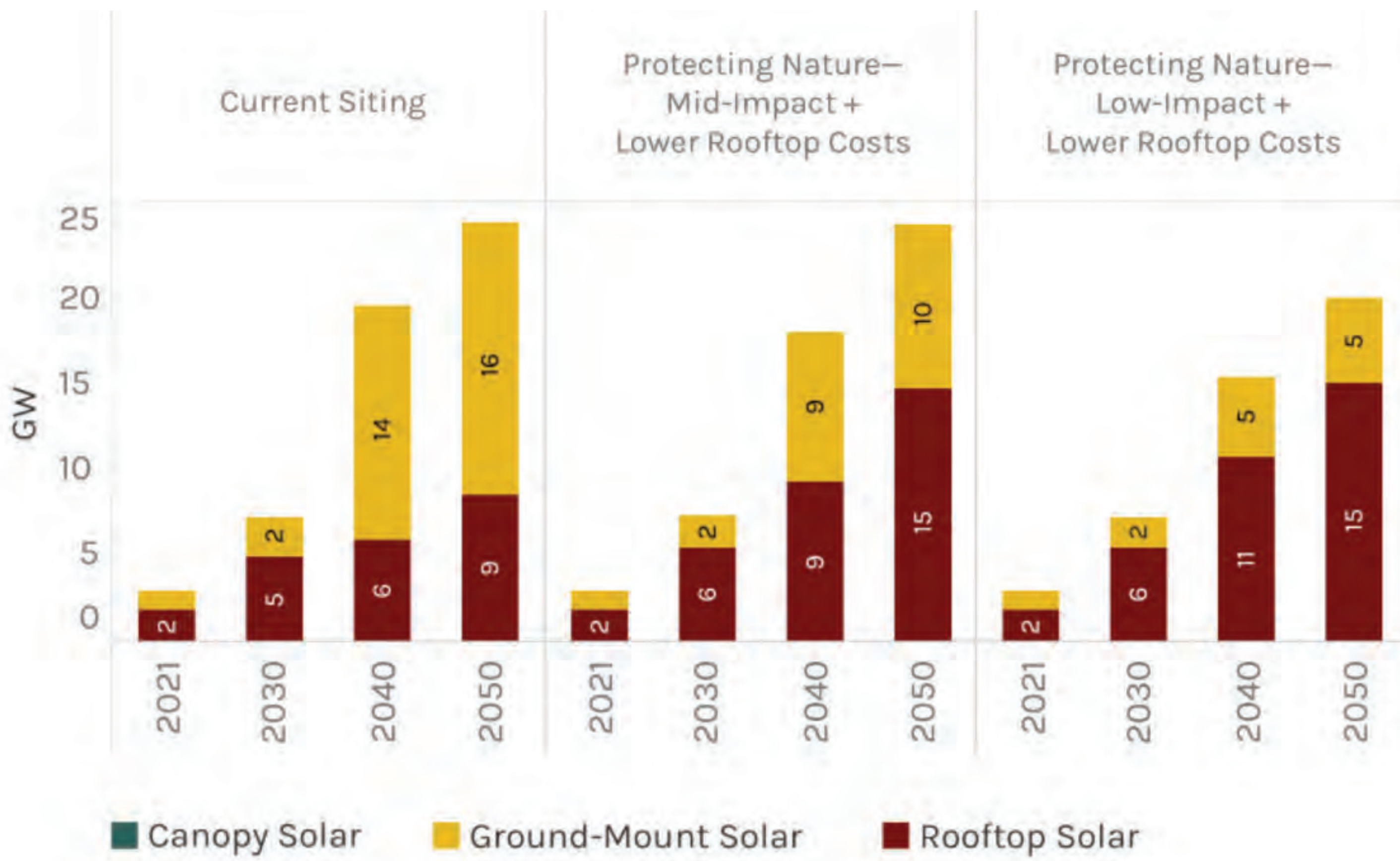

Figure 4:

Estimated Economic Solar Capacity to 2050, Lower Rooftop Costs

Under a sensitivity analysis using a reduction of 30 percent in rooftop costs, we found that the quantity of ground-mount solar needed declines, by 19 percent and 38 percent under the *Protecting Nature—Mid-Impact* and *Low-Impact* scenarios, respectively. Meanwhile, rooftop solar capacity increases by two-thirds, from 9 to 15 GW by 2050 in both scenarios. This finding strongly encourages approaches to reducing 'soft costs' of rooftop systems, including streamlining permitting and marketing, in order to increase the competitiveness of these systems and reduce the need for ground-mount systems.

It is critical to note that the cost comparisons above apply to differences in costs in the *energy system* only—when the social costs of cumulative losses to nature and farmland by 2050 are included in the analysis, the costs of different approaches to siting ground-mount solar shifts to favor lower-impact siting, as described later in these Findings.

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19 Latika Gupta et al., "Long Island Solar Roadmap Economic Research Report" (The Nature Conservancy, 2019), http://solarroadmap.org/wp-content/uploads/2021/02/Long-Island-Solar-Roadmap_Interim-Economic-Research-Report.pdf.
Our ground-mount rooftop solar cost estimates are derived from NREL's *Annual Technology Baseline* (ATB) 2021, with ground-mount costs correlated to system size using empirical data from Massachusetts Clean Energy Center's Production Tracking System. Under our 2050 assumptions, commercial and industrial rooftop solar is approximately 10 percent more costly than small ground-mount systems (smaller than 1 MW) and 20 percent more costly than large ground-mount systems (larger than 1 MW) on a dollar per kW basis. We assume that canopy systems on parking lots cost 1.8 times more than commercial rooftop systems in all years, on a dollar per kW basis, based on values from Long Island's Solar Roadmap study and developer feedback.

20 Evolved Energy Research's ground-mount solar costs are derived from NREL's 2021 ATB, which assumes a gradual reduction in cost over time to reflect improvements in solar panel performance and project installation efficiency.

21 This 30 percent reduction case is based on the National Renewable Energy Lab's "advanced technology" estimates.

KEY FINDING #4

Achieving *Protecting Nature* can be done using 100,000 acres or less for ground-mount solar.

The *Protecting Nature—Mid-Impact* scenario estimates there are 41,000 acres of highly economic ground-mount solar, which is only 10,000 fewer acres than in the *Current Siting* scenario, and another 53,000 acres that could support slightly more costly ground-mount projects. Even though the total acres identified under *Current Siting* and *Protecting Nature—Mid-Impact* are only

10,000 acres apart, the land parcels identified in the Protecting Nature scenarios are very different from those indicated in the *Current Siting* scenario. On average, the *Current Siting* scenario features the largest parcels which are located primarily in forests and on other natural and working lands. Because the *Protecting Nature* scenarios are intentionally designed to avoid sites with high-carbon, high-biodiversity forests and farmland, it shifts both the location and size of ground-mount solar sites. Results also show these scenarios would also maintain *much higher forest carbon sequestration capacity by 2050* relative to the *Current Siting* scenario, as described in greater depth in Finding #5 below. Gains in biodiversity, climate-resilient lands, and productive farmlands can also be achieved by shifting away from our *Current Siting* pathway.

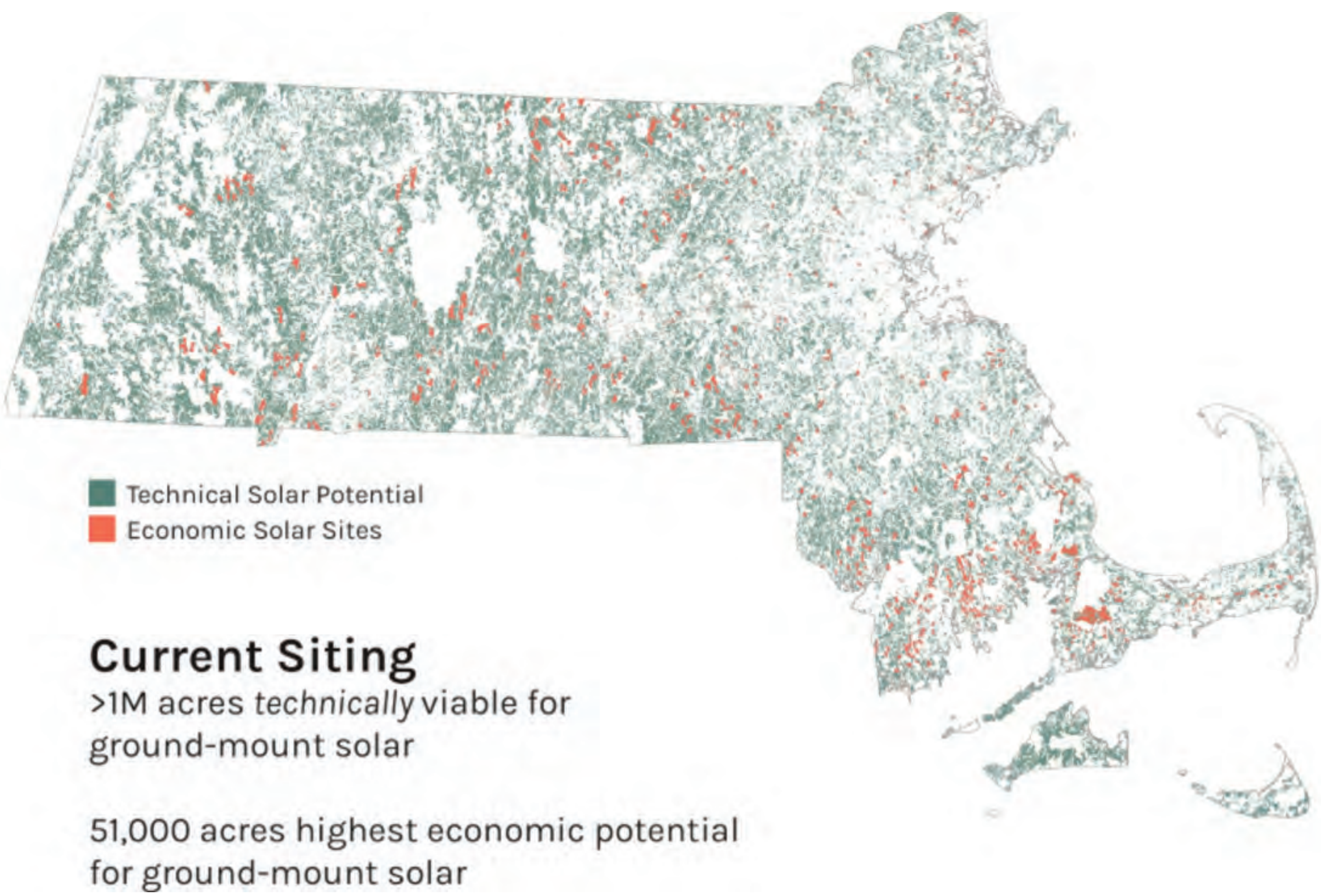

Figure 5:

Sites for Ground-Mount Solar, *Current Siting* scenario

Over half of the 14 GW of capacity for new ground-mount projects under the *Current Siting* scenario are projects larger than 10 MW, at a minimum of 36 acres in area.

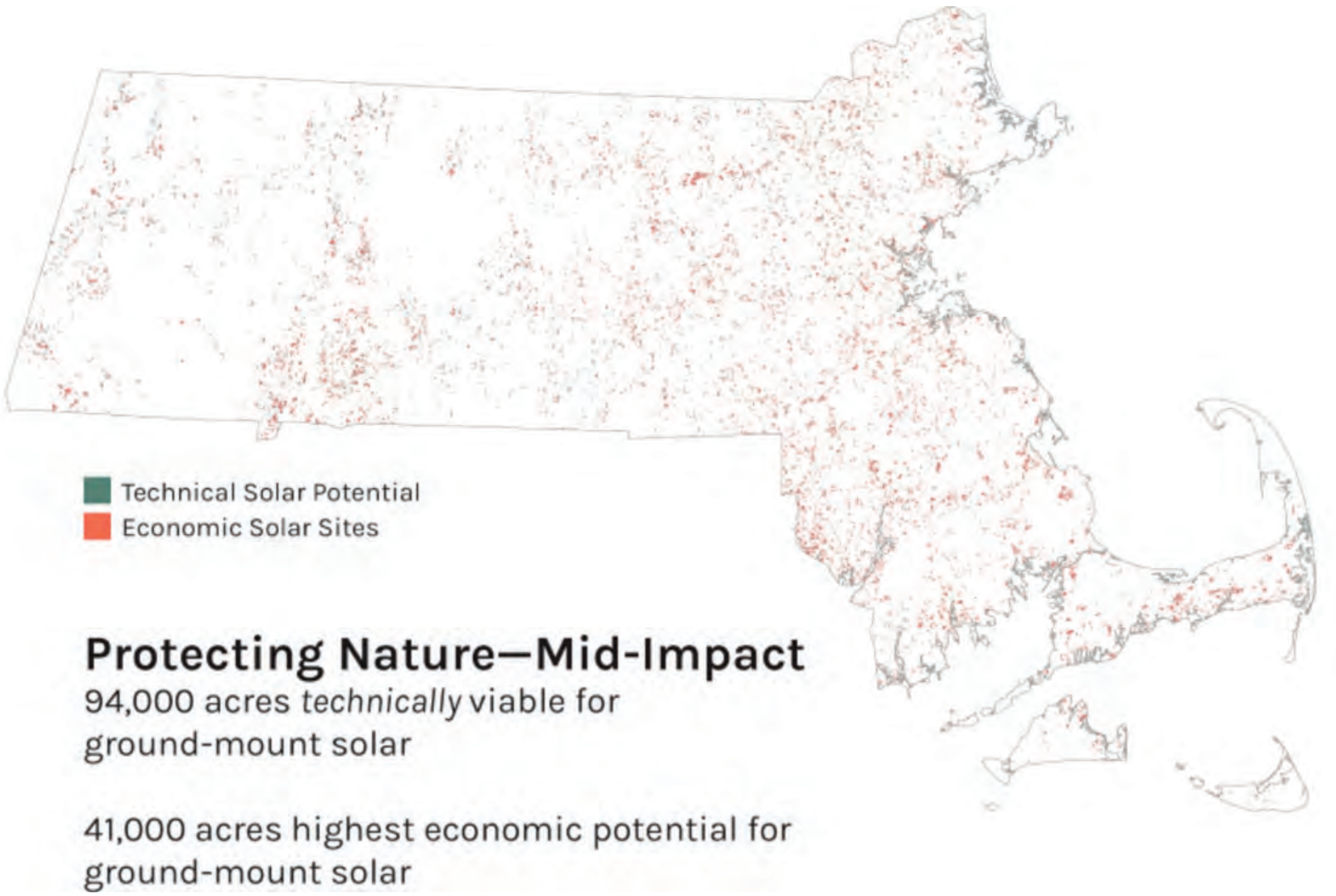

Figure 6:

Sites for Ground-Mount Solar, *Protecting Nature—Mid-Impact* scenario

In contrast, under the *Protecting Nature—Mid-Impact* scenario, the most economic ground-mount systems are smaller, with over 80 percent of economic projects ranging from 1 to 10 MW_{ac} in size, each requiring an area roughly 3.6 to 36 acres.[22]

22 Mark Bolinger and Greta Bolinger, "Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density," *IEEE Journal of Photovoltaics* 12, no. 2 (March 2022): 589–94, https://doi.org/10.1109/JPHOTOV.2021.3136805. We assume energy density (also known as a packing factor) for ground-mount solar of 1 MW_{ac} on 3.6 acres.

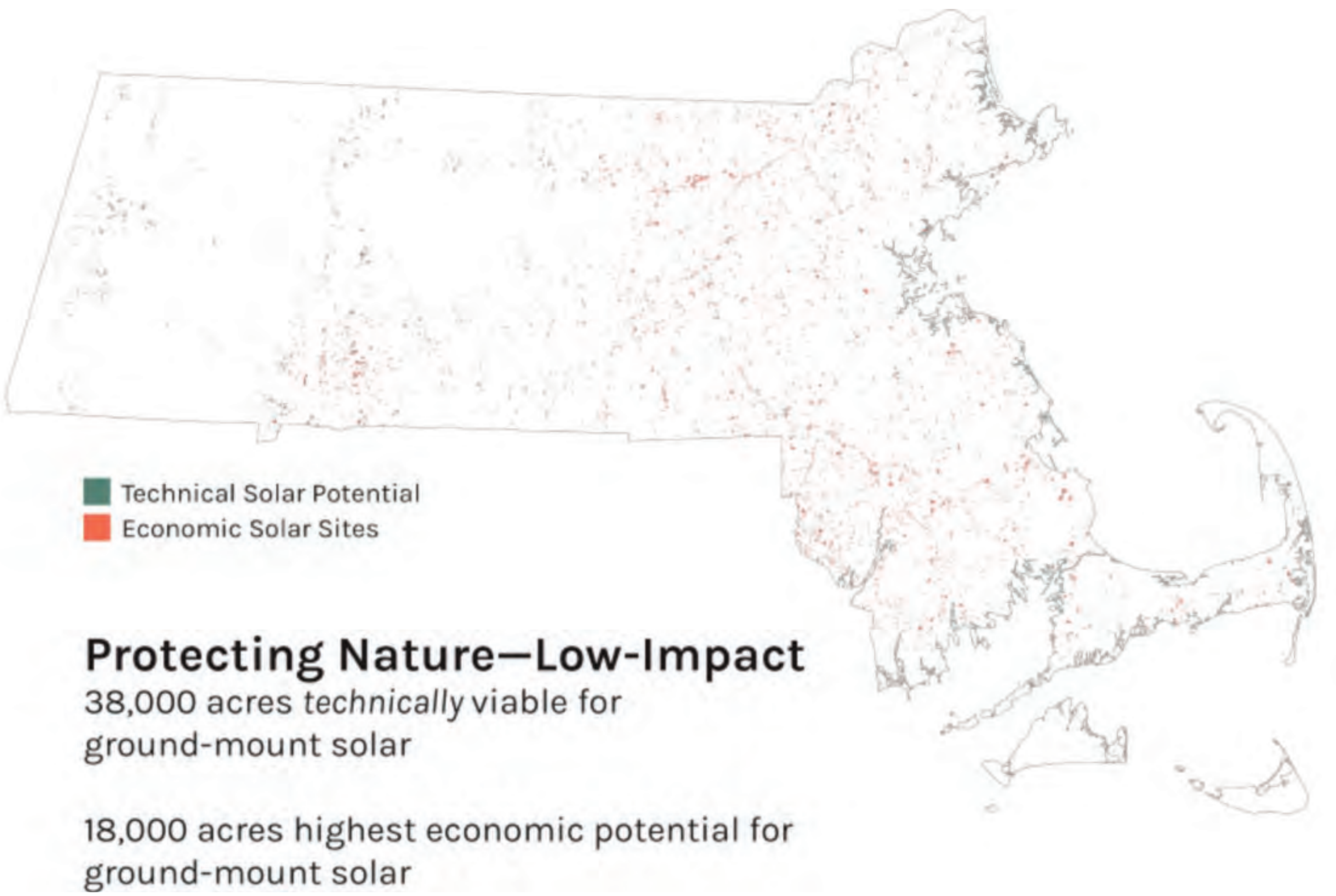

Figure 7:

Sites for Ground-Mount Solar, *Protecting Nature—Low-Impact* scenario

Capacity for economic ground-mount solar under both *Protecting Nature* scenarios is also much more geographically distributed around the state—every county in Massachusetts has many sites for these smaller systems, but no one county (or group of counties) dominates.

KEY FINDING #5

When the true value of carbon removal by forests is considered, the *Current Siting* approach is *more costly* than *Protecting Nature* through 2050.

Nature's prodigious benefits to society are not valued in markets, even though these are critical services that society needs and are not readily replaceable. Carbon removal by forests is just one ecosystem service that fares considerably worse under a continuation of current solar siting practices. The *Current Siting* scenario results in a significant loss of carbon from forests ranging from 5.7 to 5.9 $MMTCO_2e$.[23] This is 4.7 to 4.9 $MMTCO_2e$ *higher* than projected losses of forest carbon under the *Protecting Nature—Mid-Impact* and *Low-Impact* scenarios, respectively. To understand what would be needed to make up for this loss of carbon removal by forests and still meet the 2050 net-zero emissions, we calculated the costs of making up this decrement to forests' carbon removal capacity by achieving other types of GHG emission reductions.

Using an estimate that achieving additional GHG reductions from the energy system in the latter part of this timeframe (2050) will cost approximately $200/ton CO_2e, replacing this quantity of natural carbon removal alone could cost up to $940M to $980M. The cost of replacing carbon removed by forests is actually greater than the difference in the energy costs (in present value terms) between the *Current Siting* and the *Protecting Nature—Mid-Impact* scenario.[24] And because this estimate only reflects losses in carbon, and does not include the costs of losing other services when nature and working lands are converted, like flood protection, drinking water filtration, wildlife habitat, and local food production, it actually *underestimates* the costs to the public of further conversion and fragmentation of forests, other terrestrial ecosystems, and farms.

> *Adding together past and projected future effects of* Current Siting, *we estimate that by 2050, ground-mount solar will be responsible for the cumulative loss of 39,150 acres of forest, 9,397 acres of prime farmland and 22,794 acres of lands featuring high biodiversity.*

In sum, the *Protecting Nature* scenarios result in markedly lower impacts to nature and the vast number of services it provides. Indeed, continuing along the *Current Siting* trajectory would not only result in the emissions of millions more tons of carbon than the *Protecting Nature* scenarios—it would also incur major additional losses to biodiversity, acres of productive farmland, and areas most important for resilience to climate change, on top of losses already incurred from the 2000s to the present.

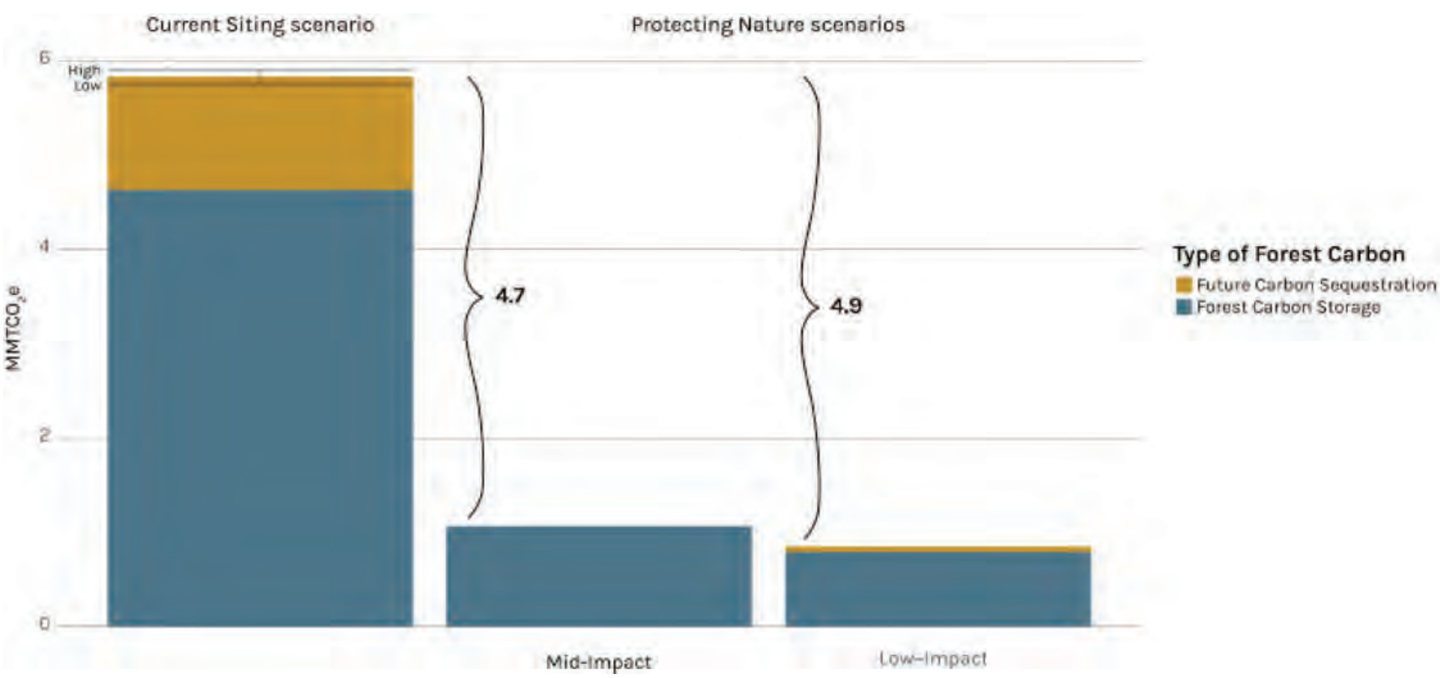

Figure 8:

Cumulative Emissions from Loss of Forest Carbon, to 2050

Under the *Current Siting* scenario, clearing of forests and high-carbon ecosystems is projected to result in 5.8 MMT of CO_2 emissions by 2050. Because the *Protecting Nature—Mid-Impact* and *Low-Impact* scenarios avoid forests and other carbon-rich sites, CO_2 emissions from forest loss are much lower, at 1.1 $MMTCO_2e$ (Mid) and 0.9 $MMTCO_2e$ (Low), respectively.

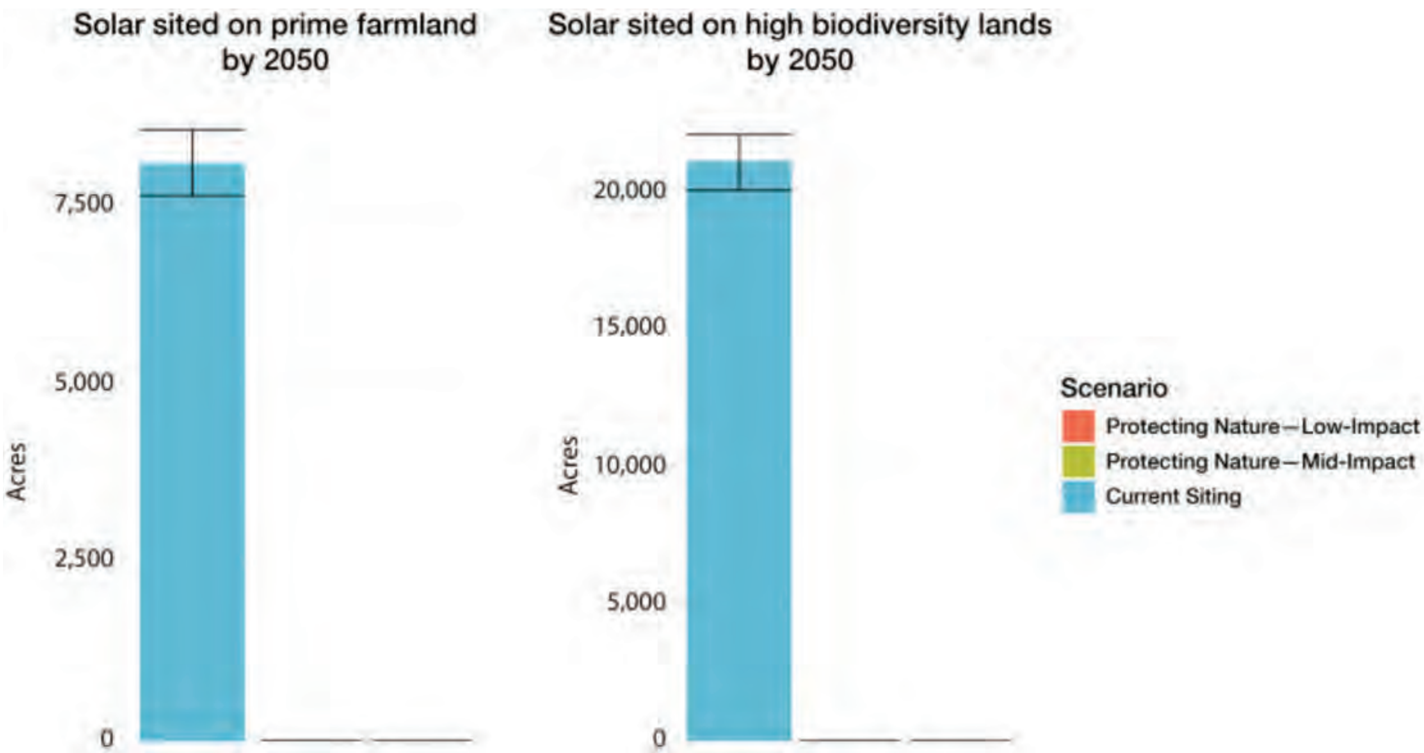

Figure 9:

Projected Impacts on Biodiversity and Prime Farmland from Ground-Mount Solar to 2050

The *Current Siting* scenario is projected to displace more than 8,000 acres of prime farmland and 21,000 acres of BioMap core habitat by 2050, while both *Protecting Nature—Mid-Impact* and *Low-Impact* scenarios would leave these sites intact. These projected losses to farmland and high biodiversity lands are *additional* to those documented earlier from ground-mount solar systems installed up to 2020. Adding together past and projected future effects of *Current Siting*, we estimate that by 2050, ground-mount solar will be responsible for the cumulative loss of 39,150 acres of forest, 9,397 acres of prime farmland and 22,794 acres of lands featuring high biodiversity.

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23 MMTCO_2e refers to million metric tons of carbon dioxide equivalents. From EPA, The unit "CO_2e" represents an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO_2), based on the global warming potential (GWP) of the gas.

24 Based on the cost of additional marginal emissions reductions from the energy system through 2050, we estimate a marginal value of carbon removal at $200/ton CO_2e. We calculated the present value (i.e., a stream of values over time discounted to a present value using a discount rate that reflects the time value of money) of additional carbon losses under *Current Siting* compared to *Protecting Nature—Mid-Impact* and *Low-Impact* as follows:

(Current Siting Carbon Emissions—Protecting Nature—Mid-Impact Carbon Emissions) * (Marginal cost of GHG abatement, 2050)
(5.8MMTCO_2e - 1.1MMTCO_2e) * $200/ton CO_2e = $940M

(Current Siting Carbon Emissions—Protecting Nature—Low-Impact Carbon Emissions) * (Marginal cost of GHG abatement, 2050)
(5.8MMTCO_2e - 0.9MMTCO_2e) * $200/ton CO_2e = $980M

KEY FINDING #6

Interconnection challenges are slowing deployment of solar and other clean energy resources. Clearing the backlog of projects waiting for interconnection is an opportunity to

support solar projects with low impacts on nature.

This analysis shows that reducing losses of terrestrial carbon and other impacts to high-value natural lands will require a shift to siting ground-mount solar away from larger, forested parcels to smaller projects on lower-impact parcels. A solar build-out which features smaller ground-mount projects also means projects would likely be more evenly distributed around the state, rather than continuing to concentrate in a few counties where the largest, least expensive land parcels are available.

Ultimately, the economic viability of ground-mount solar projects depends on the availability and cost of connecting to transmission infrastructure. As of late 2022, approximately 6 GW of proposed solar projects in New England were waiting for approval to be interconnected to the grid; many of these will not get built due to high interconnection costs.[25] In order to minimize impacts to natural and working lands, interconnection policies should favor smaller ground-mount projects located closer to electric load. Nationally, smaller solar projects (i.e., under 5 MW) are being interconnected about one year faster than large solar projects (i.e., 5-20 GW).[26] Thus, policies focused on smaller ground-mount projects may also result in more solar being brought online more quickly compared to the current pathway of siting larger projects.

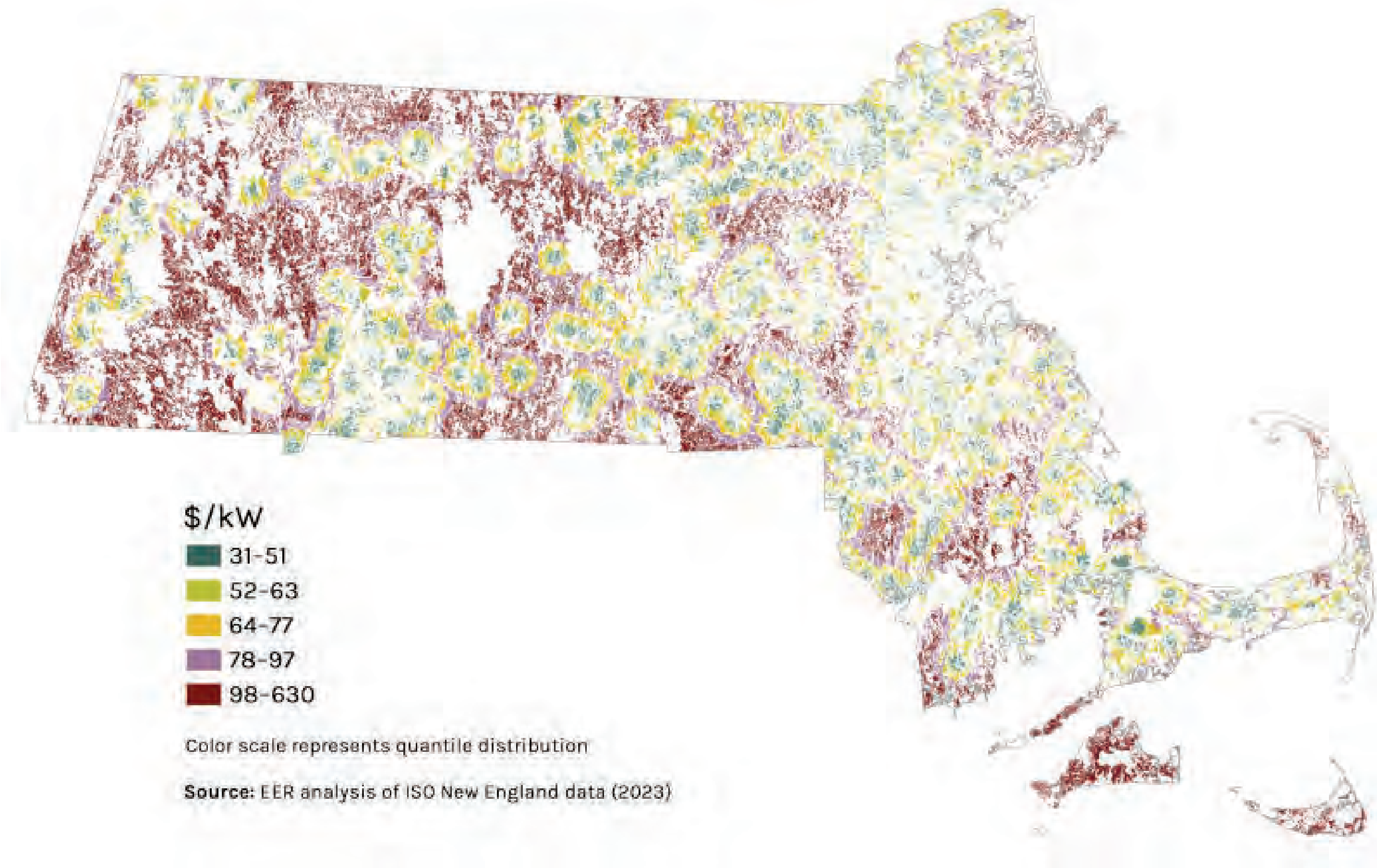


Figure 10:
Solar Project Interconnection Cost per kW

Our estimates of interconnection costs in Massachusetts assume that costs increase linearly with distance from substations, with lowest cost areas shown in green in Figure 10. Areas where ground-mount solar development has been highest coincide with many of these green areas. Our estimates, however, do not reflect the fact that hosting capacity is now very constrained at many of these sites. This lack of hosting capacity is playing a large part in driving higher costs for solar projects waiting for interconnection.

25 Lawrence Berkeley National Lab, "Generation, Storage, and Hybrid Capacity in Interconnection Queues," accessed August 15, 2023, https://emp.lbl.gov/news/grid-connection-requests-grow-40-2022-clean.
26 Julie Kemp et al., "Interconnection Cost Analysis in ISO-New England," June 21, 2023, https://doi.org/10.2172/1986022.
Lawrence Berkeley National Lab (LBNL) estimates that at the end of 2022, there was approximately 4,112 MW of solar and 1,993 MW of solar paired with battery storage in ISO-New England's interconnection queue. LBNL estimates that current interconnection costs for solar in ISO-New England are $450/kW, basically representing a doubling of costs since 2018 compared to 2010-2017.

KEY FINDING #7

New federal incentives can boost community solar in the built environment and on low-impact lands.

Massachusetts is a national leader in community solar projects, which are a way for multiple households to buy and benefit from a single solar project. Community solar is a principal means to provide access to affordable solar to low- and moderate-income households in environmental justice communities and beyond, small businesses, and other electricity customers who otherwise cannot finance or host their own solar projects. Solar developers who specialize in residential and commercial rooftop systems state that the IRA's specific provisions for community energy projects are already boosting their ability to finance these projects. Another component of IRA funding is the U.S. EPA's new $8 billion *Solar for All* competitive grant program—this is designed to boost the ability of states, territories, Tribal governments, municipalities, and eligible non-profits to expand solar's benefits more equitably to low-income ratepayers.[27] Building partnerships among the state, cities, non-profit partners, and developers to make certain that Massachusetts takes full advantage of IRA funding for solar and secures a Solar for All grant should be a paramount priority for the state. These federal funds should be used strategically to secure community solar for low-income customers, and direct deployment towards opportunities on built environment and ground-mount projects on already-developed lands, not on natural and working lands.

City of Newton: 'Leading by Example' on Municipal Solar

Governments and large non-profit institutions in Massachusetts are playing a lead role in solar and clean energy deployment. State, city, and town governments, universities, hospitals, and other non-profits own and manage large amounts of land and many large buildings and facilities, including town halls, dorms, landfills, libraries, parking lots, and many other structures, so these institutions have a significant opportunity to deploy solar on properties and buildings.

In 2013, the City of Newton began construction on solar facilities on municipal-owned land and buildings to reduce GHG emissions and produce net energy savings on behalf of residents. As of early 2023, Newton operates a solar portfolio with over 4,000 KW of capacity, including rooftop solar, innovative parking lot canopies, and a municipal landfill. Together, they generate just over 6 million kWh per year, or approximately 30 percent of total municipal electric load.

Though space is at a premium in Newton, the city has creatively maximized its available spaces to deploy solar and advance carbon reduction goals. Newton estimates that the energy savings flowing to the city from these solar installations amounted to nearly $780K in FY2022. In addition, these facilities are located in a dense area of metropolitan Boston. Locating clean energy generation close to electric demand creates other benefits to the public, including avoided distribution costs and improved grid performance.

A portion of Newton's solar is "community energy," which are projects deployed on behalf of low and moderate-income residents who are not able to host their own solar system but nonetheless benefit from lower electric bills. Savings from one of the City's 18 solar projects was used to share solar credits to all of the city's 1,300 low-income residential ratepayers, equaling approximately $40 per household per year. This program is implemented in conjunction with Action for Boston Community Development and Eversource.

Community solar projects like Newton’s make up the largest additions of solar capacity in Massachusetts since 2021. Even more community energy should be done by cities and non-profits to bring energy savings from solar to consumers and businesses who cannot host their own projects.

Newton exemplifies a city leading creative solar deployment with little to no impact on natural resources, while also delivering benefits to low-income households and municipal finances. Taking advantage of new federal incentives under the IRA and EPA's Solar for All program, plus adjustments to state incentives and programs for municipalities like Green Communities, will open up more opportunities for communities to follow Newton's lead.

One of two parking lot solar canopies at Newton North High School in Newtonville, MA, interconnected in Sept. 2021.

The IRA provides tax credits to help home and building owners and renewable energy developers deploy more solar and other clean energy systems.[28] These federal incentives will expire by 2035, which favors strong acceleration of new solar builds over the next decade. It is important to note that the IRA's tax credits are structured in a way that could further widen the gap in cost competitiveness between new ground-mount systems and rooftop and canopy systems, even with the latter being supported by net metering policy. Massachusetts' SMART incentives and net metering policy are levers that should be revisited to encourage development of rooftop and canopy systems.

27 U.S. Environmental Protection Agency. "Solar for All." Collections and Lists, June 2023. https://www.epa.gov/greenhouse-gas-reduction-fund/solar-all.

28 We modeled the following IRA solar incentives: a 30 percent Investment Tax Credit (ITC) for rooftop solar installations, and a $26/MWh Production Tax Credit (PTC) for ground-mount solar installations. Ground-mount solar projects are eligible for either the ITC or the PTC; we assume those projects elect the PTC over the ITC. The IRA's solar incentives include "Bonus" credits that can increase tax incentive levels for real-word projects above the levels represented here.

KEY FINDING #8

The Commonwealth, cities and towns, and non-profit institutions own (or manage) thousands of the best sites for low-impact solar.

In addition to Mass Audubon and Harvard University, the Commonwealth and many cities and towns such as Boston, Cambridge, Amherst, Somerville, Plymouth, and Worcester, along with many non-profit institutions, have strong public commitments to significantly reduce their GHG emissions and to protect biodiversity. Many of these institutions also own and/or manage large campuses with many buildings, parking lots, and highly developed lands that could host low-impact solar.

Moreover, many of these entities have the ability to install solar projects which may have longer payback periods in comparison to the private sector, but would benefit from incentives for more costly low-impact solar opportunities such as canopies.

Residential homeowners and commercial and industrial businesses also own significant acres of sites for ground-mount solar—ranging from nearly 15,000 on the low-end to 40,000 acres on the high end—which could be used to host economic low-impact solar. While many homeowners will prefer rooftop solar, those with large lots (e.g., >1 acre) are good candidates for creative small ground-mount systems. Some portion of the 5,000 to 10,000 acres of other already-developed open spaces that may be underutilized—such as shuttered golf courses—are also potential candidates for hosting ground-mount solar.

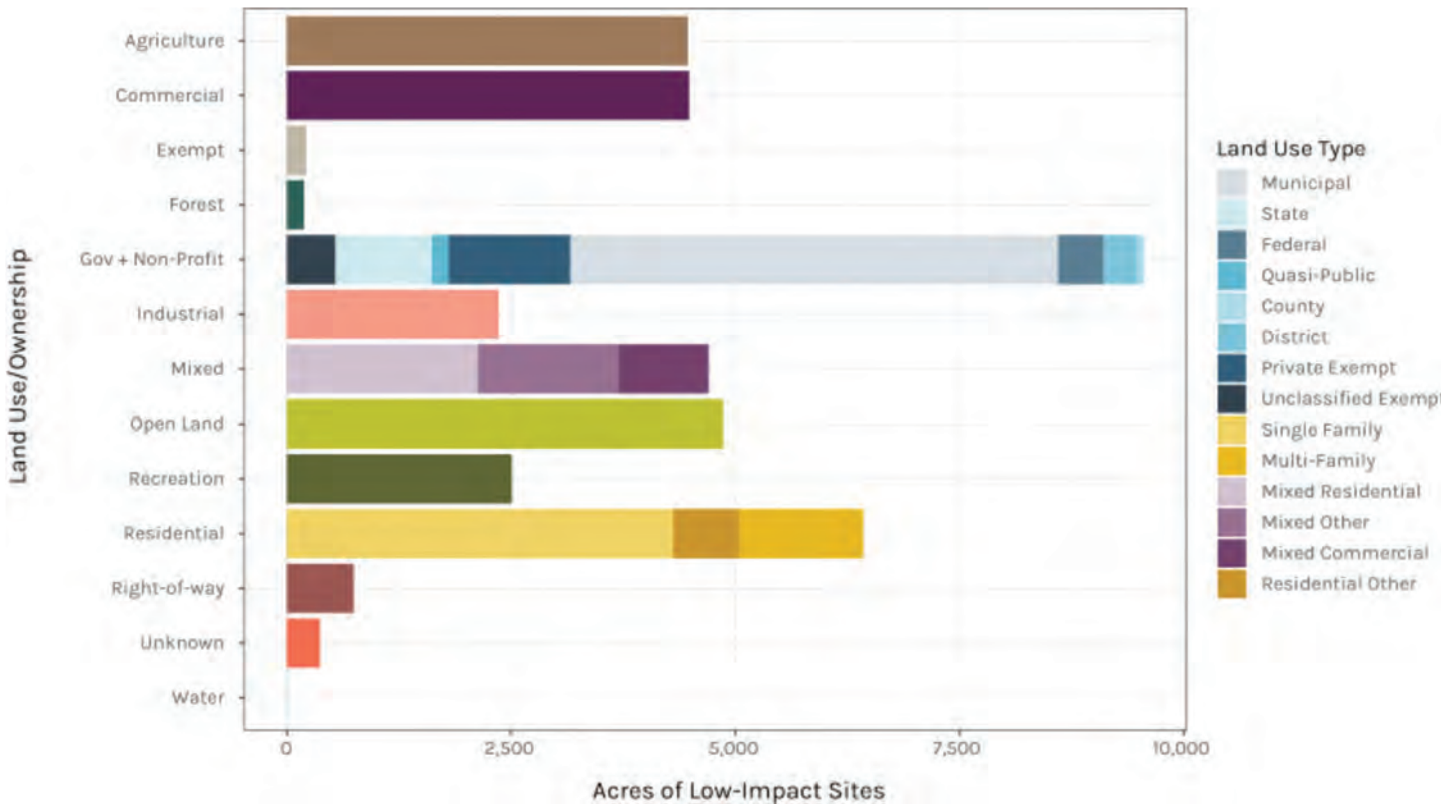


Figure 11:

Land Use/Ownership of Sites for Low-Impact Ground-Mount (Low-end)

Figures 11 and 12 show our estimated range of acres for economic low-impact ground-mount solar under the *Protecting Nature—Mid-Impact* scenario, broken out by ownership types for these sites. The Commonwealth, cities and town, and non-profits own many attractive sites for low-impact ground-mount solar, from nearly 9,600 on the low-end to almost 17,000 acres on the high-end.

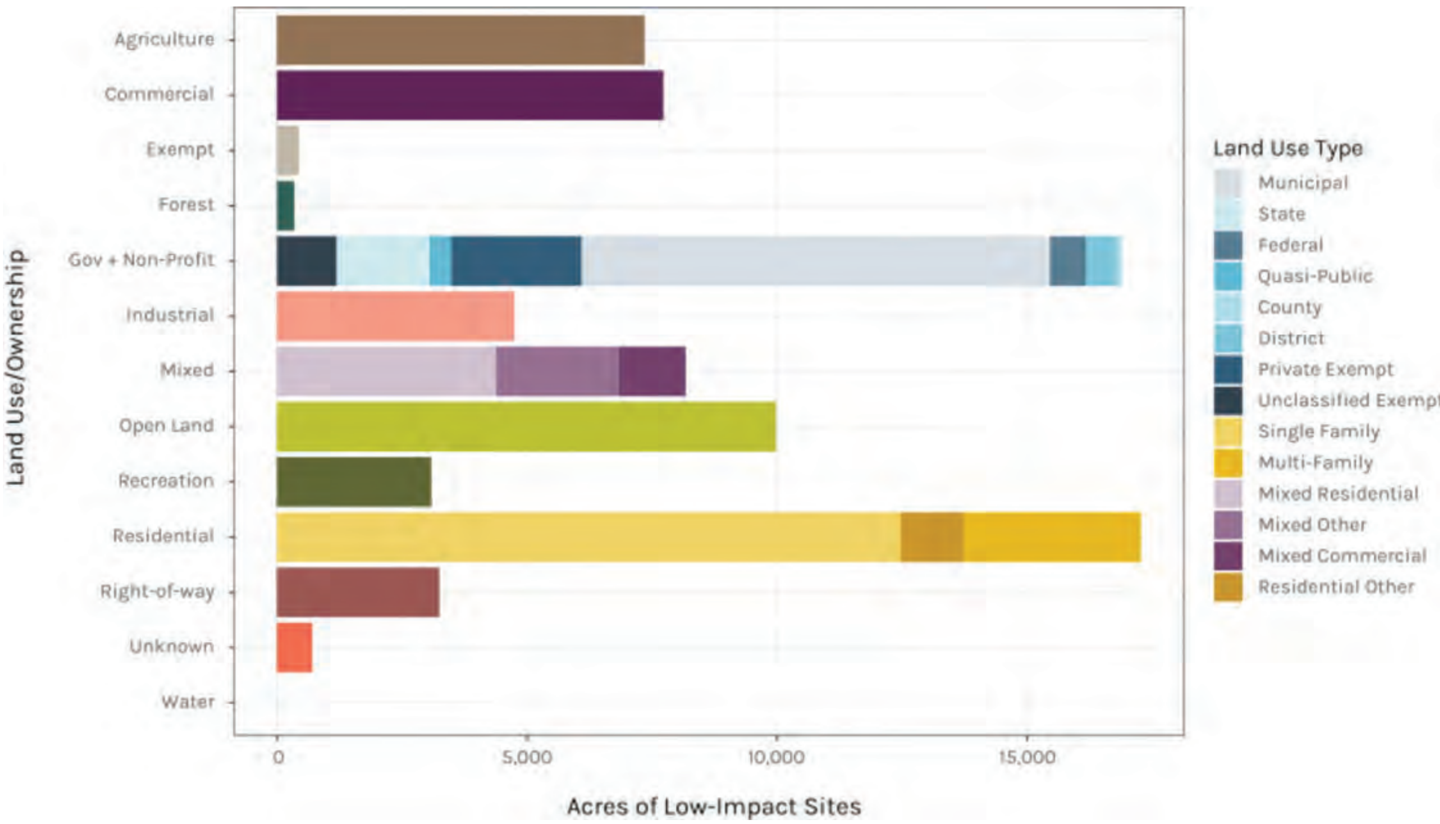


Figure 12:

Land Use/Ownership of Sites for Low-Impact Ground-Mount (High-end)

Homeowners along with commercial and industrial landowners also own many low-impact sites for ground-mount solar, ranging from nearly 15,000 on the low-end to nearly 40,000 acres on the high end. Other developed open lands under various ownerships could also host low-impact solar, on an additional 5,000 to 10,000 acres. Note that these estimates are for sites for ground-mount solar only; many of these owners of low-impact lands also own buildings and parking lots which could also host solar.

Policy Recommendations

Growing Solar, Protecting Nature shows that the current approach to siting ground-mount solar has exacted too high a price on the natural and working lands of Massachusetts. Continuing on the same trajectory will jeopardize our goals for climate, biodiversity, local food production, and climate resilience.

Solar's impacts on forests and farms are part of what is undermining public support for this resource, with many communities now seeking to slow or block new ground-mount projects. The people of Massachusetts strongly support solar, but also highly value nature as a climate solution and an irreplaceable source of biodiversity and wildlife habitat, recreation, clean water and air, and public health benefits.

Growing Solar, Protecting Nature results show that a more constructive path forward is possible, one that is both highly protective of nature AND scales up affordable solar to communities across the state.

> *To build and sustain long-term support for ground-mount solar, state policies, incentives, and plans must better align with the public's strong desire for a better balance between clean energy resources, nature, biodiversity, and local food production.*

We identify three major areas where innovative new policies, as well as changes to current policies and programs, are needed: energy incentives and investments; state and local planning and community outreach; and policies specifically focused on protection of forest carbon, biodiversity, and productive farmlands.

Energy Incentives and Investments

Solar incentives under SMART (and previous incentive programs) have played a major role in elevating Massachusetts to national leadership on solar, especially for distributed solar, community solar, and low-impact ground-mount solar on landfills and brownfields. Yet, by also supporting large ground-mount solar projects on natural and working lands, these incentives have also played a partial role in the loss of critical natural assets. Although the SMART program was adjusted in 2020 to shift incentives away from conversion of prime farmland towards solar integrated into farming activities (i.e., 'agrivoltaics'), it still supports conversion of high biodiversity lands for community solar projects. Many of the community solar projects enrolled in the SMART program over the last five years, for example, have been built on converted forests and other valued landscapes.

We strongly advocate for eliminating SMART incentives (including pass-through of federal funds) supporting large ground-mount solar projects on natural and working lands. Our results show that with just IRA funds alone, economic solar capacity of low-impact solar is nearly 80 percent of that projected under Current Siting. To boost building of low-impact solar, SMART should be further adjusted by increasing incentives for rooftop and canopy systems, especially for community solar. This will help to partially adjust for the fact that federal IRA credits are relatively more advantageous to large ground-mount systems, which are already more economically attractive than rooftop and canopy systems at the outset. Our specific recommendations include the following:

- Eliminate incentives under SMART for ground-mount solar systems on any natural and working lands and for 'public entity' solar located on BioMap Core and Priority Habitat lands.
- Increase SMART incentives for canopy, rooftop, and ground-mount systems sited on already-developed, low-impact lands.
- Create new SMART incentives for residential ground-mount and industrial and commercial rooftop projects with potential to avoid electric distribution upgrades.
- Establish interconnection rules that support smaller, low-impact solar projects located close to electric loads. Allow distributed and low-impact ground-mount projects in the interconnection queue to connect first.
- Require reporting of impacts to land use for SMART-funded projects, and produce annual SMART reports showing aggregate incentives, average cost for installed capacity, and land use impacts for all project categories.

- Set requirements for solar within the state's Lead by Example and other programs that require rooftop and canopy solar on all new buildings and parking lots receiving state funding.
- Delineate specific performance goals for rooftop, canopy, and low-impact solar within overall *Clean Energy and Climate Plan* goals for 2030, 2040, and 2050.
- Leverage existing programs focused on building efficiency and decarbonization to streamline enhance incentives for rooftop solar:
  - o Require Mass Save program to evaluate rooftops for solar suitability during energy audits and discuss with customers.
  - o Direct Clean Energy Center to create grant program for roof evaluation, repair, and replacement, with priority for low- and moderate-income households and small businesses.
- Consider separate feed-in tariff for larger ground-mount systems outside SMART that utilize already-developed, low-impact sites.
- Require solar on new buildings, parking lots, and commercial and multi-family developments receiving state funding.
- Prepare for end-of-life fate and establish recycling requirements of solar photovoltaics from all projects receiving state funding.

Planning and Community Outreach

Siting of ground-mount solar on natural and working lands in Massachusetts has been significant but haphazard, with developers of larger ground-mount systems pursuing opportunities for the largest, least expensive parcels from landowners interested in leasing or selling. Our results show that absent changes to existing incentives and policies, a similar siting pattern will likely continue over the next few decades, with a notable acceleration from now until 2035 while IRA incentives are available. Moving to a deployment of solar that leaves nature largely intact, as portrayed by the *Protecting Nature* scenarios in this analysis, will require more intentional, forward-thinking planning and guidance. Because cities and towns in Massachusetts play an essential role in local land use, the state needs to provide resources and support for municipalities to shift solar to lower-impact sites and the built environment.

Inadequate transmission infrastructure and a need for distribution upgrades are limiting deployment of solar and other clean energy resources. Space for new transmission infrastructure is only one source of potential increased demand for land over the next 25 years. Two of the state's current advisory processes—the Grid Modernization and Energy Infrastructure Siting and Permitting advisory groups—should leverage geospatial mapping from this and related analyses, and explicitly require that all recommendations for distribution and transmission system investments, respectively, must show consideration of options with lowest impact to natural and working lands.

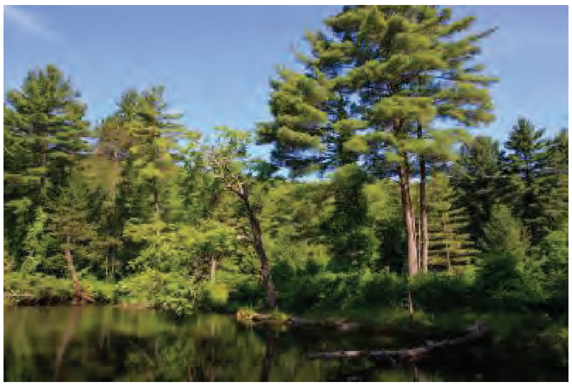
Federal and state funds should be directed to help cities, towns, non-profits, and homeowners and businesses to capitalize on these opportunities for solar with low impacts to nature and working lands. For example, the state's Green Communities program can leverage the IRA opportunity to increase incentives for cities and towns to plan for and support more low-impact solar and connect to landowners with low-impact sites for both ground-mount and distributed solar. The state's plans for transportation and building decarbonization, promulgating a clean heat standard, and energy storage should be integrated in order to capture the best opportunities for distributed and low-impact solar with clean heat, EV charging, and energy storage.

Finally, the state should conduct a statewide land-use analysis and planning effort that evaluates transmission and distribution upgrades and new capacity needed to reach all clean energy goals, and plan for co-locating ground-mount solar projects close to locations where electric load will be highest under future electrification. This analysis should also anticipate land needs for new affordable housing and commercial developments. Increasingly, communities are encountering solar projects that incorporate battery storage into project design, and seek guidance on managing siting of new energy storage technologies. Our specific recommendation include the following:

- Require Grid Modernization and Energy Infrastructure Siting and Permitting advisory processes to evaluate and reflect options with lowest impacts for natural and working lands and consistency with state goals for forest carbon, biodiversity, Healthy Soils and Resilient Lands.
- Conduct a statewide planning effort to inform and identify zones for deployment of land-efficient, low-impact clean energy resources (including storage) and transmission. These sites can also anticipate new affordable housing and commercial development, and transportation and water infrastructure. Opportunities for redevelopment of commercial (e.g. shopping malls) and industrial sites should be prioritized.
- Provide update of 2014 model zoning by-laws for solar that align with state goals for natural and working lands and streamlining permitting for solar projects within developed lands.
- Provide municipalities with updated guidance on solar project decommissioning, battery storage siting and permitting, and related technical topics. Decommissioning should include plans for solar PV end-of-life as well as future land uses.
- Conduct direct outreach to industrial and commercial landowners with highest potential for ground-mount and rooftop solar that avoids electric distribution costs.
- Review UMass Clean Energy Extension and other recent empirical research to evaluate first tranche of agrivoltaics using SMART incentives, and update incentives and guidance on farming practices, local property tax assessments, projects

in farmed wetlands and floodplains, and Agricultural Preservation Restrictions (APR).

- Add requirements for municipal eligibility under Green Communities to assess potential for low-impact solar siting on municipally-owned buildings, schools, and parking lots.
- Increase Green Communities cap on municipal solar from $300K (may depend on success in securing EPA Solar for All grant).



Nature and Carbon Removal Policies

Adjusting incentives within the SMART program to reduce support of projects with negative impacts on nature and working lands is necessary, but not sufficient to protect these lands: many large ground-mount solar projects are being financed with energy revenues and renewable energy credits alone, and thus do not rely on SMART incentives. We need stronger policies that redirect solar and other clean energy infrastructure towards already-developed lands and the built environment where feasible. Other jurisdictions with ambitious climate laws—including the European Union, Washington, and California—are advancing mandatory requirements and standards for carbon removal from natural and working lands. In response to the global biodiversity crisis, still others are setting biodiversity targets and goals to be joined with climate requirements.

Moreover, Massachusetts has major goals for natural and working lands. Under the state's Resilient Lands Initiative, the Commonwealth has goals to achieve 'No Net Loss' of forests and farmlands, and to increase carbon storage and climate resiliency capacity of natural and working lands. Over the next few years, we need policy drivers working on nature's behalf that go beyond changes to clean energy incentives alone. This requires imagining innovative policies focused on protecting forests, farms, and other natural ecosystems for long-term provision of carbon removal, biodiversity, climate resilience, and food production. Policies for financially compensating forest landowners and farmers for the carbon and ecosystem services these lands *currently* provide, as well as any additions or enhancements to these natural assets over time, will incentivize keeping these as forest and farms.

Adjusting incentives within the SMART program to reduce support of projects with negative impacts on nature and working lands is necessary, but not sufficient to protect these lands.

We advocate for an integrated policy approach that begins to internalize the non-market values of benefits provided by natural and working lands: carbon removal, biodiversity, flood protection, climate resilience, clean drinking water, local food production, and recreation, among others. The cost of replacing carbon removal services lost from forests calculated in this analysis—\$200/ton CO_2e—is a solid point of departure for such a valuation but should be considered a floor value, given that it only reflects the carbon benefits of natural lands. Our specific recommendations include the following:.

- Establish a statewide goal for biodiversity that sets clear, measurable goals at timelines aligned with climate planning intervals (e.g., 2030, 2040, and 2050).
- Establish permanent statewide funding source, at annual levels that are commensurate with goals to protect lands featuring highest carbon removal, biodiversity, and resilience to climate change.
- Develop and promulgate a performance standard for natural and working lands that embeds long-term carbon removal, biodiversity, water resource protection, climate resilience, and food productivity goals.
- Require developers to pay fees for losses of forest carbon, biodiversity, and other ecosystem services from conversion of

natural and working lands, and use proceeds to establish a revolving fund for protection of at-risk nature and farms.

- Scope the parameters of a state-level carbon and biodiversity market to draw in private capital by establishing credits that can be applied to mandatory carbon and biodiversity performance standards.

Get Involved

You can help us advocate for the policy changes we need to reach our solar goals while protecting natural and working lands. Mass Audubon's Climate Champions program is a network of hundreds of volunteer grassroots advocates working together to advance an ambitious environmental policy agenda. We hope you'll join us as we work to make Massachusetts an international leader in protecting biodiversity and the climate.

Join Today

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Participation in our Technical Advisory Group and external peer review does not reflect endorsement of our findings or recommendations. Any and all errors or misstatements are our own.

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Appendices

Appendix A: Detailed Methods Summary

Detailed Methods Summary

Appendix B: Economics of Newton's Solar Scale-up

City of Newton: 2022 Output of Online Solar Facilities (Phase 1 + 2)					
Category	Number of Facilities	Total Capacity (kW AC)	Average Annual Output per Facility (KwH)	Total Annual Output for FY22 (KwH)	Net Savings ($)
Rooftop	10	994.5	119,757	1,197,569	$210,787
Parking Lot	2	603	403,410	806,820	
Landfill	1	1,671	2,667,579	2,667,579	$446,126
2023 Projected Outputs of Phase 3 Solar Facilities					
Category	Number of Facilities	Total Capacity (kW AC)	Average Annual Output per Facility (KwH)	Estimate First-Year Output (KwH)	Net Savings ($)
Rooftop	7	449	111,983	783,881	TBD
Parking Lot	10	1,718	300,866	3,008,660	TBD

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METHODS

Step 1. Identify candidate sites for solar projects. We identified candidate project sites (CPSs) for ground-mounted solar under three scenarios incorporating different levels of natural resource protection. CPSs were mapped at 5-meter resolution with a minimum size of 900m2 based on minimum project size of 250 kw. Areas eligible for solar were identified using a combined land cover and land use dataset[1], as well as brownfield[2] or landfill[3] status. In the ***Current Siting* scenario** and ***Protecting Nature - Mid*** scenarios, all land covers except water and unconsolidated shore were eligible for solar but differ in exclusion areas. In the ***Protecting Nature - Low*** scenario, eligible ground-mount areas were limited to bare or impervious land, developed open space, landfills, and brownfields. Eligible areas were further constrained by excluding specific land uses within land covers in this scenario (Table 1). For example, we excluded developed open spaces that have a land use of agriculture or recreation.

Areas excluded for natural and cultural resource protection varied among scenarios and are summarized in Table 1. The process of CPS development involved first excluding areas based on the scenario's natural resource criteria, grouping adjacent pixels, then filtering out CPSs that fell below the minimum size. We allowed CPSs to cross parcel boundaries because we observed existing solar projects in the state on multiple parcels with different owners. We also chose not to limit CPSs to a single owner/parcel because the same landowner can be described in different ways or have multiple institutions in their control (e.g., adjacent parcels owned by family members and a family trust, a single owner in control of multiple corporations with different names, or LLCs created specifically for a solar project). Table 2 summarizes the resulting CPSs.

On a per-acre basis, aboveground carbon (AGC) loss is highest in the Current Siting scenario due to the inclusion of forests as eligible for solar. The *Protecting Nature - Mid* scenario has the lowest AGC loss per acre as CPSs tend to be selected on relatively low-carbon land covers such as pasture/hay and grassland, compared to the *Protecting Nature - Low* scenario which has proportionally more developed open space including some forested areas.

Finally, CPSs were characterized based on factors relevant to the energy-economic model, including distance to road, substation, and population center; size and slope; overlap with brownfield and environmental justice[4] areas; and dominant land cover. Canopy solar potential was quantified based on parking lot area by county, after applying a 50-ft buffer around buildings, then filtering for the same minimum project size. Total rooftop capacity was derived from a National Renewable Energy Laboratory (NREL) technical potential assessment.[5] Outside of Massachusetts, ground-mount solar potential is based on Evolved Energy Research's 2022 Annual Decarbonization Perspective (ADP)[6] and offshore wind potential is from NREL's Regional Energy Deployment System (ReEDS) model.

Table 1. Summary of lands excluded from ground-mounted solar by scenario

	Ground-mount Solar Scenarios		
Exclusion Theme	**Protecting Nature - Low**	**Protecting Nature - Mid**	**Current Siting**
Protected land[7]	Protected land (permanent or temporary/limited)	Permanently protected land	Permanently protected land
Carbon stocks[8]	Highest 25%	Highest 75%	
Biodiversity[9]	BioMap Core and Critical Natural Landscape	BioMap Core and Critical Natural Landscape	
Social values	Residential lots ≤ 1 acre[10] with building[11], cemeteries[7,10], historic places[12]	Residential lots ≤ 1 acre[10] with building[11], cemeteries[7,10]	Residential lots ≤ 1 acre[10] with building[11], cemeteries[7,10]
Wetlands[13,14]	Open water, wetlands, +100 ft buffer	Open water, wetlands, +100 ft buffer	Open water, wetlands, +100 ft buffer
Farmland[15]	Prime farmland soils	Prime farmland soils	
Flooding[16]	FEMA flood zones (1% or 0.2% annual chance flood hazard)		
Climate resilience	Hurricane surge inundation zones[17]	Terrestrial sites with above average resilience[18]	
Slope[19]	>8 degrees	>8 degrees	>8 degrees
Buildings[11]	Footprints +50 ft buffer	Footprints +50 ft buffer	Footprints +50 ft buffer
Infrastructure[20,21,22,23,2]	Roads, active rail lines, parking lots, airports, existing solar	Roads, active rail lines, parking lots, airports, existing solar	Roads, active rail lines, parking lots, airports, existing solar

Table 2. Summary of all Candidate Project Sites (CPSs) by scenario

Scenario	Total CPS Area	Median CPS Size	Mean CPS Size	Aboveground Carbon	Overlap - BioMap	Overlap - Resilient Sites
Protecting Nature - Low	36,518 ac	0.40 ac	0.77 ac	11.3 Mg / ac	0 ac	2,110 ac
Protecting Nature - Mid	94,218 ac	0.54 ac	1.37 ac	7.2 Mg / ac	0 ac	0 ac
Current Siting	1,012,599 ac	0.65 ac	3.38 ac	20.2 Mg / ac	389,015 ac	218,734 ac

Step 2. Evaluate economic potential for solar under *Growing Solar, Protecting Nature* scenarios

Electricity and fuel demand were estimated from 2021 to 2050 to design energy portfolios necessary to achieve both Massachusetts 2050 emissions targets and net-zero economy-wide emissions in the rest of the United States. The energy portfolios were developed using Evolved Energy Research's EnergyPATHWAYS and RIO models. EnergyPATHWAYS is a detailed stock-rollover accounting model that tracks infrastructure stocks, energy demand by type, and cost every year for all energy-consuming technologies. RIO is a linear programming optimization model that combines capacity expansion with sequential hourly operations over a sampling of representative days to find the lowest-cost energy supply solution. These models design energy portfolios based on current projections for technology cost and performance through 2050 but do not incorporate the possibility of additional technological breakthroughs that may occur in time to influence the clean energy transition. New interregional electricity transmission, hydrogen pipelines, and CO2 pipelines are explicitly represented in RIO with costs based on Massachusetts' 2030 Clean Energy and Climate Plan (CECP).

The ground-mount solar CPSs were aggregated based on the following parameters: geographic zone (Southeast, Northeast, or West-Central Massachusetts); capacity factor[i] as simulated in the System Advisory Model (SAM)[24]; project size (larger or smaller than 1 MW); qualification for the Energy Communities Bonus Credit under the Inflation Reduction Act; and estimated interconnection cost. The aggregated CPSs became the available supply of ground-mount solar in Massachusetts in the RIO model under each scenario. Massachusetts canopy solar and rooftop solar potentials were also included as available supply in the model.

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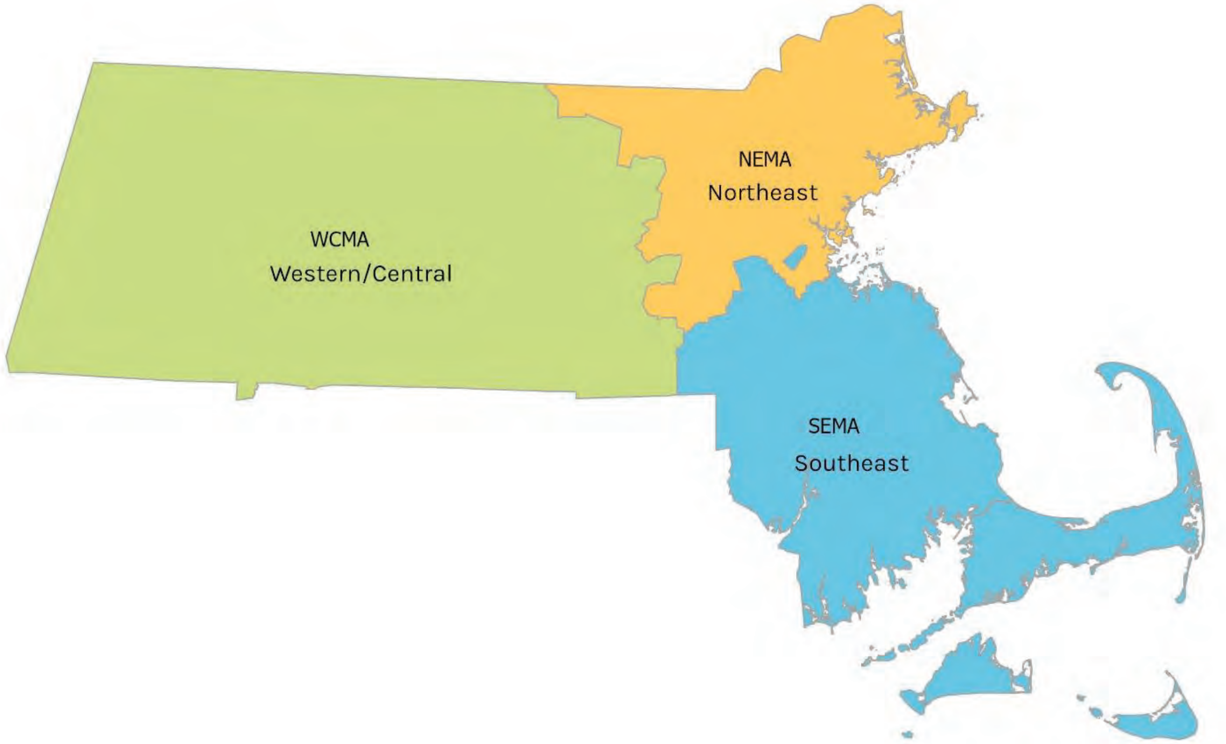
[i] A solar project's capacity factor represents its average energy output in relation to its nameplate capacity rating. For example, a 10 MW nameplate project with a 20% capacity factor produces 2 MWh of electricity in every hour of the year on average. Solar capacity factors reflect location-specific solar irradiance and weather patterns. Solar projects with higher capacity factors produce more electricity per nameplate capacity, resulting in lower levelized cost of energy.

Figure 1. Map of geographic zones modeled in Massachusetts.



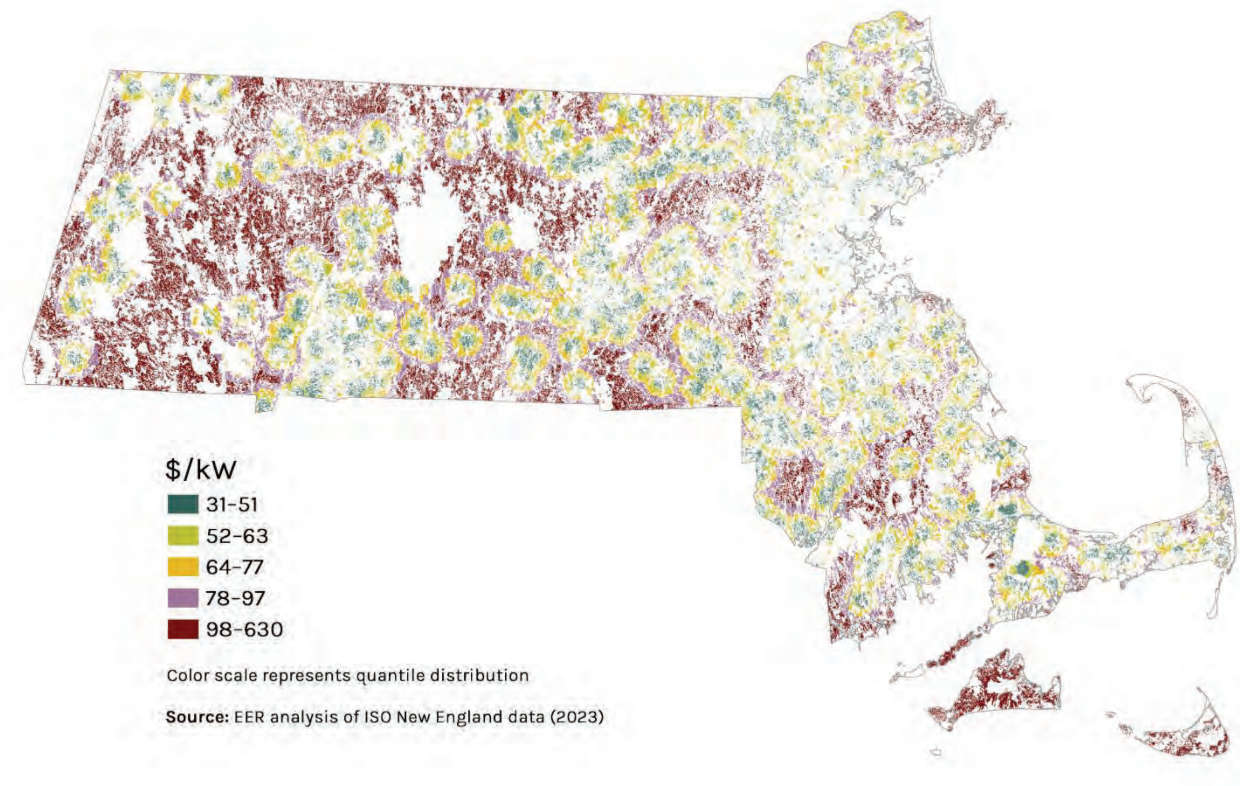
Ground-mount and rooftop solar cost assumptions were from NREL's 2021 Annual Technology Baseline (ATB), using the Moderate scenario.[25,26,27] We ran a sensitivity case using the ATB Advanced scenario to represent a 30 percent reduction in rooftop solar costs only. A project size-based cost multiplier was applied to ground-mount solar costs in Massachusetts. The multiplier, which was derived from historical Massachusetts solar cost data[28] reported by the Massachusetts Clean Energy Center's Production Tracking System, increased installed cost of smaller ground-mount solar projects relative to larger projects. Canopy solar costs were assumed to be 1.8 times commercial rooftop solar costs, based on findings from the 2019 Long Island Solar Roadmap Economic Research Report.[29]

Transmission interconnection costs were calculated for each CPS as a function of linear distance to the nearest substation using the following formula derived from NREL's ReEDS model documentation:[30,31]

Interconnection cost (\$/kW) = 30.47 + 11.97 × distance (km)

Figure 2 below shows a resulting heat map of interconnection costs in Massachusetts. This methodology assigns lower interconnection costs to CPSs that are proximate to existing substations. It does not account for variations in hosting capacity at different substations, which is an important driver of project-specific transmission interconnection costs.

Figure 2. Map of Massachusetts Solar CPS Interconnection Cost, $/kW



For each scenario, RIO selects the least-cost energy portfolio that meets modeled energy demand, with variation between scenarios driven by the changing availability and cost of ground-mount solar. Installed ground-mount solar capacity in other New England states was capped in all scenarios at the level calculated in the Current Siting scenario, such that restricting ground-mount solar development in Massachusetts in more protective scenarios did not cause an increase in modeled solar deployment in neighboring states. To determine the land impacts of Massachusetts ground-mount solar in each scenario, RIO results were disaggregated to indicate which individual CPSs were most likely to be developed based on the modeling assumptions and results. For each CPS, the hypothetical project's levelized cost of energy (LCOE) was calculated based on upfront project cost (including interconnection cost), project capacity factor, and applicable IRA incentives. CPSs were ranked from lowest to highest LCOE, with the lowest-LCOE sites assumed to represent the solar selected in the RIO energy profile for each scenario.

Step 3. Interpret results and address uncertainties. The energy-economic model estimated cost associated with building ground-mount solar in each CPS; however actual deployment on any given site is not driven solely by cost considerations. To incorporate uncertainty in the areas likely to be used for solar under each impact scenario, we identified the lowest cost CPSs that accounted for twice the CPS area selected in the optimized economic outcome. For the *Protecting Nature - Low* and *- Mid* scenarios, the doubling of area resulted in using most or all of the CPSs, as the area of CPSs selected by the optimization model was close to half of the total CPS area in each scenario. We then took 100 random samples of CPSs from this pool, with each sample meeting the target area and solar capacity established in the optimization model. For each sample, we calculated impacts on natural resources, resulting in a range (i.e., average and standard deviation) of potential impacts under different site selections using the most economic sites in each scenario.

Of the potential natural resource impacts, carbon was of particular interest. To assess carbon impacts of our ground-mount scenarios, we used spatially explicit carbon estimates derived from decadal simulations of forest AGC change used in the Commonwealth's Land Sector Report (Thompson et al 2020). From this analysis, we used the "Grow Only" simulation, which estimates forest growth without any impacts of harvest or conversion to development. For each CPS, we calculated the carbon at each available time step (2020, 2030, 2040, 2050), and then assigned the correct value for selected CPSs based on their year built. For CPSs built between decades, we used carbon data from the same decade (e.g., a CPS selected and built in 2035 uses 2030 carbon data). We assumed all aboveground carbon within the CPS was lost when converted to solar. In addition to carbon loss due to land clearing, we calculated the forgone sequestration by subtracting the initial carbon loss from the 2050 potential.

For ground-mount CPSs, canopy, and rooftops chosen as economic or uneconomic in the energy-economic model, we assessed overlap with tax-exempt and public ownership based on assessor's parcel data to understand ownership patterns of sites with lowest impact for nature and working lands. The rooftop spatial analysis is distinct from the rooftop potential used in the energy-economic model, and accounts only for raw potential as the area of rooftops, without accounting for sun exposure, roof quality, or other variables important for determining suitability for rooftop solar.

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