Agrivoltaic Leading Practices

Technical Report

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This technical report was prepared by EPRI.

Introduction

In 2012, the U.S. Department of Energy's (DOE's) Sunshot Vision Study set a goal that 14% (totaling 329 gigawatts) of the nation's electricity should come from solar generation by 2030.[1] Since then, several states have announced their own solar-generation goals, including New York State (NYS). In July 2019, NYS passed the Climate Leadership and Community Protection Act (CLCPA), committing to 70% zero-emissions electricity by 2030, and 100% by 2040. This commitment includes the installation of 6,000 megawatts of solar power by 2025. Today, New York is on target to meet this goal, and by annually installing more than 400 MW per year since 2018, it reached a combined total capacity of 3.3 GW of solar generation at the end of 2021.[2]

Currently, 92% of NYS's footprint is forest or agricultural land, which may create competition for available land area for solar development. However, recent studies suggest that agricultural land converted to solar development can still include sustainable land use features, such as a pollinator habitat, or even consumer agricultural crops.[3]

To further evaluate land use potential for solar development and help NYS achieve its ambitious clean energy goals, the New York Power Authority (NYPA) and the Electric Power Research Institute (EPRI), through an American Public Power Association (APPA) Demonstration of Energy and Efficiency Developments (DEED) grant, are examining the feasibility of "agrivoltaics" (AV) as a dual land-use solution. In the context of this research, agrivoltaics is a technological evolution of solar ecosystem stewardship, looking at agricultural crops, livestock grazing, and wildlife co-habitation as an aspect of solar co-land management to maintain the natural environment and agricultural benefit while generating solar energy. This study uses a compendium of agrivoltaics research to explore ways to optimize both agricultural yield and solar photovoltaic (PV) energy capacity.

1 "Sunshot Vision Study," United States Department of Energy (February 2012). https://www.energy.gov/sites/prod/files/2014/01/f7/47927.pdf
2 "Statewide Solar Projects," New York State Energy Research and Development Authority (2021). https://www.nyserda.ny.gov/All-Programs/NY-Sun/Solar-Data-Maps/Statewide-Projects
3 Venktesh V. Katkar, Jeffrey A. Sward, Alex Worsley, K. Max Zhang. "Strategic land use analysis for solar energy development in New York State," *Renewable Energy,* Volume 173 (2021), Pages 861–875. https://www.sciencedirect.com/science/article/pii/S0960148121004900
4 "Spring 2022 Solar Industry Update," National Renewable Energy Laboratory (April 26, 2022). https://www.nrel.gov/docs/fy22osti/82854.pdf

Methodology

Environmental Aspects of Solar

The global total of installed solar PV capacity hit 939 GWdc (Gigawatts, direct current) by the end of 2021,[4] and is expected to triple over the next decade. Solar PV is generally considered to have low adverse environmental impact, but there are many opportunities to further reduce potential environmental impacts and maintenance requirements for solar plants through land use and vegetation choices. Innovative approaches can potentially improve environmental stewardship of large-scale solar PV sites. These can include:

- agrivoltaic applications (e.g., pollinator habitat, co-located crops, and livestock grazing) and multifunctional sites that improve biodiversity
- spatial arrangements of vegetation that blocks wind and reduces dust
- native vegetation that improves stormwater retention.

EPRI's Environmental Aspects of Solar program proactively addresses four main areas of environmental stewardship, including siting and permitting, wildlife, end-of-use (EoU) management, and land use and vegetation. Much of EPRI's research into land use and vegetation issues focuses on agrivoltaics applications.

EPRI's Strategic Sustainability Science Program

Utility expectations about sustainability commitments and performance are rising as utility customers, investors, employees, and other industry stakeholders become more focused on the sustainable energy. As corporate strategies advance beyond regulatory compliance to a comprehensive focus on driving value through economic, environmental, and social responsibility, electric power companies need ways to embed sustainable practices into day-to-day operations and strategic long-range planning.

EPRI's Strategic Sustainability Science Program (P198) identifies and develops the tools and resources that utilities need to incorporate a sustainability mindset throughout their organizations. In addition, the program serves as a nexus, bringing sustainability thought leaders together and propelling forward-thinking scientific research and analysis.

Research Phases

This study began with a web-based literature review of academic sources to identify relevant research on agrivoltaic applications and projects. The literature review included search terms such as "agrivoltaics," "solar" *and* "crops," and "solar" *and* "animals," used in materials published between 2018 and the first half of 2022. The search yielded nearly 100,000 sources sorted by relevance and journal credibility. The EPRI research team read 50 of the most relevant sources based on these criteria. Using industry expertise, the EPRI research team supplemented gaps in the academic literature with relevant and timely practitioner sources such as Forbes and Bloomberg media outlets.

The literature review provided the background for the interview questions and a list of relevant stakeholder groups to consider (see Appendix A). The interviews occurred between April and July 2022. The stakeholder groups that were interviewed included utilities, solar developers and independent power producers, government representatives, and academics (Table 1).

Interviews by Stakeholder Category	
Academia	13
Government	5
Power Sector	9

Table 1: Number of Interviews by Stakeholder Category

The qualitative interview findings were supplemented with quantitative data from a grower survey, sent to growers in the mid-Atlantic and New England regions in the United States. The grower survey, fielded between June and July 2022, received 66 responses. The survey asked:

1. **Demographics: Which best describes your current geographic location?** [New York, New Jersey, Pennsylvania, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine]
2. **What is your primary agricultural product?** [Open Ended]
3. **How do you view the co-location of your crops and solar panels?** [1/Very Unfavorably through 5/Very Favorably]
4. **If you have grazing animals, what are they?** [Open Ended]
5. **How do you view the co-location of your animals and solar panels?** [1/Very Unfavorably through 5/Very Favorably]
6. **Why do you view co-location favorably or unfavorably?** [Open Ended]

The survey results are captured in the "Farmer Perceptions of Agrivoltaics" section of this report (page 10).

The final phase of the research project compiled the learnings to develop an evaluation process for considering a site for co-location. The criteria were used to examine three sites – all in operational capacity – selected by the EPRI and NYPA research teams. The sites selected – all managed by the University of Massachusetts, Amherst – were chosen because of their similar climate to New York State.

Results

Conventional Solar Siting Basics

A PV module converts sunlight into electricity. The National Electrical Code® (NEC) defines PV cells, modules, panels, arrays, subarrays, and power sources distinctly (Table 2). An array is a mechanical integration of modules or panels with a support structure, foundation, and other electrical wiring components, which form a dc power-producing unit.[4]

PV panels installations can have either monofacial or bifacial modules. Monofacial modules only collect light from the front side, and typically have a transparent front and an opaque back. Bifacial modules collect light from both sides, capitalizing on the light reflected off the ground below. Bifacial modules are

4 Michael Bolen. "Photovoltaic (PV) Plant Design Specifications: Revision 2 – Inverters, Module Mounting Systems, and Electrical Balance of Systems," EPRI, Palo Alto, CA, page 2–2 (December 2020). 3002017648

Term	NEC 2017 Definition
Solar Cell	The basic PV device that generates electricity when exposed to light
Module	A complete, environmentally protected unit consisting of solar cells, optics, and other components (exclusive of tracker) designed to generate dc power when exposed to sunlight
Panel	A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit
Array	A mechanically integrated assembly of module(s) or panel(s) with a support structure and foundation, tracker, and other components, as required, to form a dc or ac power-producing unit
Subarray	An electric subset of a PV array
PV Power Source	An array or aggregate of arrays that generates dc power at system and voltage current

Table 2: NEC 2017 Definitions

estimated to generate 5–30% more electricity than monofacial modules, but the technology is still gaining prominence.[5]

PV panel configurations can be used in a variety of installation sizes, most commonly in smaller-scale residential projects, medium-scale commercial projects, and large-scale utility-projects. According to the Lawrence Berkeley National Lab, a utility-scale solar field is any ground-mounted project generating more than 5 megawatts.[6] Site design for utility-scale solar projects is a multidisciplinary process accounting for site selection, performance and financial modeling, setbacks, earthworks, erosion control, vegetation management, and access and security. Earthworks is the process of site clearing, grading, and other work that disturbs the existing land to prepare a site for construction.[7] Ground-mounted PV arrays can be built on land that slopes from 0% to 20%; depending on the degree of slope, there is a need to grade the land (cut and/or fill) to prepare for the solar field. The greater the required preparation, the higher the site development cost.[8]

At the beginning of the siting process for solar projects, the developer often solicits community feedback on the design. These community feedback sessions can be in the form of townhalls or virtual requests for feedback. Some states require demonstrated community input on any permitting requests.

Additional long-term cost (post-development) considerations for establishing a solar site include vegetation management, which is any methods used to control the various flora on the site. Solar sites often need vegetation management to prevent the overgrowth of vegetation, which can result in safety hazards as well as a reduction in power generation when vegetation shades panels. Traditional forms of vegetation management include mowing, herbicide applications, or a combination of both. Regional weather characteristics impact plant growth and will determine the frequency of required vegetation management across the growing season.[9]

Solar panel design varies regionally and with project goals. Traditional utility-scale solar arrays in the United States typically mount panels with a drip edge height 20 inches (50.8 centimeters) above the ground surface. However, developers in the Northeast often build arrays with a 36-inch (91.44-centimeter) clearance, which allows for winter snowpack and reduces snow obstructing panels.[10] Two options are widely used for mounting panels:

1. fixed-tilt systems
2. tracking systems.

A fixed-tilt system built facing south may be oriented in an easterly or westerly direction to maximize production during different times of the day. If there are no land constraints and the goal of the array is to maximize power production, high efficiency module tracking arrays are often used to follow the sunlight from east to west, capturing more sunlight throughout the day; however, this sort of technology might require rows to be spaced further apart to avoid shading each other, and more earthworks may be needed to accommodate a level-tilting shaft.

5 Michael Bolen. “Photovoltaic (PV) Plant Design Specifications: Revision 2 -- Inverters, Module Mounting Systems, and Electrical Balance of Systems,” EPRI, Palo Alto, CA, pages 3–20 (December 2020). 3002017648

6 Mark Bollinger, Joachim Seel, Cody Warner, and Dana Robson. “Utility-Scale Solar, 2021 Edition: Empirical Trends in Deployment, Technology, Cost, Performance, PPA Pricing, and Value in the United States,” Lawrence Berkeley National Laboratory, page 7 (October 2021). https://emp.lbl.gov/sites/default/files/utility_scale_solar_2021_edition_slides.pdf

7 Michael Bolen. “Photovoltaic (PV) Plant Design Specifications: Revision 2 – Inverters, Module Mounting Systems, and Electrical Balance of Systems,” EPRI, Palo Alto, CA, pages 3–13 (December 2020). 3002017648

8 Ibid. pp. 3–14.

9 Ibid. pp. 3–17.

10 Cara Libby et al, “Solar Land Conversion,” EPRI, Palo Alto, CA, page 34 (2022).

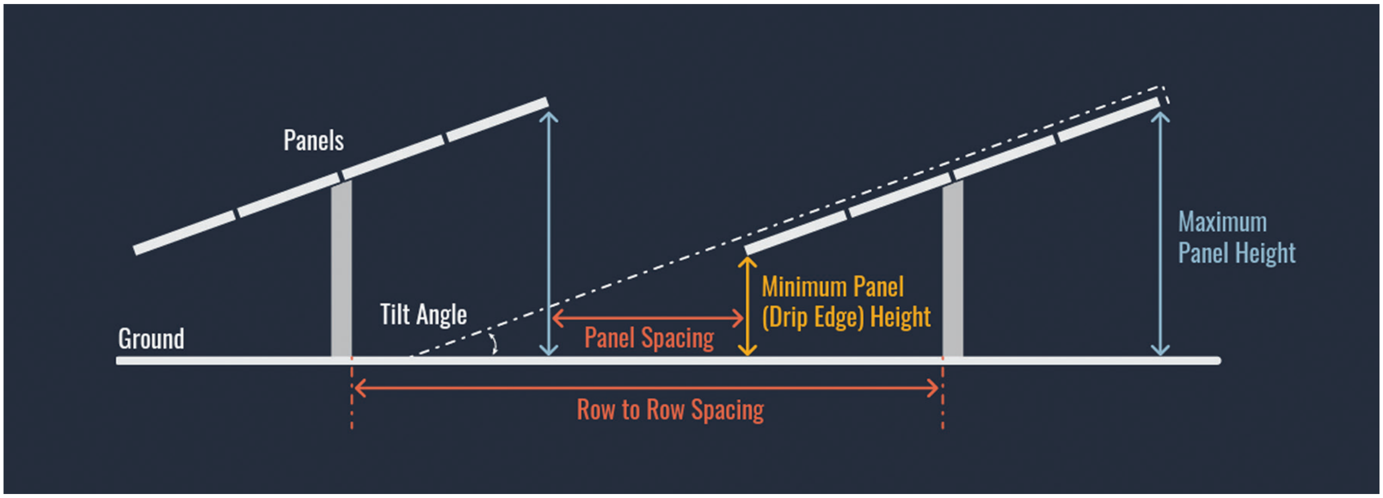

Figure 1: Solar Site Design Diagram

In fact, row-to-row spacing of PV panels is a design consideration for any solar site, as sites require "access rows," which are spaces between each row of PV modules. The width of the access rows prevent panels from shading each other, allow access by maintenance vehicles, and facilitate vegetation-management activities. The row-to-row spacing is determined during design, accounting for racking type and manufacturer, module specifications, and site topography. According to interviews with solar developers, sites are designed to minimize row-to-row spacing to maximize generation while accommodating maintenance vehicles and equipment.

For solar sites that are built to incorporate agricultural production, access rows are critical to maximizing both solar and crop production, and ensuring equipment can easily access intended planting areas to perform needed tasks. Sites not designed for agrivoltaic use often space access rows at a width that is roughly 2.5 times the row height. Currently, the typical commercial solar panel is approximately 65 x 39 inches (165.1 x 99.06 centimeters), meaning access rows can be as narrow as 5 feet wide. The ratio between the PV module area and the total ground area is referred to as the ground coverage ratio (GCR). The smaller the access row, the greater the GCR and the higher the PV power density on the land.[11]

Effectively operating and maintaining a solar array requires a strategy that accounts for a variety of regulatory, economic, organizational, and environmental components.[12] To generate enough electricity to justify the cost of building the array, ground-mounted solar arrays have historically required approximately eight to ten acres of land per megawatt.[13] Additional financial considerations affecting the economics of the array include the Operations and Maintenance (O&M) cost, which includes the administrative or regularly scheduled preventative maintenance.[14] Construction and operational requirements include installing suitable ground cover at the site to prevent storm water runoff and erosion. A conventional approach to ground cover maintenance in the Midwest and Southeast is installing low-lying turf grass.[15] Turf grass provides minimal benefit to the ecosystem when compared to natural vegetation's ability to control water runoff and soil erosion, and requires routine mowing to be maintained.[16]

The choices made in the site design for an array can impact the cost of construction, the annual O&M costs of the project, and the profit from selling the electricity. These design and cost considerations provide a baseline for quantifying the cost and benefits of incorporating agricultural applications (e.g., crops) into a solar site.

11 Michael Bolen. "Photovoltaic (PV) Plant Design Specifications: Revision 2 -- Inverters, Module Mounting Systems, and Electrical Balance of Systems," EPRI, Palo Alto, CA, pages 3–20 (December 2020). 3002017648

12 N. Enbar. "Solar Photovoltaic System Operations and Maintenance," EPRI, Palo Alto, CA, pages 1–4 (2011). 1021988

13 "Overview of Pollinator-Friendly Solar Energy," EPRI, Palo Alto, CA, page 2 (December 2019). 3002014869

14 Andy Walker et al., "Model of Operation-and-Maintenance Costs for Photovoltaic Systems," National Renewable Energy Laboratory, page 2 (June 2020). https://www.nrel.gov/docs/fy20osti/74840.pdf

15 L.J. Walston; S.K. Mishra; H.M. Hartmann; I. Hlohowskyj; J. McCall; J. Macknick. "Examining the potential for agricultural benefits from pollinator habitat at solar facilities in the United States," *Environmental Science & Technology*, 52, pp. 7566–7576 (2018).

16 Leroy Walston et al. "Modeling the ecosystem services of native vegetation management practices at solar energy facilities in the Midwestern United States," *Ecosystem Services*, page 2 (February 2021).

Ecosystem Stewardship Conscious Siting Practices

Historically, ground-mounted solar energy sites were considered anthropogenic disturbances to native ecosystems because their construction included replacing native vegetation with low-maintenance non-native grasses.[17] Scientists caution against using alternative groundcover choices, such as a gravel underlay, for PV sites because of how they contribute to heat island effects that increase the ambient temperature below the PV structure.[18] This increase in temperature can potentially decrease the efficiency of the panels.[19] Using herbicides to control grasses or laying gravel has also been shown to cause erosion or drainage issues, spurring site developers to look for alternative forms of ground cover.[20]

Solar ecosystem stewardship involves managing land that hosts a PV array in a way that is environmentally responsible by utilizing native vegetation. In fact, as the demand for ground-mounted solar grows, using native vegetation as an ecosystem service has correspondingly become more common. A solar canopy can provide a favorable microclimate, with lower temperatures and increased moisture for native plants that promote biodiversity, carbon storage, water conservation, and soil retention.[21] In addition, native grasses and forbs typically have deeper root systems that can improve soil stabilization and decrease water runoff.[22]

Currently, one of the most well-researched forms of ecosystem-conscious siting practicing is co-locating pollinator habitats on solar sites. Pollinators, such as bees and butterflies, are particularly susceptible to habitat loss and are experiencing population decline. This is particularly true in the case of monarch butterflies, threatening the long-term viability of the species.[23] There are various forms of pollinator habitat and seed mixes that can be planted around and under the solar canopy, including forbs, native grasses, sedges, legumes, and an oat nurse crop. Research has shown that factoring pollinator habitat into the siting and design process of the solar site is the most fiscally efficient option, compared to integrating pollinator habitat onto an existing site. During the construction phase of a project, it is standard practice to remove the topsoil and grade the site; however, these actions eliminate existing pollinator habitat, compact the soil, and remove valuable topsoil needed for revegetation.[24]

Recognizing the harm caused by displacing the topsoil, researchers at the University of Maine studied the effect of changing this aspect of site construction. The research team examined three approaches to construction – careful installation, mindful treatment, and business as usual – and their impact on the site's wild blueberry crop yield. In the first grow cycle, researchers noted that the moisture under the panels is higher and there is more disease on the plants along the drip edge. Otherwise, all the wild blueberry plants came back within a year, regardless of how carefully the solar panel was installed.[25] Although this project yielded a positive finding for plan rejuvenation after installment, the researchers cautioned that the results might not be particularly applicable to other crop types.

For effective solar ecosystem stewardship, the specific seed mixes for planting should be determined by the site's microclimate. Some states have pollinator scorecards that request certain seed mixes. For example, in Massachusetts, the requested seed mix limits the percentage of legumes and requires a high diversity of native forb species. A Massachusetts vegetation management specialist reported that this seed mix can cost up to $1,400 per acre, increasing the upfront costs of the site.[26]

Additional research has found that the upfront cost of seeding a pollinator habitat is more expensive than conventional turfgrass. However, the increased upfront cost can potentially be offset by reduced O&M costs over time because of the reduced cost of mowing,[27] increased electricity generation from bifacial mod-

17 "Overview of Pollinator-Friendly Solar Energy," EPRI, page 3 (December 2019). 3002014869

18 Mohd Ashaf Zainol Abidin. "Solar Photovoltaic Architecture and Agronomic Management in Agrivoltaic System: A Review," *Sustainability*, page 2 (2021). https://www.mdpi.com/2071-1050/13/14/7846

19 R.R. Hernandez; A. Armstrong; J. Burney; G Ryan; K. Moore-O'Leary; I. Diédhiou; S.M. Grodsky; L. Saul-Gershenz; R. Davis; J. Macknick et al. "Techno–ecological synergies of solar energy for global sustainability," *Nat Sustain 2*, 560–568 (2019). https://doi.org/10.1038/s41893-019-0309-z

20 M. Abdullah Al Mamun et al. "A review of research on agrivoltaic systems," *Renewable and Sustainability Energy Reviews*, 2022. https://reader.elsevier.com/reader/sd/pii/S1364032122002635?token=A1E430D66482F865186B3600789B007A194567CEF0F1057444CF6F92BEAE6478FF6FE01F79883740BD93466029280EC7&originRegion=us-east-1&originCreation=20220901175725

21 V. Hernandez-Santana. "Native prairie filter strips reduce runoff from hillslopes under annual row-crop systems in Iowa, USA," *Journal of Hydrology* (January 2013). https://www.sciencedirect.com/science/article/pii/S0022169412009651

22 Ibid.

23 Rickets T. Kremen. "Global perspectives on pollination disruptions," *Conservation Biology*, pages 1226–1228 (2000).

24 Brenda Beatty, et al. "Native Vegetation Performance under a Solar PV Array at the National Wind Technology Center," NREL (May 2017). https://www.nrel.gov/docs/fy17osti/66218.pdf

25 Lily Calderwood. "Investigating the Impacts of Various Solar Installation Construction Methods on Wild Blueberry Growth and Development," University of Maine (August 2022). https://extension.umaine.edu/blueberries/wp-content/uploads/sites/41/2022/06/UMaine-Extension-Rockport-Research-Report-2021.pdf

26 Jessica Fox. "Pollinator-Friendly Solar Scorecards: Comprehensive Analysis of Scorecard," EPRI (2021). 3002022121

27 B. Rainer; Q.K. Nguyen. "Dual-Use Approaches for Solar Energy and Food Production International Experience and Potentials for Viet Nam," Green Innovation and Development Centre (GreenID), Hanoi, Viet Nam (2020).

State	Pollinator-Friendly Scorecard Summary
Florida	Florida has a one-page scorecard. A separate maintenance scorecard is not available. The Florida scorecard does not have an accompanying companion guide, but rather refers to separate documents for some de-tails about site preparation and recommended plant species. Florida has no state law or incentive program.
Illinois	Illinois has a one-page scorecard, developed with the University of Illinois. A separate maintenance score-card is also available, as well as a short (three-page) guide. Illinois has a "voluntary designation" state law.
Indiana	Indiana has a one-page scorecard developed by Purdue University. The companion technical guide provides a significant level of detail beyond the scorecard. A separate maintenance scorecard is absent. The score-card has a strong emphasis on differentiation between the array zone and buffer zone (points can be obtained for pollinator-friendly vegetation separately in these areas). There is no state law or incentive pro-gram, but some counties have adopted some form of pollinator-friendly ordinances.
Maryland	Maryland has a one-page scorecard. A separate maintenance scorecard is not available. Maryland has not published a unique companion guide, but rather refers to the United States Department of Agriculture (USDA) Conservation Cover – 327, "Herbaceous Plantings for Pollinator Habitat," which provides a significant level of detail particularly in site preparation and maintenance. There is a "voluntary designation" type state law.
Massachusetts	The Massachusetts pollinator-friendly solar program does not use the typical "scorecard," but instead includes checklists with the certification criteria. A basic certification level is available, plus increasingly rigorous "silver," "gold," and "platinum" levels. The Massachusetts program relies on independent review by the University of Massachusetts Clean Energy Extension (CEE). The checklists and companion guidance include a significant level of detail. Maintenance and recertification are also more rigorous compared to scorecards in other states, including frequent recertification schedule and inspections. The cost for pro-gram participants ranges from $2,000-$15,000 depending on the site size, plus $5,000 every three years. The state law in Massachusetts is unique – it is the only known law to include a financial incentive in the form of a $0.0025/kWh rate add-on (applicable only for site "units" equal to or less than 5 MWAC).
Michigan	The Michigan scorecard is a one-page format covering the core considerations (planning, site preparation, plant diversity, and insect health), but with limited detail in other areas. No guide, landing page, or source of readily accessible information on such areas as planning and management is available. The state incentive program (the Farmland Preservation Program) is unique, allowing the use of otherwise-protected farmlands for solar power production provided that the site receives a score of 76 or higher on the scorecard. Maintenance is a soft requirement specified in the Farmland Preservation Program but is not covered in the scorecard. A separate maintenance scorecard is not available.
Minnesota	The Minnesota scorecard is a one-page format. A separate maintenance scorecard is also available. The two available guides – one from the Department of Natural Resources (DNR) and one from the Minnesota Board of Water and Soil Resources (BWSR) – cover a significant amount of detail. Minnesota has a "voluntary designation" type state law.
Missouri	The Missouri scorecard covers the core considerations (Site Planning and Management, Site Preparation, Plant Diversity, and Insect Health). No website, guide, or source of readily accessible information on such areas as planning and management is available. Missouri has a "voluntary designation" type state law. Maintenance is not covered in the state law or the scorecard.
North Carolina	The North Carolina scorecard is a one-page format. There is no state law or incentive program in North Carolina. Consequently, relatively few details are provided about maintenance practices, mostly limited to the guide (not present in the scorecard).
Northern California/ Oregon	A one-page scorecard developed in a collaboration between Pollinator Partnership and Fresh Energy covers Northern California and Oregon. There is no companion guide. The only known use of this scorecard is MCE (aka Marin Clean Energy), a public electricity provider serving four counties in the San Francisco area. There is no state law or incentive program in either California or Oregon.
Ohio	The Ohio scorecard is a one-page format. A short companion guide is also available, providing additional details on many of the scorecard topics. A separate maintenance scorecard is not available. There is no state law or incentive program in Ohio.
South Carolina	The South Carolina scorecard program was designed in coordination with Clemson University. South Carolina's solar pollinator designation program does not follow the typical scorecard format, but instead it takes the form of a detailed application for initial site development. This approach allows for more qualitative consideration compared with other scorecards. The applicant must attend a mandatory "training and field day." Following the initial "in-progress" designation, inspections and recertifications apply. There is a points-based scorecard for use at two-year monitoring intervals. Additionally, a detailed companion guide is available from the South Carolina Department of Natural Resources (DNR). South Carolina has a "voluntary designation" type state law.
Vermont	The Vermont scorecard is a one-page format. A companion guide is not available. The landing page provides a few useful links and resources but does not replace a comprehensive guide. A separate maintenance scorecard is not available. Vermont has a "voluntary designation" type state law.
Virginia	The Virginia program has both an "initial" and a separate maintenance scorecard. Participation in the "Pollinator-Smart" program is quite a bit more rigorous than the scorecards themselves indicate at first glance, as several detailed attachments and worksheets are required. The amount of information contained in the Virginia Pollinator-Smart program is substantial, including a 127-page guide. There is no state law or incentive program in Virginia.
Wisconsin	The Wisconsin Pollinator-Friendly Solar Certification Program uses a two-page "establishment plan" and a one-page "seasonal assessment" (for use three times per year). Some additional guidance is provided, including a concise "job sheet," but this does not include the level of detail of a more comprehensive guide. Yearly submittal of the seasonal assessments is required to maintain certification. There is no state law or incentive program in Wisconsin.

Table 3: Pollinator-Friendly Solar Scorecards by State

ules due to the more reflective ground cover[28] (which are still in testing phases of research), and the positive public perception.[29] There is ongoing research to explore the economic feasibility in this area.

Grazing, the solar ecosystem stewardship alternative to mowing, typically uses sheep to maintain vegetation. Although there is not robust peer-reviewed academic literature in this space, interviewees reported that there are numerous professional, utility-scale grazers nationwide. Sheep were the preferred animal for this task because, unlike goats, cows, and hogs, they do not chew cables, require that solar panels be built at an increased height, or trample the sites' vegetation. Moreover, research shows that using sheep instead of mowers is safer, almost eliminating the probability of fires as well as any occurrence of mower-flung rocks damaging the infrastructure. The grazers interviewed also indicated there are high levels of community support for their efforts and that they were applauded for bringing agriculture back to the region.[30]

Controlled Environment Agriculture and Solar Panels

Controlled environment agriculture (CEA), also referred to as indoor agriculture, offers opportunities to augment traditional agriculture production while addressing the challenges of water, space, resources, and food supply chain logistics. CEA can also reliably provide high value, short-shelf-life crops near the point of consumption by locating CEA facilities close to urban areas or other locations where the crops are consumed, resulting in reduced logistics for transportation and delivery.[31]

CEA commonly refers to any totally enclosed structure, or augmented greenhouse, that actively controls the lighting, temperature, carbon dioxide levels, humidity, and oxygen that surrounds the crops. CEA facilities often require large quantities of electricity to operate the necessary lighting, HVAC, water-heating, pumping, and other elements needed for crop production. Research has shown CEA delivers an increased yield per plant; reduces water usage per plant; reduces delivery time to local customers; decreases the farm's overall local CO2 footprint by reducing food miles and eliminating the use of fossil fuels in planting, tending, and harvesting crops; expands diversity of accessible food in land-constrained areas; and provides additional annual crop cycles.[32] However, CEAs have high upfront costs and typically demand high quantities of electricity to operate.

To offset the electricity demand, recent research has explored the feasibility of co-locating rooftop solar panels on, or adjacent to, CEA structures. Smaller CEA structures, such as individual shipping containers, have a small physical footprint, meaning there is inadequate rooftop space to accommodate enough solar to fully cover the container's daily energy consumption. Solar only works for these smaller CEAs if paired with storage co-located on a larger, nearby structure, or developed as a ground-based option. In addition, these smaller CEA structures often have high ceilings and a high density per cubic foot of energy consumption. In designing an effective rooftop semi-transparent PV panel greenhouse, research indicates there is a need for increased gutter height, and that the PV panels need to be evenly distributed across the roof in a checkboard pattern.[33] Thus, rooftop solar, even when paired with storage, may or may not be capable of fully addressing the energy needs of the small CEA structure.

Larger CEA structures, such as traditional greenhouses or those augmented with traditional non-translucent panels, require the use of adjacent or paired PV fields to meet their energy needs. As noted above, such systems can allow for beneficial crops, grasses, or other activities to occur beneath the panels. However, the use of semi-transparent solar panels can provide a potential solution, even if they are more costly and deliver less energy density than non-transparent panels. When semi-transparent solar panels are used, a PV-powered greenhouse could balance the needs of local and grid PV generation while meeting the demands of crops.[34] Such systems may potentially meet the farm's energy demands while making the farm more competitive by generating income from both energy and crop production on the same land unit.[35]

https://docslib.org/doc/4394010/dual-use-approaches-for-solar-energy-and-food-production-international-experience-and-potentials-for-viet-nam

28 O. Katsikogiannis, et al. "Integration of bifacial photovoltaics in agrivoltaic systems: A synergistic design approach," *Applied Energy* (2022). https://www.sciencedirect.com/science/article/pii/S0306261921016986

29 "Solar Land Conservation," EPRI, Palo Alto, CA, page 36 (2022).

30 Ibid. page 48.

31 "Food Security and Controlled Environment Agriculture (CEA): How Indoor Food Production Can Reduce Societal Impacts During a Crisis," EPRI, Palo Alto, CA, page 2 (June 2020). 3002019561

32 "Food Security and Controlled Environment Agriculture (CEA): How Indoor Food Production Can Reduce Societal Impacts During a Crisis," EPRI, Palo Alto, CA, page 3 (June 2020). 3002019561

33 A. Yano; M. Kadowaki; A. Furue; N. Tamaki; T. Tanaka; E. Hiraki; et al. "Shading and electrical features of a photovoltaic array mounted inside the roof of an east–west oriented greenhouse," *Biosystem Engineering*, 106, pp. 367–377 (2010). 10.1016/j.biosystemseng.2010.04.007

34 Marco Cossu, et al. "Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe," *Renewable and Sustainable Energy Reviews* (October 2018). https://www.sciencedirect.com/science/article/pii/S1364032118304374#bib6

35 E. Cuce; D. Harjunowibowo; P.M. Cuce. "Renewable and sustainable energy saving strategies for greenhouse systems: a comprehensive review," *Renewable Sustainable Energy Reviews* 64, pp. 34-59, (2016). 10.1016/j.rser.2016.05.077

For a translucent solar array to be worth the investment, it should produce enough electricity to power the technologies in the greenhouse, while limiting the shading on the crops below to preserve the quality of crops grown.[36]

There are ongoing studies to examine which crops will thrive in the semi-shaded area of a PV greenhouse. Specific crop research indicates that PV cover ratios of around 20% or less are needed to minimize or avoid crop yield losses and the negative effects on fruit quality.[37] When grown in a greenhouse with increased shade, tomatoes were found to elongate their stem and increase leaf size, causing a 70% decrease in crop yield.[38] The evapotranspiration of lettuce under PV panels decreased by 10–30% when the available light equaled 50– 70% of the full sun radiation, depending on the season, increasing crop yield.[39]

Past research has demonstrated that there are both benefits and disadvantages to co-locating solar generation on or near CEA sites. According to Leon and Ishihara (2018), tomatoes cultivated in a PV greenhouse reduced CO2 emissions by 12% compared to traditional field practices.[40] In the future, additional research will likely provide new knowledge related to the feasibility of CEA to meet food and energy demands.

Commodity Producing Agrivoltaics

An "agrivoltaic system" refers to the combination of photovoltaic panels and traditional agriculture on the same land area. According to researchers at the Fraunhofer Institute in Germany, agrivoltaics includes the cultivation of specialty crops and intensive arable crops with special solar mounted systems, as well as using land for extensive grazing with marginal adjustment to a solar system.[41] Agrivoltaics can sometimes include co-locating food producing systems – such as fisheries – with a floating photovoltaic system.[42] In these systems, the "floatovoltaics" power the oxygenation pumps and LED lighting for the fish while the water keeps the panels cool, creating an efficient system. In addition, the United States Department of Energy includes ecosystem services and pollinator habitat in its description of an agrivoltaic site.[43] This section focuses on commodity producing agrivoltaic systems and how solar sites are adjusted to accommodate the crop.

$$\text{LER} = \left(Y_{\text{cropin AV}} / Y_{\text{monocrop}}\right) + \left(Y_{\text{electrictyAV}} / Y_{\text{electricityPV}}\right)$$

Figure 2: Land Equivalent Ratio.

The LER adds together two factors:

1. *the crop yield from the co-located site (YcropinAV) divided by the crop yield from a non-agrivoltaic (monosystem) site (Ymonocrop)*
2. *the solar generation from the co-located site (YelectricityAV) divided by the solar generation from a monosystem site (YelectricityPV).*

If the LER equals one or more, that means there is a benefit to the combined system.

One of the first studies on agrivoltaics occurred in France in 2010. Durpaz et al (2010) developed the Land Equivalent Ratio (LER) (see Figure 2) to compare the production of agriculture and solar panel monosystems – sites that produce either solar energy or agricultural products – to two agrivoltaic systems of different panel densities.[44] The LER adds together the sum of the co-location crop yield revenue (YcropinAV) divided by the monosystem crop yield revenue (Ymonocrop) and the co-location solar generation revenue (YelectricityAV) divided by the generation capacity revenue of a monosystem on the same site (YelectricityPV). An LER above 1 means that there is a higher combined yield of, or benefit to, the combined system.

Since the original Dupraz et al. agrivoltaics site study, several research projects have tested the same feasibility hypothesis on whether agrivoltaics is efficient by altering their crop selection and site design. Also in 2010, researchers established two agriv-

36 Marco Cossu, et al. "Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe," *Renewable and Sustainable Energy Reviews* (October 2018). https://www.sciencedirect.com/science/article/pii/S1364032118304374#bib6

37 M. Cossu; L. Murgia; L. Ledda; P.A. Deligios; A. Sirigu; F. Chessa; et al. "Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity," *Applied Energy* 133 pp. 89–100 (2014). 10.1016/j.apenergy.2014.07.070

38 N. Bertin; H. Fatnassi; G. Vercambre; C. Poncet. "Simulation of tomato production under photovoltaic greenhouses," *Acta Horticulture*, pp. 425–432 (2017). 10.17660/ActaHortic.2017.1170.52

39 H. Marrou; L. Dufour; J. Wery. "How does a shelter of solar panels influence water flows in a soil–crop system?" *European Journal of Agronomy* 50, pp. 38–51 (2013). 10.1016/j.eja.2013.05.004

40 A. Leon A. and K.N. Ishihara. "Influence of allocation methods on LC-CO2 emission of an agrivoltaic system," *Resource Conservation Recycling* (2018).

41 Max Trommsdorff. "Agrivoltaics," Fraunhofer Institute for Solar Energy Systems, 2022, Accessed October 25, 2022. https://www.ise.fraunhofer.de/en/key-topics/integrated-photovoltaics/agrivoltaics.html

42 Pringle, Adam, et al. "Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture," *Renewable and Sustainable Energy Reviews* (2017). https://reader.elsevier.com/reader/sd/pii/S1364032117308304?token=572218F07C82F8165624BC044D5C21E5C6CAE28186333D8F2EFFC77021933F8B4EC1EFABA4C2D8EBA579E36DD865B106&originRegion=us-east-1&originCreation=20221025162452

43 Rob Davis and Jordan Macknick. "ASTRO: Facilitating Advancements in Low-Impact Solar Research, Deployment, and Dissemination," NREL (August 2022). https://www.nrel.gov/docs/fy22osti/83442.pdf

44 Christian Dupraz, et al, "Combining solar photovoltaic panels and food crops for optimizing land use: towards new agrivoltaic schemes," *Renewable Energy*, page 2730 (2010). https://www.researchgate.net/publication/229408925_Combining_solar_photovoltaic_panels_and_food_crops_for_optimising_land_use_Towards_new_agrivoltaic_schemes

	Crop	Panel Spacing	Panel Height and Tilt	Incident Radiation	Yield	LER	Summary Conclusion
Dupraz et al.	Durum Wheat	5 ft	13 ft at 25 degrees	43%	71%	1.43	Both dual-system sites were more efficient than a monosystem site
		10 ft	13 ft at 25 degrees	71%	89%	1.19	

Table 4: Agrivoltaic system studies data

oltaics plots of durum wheat (an annual crop).[45] The first study plot evaluated a system at full density – panels positioned 5 feet apart allowing 50% of the solar radiation to the crop below. The second study plot evaluated a system at half density, where panels were positioned 10 feet apart, allowing 70% of the solar radiation to reach the crop below. Both sets of panels were mounted at 13 feet with a tilt of 25 degrees. The study compared these two systems to the industry standard PV software model at the time, PVsyst, Version 6.85. The study found that on the full density plot, the wheat yield declined by 29%, and on the half density plot, the wheat declined by 11%. However, the LER of the half density plot was 1.19 while the LER of the full density plot was 1.43, demonstrating that both plots were more efficient – having a higher LER – than the monosystem. The study concluded that the full density site had a higher LER because of the greater solar capacity, while the half density site produced more wheat, still making it more efficient than the monosystem [Table 4]. The results of the study raised the question of yield prioritization for a site and how design can impact crop production.

Since 2010, there have been a variety of additional projects demonstrating agrivoltaic land use. These projects tested different panel heights and access row dimensions. Solar arrays commonly have panels mounted at 20 inches (50.8 centimeters), with 5-foot-wide (1.524-meter) access rows to maximize generation without shading. In an agrivoltaic system, the distance from the panel to the crop affects the amount of shade on the plant; when the panels are close to the ground, the shade is denser, whereas when the panels are higher off the ground, the spatial distribution of the radiation increases, making the shadow less intense.[46] Some small-scale studies in New York State (NYS) found that specialty crops such as lavender work well for co-location at a small scale. One ongoing Cornell College of Agriculture and Life Sciences study found that the panels sited over the lavender plants generated enough power to supply the farm and did not impact the farmer's ability to harvest the crop. In addition, this research project showed that lavender and other hand-harvested crops are more compatible in agrivoltaic systems because they require minimal heavy machinery to plant, tend, and harvest.

Additional studies have found that using fixed-tilt or sun-tracking (ST, also known as single-axis tracking) panels can increase generation capacity, but could decrease crop yield depending on the crop, relative to mono-agricultural systems.[47] According to recent research conducted in Vermont, the variety of production between saffron corms grown in the aisles, edges, and under the panels on a solar site in the 2020 and 2021 growing cycles was comparable.[48] This area of research continues to be explored, studying various crops and module designs to maximize co-location benefits.

Compared to a monosystem, agrivoltaic systems require two distinct labor skill sets – farmers trained to tend to the crops and engineers trained to maintain the panels. Another cost to factor in is that when solar facilities are designed to accommodate agriculture, higher panel heights are needed. The increased cost is due to the materials and labor required to loft the panels higher on the system.[49]

Additionally, from the baseline costs associated with either gravel or turfgrass, which require minimal upkeep, a farm system requires irrigation technology and specialized personnel to maintain and harvest the crops. The increased cost of the system may fall onto developers, deterring them from adopting an agrivoltaic design.

45 Christian Dupraz, et al, "Combining solar photovoltaic panels and food crops for optimizing land use: towards new agrivoltaic schemes," *Renewable Energy*, page 2730 (2010). https://www.researchgate.net/publication/229408925_Combining_solar_photovoltaic_panels_and_food_crops_for_optimising_land_use_Towards_new_agrivoltaic_schemes

46 Christian Dupraz, et al, "Combining solar photovoltaic panels and food crops for optimizing land use: towards new agrivoltaic schemes," *Renewable Energy*, page 2730 (2010). https://www.researchgate.net/publication/229408925_Combining_solar_photovoltaic_panels_and_food_crops_for_optimising_land_use_Towards_new_agrivoltaic_schemes

47 Y. Elamri, et al. "Rain concentration and sheltering effect on solar panels on cultivated plots," *Hydrology and Earth System Science* (September 2018). https://hal.archives-ouvertes.fr/hal-01883410/document

48 M. Skinner, et al. "Saffron on Solar Farms: A Win/Win for the Environment and Agriculture," University of Vermont, College of Agriculture and Life Sciences (2022). https://www.uvm.edu/~saffron/info/reports/FinalreportiSunFebruary22022.pdf

49 "Solar Land Conservation," EPRI, Palo Alto, CA (2022).

Besides the increased costs, there are also generation capacity challenges when co-locating crops and solar. The baseline design for a PV site is built to maximize the generation capacity. When the site design is altered to increase spacing or mounting height, the solar capacity per acre decreases, decreasing revenue for the developer. According to the developers interviewed, when the system's revenue decreases and the cost to build and operate the system remains stagnant, the economics on the project becomes less feasible.

In practice, calculating a system's value allows stakeholders to have a holistic view of the value of the land, according to a developer interviewed as a part of this study. One developer said that they separate the financials of the system into the farmer profits and developer profits. For example, if the system has panels that are less densely spaced, allowing the farmer to continue to harvest crops at minimal deficit, the farmer is not losing profit. When the farmer can make the same profit on the crop, there have been instances of the farmer leasing the land for less to the developer. The developer then has less cost to build and maintain the system, making the financials of the site more feasible for the increased spacing of the panels even when they decrease the site's capacity.

Other challenges associated with agrivoltaic development referenced surfaced in several interviews, include a lack of farmers who support agrivoltaics, and physical security concerns. In conversations with developers, they explained that many farmers are ceasing to farm their land because of increased financial burdens. Specifically, the researchers at the Cornell College of Agriculture and Life Sciences found that climate shifts, the globalization of the food system, and depleting distribution infrastructure contributed to farmers' dissuasion from farming. Developers and utility personnel also expressed concerns over a site's physical security. The current protocol for who gets access to the solar site inside the fence line is stringent; the utility interviewees expressed concern over allowing additional farmers into the site.

Farmer Perceptions of Agrivoltaics

The survey aspect of this research project was conducted with farmers between June and July 2022, collecting 66 responses from Maine, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont (Appendix B – Figure 9). One prominent finding from the interviews concerned farmer sentiment about solar development. According to members of the Agrivoltaics Working Group out of the Cornell Cooperative Extension and researchers at the University of Vermont, farmers' perceptions of solar development depends on their desire to continue to farm their land. Farmers that look favorably on developing solar generally have little to no interest in farming their land, while the farmers that look least favorably on solar development have expressed a desire in continuing to farm. To glean quantitative data on farmer perceptions of co-location, the EPRI research team partnered with an external organization to survey farmers in New England and the Mid-Atlantic. They were asked:

1. **Demographics: Which best describes your current geographic location?** [New York, New Jersey, Pennsylvania, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine]
2. **What is your primary agricultural product/crop grown?** [Open Ended]
3. **How do you view the co-location of your crops and solar panels?** [1/Very Unfavorably through 5/Very Favorably]
4. **If you have grazing animals, what are they?** [Open ended]
5. **How do you view the co-location of your animals and solar panels?** [1/Very Unfavorably through 5/Very Favorably]
6. **What are the reasons for how you responded to the above questions?** [Open Ended]

Survey Results and Findings

Of the 66 responses, the primary agricultural products reported were vegetables with 20 responses, followed by flowers with 9, corn with 8, and berries with 7 (Appendix B – Figure 10). Of the 48 responses who reported having grazing animals, the most common was cattle with 13 responses, followed by sheep and horses with 7 responses each (Appendix B – Figure 11).

Both groups – farmers with crops and those with grazing animals – were asked about their views on co-location. Overall, both groups had varied responses, skewing toward more positive views (Figures 3 and 4). Those who grow crops were slightly more polarized in their views than those with grazing livestock, with double the number of "very unfavorably" responses.

In the open response section, the farmers were given an option to explain their experiences and thought processes. Several respondents noted that they already have solar panels on their farms, primarily located on either the roofs of their homes or barns, and a couple who had crops co-located within solar arrays. This demographic was broadly in favor of solar generation and the opportunity to learn about the ongoing research. Others expressed a lack of understanding of how an agrivoltaic system would work, with an openness to learn, while others expressed that they felt the concept was unfeasible. The following reflects the range of feedback:

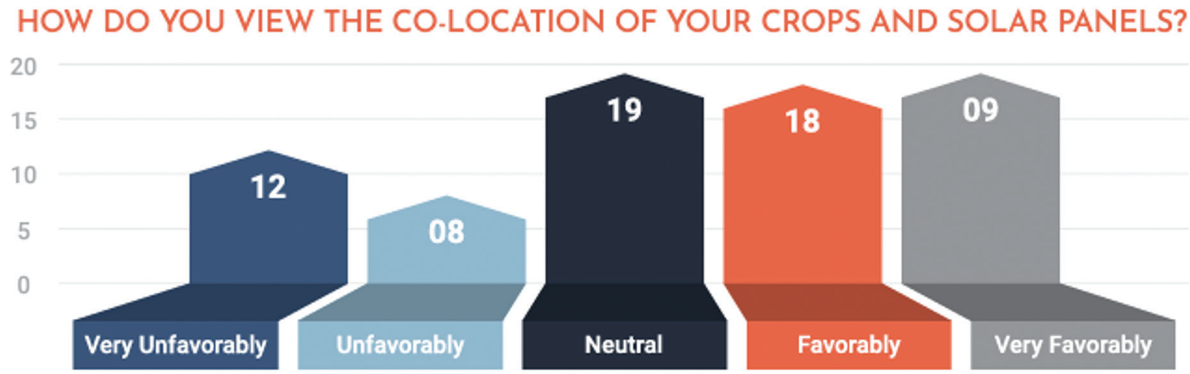

Figure 3: Farmer Views of Co-Location of Crops and Solar Panels

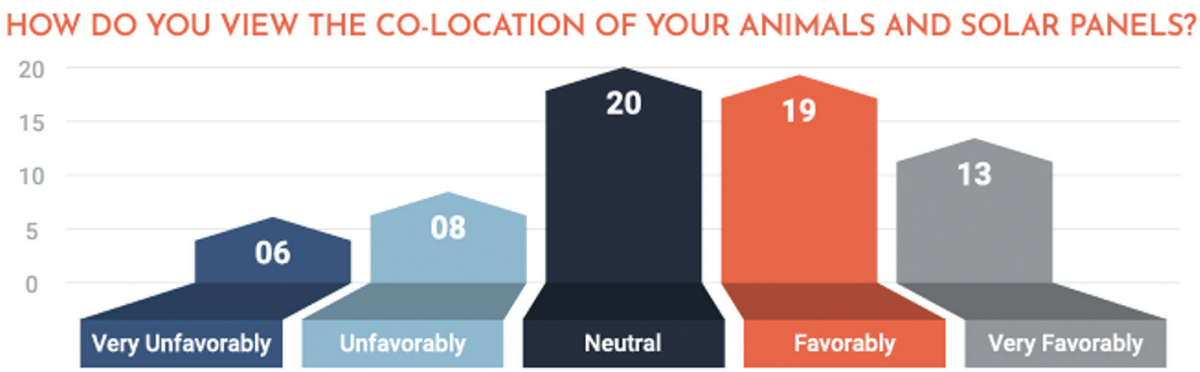

Figure 4: Farmer Views on Co-Location of Animals and Solar Panels

Positive:

- "Solar panels are a good option for clean energy."
- "I don't feel the panels will affect the grazing ability or quality of grazing of my animals."
- "Dual use of land and income streams could be really positive for improving the viability of livestock farms."
- "I am a huge proponent of renewable energy and hope the future of farming involves solar/wind production and livestock/crop production."
- "I think if the panels were a little higher you could graze other animals besides sheep. We hope to plant our pumpkins and other row crops between our solar panels. We have narrow tractors that will go between the panels."

Concerns:

- "Grazing animals eat fresh grass and solar panels have hindered grass growth."
- "It is felt that taking high quality ground away from crop production to put to use as solar grounds is going to negatively affect the overall world food sources."
- "PV panels are a tremendous waste of space, and contain hazardous chemicals that I would not want my cows to eat."
- "Horses are skittish, not sure if they would be afraid of the panels."
- "Solar sucks. Fossil fuels and nuclear are how you power a civilization."
- "I fear the horse would damage the panels."

The feedback from the farmer survey aligned with the desktop research and interviews – representing both gaps in research around site design for agrivoltaic systems and the challenges with farmer and community engagement and education.

Agrivoltaic Considerations in New York State

New York State produced $5.364B in agricultural commodities, making up 1.5% of total U.S. production.[50] The United States

50 "Cast Receipts by Commodity State Ranking," Economic Research Service, U.S. Department of Agriculture (2021). https://data.ers.usda.gov/reports.aspx?ID=17844

NYS'S TOP TEN AGRICULTURAL PRODUCTS ARE:

- MILK
- CORN FOR GRAIN
- HAY
- CATTLE & CALVES
- APPLES
- FLORICULTURE
- CABBAGE
- SWEET CORN
- POTATOES
- TOMATOES

Figure 5: U.S. Department of Agriculture, New York State Top Agricultural Products

Department of Agriculture 2017 Census determined the top agricultural products produced in New York State (Figure 5).

New York State, however, is topographically diverse, and certain crops grow best in certain regions. According to a researcher at Alfred State College in Western New York, the most common crops are grasses – predominantly hay. Because of the mechanized demands to farm hay, the researcher hypothesizes that co-locating hay on a solar site is inefficient. His hypothesis is being tested in an ongoing demonstration project site in Massachusetts.

Energy analysts at the NYS Department of Agriculture and Markets expressed favorable views on agrivoltaic demonstration projects that support the dairy industry – one of the largest sectors of the state's agro-economy. The analysts, however, recognized the challenges of co-locating solar panels and cattle pasture; particularly noting the animals' size and potential to break the panel systems if they rub against them. Additionally, members of the Cornell Cooperative Extension Agrivoltaics Working Group expressed concern over the depleting agriculture infrastructure and the increasing challenges for farmers to get their crops to markets. According to their research, globalization has caused a shift in the New York State agriculture sector, making it more challenging for local farmers to be competitive. Because of the infrastructure depletion, many generational, family-owned farms have started to abandon farming for alternative income, such as leasing land to solar developers or hunters.

Through a series of interviews, researchers at Cornell University shared their ongoing agrivoltaics research – emphasizing that the projects are still in early stages. All of these projects are small scale or under 100 kW, and focus on using solar panels to supply energy to the farm. Some of these small-scale projects use three or four panels to provide shading to a crop (such as lavender) that is maintained and picked by the single farm owner. These small-scale operations have found their agrivoltaic system increases the efficiency of their solar system, but there is skepticism on whether these systems are scalable into a community- or utility-scale site.

New York State Agrivoltaic Policies and Programs

The New York State Energy Research and Development Authority (NYSERDA) is the primary New York-based entity driving agrivoltaics projects and facilitating PV education for agricultural entities. NYSERDA has developed educational materials such as the "Fact Sheet for Solar Installations in Agriculture Districts" to provide a tool for those considering converting farmland to solar development.[51] In conjunction with NYSERDA's available research and guidance, the NYS Department of Agriculture and Markets (NYSDAM) has also created "Guidelines for Solar Energy Projects Construction Mitigation for Agricultural Lands."[52] NYSDAM's guidelines describe approaches to agrivoltaics projects and necessary oversight processes. For example, an environmental monitor must be on site during any construction or restoration projects that involve ground disturbance. In cases where land will continue to be used for agricultural purposes following completion of solar energy construction, this environmental monitor serves as an oversight entity throughout the entire project. NYSDAM's guidelines on environmental oversight also discuss provisions about soil testing, utility impact on agriculture, and plans for postconstruction, remediation, and decommissioning.

Outside of departmental guidance, there are more stringent regulations for developers to follow when establishing a major electricity-generating facility in NYS. NYS Public Service Law, Article 10 gives the NYS Board on Electric Generation Siting and the Environment the authorization to issue Certificates of Environmental Compatibility and Public Need, which authorizes the construction and operation of electricity-generating facilities of more than 25MW. Instead of requiring numerous permits and certificates that are dependent on local laws, NYS utilizes Article 10 to streamline the application process for major electricity-generation facilities. The review process as outlined in Article 10 is:

1. Public Involvement Program: implementation of public involvement programs within host communities at least

51 NYSERDA. "Understanding Solar Installation in Agricultural Districts," New York State Energy Research and Development Authority (2016). https://s3.amazonaws.com/assets.cce.cornell.edu/attachments/17180/NYSERDA_Fact_Sheet_-Solar_Installations_in_Ag_Districts.pdf?1471276425

52 NYSDAM. "Guidelines for Solar Energy Projects – Construction Mitigation for Agricultural Lands," New York State Department of Agriculture and Markets (2019). https://agriculture.ny.gov/system/files/documents/2019/10/solar_energy_guidelines.pdf

150 days before submitting preliminary scoping and applications to the siting board

2. Preliminary Scoping: informing the siting board and community about the project, including descriptions of the proposed facility, environmental/health impacts, studies to evaluate impact, mitigation measures, and alternatives to the project
3. Formal Application: submit a formal Article 10 application to Siting Board
4. Siting Board Decision: issue or deny the certificate within 12 months of the date of the application completion[53]

Local regulations and permitting requirements may also apply.

An accompanying regulation related to co-locating solar and agricultural operations is the New York State Environmental Quality Review Act (NYSEQRA), parallel to the National Environmental Policy Act (NEPA), which includes requirements for transportation and storm water management, submission of environmental assessments, and the involvement of local planning boards or zoning board of appeals. Some recommendations for complying with NYSEQRA are to:

1. negotiate with local government staff in pre-application meeting to avoid a full Environmental Impact Statement (EIS);
2. and engage NYS Department of Environmental Conservation during pre-application and early planning.[54]

In the NYS Senate, Senate Bill 7861A: Guidance and Education Materials for Farmers on Agrivoltaics was written in coordination with NYSERDA to promote agrivoltaics as a response to NYS' Climate Leadership and Community Protection Act, and was passed by the senate in October 2022.[55] This proposed bill requires NYSERDA and NYSDAM to develop and distribute educational materials regarding the use of agrivoltaics containing:

1. information about available resources to assist farmers to maximize agricultural production on land with co-located solar panels
2. information on the use of high value shade-resistant crops
3. information about potential marketing opportunities to consumers interested in purchasing food and other agricultural projects from farms that produce renewable energy
4. the potential for benefits such as reduced electricity costs, diversified revenue streams, and water use reduction.

Although this regulation would provide few tangible incentives for farmers that co-locate solar and agriculture, it would help introduce agrivoltaics to NYS's agricultural districts and support agrivoltaics projects across the state.

After a series of interviews with key stakeholders and agrivoltaics experts in NYS, there is a core theme of NYS's agricultural industries and communities being reluctant to support policies or regulations that may reduce local autonomy of NYS lands.[56] [57] NYSERDA interviewees indicated that NYS farmers have been declining offers to lease their land to solar developers, regardless of the profitability of the farm. Some farmers referenced concerns over the risk of losing autonomy of their land and having long-term negative effects to their land or business. These hesitancies are met with scientifically grounded solutions to co-locate solar and agriculture along with a variety of policies to help ensure that agricultural communities thrive during co-location project development. The NYS Agricultural Technical Working Group (A-TWG) is comprised of a variety of subject matter experts and key stakeholders concerned with responsible renewable energy development in NYS. This working group provides advice and guidance to NYS to advance solar development in collaboration with NYS's agricultural operations.[58] Several interviewees noted that A-TWG is a key resource for understanding farmer interests and for informing decision-making at the state-government level.

Originally published in 2016, and updated in 2022, NYSERDA released the *NY–Sun Solar Guidebook for Local Governments in New York State* with a specific section titled "Solar Installations in Agricultural Districts."[59] The guidebook references a NYSAM law that "provides a bottoms-up approach for the protection of viable farmland including land within an Agricultural District."[60] To understand the overlap between NYS's solar and agricultural

53 NYS Department of Public Service. "Article 10 of the Public Service Law," The New York State Senate (2011). https://www3.dps.ny.gov/W/PSCWeb.nsf/0/d12e078bf7a746ff85257a70004ef402/$FILE/Article10LawText%20.pdf
54 NYS Department of Environmental Conservation. "State Environmental Quality Review," New York State Department of Environmental Conservation. https://www.dec.ny.gov/permits/357.html
55 NYS Senate. "Proposed Senate Bill 7861," New York State Senate (2022). https://legislation.nysenate.gov/pdf/bills/2021/S7861A

56 EPRI Interview with NYSERDA Managers Dian Bertok and Jeremy Wyble, WebEx Interview (May 5, 2022).
57 EPRI Interview with Cornell University's Associate Dean, CALS, Julie Suarez, WebEx Interview (May 11, 2022).
58 NYS Agricultural Technical Working Group. "Who we are: A-TWG," Agricultural Technical Working Group (2022).
59 NYSERDA. "NY–Sun Solar Guidebook for Local Governments in New York State," NY-Sun and New York State Energy Research and Development Authority (September 2016). https://nysolarmap.com/media/1687/ny-sunsolar-guidebook.pdf
60 NYSERDA. "Solar Installations in Agricultural Districts," New York State Energy Research and Development Authority (2022). https://www.nyserda.ny.gov/-/media/Migrated/NYSun/files/understanding-solar-installations-in-ag-fs.pdf

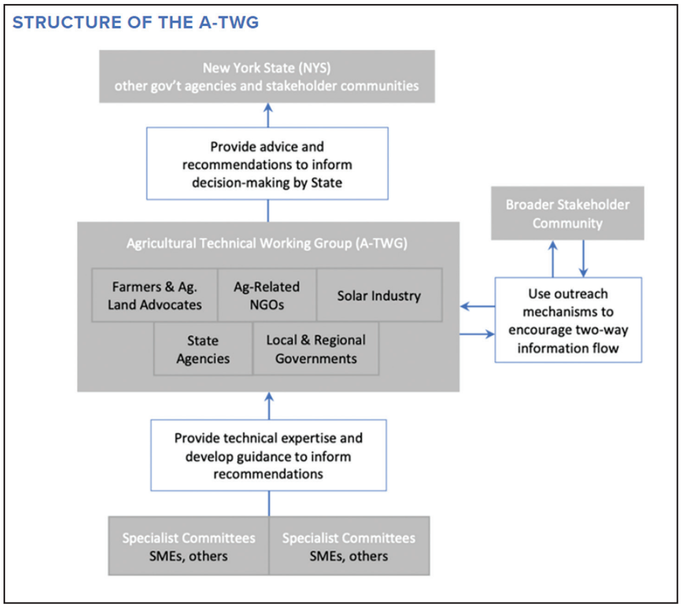

Figure 6: A-TWG (2022) "Structure of A-TWG" Agricultural Technical Working Group

policies, one must consider the laws and penalties related to solar development within agricultural districts. While few policies account for the co-location of utility-scale solar and agricultural operations, there is a conversion penalty imposed when farmland that is subject to agricultural assessment in an agricultural district is converted to a nonagricultural use within five years of the last assessment.[61] This conversion penalty also applies to farmland outside of agricultural districts if an agricultural assessment has been made within the last 8 years. However, there are no details regarding how this law affects developers who plan to continue agricultural operations post-solar installation and development. A stipulation of this penalty notes, "when only a portion of a parcel is converted, the assessor apportions the real property tax assessment and the agricultural assessment, determines the tax savings attributed to the converted portion, and computes the conversion payment passed on that portion. If the remaining land within a parcel is used for agricultural purposes and the eligibility criteria are met, that land may still receive an agricultural assessment."[62]

There are other disincentive policies NYS currently uses to secure agricultural lands for agricultural entities, such as NY-Sun's policy stating that participating contractors that apply for ground-mount projects with facility-areas larger than 30 acres in NYS agricultural districts are required to identify mineral soil group maps for the entire defined facility-area.[63] Similarly, the NYS Agricultural Mitigation Payment was designed to preserve prime farmland by requiring payment from solar developers that have projects mounted on mineral soil groups deemed "prime" for agricultural use. According to interviews with the Department of Agriculture and Markets, prime farmland is scored based on soil quality on a scale from one to four. The soil, however, does not have to be on an operating farm or used for agricultural purposes. Although interviewees noted that some developers had shifted away from solar siting on prime farmland partially due to these disincentive policies, today there are still few policy incentives for farmers and developers to co-locate PV systems on agricultural lands aside from NY-Sun and NYS tax credits/rebates for businesses that install solar panels. More research is required to determine what methods and incentives could gain the support of agricultural communities on utility-scale agrivoltaics sites.[64]

Without clear incentives in favor of agrivoltaic design, developers have found it challenging to co-locate in many regions in the state. In particular, in Western New York, hay is one of the main crops. To co-locate solar panels and hay, the racking system (upon which the solar panels are mounted) would need to increase in height significantly to accommodate the crop height and the harvesting machinery, making the economics unfeasible for the developer. While there is a research site in Massachusetts that is using a smaller tractor to harvest the hay under panels mounted at ten feet, when asked about the scalability of this approach, the owner of the farm hypothesized that this would not be economically feasible on a larger piece of land because the increased racking costs make it unprofitable in the short term.

Implementation

When considering an agrivoltaic site, there are two design strategies currently being tested:

1. retrofitting an existing site
2. planning for co-location at the beginning of site design.

Many of the ongoing demonstration projects around the United States have demonstrated co-location on smaller solar systems such as residential or community-scale systems. There have yet to be demonstration projects on sites larger than 10MW. However,

61 Ibid.
62 Ibid.

63 NYSERDA. "Commercial Solar Incentives and Financing," NY Sun and New York State Energy Research and Development Authority. https://www.nyserda.ny.gov/All-Programs/NY-Sun/Solar-for-Your-Business/Financial-Support/Incentives-and-Financing
64 Ibid.

lessons learned from community-scale agrivoltaic sites may apply to utility-scale sites.

A retrofitted solar site maintains the baseline site design to maximize generation capacity, and a crop that can exist within those site design constraints. For example, the University of Maine placed a standard-designed array above a wild blueberry patch in Rockport, Maine. Located on the south-facing 12 acres of a 40-acre plot, the study examined how the construction of the solar panels affected the existing blueberry crops. The results found that there was increased soil moisture and shade under the panels, causing increased leaf chlorophyll content. Researchers noted that the plants' recovery timeline was faster than expected. [65] Over the next few years, the researchers will continue to collect data to compare their agrivoltaic site to traditionally grown wild blueberries.

Alternatively, agrivoltaics could be considered in the design phase of a solar project, but may potentially reduce the site's solar capacity to improve the crop yield. These projects are rare because they increase capital expenditure (CapEx) cost, disincentivizing developers to build. At Arizona State University's Biosphere Two research laboratory, an agrivoltaic site is designed with the panels on stilts to allow heavy machinery to move underneath.[66] The study demonstrated no change in the generation capacity of the higher mounted panels; however, the initial cost of construction was higher, making the entire system less economically feasible for developers. The researchers also noticed that the increased mounting height diversified the options for crops that can be grown on the land, enabling the farmers to rotate crops and produce more annually, offsetting some of the increased construction cost. Given the diversity of crop and site design opportunities, there are a variety of available research opportunities for continued exploration.

Relevant State Practices

Aside from the pollinator-friendly scorecards, some states have alternative policies that incentivize or disincentivize co-location. Of the states with a related program, Massachusetts offers a variety of incentives for "dual-use," such as the Agricultural Energy Grant Program (ENER) and the Solar Massachusetts Renewable Target (SMART) program.

The 5 Cs of Agrivoltaic Project Success

During its InSPIRE agrivoltaic field research project, NREL studied elements that enable the successful installation of agrivoltaic projects and that facilitate research at those sites. Some factors that apply across all types of agrivoltaic projects include:

- **Climate, Soil, and Environmental Conditions (C1):** Conditions at the location beyond the control of the solar owners/operators, agrivoltaic practitioners, and researchers.
- **Configurations, Solar Technologies, and Designs (C2):** The technology, layout, and other infrastructure that can affect light availability and solar generation.
- **Crop Selection and Cultivation Methods, Seed and Vegetation Designs, and Management Approaches (C3):** Methods, vegetation, and agricultural approaches used for agrivoltaic activities and research.
- **Compatibility and Flexibility (C4):** Making the solar technology design and configuration compatible for solar owners/operators, agricultural practitioners, and researchers.
- **Collaboration and Partnerships (C5):** Understandings and agreements supporting agrivoltaic installations/research, such as community engagement, permitting, and legal agreements. [67]

ENER is a grant program that funds agricultural energy projects to improve energy efficiency and the adoption of alternative energy by Massachusetts's farms. The grants go to the owner of the agricultural operation with proof of substantial direct management experience in farming.[68] Alternatively, the SMART program, effective as of April 2018, provides guidance for how solar sites can qualify for the Agricultural Solar Tariff Generation Unit (ASTGU). According to SMART program guidelines, the following criteria must be met to receive the dual-use incentive:

1. Panel Requirements:
   a. For fixed-tilt systems, the minimum height of the lowest panel point shall be eight feet above the ground, and
   b. For tracking systems, the minimum height of the panel at its horizontal position shall be ten feet above the ground;
2. Maximum Direct Sunlight Reduction Requirements: All ASTGUs must demonstrate that the maximum sunlight reduction from the panel shading on every square foot of land directly beneath, behind, and in the areas adjacent to

65 Lily Calderwood. "Investigating the Impacts of Various Solar Installation Construction Methods on Wild Blueberry Growth and Development," University of Maine (August 2022). https://extension.umaine.edu/blueberries/wp-content/uploads/sites/41/2022/06/UMaine-Extension-Rockport-Research-Report-2021.pdf

66 Dinesh Harshavardhan. "The Potential of Agrivoltaic Systems," *Renewable and Sustainability Energy Reviews* (February 2016). https://www.sciencedirect.com/science/article/pii/S136403211501103X?via%3Dihub

67 "The Five Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study," The National Renewable Energy Laboratory (NREL) (2022). www.nrel.gov/docs/fy22osti/83566.pdf

68 The Commonwealth of Massachusetts. "Agricultural Energy Grant Program," Climate Smart Agriculture Program (2022). https://www.mass.gov/service-details/agricultural-energy-grant-program-ener.

Figures 7 and 8: AES Dual-Use Site, Grafton, Massachusetts (Photo credit: EPRI/Arin Kaye)

and within the ASTGU's design shall not be more than 50% of baseline field conditions;

3. Growing Season/Time of Day Considerations: The typical growing season shall be considered March through October, with sunlight hour conditions with maximum 50% sunlight reduction to be between 10AM and 5PM for March and October, and from 9AM to 6PM from April through September;
4. Maximum Size: The maximum AC-rated capacity of an ASTGU shall be two MW in the first two Capacity Blocks of each Distribution Company's service territory. The Department, in consultation with MDAR, will make an evaluation as to whether or not this provision shall be adjusted in subsequent Capacity Blocks.[69]

The proposed sites are reviewed by the team at the University of Massachusetts, Clean Energy Corporate Extension with commentary provided to the Commonwealth team. One example of an operational site that meets specifications to receive ASTGU benefits is pictured above [Figures 7 and 8].

In alignment with the Massachusetts ASTGU, New Jersey developed a dual-use solar energy pilot program ("Dual-Use Pilot") to permit development of solar-generation facilities on unpreserved farmland while keeping the affected land in active agricultural or horticultural use.[70] The goal of the Pilot Program is to test what techniques work best on farms to keep the farm productive and viable, capping the solar array size to 10 MW or between 100 and 200 acres. The proposed project must meet the requrements of New Jersey's Department of Energy and Department of Agriculture to receive the financial incentive set by the Board of Public Utilities (BPU). The Dual-Use Act restricts where pilot programs can be located – such as on prime farmland – unless the BPU grants an exception.

Under the bill, the pilot program would continue for 36 months, at which time the BPU would be authorized to extend the pilot program for a maximum of two additional 12-month periods. The BPU would also be authorized to increase the overall power limit of the pilot program by 50 megawatts each time it extends the program. The projects have to adhere to the following stipulations:

1. a 10 megawatt, as measured in direct current, capacity limit for each individual dual-use solar energy project;
2. annual capacity targets, such that the total capacity of all dual-use solar energy projects approved under the pilot program shall not exceed 200 megawatts, as measured in direct current, for all dual-use solar energy projects approved under the pilot program, except as otherwise provided pursuant to subsection "e." of this section;

69 Commonwealth of Massachusetts. "Guidelines Regarding the Definition of Agricultural Solar Tariff Generation Units," Solar Massachusetts Renewable Target Program (April 2018). https://www.mass.gov/doc/agricultural-solar-tariff-generation-units-guideline-final/download

70 State of New Jersey. "Summary of Solar Bills," *Dual Use* (2021), Accessed on November 7, 2022. https://www.nj.gov/agriculture/sadc/documents/Summary%20of%20Solar%20Bills%207-9-21.pdf

3. financial incentives available to dual-use solar energy projects approved pursuant to the pilot program;
4. a prohibition on siting a dual-use solar energy project on prime agricultural soils and soils of statewide importance, as identified by the United States Department of Agriculture's Natural Resources Conservation Service, which are located in Agricultural Development Areas certified by the State Agriculture Development Committee, unless the project is in association with a research study undertaken in coordination with a New Jersey public research institution of higher education, as approved by the board in consultation with the Secretary of Agriculture;
5. and a prohibition on siting a dual-use solar energy project on any of the following unless the board, in consultation with the Department of Environmental Protection and the Secretary of Agriculture, grants a waiver based on unique factors that make the project consistent with the character of the specific parcel.[71]

Using the results from the pilot projects, the bill directs the BPU to adopt rules and regulations for dual-use systems in New Jersey.[72]

Contrary to Massachusetts's progam, Michigan took an alternative approach to disincentivize solar development on agricultural land. The Michigan Department of Agriculture and Rural Development provides a tax credit to farmers who enroll their land under the Farmland and Open Space Preservation Act intended to keep prime farm land in use. Lands eligible for the tax credit must meet the following criteria:

1. It is 40 acres or more in size, and at least 51% of the land is in active agriculture.
2. It is less than 40 acres in size but at least 5 acres in size, more than 51% of the land is in active agriculture, and the agricultural land produces a gross annual income in excess of $200 per tillable acre.
3. The farm has been designated as a specialty farm by the Michigan Department of Agriculture, is at least 15 acres in size, and has a gross annual income in excess of $2,000 per year.[73]

For qualifying farms, the tax credit depends on the property tax assessed against the property and the landowner's income. For example, if the owner has an income of $20,000 and the property taxes on the farm total $2,000, they would receive a credit of $700, or 3.5% of farm income, on their property taxes.

If a farmer wishes to build solar on enrolled land, they can be granted an exception and forgo the tax credit.[74] Alternatively, depending on whether the site's design allows the farmer to continue farming within the solar system, there is the potential for the farmer to keep the land enrolled and get the tax credit.

The variety of these statewide policies that consider dual-use of agricultural lands establishes agrivoltaics as a pertinent topic for any state with decarbonization goals and/or finite agricultural land. The progression of agrivoltaics from an emerging topic to a concrete consideration for solar developers, power companies, or agricultural entities is further solidified by the requests, incentives, and growing research surrounding dual land use demonstrations.

RFP Language

To encourage solar developers to design agrivoltaic systems, there is specific language that is useful for RFPs and similar requests. For example, some RFPs may request information from the developer such as a plan of action with measurements for the site design – panel height, spacing, etc. – as well as the crop and agricultural technique. RFPs may also specify how maintenance should be conducted during project operation. The following language is an example of a vegetation management plan in a water-scarce region:

> If the project is located in an area where vegetation management will be required, before the start of project operation, the contractor shall prepare a vegetation management plan for review and approval by the company. The plan shall include measures to reduce the height and amount of vegetation and maintain defensible space around the perimeter of the site and around the inverters. Herbicide use shall be limited to areas with heightened fire risk, such as around inverters and combiner boxes; it cannot be applied site-wide. During project operation, the contractor shall conduct routine maintenance activities to prevent the growth of weeds, dry grass, or other vegetation that may be used as a fuel for fire. Such activities may include the following or equally effective measures:

71 State of New Jersey. "Chapter 170," Accessed November 7, 2022. https://pub.njleg.state.nj.us/Bills/2020/PL21/170_.PDF

72 State of New Jersey. "Senate Environment and Energy Committee: No. 3484," Accessed November 7, 2022. https://www.njleg.state.nj.us/bill-search/2020/S3484/bill-text?f=S3500&n=3484_S1

73 State of Michigan. "Farmland and Open Spaces Preservation Act," Accessed October 25, 2022. https://www.michigan.gov/mdard/environment/farmland/pa116/farmland-and-open-space-preservation-frequently-asked-questions#:~:text=The%20Farmland%20and%20Open%20Space%20Preservation%20Act%20enables%20a%20farm,in%20a%20non%2Dagricultural%20use.

74 State of Michigan. "Policy for Allowing Commercial Solar Panel Development on PA 116 Lands," Michigan Department of Agriculture and Rural Development (October 26, 2021). https://www.michigan.gov/-/media/Project/Websites/mdard/documents/environment/farmland/mdard_policy_on_solar_panel_and_pa116_land.pdf?rev=bac9bcabe2a54878a76bfbe9fa8b9b06

- A 30-foot minimum defensible space around the perimeter of the site and around the inverters shall be maintained.
- The contractor shall survey the site on a weekly basis to check for growth of vegetation in critical areas near transformers or other structures;
- Vegetation height shall be reduced and maintained with routine maintenance; and
- Use of herbicides for weed control shall be subject to the approval of the company and any necessary regulatory oversite agencies. Herbicides containing glyphosate will not be allowed.

The vegetation management plan shall describe how the contractor will be revegetated with pollinator habitat and will ensure increased use of the site by pollinators. This would include incorporation of pollinator-friendly seed material at the project site and a long-term management strategy to maintain use by pollinators. The company expects seed mixes that have a high proportion of native species, a high diversity of species types, and a species mix that will bloom over throughout the year (in different seasons).

There is the potential for similar language to be used to encourage agrivoltaic system adoption in RFPs. In an agrivoltaic RFP, the language should align with the applicable state and regional regulation. For example, in Massachusetts, if an RFP is supposed to adhere to the stipulations of the ASTGU, the RFP should include language about racking height, shading, and crops.

Identified Leading Practices

Stakeholder Collaboration: collaboration between the farmer, solar developer, and power off-taker early in the site-selection process to mitigate concerns and establish protocols for developing and managing the solar site that work for the farmer's needs.

Community Education: educational programming that creates a two-way dialogue between the farmers and the solar developers to create a site that is mutually beneficial.

Policy Incentives: state-level incentive policies for co-location that make the increased materials cost more affordable for the site developer.

Site Safety Practices: develop the solar site safety practices in tandem with the partnering farmer to ensure that they can access the site to tend to their crops or herd.

Crop Selection and Array Design: Continued research to identify site specific crops and array design alterations to accommodate the selected crop where appropriate.

Opportunities for Continued Research

As the concept of agrivoltaics gets explored, there are many opportunities for continued research. One of the key areas for additional research is building on the foundation of the farmer survey to gain a better perspective on farmer and community perception of agrivoltaics. Focusing on the social and economic impact of agrivoltaic application could include research questions on topics such as:

- the economics of site establishment, comparing the cost of co-location with conventional solar siting practices;
- the community impact of agrivoltaics;
- leading practices for solar developers to identify and engage with interested farmers;
- and the attractiveness of agrivoltaics to inspire the next generation of farmers to continue farming.

Additionally, as states mandate that pollinator habitat or certain plant mixes be used as ground cover on solar sites, there is going to be an increasing demand for seed. There is an additional opportunity for co-location of the seed needed on large-scale sites and solar to meet both the regulation stipulations and demand for the crop.

EPRI's Environmental Aspects of Solar will continue to research the nexus of agricultural production and solar generation. For more information on its research offerings, contact Terry Jennings at tjennings@epri.com.

Appendix A: Stakeholder Interview Questions

Interview Questions by Stakeholder Type

Government and Regulators

1. What has been your involvement in solar development? Please describe your educational/professional background and your area(s) of professional expertise.
2. What types of land do you deem ideal for conversion to solar power?
3. Are any lands prohibited for development?
    - Are there some lands that are not ideal but still legally acceptable and acceptable to your agency? (e.g., forested land that must be cleared, grassland, wetlands, prime farmland)

4. What restrictions apply in your state for conversion of land to solar power or co-location of solar power and agriculture? Are there any incentives in place for co-location?
5. What challenges and benefits have you faced with land conversion to solar as related to water management, such as changes in water quality, stormwater runoff, flooding of the solar facility, watershed basin improvement, or maintaining field tiling on former ag land?
6. Are you aware of any financial incentives for solar development related to nutrient trading programs or carbon sequestration from vegetation management?
7. Do you have any financial or regulatory incentives for development on brownfields or other types of degraded lands in the state, such as exempting developers from environmental remediation costs or guaranteeing that they are not legally liable for remediation issues?
8. What benefits should the public and those living near these facilities expect to receive (e.g., increased public services from tax revenue, diversification of farmland income, etc.)?
9. What have been some areas of resistance or pushback from the public in solar development process in your state? (e.g., glare, aesthetics, concern about property values, construction noise, opposition to use of prime farmland or farmland in general, support or opposition to pollinator habitat)

Utility Companies and Solar Developers

1. How much solar power is included in your portfolio?
2. **[Utility companies]** What are your goals for solar-power development, or for renewables in general?

   [Developers] How many projects and megawatts do you develop?
3. **[Utility companies]** Do you bid out your solar projects, develop them yourselves, or some of both?

   [Developers] What is your business model? For example, do you acquire existing solar projects or sell solar projects after you develop them, or do you also manage them?
4. **[Utility companies]** If you bid out your projects through an RFP, what qualitative factors are included, such as development of agricultural land? How are these factors prioritized/ weighted? Do they lessen the land conversion issues?

   [Developers] When you submit bids to an RFP process, what qualitative factors are included, such as development of agricultural land? How are these factors prioritized/ weighted? Do they lessen the land conversion issues?
5. Are there methods to recoup the cost of initiatives that may reduce the land conversion drawbacks, such as pollinator habitat or attractive fencing?
6. What are the most important policies and regulatory incentives you've encountered in the state(s) where you operate?
   - Do any programs exist to credit you for carbon mitigation or carbon sequestration if applicable?
   - Do nutrient trading programs exist?
7. What are regulatory and policy drawbacks and challenges you have encountered in the state(s) where you operate?
8. Do you have any experience with language in PPAs around agrivoltaic systems?

Let's discuss the projects you have developed so far….

9. What types of lands do you see as ideal for siting solar power?
   - Are there some lands that are not ideal but still accepted by your company and by regulators (e.g., forested land that must be cleared, grassland, wetlands, prime farmland)?
10. What areas of public opposition have you encountered (e.g., glare, aesthetics, use of prime farmland)? How have you addressed these issues, or did they stop the project?
11. What community benefits and drawbacks have you seen related to your projects?
12. What challenges and benefits have you faced with land conversion to solar related to soil quality?
    - Do you expect that solar facilities will improve the soil quality, detract from it due to erosion and compaction from equipment, or some of both?
13. What challenges and benefits have you faced with land conversion to solar related to water management, such as changes in water quality, stormwater runoff, flooding of the solar facility, watershed basin improvement, or maintaining field tiling on former ag land?
14. What challenges and benefits have you faced with land conversion to solar related to wildlife, such as impacts to threatened and endangered species, birds hitting the solar

panels, or creation of habitat within the solar facility or pollinator planting?

15. What initiatives have you taken to reduce land use or reduce impacts on the land?
    - Have you developed pollinator habitat? Used grazing? Co-located with agricultural production?

Farmers and Community Members

1. [Farmers only] We'd like to learn more about your farming operation. How big is your farm? What kind of crops do you grow? Do you raise any livestock?
2. [Famers only] What is your level of interest in co-locating solar on your farm?
3. Do you have any previous experience with energy installations in your community and/or on your farm, such as wind, solar, natural gas, coal, hydroelectricity, or fracking?
    - If so, does this previous experience affect how you view solar siting on agricultural lands? Or on your land specifically?
4. What are your perceptions of siting utility scale solar power plants on agricultural land? Do you distinguish between siting on preserved farmland and other types of farmlands?
5. What are the financial trade-offs between use of land for crops versus energy? What financial models would support solar for on-farm use?
6. [Farmers only] Is diversifying your income important for you? If so, do you see solar power as a means of doing so?
7. If you were to have solar panels built on some of your land, do you have an opinion on whether the solar energy is exported or used locally or both?
8. Do you perceive climate change as a threat to farming [to your community]?
    - If yes, is it a current or future threat or both?
    - If yes, how do you anticipate you will adapt to changing weather patterns?

Appendix B: Survey Responses

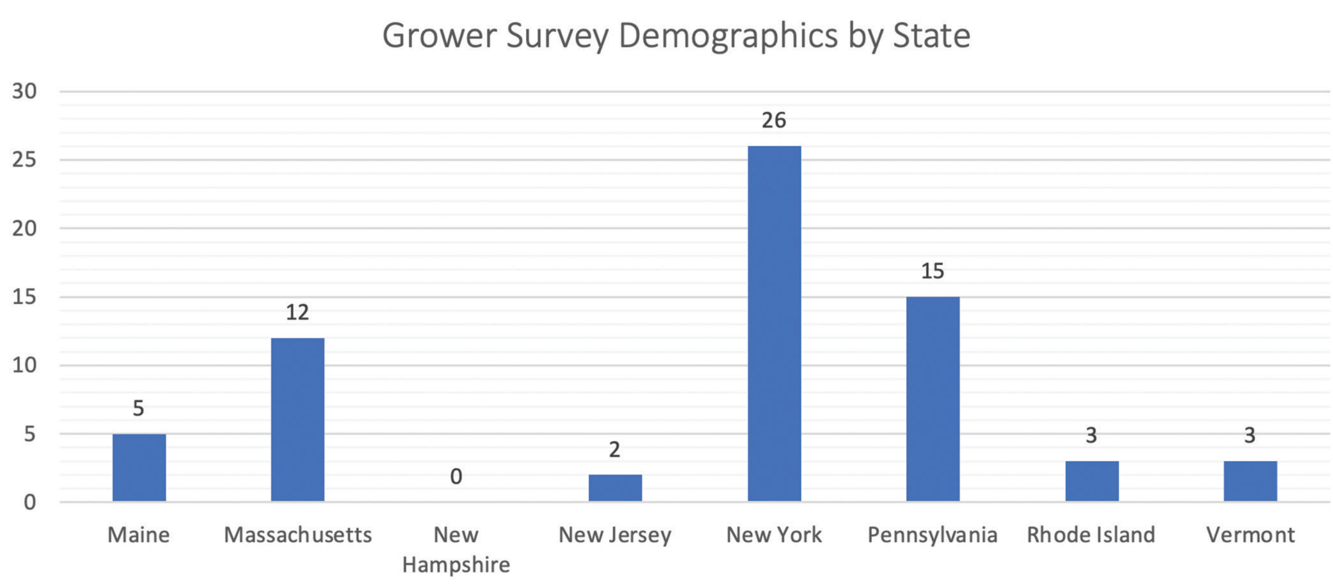

Figure 9 – Respondent Demographics by State

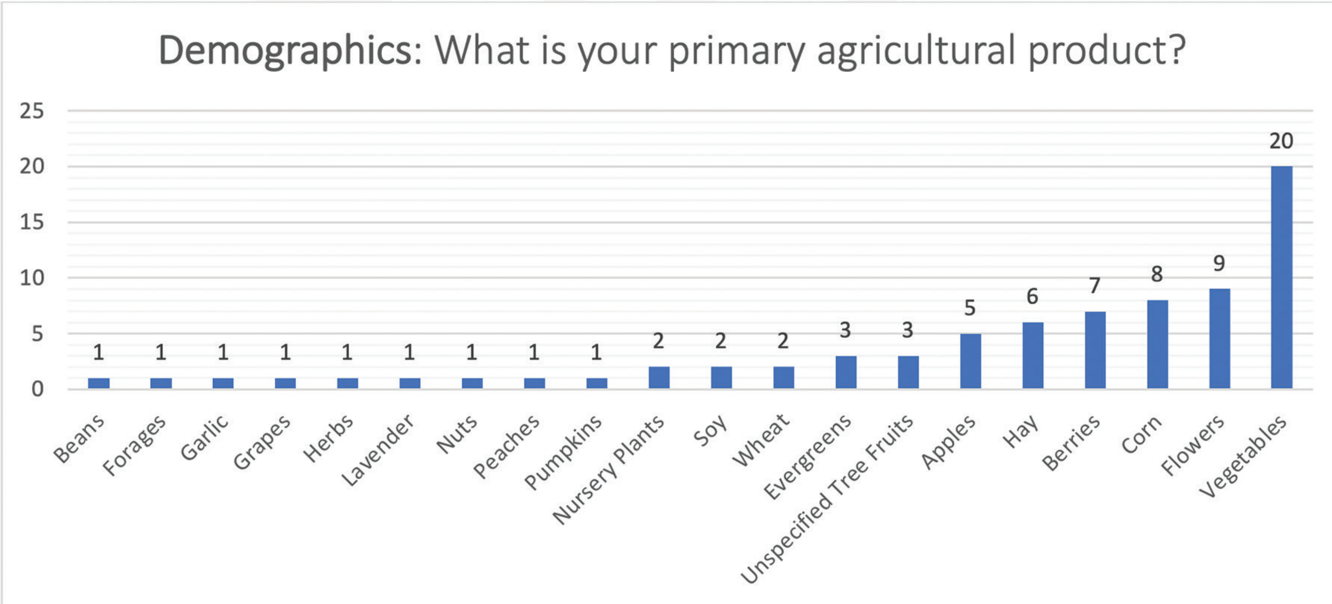

Figure 10 – Respondent Agricultural Crops

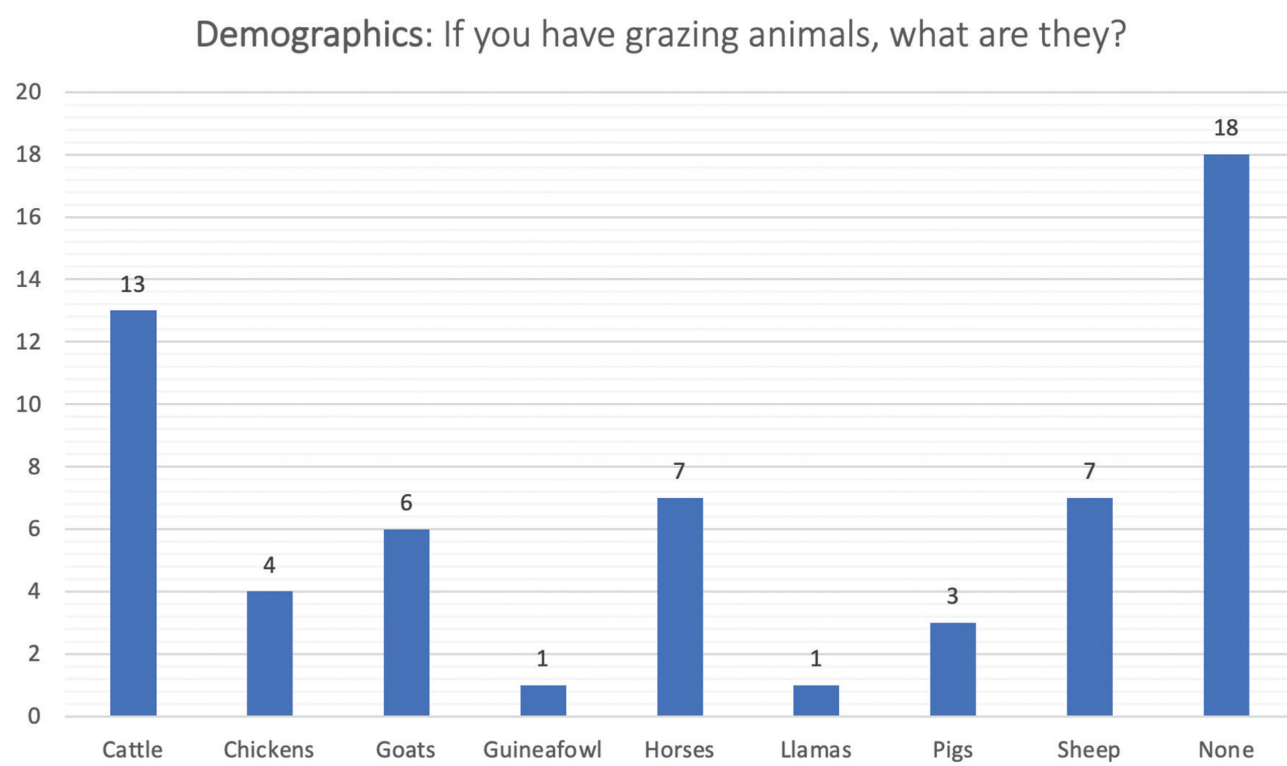

Figure 11 – Respondent Grazing Animals

Appendix C: Agrivoltaic Evaluation and Site Selection Considerations (DRAFT)

Stakeholder Considerations

- Stakeholder education
  - Are local landowners familiar with agrivoltaic practices, cost, benefits, etc.?
  - Are local landowners and farmers willing/interested to learn and apply agrivoltaic principles?
- Stakeholder acceptance
  - Are local stakeholders accepting of solar development? If not, would they be more so if agrivoltaic practices were applied?
  - Are local stakeholders accepting of specialty crops or native/pollinator habitat? May not be favorable due to lack of knowledge or concerned about impacts to current crop type/yields.
- Willingness/interest in cultivating co-located crops. Co-located crops may require more planning and higher costs. Farmers may require training for new or specialty crops suitable for solar co-location.
- Available incentives to farmers/landowners for cultivating co-located crops.
- Availability of specialty resources for planting and harvesting – e.g., smaller equipment, labor resources for hand planting and harvesting.

Current and Future Land Use

- Actively farmed vs fallow – disturbed land may be more desirable for solar applications with potentially less impact on native habitat/species.
  - Coordination with landowner to identify suitable agrivoltaic application
    - ∗ Landowner may be more amenable to specialty crops if land is actively farmed.
    - ∗ If landowner does not want to farm, pollinator habitat may be more suitable/acceptable.
    - ∗ If not actively farmed, is there an opportunity for landowner to resume specialty crop production or to sublet to tenant farmer?
- Native (undisturbed) habitat – may not be desirable if solar applications will adversely alter habitat/species.
- Impaired land – from overuse resulting in soil nutrient depletion/over grazing
  - Impaired land may benefit from reintroduction of native or pollinator habitat.

Cost and Contracting Considerations

(these are provided more to address financial concerns than as screening criteria)

- Opportunities to offset solar developer CapEx and OpEx
  - Higher PPA rates from off-taker if not utility-owned
  - Lower land lease rates if land is leased – potential additional benefit to landowner with agrivoltaic applications
  - Expedited permitting and agrivoltaic guidance from regulators or permitting authorities
  - Tax credits to developers/solar asset owners
- More lenient and supportive general construction permitting (SWPPP) – crops/pollinator habitats may take longer to establish and may require longer and more costly regulatory compliance.

PV Solar Array Design/Layout

influences crop and pollinator selections

- Available area, dependent on agrivoltaic application requirements
- Project scale
  - Utility-scale (>10MW) vs Commercial and Industrial (C&I) scale (<10MW)
    - ∗ Utility-scale projects primarily use single-axis tracking and racking systems with higher Ground Cover Ratio (GCR), smaller row-to-row spacing, and above-ground driveshafts perpendicular to array rows.
    - ∗ Access to/for crop production may be more significantly limited at a utility-scale project utilizing single-axis trackers.
    - ∗ C&I-scale projects typically use fixed-tilt racking systems with lower GCR, greater row-to-row spacing, and may not be as land constrained as utility-scale systems.
    - ∗ Due to economies of scale between the two types of projects and racking systems, C&I scale projects may offer more "customizable" design options (variable row-to-row spacing and racking heights) to better accommodate specialty agrivoltaic applications.
    - ∗ C&I-scale projects utilizing fixed-tilt racking systems may provide more opportunity for food or specialty crop production than utility-scale projects utilizing single-axis tracker systems.
- Type of racking system
  - Single-axis tracker (most common for large scale, > 1 MW applications)

    - N/S-oriented rows
    - E/W-oriented driveshaft (limits equipment access)
    - Variable shading throughout the day
    - Bi-facial modules vs mono-facial; bi-facial – higher energy production with greater albedo, which will be, in part, a function of crop type
  - Fixed-tilt system
    - E/W-oriented rows
    - 30-degree tilt to south – constant shade under panels
    - Narrower rows relative to tracker systems
- Ground Cover Ratio (GCR) – lower GCR provides potentially more area for agrivoltaic application; lower GCR provides greater insolation.
- Racking/panel height – ground cover stem height optimally no higher than lowest panel edge height
- Cabling system – buried (3-4 ft below ground surface) or above ground cable trays; both may impede access and means of planting/harvest depending on design configuration.

Crop and Pollinator Habitat Selection

- Food and specialty crops
  - Market demand/value
  - Climate suitability – local and regionally
  - Soil suitability for intended crop
  - Shade tolerance/insolation requirements – what is the optimal amount of sunlight to maximize growth?
  - Means of/access to irrigation for crops
  - Stem/foliage height – optimal to maintain height below lowest solar panel height to prevent shading
  - Means of harvest – mechanical vs hand harvesting. Limited access for machine harvesting at most solar facilities
  - Depth and means of tillage for planting – must be shallower than underground electrical infrastructure (cables). Ideally, minimize/eliminate tillage to improve soil health and reduce erosion and stormwater runoff
  - Suitability to prevent erosion and stormwater runoff – function of rooting depth, ground coverage, and growth rate
- Pollinator Habitat
  - Compatibility with local ecology – native habitat or amended habitat (additional flowering plant species beyond native habitat)
  - Compatibility with adjacent or nearby agriculture. Ideally, located near crops benefiting from pollinator activity
  - Stakeholder (neighboring farmer/landowners) acceptance. May be perceived as propagating nuisance weeds
  - Climate suitability – local and regionally
  - Soil suitability for pollinator habitat
  - Shade tolerance/insolation requirements – what is the optimal amount of sunlight to maximize growth?
  - Means of/access to irrigation for establishing habitat
  - Stem/foliage height – optimal to maintain height below lowest solar panel height to prevent shading
  - Suitability to prevent erosion and stormwater runoff – function of rooting depth, ground coverage, and growth rate

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January 2023

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