Best Practices in
AGRISOLAR

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Executive Summary

Agrisolar is the co-location of agriculture and solar energy in a landscape. This guide covers the state-of-the-art best practices for growing crops, grazing, beekeeping, and creating pollinator habitat under and around solar arrays. A chief strength of the AgriSolar Clearinghouse is our partner network, and, in this guide, the AgriSolar Clearinghouse team has gathered the country's leading voices in co-location.

This guide first defines best practices for five branches of agrisolar: solar and crop co-location, solar grazing, solar apiaries, solar pollinator habitat, and solar thermal. Greg Barron-Gafford and the team from the University of Arizona describe the delicate balance of planning, implementation, and maintaining crop and solar energy production and best practices for land access, solar panel configuration, crop selection, and water management. The guide then describes the importance of solar shade and protection in farmworker health.

The American Solar Grazing Association details the best practices in solar grazing, including land access, contracts, safety, operations, and maintenance, and provides examples of solar graziers employing these practices throughout the country. Argonne National Laboratory then describes the ecosystem services at habitat-friendly solar arrays and introduces the concept of ecovoltaics, a form of co-location that minimizes ecological impacts and improves the ecological value of solar development through habitat enhancement. Rob Davis then broadens the potential of solar pollinator habitat to include honeybee apiaries and provides details on the best practices for success in this category. The agrisolar team then illustrates agricultural applications of solar thermal, where energy from the sun is converted into solar thermal energy and then utilized in crop drying, processing, and storage.

The guide then expands into best practices that are important to all branches of agrisolar. This begins with a framework for stakeholder engagement. The National Renewable Energy Lab (NREL) and American Farmland Trust then provide an in-depth description of low-impact solar design, which aims to reduce the environmental footprint and impact of solar energy projects in design, construction, and operation. The elements of low-impact solar design include minimal soil compaction; minimal land grading; the use of native vegetation; respect for cultural heritage; community engagement and employing strategies to reduce soil erosion, enhance water retention, support biodiversity, and maintain or improve the local ecosystem.

The guide then provides an overview of best practices related to ownership and policies and shines a light on the opportunities existing solar can provide for farmland access by highlighting a case study of Big River Farms and US Solar. The Center for Rural Affairs concludes the guide with a delineation of tax considerations for co-location projects. Altogether, this guide provides a comprehensive strategy for incorporating best practices into agrisolar projects for farmers, community planners, solar developers, and researchers.

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Abbreviations

ASGA - American Solar Grazing Association

ASTGUs - Agricultural solar tariff generation units

AV - Agrivoltaic

BMP - Best management practices

CAB - Cable array bundle

CST - Concentrated solar thermal

DOE - Department of Energy

EERE - Energy Efficiency and Renewable Energy

EIA - Energy Information Administration

FARMS - Foundational Agrivoltaic Research for Megawatt Scale

FPV - Floating solar photovoltaic

InSPIRE - Innovative Solar Practices Integrated with Rural Economies and Ecosystem

IVM - Integrated Vegetation Management

LOI - Letter of intent

MAOM - Mineral associated organic matter

MSA - Master Services Agreement

MNL - Minnesota Native Landscapes

M-RETS - Midwest Renewable Energy Tracking System

NPDES - National Pollutant Discharge Elimination System

NREL - National Renewable Energy Laboratory

O&M - Operations and maintenance

PGP - Prescribed grazing plan

PHASE - Pollinator Habitat Aligned with Solar Energy

PPA - Power purchase agreement

PPE - Personal protective equipment

PV - Photovoltaic systems

REAP - Rural Energy for America Program

REC - Renewable energy credits

REFAIM Act - Renewable Energy facilities Agricultural Impact Mitigation

ROI - Return on investment

SEIA - Solar Energy Industries Association

SETO - Solar Energy Technologies Office

SMART - Solar Massachusetts Renewable Target

SOW - Statement of work

SWPPP - Stormwater Pollution Prevention Plan

USDA - United States Department of Agriculture

VMP - Vegetation management plan

Working Definitions

Agrisolar The co-location of agriculture and solar within a landscape or biome. This can include solar co-located with crops, grazing, beekeeping, pollinator habitat, aquaculture, dairies, and crop processing. In addition to photovoltaics, it also includes concentrated solar installations, which are not photovoltaic technology.

Agrivoltaics The co-location of crops and livestock grazing under and adjacent to solar photovoltaic panels.

Agroforestry The integration of trees and shrubs into crop and animal agricultural systems.

Aquavoltaics The co-location of solar and aquaculture. Aquaculture is the cultivation of fish, shellfish, and aquatic plants. Other terms include aqua-pv, floatovoltaics, and FPV (floating photovoltaics).

Apiary The co-location of solar and beekeeping operations, including beehives and honeybees.

Brownfield Lands that have been used for commercial or industrial purposes in the past but are not necessarily contaminated.

CAB system A “cable-array bundle” system that bundles and stores cables at solar sites.

Co-location The integration of agriculture and solar energy production on the same land.

Development The preparation and construction of the solar site to be energized and operational.

Dual-use The use of land for two purposes. In this guide, it is meant to describe lands used for both agriculture and solar energy production. Ecosystem services - The benefits that people and society receive from ecosystems. Four classes of ecosystem services include (MEA, 2005): provision services, such as the production of food, water, and energy; regulating services, such as climate stabilization, carbon sequestration, flood control and erosion control; cultural items, such as education, recreation, aesthetics, and spiritual meaning; and support services, that unpin other services, such as soil formation, photosynthesis, and nutrient cycling.

Ecovoltaics The co-location of habitat for pollinators and insects that are beneficial to the habitat under, adjacent to, and surrounding solar photovoltaic panels, for the benefit of ecosystem services. Two common ecosystem service types are pollination, e.g., bees moving pollen between flowers; and predation of crop pests, e.g., hoverfly larvae that feed on ladybugs, wasps that feed on crop pests, etc.

Floatovoltaics Photovoltaic panels that are engineered to float on a water body such as a pond, canal, harbor, bay, or lake.

Greenfield Undisturbed lands that have never been developed or used for agricultural or energy production purposes.

Habitat-friendly solar Also known as pollinator-friendly solar, this is a form of solar development and design that focuses on planting and establishing deep-rooted and regionally appropriate native grasses, wildflowers, and other non-invasive naturalized flowering plant species.

Hedgerow A row of shrubs or trees that encloses or distinguishes field boundaries.

Low-impact solar design A development strategy focused on reducing the environmental footprint of solar energy projects during both the construction and operational phases. Unlike traditional solar development, which gives more consideration to energy production than environmental impacts, low-impact solar design seeks to minimize land disturbances, enhance ecological resilience, and support sustainable land use. Low-impact solar design practices encompass a range of strategies, including the use of native vegetation, minimal land grading and impaction, and thoughtful integration with other land uses. These strategies aim to reduce soil erosion, enhance water retention, support biodiversity, and maintain or improve the health of the local ecosystem.

Mounting system The equipment used to affix solar panels to the ground, roof, building, or water body. Two of the most common designs are fixed-tilt, where the mounting system is in a fixed position and does not track the sun, or tilt-mount, where the mounting systems move the solar panel to follow the path of the sun. Dual-axis trackers allow the solar panels to follow the sun on two axes and increase the amount of sunlight collected by the panel.

Operations and Maintenance (O&M) Ongoing activities to keep the solar site producing energy and in compliance with safety and other state or federal regulations.

Siting The geographic location of a solar site and the location's environmental, cultural, and social characteristics such as community support.

Solar grazing The co-location of livestock grazing and solar photovoltaic arrays.

Solar pollinator habitat Lands under, around, and adjacent to solar development that support pollinators, such as bees, birds, bats, and insects, through flowering plants, grasses, shrubs, hedgerows, healthy soils, and fencing that reduces the presence of predators, specifically insect pests that result in a negative impact on crops or agriculture.

Solar thermal Solar thermal is a term used to describe a technology, such as a crop dryer or solar water heater, that converts the energy from the sun into thermal energy. This thermal energy can be used to heat, dry, and distribute air, water, or heat transfer fluids. Solar thermal principles can be employed in crop drying, processing, and storage, as well as in water-intensive operations, like dairies.

Solar thermal drying Solar thermal drying is a method of dehydrating food crops and grains using solar energy. Solar dryers are further categorized as either passive (using natural convection) or active (using powered convection).

Stakeholder An individual or organization that has an interest or is impacted by a project. In this guide, a stakeholder can include, but is not limited to, landowners, farmers, ranchers, producers, graziers, community members, researchers, solar developers, local officials, advocacy groups, and local organizations.

Stakeholder engagement plan A stakeholder engagement plan is a framework that includes considerations for communication, participatory planning, feedback strategies, and target outcomes. The plan sets forth a process to identify, listen to, and collaborate with project stakeholders. A good plan features clear objectives, roles, resources, timelines, and actions, and has dedicated the proper internal capacity to be managed over the lifetime of a project.

Vegetation management plan A plan for the management of vegetation at a solar array. This can vary greatly, based on site characteristics, but can include the following components: summary of site characteristics and conditions, vegetation goals and objectives, planting plans, planting design, site layout, planned seed mixes, site preparation and installation provisions, establishment provisions, anticipated maintenance provisions, integrated vegetation management, inspections and monitoring, grazing plans, modification and removal of fuels, environmental compliance plans, regulatory compliance information, and mitigation plans.

Chapter 1

Getting Started

Agrisolar in Illinois. Photo: AgriSolar Clearinghouse

Stacie Peterson, National Center for Appropriate Technology

Agrisolar is the co-location of agriculture and solar within the landscape. This can include solar co-located with crops, grazing, beekeeping, pollinator habitat, aquaculture, dairies, and crop processing. In addition to photovoltaics, agrisolar also includes concentrated solar installations.

In an agrisolar system, you can harvest the sun twice. Once with the solar panel and again with crops, forage, honey, and habitat. Agrisolar can help you get the most productivity out of your land, while also supporting the land, community, and ecosystem around it.

A few common terms associated with agrisolar are dual-use, co-location, and agrivoltaics, which typically refers to crops grown under and around solar photovoltaic panels. Solar grazing typically refers to grazing sheep under and around solar arrays. Cattle, rabbits, llamas, and birds can also graze solar sites.

The first steps in an agrisolar project are to determine the scope, size, ownership, goals, funding, relevant policies, solar design, tax ramifications, and a community engagement plan. It's important to remember that any site can have many types of agrisolar and that there

You are a:

Farmer/Landowner

Solar Developer

Policymaker

Solar Pollinator Habitat Developer

Beekeeper

Grazier

Community Planner

Researcher

NEXT: How to move your project forward

Figure 1. How to Get Started in Agrisolar Tutorial

could be a change of use in the future. A solar pollinator habitat with an apiary could become a solar and crop co-location site in the future, if planned well.

The AgriSolar Clearinghouse tutorial How to Getting Started walks the reader through the decision process of an agrisolar project through the lens of farmer/landowners, solar developers, policy makers, beekeepers, graziers, pollinator habitat developers, community planners, and researchers.

This resource then leads the reader through the process of moving the project forward. It describes potential funding sources, procurement, example contracts, case studies, contractors, and technical assistance options. This Best Practices Guide is meant to further assist in the development of agrisolar projects, with more in-depth, practical information. The goal of the guide is to assist farmers, landowners, graziers, beekeepers, community planners, solar developers, policy makers, and researchers with a framework to create a well-planned agrisolar project. The guide is written by the leading experts in agriculture and solar co-location. The authors of each chapter have created a wealth of research, demonstration, technical assistance, and education, and are the creators of more in-depth information in their area of expertise.

This guide begins with a presentation of best practices for five branches of co-location: solar and crops, solar grazing, solar pollinator habitat and apiaries, and solar thermal. It then dives deeper, into best practices that apply to all agrisolar projects: stakeholder engagement, soil health, low-impact solar design, ownership, policies, and tax ramifications. Together, the following chapters provide a guide to a successful co-location project and help inspire farmers, solar developers, community planners, and researchers to create a healthy, equitable, and profitable project that benefits all of the stakeholders involved.

Chapter 2

Best Practices for Crop Agriculture in Agrivoltaic Systems

Greg A. Barron-Gafford, University of Arizona; Nesrine Rouini, University of Arizona; Talitha H. Neesham-McTiernan, University of Arizona; and Kai Lepley, University of Arizona/National Renewable Energy Laboratory

EXECUTIVE SUMMARY

Agrivoltaic systems combine solar energy production with agricultural land use and represent a promising pathway for sustainable, dual-purpose land management. Integrating solar panels with crop production can improve land-use efficiency, enhance water conservation, and increase farm profitability. Successful implementation of agrivoltaic systems requires careful planning and management to balance both agricultural and energy-production needs. This chapter outlines best practices for managing and optimizing crop production within agrivoltaic systems, focusing on summaries of insights over the past decade and practical considerations for farmers and solar developers.

INTRODUCTION TO CROP-BASED AGRIVOLTAIC SYSTEMS

Agrivoltaics can be established in nearly every climate zone, if specific and intentional considerations are made regarding crop selection and solar panel design. While initial trials involved elevated photovoltaic (PV) installations with crops grown directly below the panels, there are a range of agrivoltaic installation designs that include ground-mounted or elevated tracking and fixed-tilt PV arrays. Just as agriculture grown with full-sun exposure varies greatly across the climatic spaces of the globe, so will the crop choices and primary drivers of crop planting approaches.


Agrivoltaic peppers in Phoenix, Arizona. Photo: AgriSolar Clearinghouse

Within full-sun agriculture, biophysical factors, such as maximum and minimum temperatures, relative humidity, frequency and amount of precipitation, and texture and water-holding capacity of the soil, as well and social factors, such as pathways to access markets for the crops grown, water availability/rights, and the demand for the crops produced, must be considered. Many of the biophysical characteristics of a site are modified within an agrivoltaics approach, requiring a reevaluation of food production within crop-based agrivoltaic systems. The central challenge of agrivoltaics is partitioning incoming sunlight among the crop and the photovoltaic panels to support adequate crop and electricity production. To date, the agrivoltaics field has not systematically evaluated design approaches—largely because the optimal partition of sunlight depends on geography and crop needs. The diversity of agrivoltaic pilot projects reflects agricultural diversity, but translating the knowledge between settings is challenging without understanding the interplay between system components and the effect of local climate conditions on those interactions.

Key Considerations:

- **Land access:** Agrivoltaics can be conducted across a range of ownership structures, from family farms to the land of PV developers. Creating a site access agreement between the food and energy producers is critical.
- **Solar panel configuration:** Different panel designs (e.g., fixed tilt, tracking systems) differentially affect light availability, shading patterns, temperature regulation, and soil moisture for crops beneath the panels.
- **Crop selection:** Some crops are better suited to shaded environments than others. Plant types, growth cycles, and shade tolerances must be considered when designing an agrivoltaic system.
- **Water management:** Agrivoltaic systems can reduce water evaporation, improving water use efficiency, but this benefit depends on the specific crops and irrigation methods used.

LAND ACCESS

Implementing agrivoltaics, rather than just installing PV, provides an opportunity to continue or even introduce food production in areas that were previously losing or did not have that potential. Therefore, site access has become the primary factor in testing and deploying agrivoltaic systems.

The economic stability that comes with having PV installed on a site can mean that landowners can see not only significantly greater income but also more stable income that isn't based on fluctuations in production, markets, and tariffs. However, implementing agrivoltaics within an operational PV site requires permission from the site operators and an acknowledgement that the primary income is electricity generation. This ultimately develops into a primary mission of the site, and as agrivoltaics grow into larger implementations, access to these facilities by those conducting farm operations becomes increasingly important.

When negotiating site access, it is important to anticipate the regularity and necessity of site visits. Early in the growing season, more frequent visits (and some beginning at "farmer's hours") for land preparation, seeding, tracking germination, and replanting due to plant loss should be anticipated. During the primary growing season, site visits can lessen depending on the crops selected, but access is still required for maintenance, such as weeding, irrigation checks, etc. The number of site visits increases again towards the end of the growing season when it's time to harvest and plants move toward senescence. Because PV developers and site operators typically manage a PV site with minimal visits, this will likely be a different approach for them.

In some instances, PV developers will need to have staff accompany the farm team while onsite, especially within an industrial PV site. When crafting a Site Access Agreement, it is common practice to establish a minimum distance required to prevent panels, junction/disconnect boxes, wiring bundles, and inverters from being touched.

Establishing distances and working conditions that meet both agricultural and PV industrial requirements can be a challenge for larger scale agrivoltaic installations but are necessary to build trust and confidence in the ability of food production within larger PV arrays.

Key Best Practices:

Site Access Agreement: Balance the needs of food production with the requirements of working within an active PV array.

Recommendations:

- **Site Access:** Ensure that all parties understand the need for site access to prepare land and to plant, cultivate, and harvest. Think through decision pathways for how PV developers need to access panels and how this might interrupt farming operations. Create a plan that ensures farm access for all parties, despite potential needs from the PV developer to accompany farm workers during periods of high energy demand.
- **Training and Education:** Ensure that all site visitors are trained in the specific hazards associated with both solar installations and agricultural practices. This includes understanding electrical safety, farm equipment operation, and emergency procedures.
- **Personal Protective Equipment (PPE):** Use appropriate PPE, such as gloves, helmets, safety glasses, and high-visibility clothing, to protect against physical and electrical hazards that meet the minimums across both the agricultural and PV industries. For example, to operate within PV sites, agricultural workers may be required to wear Class E hard hats designed specifically for electrical work.
- **Communication:** Maintain clear lines of communication among all workers and stakeholders. Regularly hold safety meetings to discuss concerns and updates related to both agricultural and solar operations. Using two-way radios or walkie-talkies while on-site helps maintain communication across the site when line of site may be difficult to maintain.
- **Emergency Preparedness:** Develop emergency response plans tailored to the unique challenges of working in a solar facility, including electrical hazards and weather emergencies. Apps that utilize a worker's location can be used to notify when lightning is within a certain radius. Establish safety guidelines that specify the minimum distance from lightning before one leaves the agrivoltaic site, ensuring that the distance meets the minimums of both agricultural and PV industries.

DESIGNING AGRIVOLTAIC SYSTEMS FOR OPTIMAL CROP GROWTH

The success of an agrivoltaic system depends largely on its design. A well-designed system accounts for solar panel spacing, orientation, and height, ensuring that crops receive enough light and space to grow effectively while maximizing energy production.

Solar Panel Spacing

The spacing of solar panels is a critical design factor in an agrivoltaics system. Panels must be arranged to allow adequate sunlight to reach the crops below. Spacing that is too close can result in excessive shading, which can hinder photosynthesis and reduce crop yields in some crops. Conversely, spacing that is too wide can lead to underuse of available land and reduced energy production. Optimal spacing depends on the specific crops being grown, their light requirements, and the geographic location of the system.

For instance, leafy greens that thrive in partial shade may benefit from closer panel spacing, while sun-loving crops like tomatoes may require wider gaps. These general principles vary with the climatic zone of an agrivoltaic system. Panels must be arranged to allow adequate sunlight to reach the crops below. In tropical climates, where sunlight is abundant, panels may be spaced more closely together without significantly impacting photosynthetic rates, providing that adequate ventilation allows for the moist air to dry out on occasion to avoid introducing molds or fungus. However, in temperate climates with more variable sunlight, wider spacing may be necessary to ensure that

Panel spacing at Jack's Solar Garden in Longmont, Colorado. Photo: AgriSolar Clearinghouse

crops receive enough light, especially during shorter, winter days. In arid regions, where sunlight is intense, but water is scarce, spacing can be optimized to provide partial shading, reducing water evaporation and protecting crops from excessive heat.

Orientation and Height

The orientation of solar panels in an agrivoltaic system is another crucial design element. Panels are typically oriented to maximize solar energy capture, which often means facing south in the northern hemisphere and north in the southern hemisphere. However, this orientation must also consider the angle of sunlight and its impact on the crops below. In high-latitude regions, where the sun's path is lower in the sky, panels may need to be tilted more steeply to capture the maximum amount of sunlight. In contrast, in equatorial regions, a nearly horizontal orientation can be effective due to the high angle of the sun throughout the year.

The height at which solar panels are mounted also plays a significant role in determining the amount of light that reaches the crops. Higher mounting heights can reduce shading and allow for taller crops to be grown underneath. However, increasing the height of the panels can also lead to higher construction costs and potential structural challenges. The ideal height must balance these factors, ensuring that crops receive adequate light while maintaining the economic viability of the system.

Fixed-tilt versus Tracking PV Systems

When designing an agrivoltaic system, one of the key decisions is whether to use fixed-tilt or tracking solar panels. Each type has its own set of advantages and disadvantages that can impact both crop growth and energy production, and these considerations can vary significantly across different climatic locations.

Fixed-tilt solar panels are generally less expensive to install due to their simpler design and fewer moving parts compared to tracking systems. This means lower maintenance requirements for fixed-tilt systems, making them a cost-effective option for many installations. Fixed-tilt systems are particularly advantageous in regions with harsh weather conditions, such as strong winds, heavy snow, or intense heat, where their stabilized structural design provides greater reliability. However, fixed-tilt panels do not follow the sun's movement, which can result in lower overall energy production compared to tracking systems. This limitation is especially pronounced in areas with variable sunlight, where the fixed angle may not always be optimal for capturing solar energy.

In contrast, *tracking solar panels* are designed to follow the sun throughout the day, increasing energy production by 15% to 25% compared to fixed-tilt systems. This increased efficiency makes tracking systems particularly beneficial in regions with high levels of direct sunlight, such as arid or tropical climates. The ability to adjust to the sun's position ensures that the panels can capture the maximum amount of sunlight available, which is crucial in maximizing energy yield. However, tracking systems come with higher initial costs and increased maintenance needs due to their mechanical complexity. They are also more susceptible to damage from extreme weather conditions, which can be a significant drawback in regions prone to severe weather events.


Panel spacing at Jack's Solar Garden. Photo: AgriSolar Clearinghouse

In high-latitude regions, where the sun's path is lower in the sky, tracking systems can be particularly effective in capturing the limited sunlight available during the shorter, winter days. In equatorial regions, where the sun is nearly overhead throughout the year, fixed-tilt systems can be set at a relatively flat angle to efficiently capture solar energy without the need for complex tracking mechanisms. In temperate climates, where sunlight hits the panel at an angle and weather conditions vary significantly throughout the year, the choice between fixed-tilt and tracking systems may depend on a detailed cost-benefit analysis that considers both initial investment and long-term energy production potential.

New, novel agrivoltaic systems include *adjustable* or *dynamic panel* systems. These panel systems can change orientation throughout the day, providing an opportunity to optimize light distribution for both energy production and crop growth in time, rather than spatially. This can be especially beneficial in crop-based agrivoltaic systems, where the value of the crop requires additional design infrastructure or tracking software.

Key Best Practices:

- **Panel Height and Spacing:** A balance between solar energy capture and crop productivity is crucial. Taller panels or wider spacing can reduce shading and promote better airflow but may also reduce energy output. Typical panel heights range from 1.5 meters to 2.5 meters above the ground.

  Recommendation:

  - For crops requiring more sunlight, design panels with higher clearance (at least 2 meters above the crop canopy).
- **Orientation of Panels:** In most regions, solar panels should face poleward to capture optimal sunlight. However, if shading crops is a concern, east-west orientation might be preferable.

  Recommendations:

  - Use panels oriented east-west to provide more uniform shading throughout the day, reducing the risk of extreme temperature fluctuations and drought stress on crops and to increase uniformity among crops within the agrivoltaic system.
  - In equatorial regions, use a nearly horizontal orientation to efficiently capture solar energy, but utilize a minimum 10° poleward tilt to create sufficient water runoff and reduce panel soiling.
- **Fixed-tilt versus Tracking PV Systems:** Ultimately, the decision between fixed-tilt and tracking solar panels in an agrivoltaic system should be based on a comprehensive evaluation of the specific climatic conditions, project size, budget, and energy-production goals. In terms of the impact on the crops within an agrivoltaic system, fixed-tilt arrays create more spatial heterogeneity because of distinct patterns of shade directly behind the panels and more full sun in front of the panels. Tracking panels also introduce heterogeneity in the timing of shade, but these patterns vary throughout the day and allow all understory vegetation to receive direct and indirect light within a single day.

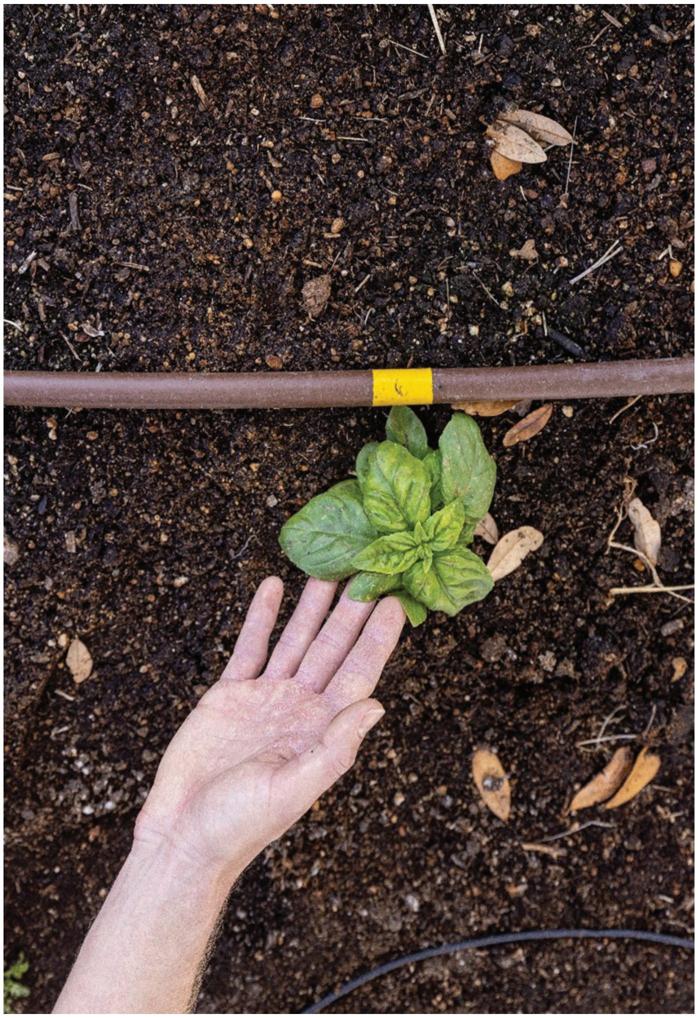
MANAGING SOIL MOISTURE – ACCESS, EXCESS, AND NEW RATES OF DELIVERY

Solar panels in agrivoltaic systems create a novel microclimate beneath them, often characterized by cooler temperatures and higher humidity levels (Barron-Gafford et al., 2019; Weselek et al., 2021 Marrou et al., 2013). Traditional irrigation methods designed for open-field crops may not be optimal in an agrivoltaics environment, meaning it may be necessary to adjust irrigation strategies.

While climate change is decreasing water availability, it is also increasing the need for irrigation in traditional agricultural setups by increasing evapotranspiration (Careta et al., 2022). Evapotranspiration is the combined processes of water transpiration from plants and evaporation from soil. It represents a critical factor in agricultural water dynamics and varies significantly across global ecoregions. This makes the imperative for adjusted irrigation strategies in agrivoltaic systems even more pressing—not only for crop growth optimization but also as a climate adaptation strategy.

Benefits of Agrivoltaics in Drier Environments

In arid and semi-arid regions, such as the Southwestern United States, the Sahel region, North Africa, parts of Australia, and South and Eastern Asia, evapotranspiration rates often



Moist soil surrounding basil grown under solar in Tucson, Arizona. Photo: AgriSolar Clearinghouse

exceed precipitation inputs. This imbalance induces significant water stress on crops in traditional agricultural systems, requiring high water inputs for irrigation. A primary driver of the potential for agrivoltaics within these drier regions is the persistent and often growing challenge of access to water for irrigation. Agrivoltaic systems can be an effective climate adaptation strategy because of their ability to mitigate these challenges through their microclimate modifications, specifically by reducing evapotranspiration and crop water needs.

The shading provided by solar panels reduces the amount of direct sunlight reaching the soil and plants, thereby lowering soil temperatures and reducing water evaporation. This cooler, more humid microclimate beneath the panels decreases the water demand of crops, making irrigation more efficient and less frequent. As a result, agrivoltaic systems can significantly reduce the overall water use in agriculture, which is particularly beneficial in water-scarce regions. Moreover, the reduced evapotranspiration rates in agrivoltaic systems help maintain soil moisture levels, further enhancing crop resilience to drought conditions. This is crucial as climate change continues to decrease water availability and increase the need for irrigation in traditional agricultural setups by raising evapotranspiration rates. By optimizing water use, agrivoltaic systems not only support sustainable agriculture but also serve as an effective climate adaptation strategy.

Considerations for Wetter Climates

In wetter climates, where water availability is less of a concern, the primary focus of agrivoltaic systems shifts from drought mitigation to optimizing crop growth and energy production. While the cooler, more humid microclimate created by solar panels can still benefit crops by reducing heat stress, the irrigation strategies must be adjusted to prevent waterlogging and ensure proper drainage.

In these regions, traditional irrigation methods may still be applicable, but they need to be fine-tuned to account for the modified microclimate. For instance, the increased humidity under the panels can lead to higher risks of fungal diseases and other moisture-related issues. Therefore, it is essential to monitor soil moisture levels closely and adjust irrigation schedules accordingly to avoid overwatering.

Additionally, the choice of crops in wetter climates should consider the shading effects of the solar panels. Crops that thrive in partial shade, such as certain leafy greens and herbs, can benefit from the modified microclimate. It is important to ensure that these crops do not receive excessive moisture to prevent a negative impact on their growth.

Sensors measuring soil moisture, plant, and microclimate conditions at Biosphere Agrivoltaic Site in Oracle, Arizona. Photo: AgriSolar Clearinghouse

Optimizing Water Resources in Agrivoltaic Systems

Regardless of the climate, optimizing soil moisture is a fundamental consideration in the design and operation of agrivoltaic systems. Several well-established irrigation techniques can help optimize soil moisture. Subsurface drip irrigation represents one of the most advanced approaches, delivering water directly to the root zones while minimizing water loss through evaporation. This method is particularly effective in both dry and wet climates, as it ensures precise water delivery and reduces the risk of overwatering.

Sensor-based, real-time monitoring of soil moisture, plant stress, and microclimate conditions can further enhance irrigation efficiency. By providing accurate data on the water needs of crops, these sensors enable farmers to adjust irrigation strategies dynamically, ensuring that water is used efficiently and effectively. Precision irrigation can be the most efficient tool for delivering water only when the plants need it, based on differential rates of soil dry down. This is because irrigation needs can be determined, and the water can be delivered when the soil reaches preset limits. This technology is especially valuable in agrivoltaic systems, where the microclimate can vary significantly from traditional open-field conditions, and farmer experiences of irrigation demands are based solely on prior, full-sun conditions.

Key Considerations:

- **Microclimate Effects**: Solar panels help reduce soil evaporation by providing shade, which may reduce the need for irrigation, particularly in arid regions. The cooling effect of the panels reduces heat stress on crops.

Benefits:

  - Reduced water evaporation can improve water-use efficiency, especially in hot climates.
  - Solar panels can help retain soil moisture during dry periods.

- **Irrigation Systems:** Integrated irrigation systems such as drip irrigation or subsurface irrigation are recommended in agrivoltaic systems to ensure efficient water delivery directly to the root zone.

Recommendation:

  - Use drip irrigation with automated controls to optimize water distribution, reducing waste and increasing crop yields.

- **Rainwater Harvesting:** Collecting rainwater from solar panel surfaces can help manage water resources, particularly in areas with irregular rainfall patterns. Storing this harvested water on-site for future irrigation can help create more water sovereignty for a site.

A NEW MICROCLIMATE – SAME OLD CROPS AND NEW OPPORTUNITIES

As described above, agrivoltaic systems create a unique microclimate characterized by modified temperature, light, moisture, and plant growth conditions. Daytime temperatures tend to be marginally cooler in the shade of solar panels, while nighttime temperatures tend to be higher, providing a stabilizing effect that can protect crops during periods of significant temperature fluctuations. This temperature stabilization, along with modified light intensity and availability, offers both challenges and opportunities for crop growth. Understanding these microclimate modifications is crucial for selecting crops that will thrive in agrivoltaic systems.

Benefits of Continuing to Grow Existing Crops

A primary benefit of agrivoltaic systems is their ability to create more consistent growing conditions through temperature stabilization. For farmers already cultivating certain crops, this can mean enhanced resilience against extreme weather events and temperature fluctuations. Crops that are already well adapted to the local climate can benefit from the moderated microclimate, potentially leading to improved yields and quality.

Leafy greens such as lettuce and spinach are sensitive to high temperatures and thrive under the partial shade provided by solar panels. The cooler daytime temperatures can reduce heat stress and prevent bolting, while the higher nighttime temperatures can protect against frost damage. Similarly, crops like strawberries, which require consistent moisture levels and are prone to heat stress, can benefit from the moderated microclimate and improved moisture retention under the panels.

Crops under morning solar panel shade at Jack's Solar Garden. Photo: University of Arizona

Crops under solar panel at noon at Jack's Solar Garden. Photo: University of Arizona

Continuing to grow existing crops in an agrivoltaic system also allows farmers to leverage their existing knowledge and experience with these crops. This can reduce the learning curve and risks associated with transitioning to new crops, while still reaping the benefits of the agrivoltaic setup. Additionally, maintaining the same crops can help preserve established markets and customer bases, ensuring a steady income stream.

Potential Benefits of Growing New Crops

While continuing to grow existing crops has its advantages, agrivoltaic systems also open up opportunities for cultivating new crops that can take full advantage of the modified microclimate. The unique environmental conditions created by solar panels can support the growth of crops that might not thrive in traditional, open-field conditions.

For example, shade-tolerant crops such as certain varieties of mushrooms, herbs like basil and cilantro, and specialty greens like arugula and kale can flourish under the reduced light intensity of agrivoltaic systems. These crops often have higher market values and can cater to niche markets, providing farmers with new revenue streams. The cooler, more humid microclimate can also support the growth of crops that require specific environmental conditions, such as certain medicinal plants and high-value horticultural crops.

Exploring new crops can also help farmers diversify their production, reducing the risks associated with monoculture and market fluctuations. Diversification can enhance farm resilience and sustainability, making agricultural practices more adaptable to changing climate conditions and market demands.

Specialty crops and high-value products that thrive in the agrivoltaic microclimate can attract premium prices and cater to health-conscious consumers, gourmet restaurants, and niche markets. This can significantly increase farm profitability and provide a competitive edge in the agriculture sector. The sustainable and innovative nature of agrivoltaic farming can

Crops under afternoon solar panel shade at Jack's Solar Garden. Photo: University of Arizona

appeal to environmentally conscious consumers and businesses. Marketing products as being grown in an agrivoltaic system can enhance their appeal and marketability. This strategy taps into the growing demand for sustainable and eco-friendly products.

Regardless of whether new or the same crops are grown, farmers should look for changes in the phenology (timing of a plant's life stages) that can sometimes come with agrivoltaics. Earlier and later timing of germination, bud and fruit-setting, and senescence have all been documented in agrivoltaic systems due to the changes in soil surface and air temperature, seasonality of dry/wet periods, and fluctuations in day lengths.

Key Considerations:

- **Plant Shade-tolerance:** Some crops thrive in shaded conditions, while others may suffer from reduced yields under the canopy of solar panels. Shade-tolerant crops such as leafy greens (e.g., lettuce, spinach), herbs (basil, cilantro), and root vegetables (e.g., radishes, carrots) often perform well under partial shading.

  Recommended Crops:

  - Shade-tolerant: Lettuce, kale, spinach, arugula, microgreens, herbs
  - Moderate shading: Tomatoes, peppers, cucumbers, beans, and squash

- **Growth Stage Considerations:** Plants that require intense sunlight during their early growth stages may be less suited for agrivoltaic systems. However, crops with staggered growth cycles, where shading is more beneficial during hotter months, may benefit from reduced stress.

  Recommendation:

  - Incorporate crops with growth cycles that can adapt to intermittent shading or select crops that have shorter growing seasons.

- **Water Efficiency:** Crops that require less water or are drought-resistant, such as certain grains (e.g., millet) and pulses (e.g., chickpeas), may perform better in regions where water availability is a constraint.

- **Cover Crops:** Planting cover crops like clover, vetch, or a mix of legumes can improve soil health and prevent erosion while benefiting from the reduced sunlight. This regenerative and climate-smart practice is well-aligned with agrivoltaics, in that many cover crop species perform well within the partial shade of PV arrays and can help mitigate the adverse effects of compaction associated with PV installations.
- **Temperature Variations:** While panels can provide shade, they can also create: 1) microclimates that might not be ideal for all crops; or 2) vary dramatically throughout the day as the apparent migration of direct sunlight tracks overhead. Within high light environments and cropping systems with multiple rows, direct sunlight may hit one row in the earlier hours (creating a net benefit), whereas other rows might receive direct sunlight later in the day when temperatures exceed the thermal optimum of the plant.

  Recommendation:

  - Intentionally plant more shade-tolerant or temperature-stressed plants in the beds that receive morning sunlight and plant the sun-loving plants that are less stressed by higher temperatures in the beds that receive direct sunlight in the afternoon.
- **Accessibility for Maintenance:** The placement of solar panels can limit access for farming equipment and workers, making it difficult to perform necessary agricultural tasks like planting, harvesting, or maintenance.

Additional Benefits:

- Beyond agricultural considerations, these microclimate modifications can improve solar panel performance. Cooler panel temperatures have been shown to enhance energy generation efficiency, creating a win-win scenario for energy and agriculture production.

BENEFITS FROM CROP-BASED AGRIVOLTAICS CAN TIP THE SCALE OVER THE NEW CHALLENGES ASSOCIATED WITH FARMING AMONG SOLAR

Agrivoltaic systems offer great promise for sustainable agriculture and renewable energy production, but successful implementation requires a careful balance of agricultural practices and solar energy considerations. By applying best practices related to system design, crop selection, water management, and regular maintenance, farmers and solar developers can optimize both crop yields and solar energy output. Across the global network of agrivoltaics research, some negative impacts of growing within a solar array have been documented. However, from these sites, we have learned of the need to alter the amount of sunlight captured by the PV panels and the amount shared with the accompanying agriculture. Building upon these lessons and using the recommendations described here can tip the scales of nearly any agrivoltaics installation to a net-positive impact for both food and energy production.

Final Recommendations:

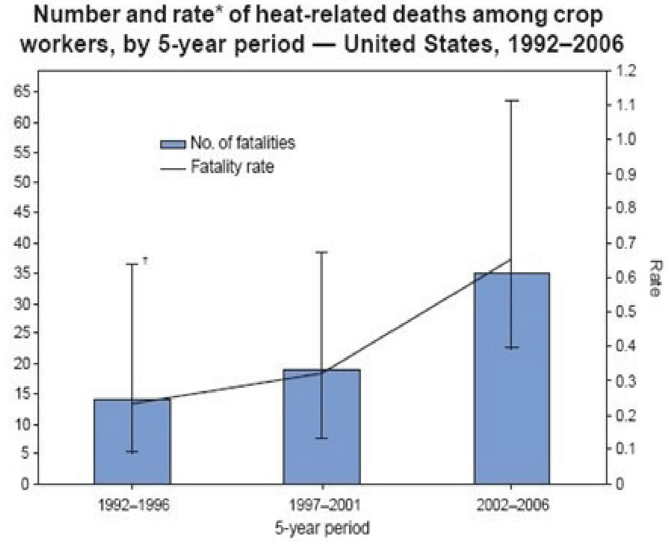
- Focus on the **Five Cs of Agrivoltaic Success:** Context, Collaboration, Communication, Compatibility, and Capacity.
- Invest in **adaptive management practices** that can adjust to changes in climate, crop performance, and system output.
- Use **precision agriculture** techniques and data-driven decision-making to optimize resource use and system performance.

By integrating these strategies, agrivoltaic systems can become a sustainable and profitable solution for farmers and solar developers, contributing to both food security and clean-energy goals.

Chapter 3

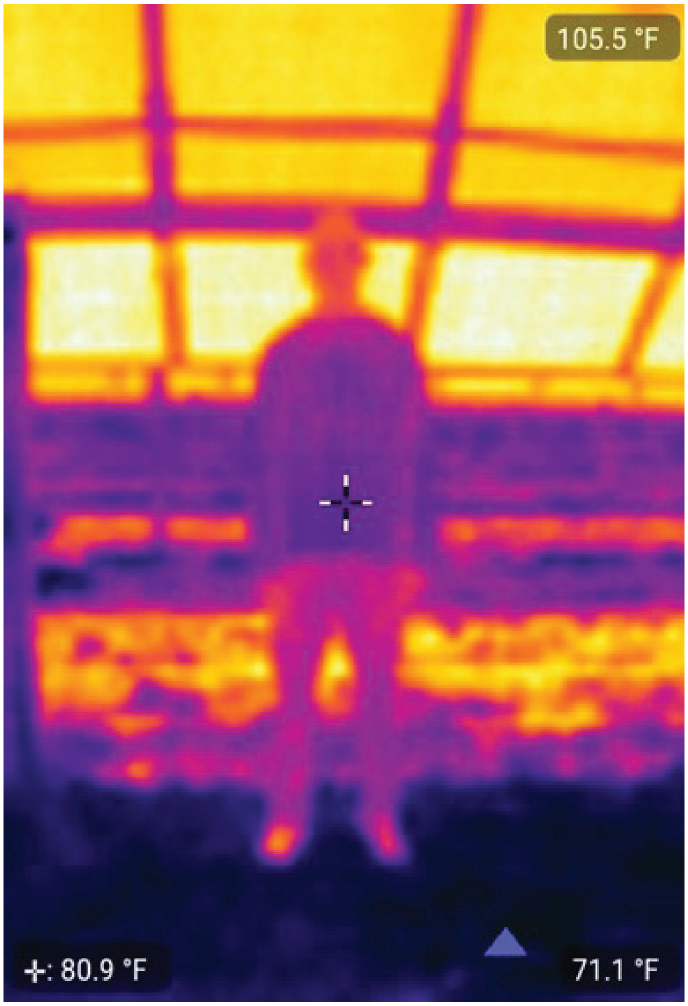
Solar Panel Shade and Potential Health Impacts

Stacie Peterson, National Center for Appropriate Technology
Talitha H. Neesham-McTiernan, University of Arizona



* Per 100,000 workers. Rates calculated using annual national average estimates of employed civilians aged ≥15 years based on the Current Population Survey.
† 95% confidence interval for fatality rate.

Figure 1. Mortality Rate of Heat-Related Deaths Among U.S. Crop Workers (CDC, 2008)



Thermal image of farm worker under solar panel, showing external body temperature of 80.9°F with outdoor temperature of 90°F. Photo: NCAT

Farmworkers are a particularly vulnerable population for heat-related illnesses because they perform manual labor outdoors, in direct sunlight, often in heavy, impermeable work clothing, during the hottest season (Association of Farmworker Opportunity Programs, 2024; El Khayat et al., 2022; EPA, 1983; Bethel and Harger, 2014). The trend of increasing temperatures globally will lead to an increase in heat-related deaths, heat stroke, and dehydration, as well as cardiovascular, respiratory, and cerebrovascular disease, particularly in sensitive populations (USGCRP, 2016). The United Federation of Farm Workers has called for workplace protection because farmworkers "are at the frontlines of climate change as extreme heat continues to expose them to more danger" (UFW, 2023). The workplace mortality rate for farmworkers from heat-related illness is 20 times higher than the U.S. civilian working population and this trend is increasing, as shown in Figure 1. A separate study by the National Institute of Health showed agricultural workers suffered heat-related mortality at a rate 35 times higher than all industries in the United States during

Sheep grazing in the shade of solar panels. Photo: NCAT

the 10-year period of 2000 to 2010 (Gubernot et al., 2015).

In addition to mortality, many farmworkers experience heat-related illnesses such as heat exhaustion, heat stress, heat stroke, cramps, and rashes (Association of Farmworker Opportunity Programs, 2024). Several strategies can successfully alleviate heat stress and mortality. A consistent recommendation is providing farmworkers with access to shade (OSHA, 2023; EPA, 2023). However, farmworkers do not always have consistent access to shade (El Khayat, 2022). Solar arrays could provide this consistent shade, if designed to accommodate farmworkers, with a panel heigh of 6 to 8 feet.

Heat stress also affects farm animal health. In a study of the thermal comfort and wellbeing experienced by dairy heifers provided solar panel shade, researchers showed that shade provided by the solar panels efficiently relieved heat load on the cattle, cooled off their body surface and skin temperatures by 10.8°F, and decreased the costs of thermoregulation (Faria et al., 2023). A study of heat stress, solar panels, and dairy cattle in Minnesota found a decrease in heat stress in dairy cattle under solar panel shade, corresponding to a decrease in body temperature (Sharpeet al., 2020).

A separate study on heat stress and sheep with access to solar panel shade found a decrease in wool-surface temperature in ewes ranging from 44.6°F to 46.4°F and a decrease in skin temperature of 33.8°F to 34.7°F (Fonsêca et al., 2023).

POTENTIAL SOLAR SHADE HEALTH IMPACTS

Agrivoltaic systems have been primarily designed to optimize electricity production and crop yield; however, the altered microclimate created by these installations can also have significant impacts on human health. The nature of agrivoltaic systems modifies key environmental factors, including direct sunlight, air temperature, humidity, and wind speed, each of which can influence a person's thermal comfort. This means that the same design considerations that change the growing environment for crops or electricity production also shape the working environment for farm workers.

Overhead agrivoltaics can shield workers from direct sunlight, significantly reducing their heat exposure compared to open-field farming. This reduction in direct sunlight, along with increased evaporative cooling from higher water availability in agrivoltaic systems, can also reduce air temperature below the panels. In hot, dry regions, where water is naturally limited, this reduction in air temperature can be more pronounced.

In more temperate or humid climates where natural, evaporative cooling is already present, these cooling effects may be less pronounced. In these regions, while farm workers still benefit from the shade, the overall effect of agrivoltaics on thermal comfort is likely to vary from what is observed in hot, dry climates. The impact of agrivoltaic systems on wind patterns complicates things by either blocking or redirecting airflow, which can impact ventilation and change how the temperature is experienced by those working in and around the agrivoltaic system.

The complexity of agrivoltaic design, as well as variations in geographic and climatic conditions, means that it is challenging to make general conclusions about the impact of these systems on human comfort and health. The interactions between panel height, spacing, orientation, and the local climate have the potential to create diverse microclimates that require careful consideration of their impact on labor conditions. Panel design and configuration significantly influence the patterns of shade and direct sunlight within the agrivoltaic system. These patterns create dynamic thermal environments that vary throughout the day and across the season. Understanding these patterns and developing work schedules around them can help minimize the risk of heat stress and maintain favorable working conditions through the growing season.

While touring agrisolar sites, the AgriSolar Clearinghouse team performed skin temperature readings under solar panels and in full sun. Table 1 shows the consistent decrease in skin temperature throughout the country, ranging

Agrisolar Location	Full Sun Skin Temperature (Fahrenheit)	Solar Shade Skin Temperature (Fahrenheit)	Skin Temperature Decrease (Fahrenheit)
Lake Pulaski, Minnesota	100.5	80.6	19.9
Monson, Massachusetts	101.3	93.5	7.8
Boulder, Colorado	90.7	75.4	15.3
Butte, Montana	101.2	81.8	19.4
Phoenix, Arizona	100.6	79.8	20.8
Champaign, Illinois	102.5	94.1	8.4

Table 1. Skin Temperature Readings in Full Sun and Under Solar Panels.

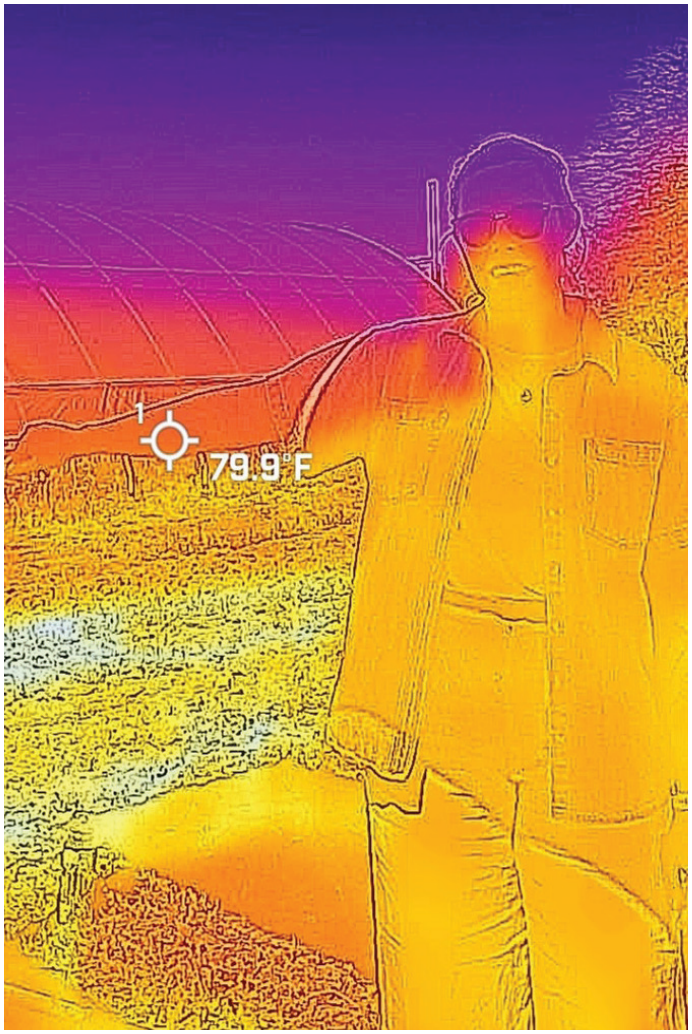
from 7.8°F to 20.8°F, and the subsequent photos show infrared reading and skin temperature of a farm worker in Phoenix, Arizona.

Based on skin temperature tests and animal testing at solar arrays, there is a potential for solar panels to provide shade to farmworkers and help alleviate heat stress. While other farmworker safety measures can and should be incorporated, such as water, rest, and acclimatization, a decrease of 10°F to 20°F could potentially alleviate heat-related illnesses and curb heat-related mortality.

Additionally, timing agricultural work to coincide with the full shade of the solar panel and designing panel heights to accommodate farmworkers and animals, meaning a panel height of 6 to 8 feet, would ensure consistent access to the shade and its benefits.

In addition to temperature effects, the potential impacts of these systems on farmworker wellbeing extend beyond just temperature. As we recognize the complexities of optimizing these systems for crop yields or electricity production, agrivoltaic research and practice should consider the human health dimension at the core of system design. This expanded focus will be key in developing systems that not only optimize electricity and agriculture production but also create more comfortable and safer work environments for the workforce that maintains them.

Skin temperature of 100.6°F in direct sunlight in Phoenix, Arizona.



Skin temperature of 79.9°F in the shade of a solar panel in Phoenix, Arizona.

Chapter 4

Solar Grazing Best Management Practices

American Solar Grazing Association

INTRODUCTION TO SOLAR GRAZING

Solar grazing is a relatively new and growing industry that uses livestock—most commonly sheep—to graze solar sites as a form of vegetation management. Within these systems, graziers form a contract with site owners to be compensated a fee for grazing to promote a shared purpose of the land and reduce the usage of traditional, mechanical mowing. Solar grazing compared to traditional (gas-powered) vegetative maintenance offers benefits for the solar operator, grazier, and animals.

Graziers receive additional land access to expand their grazing operation in a financially stable way, while their animals have access to improved forage quality and shaded environments (Kampherbeek et al., 2023; Andrew et al., 2021; Maia et al., 2020). Solar operators gain community support from co-locating solar and agriculture while also improving soil health through proper grazing management (Pascaris et al., 2022; Makhijani, 2021). This section seeks to identify best management practices for solar grazing to capitalize on maximum benefits for those involved in the solar-grazing industry.

LAND ACCESS

One main component of solar grazing practices is to understand the importance of a contract that aligns with the specific elements of the operation and agreements between the involved parties. While solar grazing allows graziers to expand their access to land beyond their home farm, there are many factors to consider before getting involved in a (solar grazing) contract. The ability to have livestock on solar sites is dictated by the state, city, and site owner. For graziers interested in starting solar grazing, EIA's Energy Mapping Tool is useful for finding constructed solar arrays across the United States.

A strong network of connections during this process is one of the greatest resources a potential solar grazier can have. The American Solar Grazing Association (ASGA) is a valuable organization for helping to establish connections with farmers and solar developers, providing several resources and recommendations to get started. The process of starting grazing at a solar site may not always be quick and easy, but with some patience, the benefits from having additional land access from solar greatly outweighs the challenges. As one of the first solar graziers in the U.S., Solar Sheep LLC's Julie Bishop has experienced this firsthand.

Case Study: Julie Bishop, Solar Sheep LLC

Julie Bishop's involvement in the solar grazing industry began with a snowball effect after receiving a herding dog. Once she acquired a herding dog for her grazing operation, she trained it in herding at her home, which progressed to owning ewes and lambs and operating a hobby sheep farm. Then, in 2013, Bishop discovered that there was a solar field just five miles from her New Jersey home. She soon realized that sheep could manage the vegetation just as well as the traditional gas-powered mowers that were used on the site. She then got to work to make her idea a reality.

Bishop began the lengthy process of getting her sheep on that solar site. The land had originally been used as agricultural land but had been forfeited for the sole use of solar. Bishop and the solar company had to go to the municipality to ask for agriculture to be reinstated at that site. Additionally, they had to appear in front of the zoning and planning departments, send a letter to the community, and hold an open comment period in order to receive a variance. Finally, after nearly a year, Bishop was approved to move forward and was able to bring her sheep on-site for grazing.

Despite being one of the first solar graziers and not having connections to consult, Bishop was able to successfully manage her first site. News of this success spread, and additional companies reached out to Bishop to form new contracts. Since then, she has grazed in three states.

Bishop says that solar grazing changed her life. Once a teacher, she is now a successful farmer who is only able to have her sheep operating at a larger capacity than she initially anticipated because of solar grazing. Her home farm is six acres, but the solar sites she grazes provide her the space she needs to expand her operation. She is now at the point of maximum capacity unless she changes her management style.

Currently, Bishop puts dry ewes on the solar site in the spring, then adds and removes rams, and brings the ewes home at the end of the grazing season to lamb around November and December. The lambs are then weaned, and the dry ewes return to the solar site. To expand her operation, Bishop would instead start lambing on the solar site around April and May. While the lambing process requires a lot of initial work, it would lead to a less labor-intensive and lower input management for Bishop. Along with changing the way she grazes, Bishop is waiting for more solar sites that are in close proximity to her home farm.

A sheep under solar panels. Photo: American Solar Grazing Association

In addition to the challenges with expanding, Bishop identified some aspects of solar sites that can prove difficult when compared to traditional sheep management, such as site layout, trucking in water, and exterior perimeter fences that lack proper predator-proofing. After years of experience, Bishop has the knowledge and practice to overcome these challenges. For example, she worked with the solar developer at a site to build a bracket to prevent sheep from rubbing up against an emergency switch. The bracket keeps the equipment safe from the sheep but still provides easy access for a person as needed.

The sites that Bishop grazes were not created with the intention of solar grazing, and this can lead to difficulties such as a poor line of sight when moving sheep. Bishop has been able to overcome this issue with the assistance of a well-trained herding dog. It is only fitting that the reason she became involved in the solar grazing industry is now one of her greatest assets.

Sheep moving through a solar site. Photo: AgriSolar Clearinghouse

In her solar grazing work, Bishop has seen a shift in community perception. During the initial stages of solar development, there was pushback from communities that did not want agricultural land being used for solar development. Once Bishop brought the idea of solar grazing to the community, there was still some hesitation toward the new concept, and no one knew what to expect. Her success has allowed the community to view dual-use solar in a different way, and there is now a positive perception of solar grazing in her area.

As one of the first solar graziers, Bishop is well equipped to provide advice to those looking to join the industry. She suggests teaming up with someone who has experience in solar grazing to learn the ins and outs of the practice. Additionally, patience is necessary. It is difficult to plan, and there are often periods of waiting for approvals and construction. Finally, she recommends carefully selecting sheep that will be a good fit for the management system.

Bishop is a true example of the beneficial opportunities that solar grazing can provide. The additional land access granted to her through her contracts allowed her to not only expand her operation, but also to become an innovator in the expanding industry.

CONTRACTS

Once a grazier and solar developer have agreed to partner together to manage a site, a contract is needed. ASGA has partnered with the Food and Beverage Law Clinic at Pace University's Elisabeth Haub School of Law to provide sample contracts for solar grazing. The contract serves as a template for a Master Services Agreement (MSA) involving all arrangements between the farmer and solar company. Additional Statements of Work (SOW) are included for specific terms within the contract.

ASGA's sample contract provides an ideal starting point for conversations between solar graziers and solar operators. It is important to consider that every site will be different, and the contract can be adjusted as needed. To ensure proper maintenance of the site and the relationship between the grazier and solar operator, both parties must fully understand what services are included in their contract. As solar grazing gains popularity, many farmers enter into contracts that allow them to provide a hybrid vegetation-management approach where the graziers maintain all or most of the vegetation at the site, including clean-up mows following grazing or spot-spraying as needed. Contract lengths and fees will vary depending on the site, and it is important to determine the best approach for both parties. This concept is one that United Agrivoltaics is familiar with.

Caleb Scott of United Agrivoltaics at a solar site. Photo: Caleb Scott

Case Study: Caleb Scott, United Agrivoltaics

In 2012, Caleb Scott was working with solar developers to help seed and build sites. As he got more involved in the industry, his job expanded to help properly maintain these sites. Scott began mowing the solar sites but quickly realized it was a challenging task. Every site was different, with varying degrees of ground levelness, infrastructure spacing, and site vegetation-management requirements. Additionally, he had to be careful around the panels to avoid any damage from his equipment.

When not working on-site, Scott, a seventh-generation farmer, took care of his flock of sheep. He realized that sheep would do a much better job at vegetation management than mowers and would get around easier. However, despite his experience in managing sheep and solar vegetation, it was difficult to convince the industry that sheep could be a valuable form of vegetation management. Scott began to work with Cornell University to collaborate with solar developers and use the University's property to perform a demonstration site for solar grazing. This work gave him proof of concept, and he began grazing on solar sites in 2013.

After Scott received his first solar grazing contract, he was able to grow and strengthen his practice. In addition to being a founding board member of the American Solar Grazing Association, he also created United Agrivoltaics, one of the first and oldest agrivoltaic sheep-grazing firms in the U.S. United Agrivoltaics functions as a co-operative to promote expansion of the solar grazing industry and now has 103 sites in nine states. The organization uses Scott's unique background to provide vegetation management with solar grazing, as well as consulting to implement agrivoltaics on solar projects.

Scott and the other 80+ graziers involved with United Agrivoltaics pride themselves on creating a healthy, shared-use system. While their specialty is in solar grazing with sheep, they have also used chickens, turkeys, rabbits, and pigs to help maintain the site vegetation and increase the overall productivity of the site. Scott uses three different styles of grazing: mob, rotational, and low-impact sustained grazing. These management methods provide financial benefits in some cases and health benefits in others. Scott's main priority when deciding which style to use depends on what is going to work best for the on-site forage content, as well as for his farm and animals.

United Agrivoltaics recognizes the variability between sites and offers different tiers of service to help overcome this. This is a major benefit for asset owners as it allows them to form a contract and relationship with one party for all their site-management needs. Scott's full management package includes services such as exterior perimeter mows, spraying herbicide as needed to control noxious or invasive species, and a clean-up mow to manage the vegetation the sheep did not eat.

The flexibility of United Agrivoltaics' services has helped the organization grow over time. They are currently grazing 15,000 sheep on more than 5,100 acres of solar sites, with a goal to double the number of sheep in the upcoming year. Scott himself is grazing 650 sheep on 200 acres, and this growth allowed solar grazing to become his full-time job. He and United Agrivoltaics have purchased and acquired other companies along the way to help them grow.

As United Agrivoltaics continues to expand, they ensure that their services remain competitive with the costs of mechanical mowing. The grazing costs will vary depending on location and which rating scale the site owner chooses for their site. In an area with farm readiness considerations being met, fees can range from $380/acre for the full management package to more than $1,500/acre. Despite the large range in pricing, Scott recognizes that generalizing pricing would have a negative impact on the solar grazing industry due to the number of variables that determine contract pricing, such as site management requirements and feasibility for the grazier.

In addition to difficulties associated with selecting the correct pricing for a site, insurance can be an added challenge when solar grazing, as extra costs typically do not outweigh the value of the contract. One of Scott's biggest initial challenges in the solar grazing industry was learning to manage the site as dictated by the contract. In some cases, he has had to change his vision of what he thinks the site should look like in order to meet the site owner's needs. Farming motives can differ from solar operation motives and requires calculating the correct stocking densities.

Sheep grazing the vegetation at a solar site. Photo: Caleb Scott

To help overcome these challenges, Scott's advice is to reach out and talk to someone who has done it before to ask a lot of questions and educate yourself.

> ***"This industry requires a lot of teamwork, especially since the solar grazing industry is so young and we have so few sheep in the country. We need to help and support one another." — Caleb Scott.***

Teaming up with individuals who have prior experience could allow for sharing things like insurance (costs), equipment, and other resources, which could mean saving additional money. It is also beneficial to discuss contracts with those who have experience. Scott recommends finding an organization, like ASGA, that helps farmers and joining them to learn and share ideas.

A trio of sheep on a solar site. Photo: American Solar Grazing Association

This teamwork represents Scott's overall goal for the solar grazing industry and United Agrivoltaics, which is to have as many sheep in the organization as are currently in the U.S. right now–over 3 million. He wants to accomplish this by expanding his company and farming group nationwide. By doing so, he hopes to see the sheep industry increase tenfold in the next 20 years, and he wants to be a part of that change. If this were to be accomplished, it would undoubtedly afford tremendous benefits for the solar-grazing industry.

OPERATIONS AND MAINTENANCE CONSIDERATIONS

As mentioned in the Bishop and Scott case studies, when solar grazing was first introduced, the solar sites were created without any consideration for bringing animals on-site. With solar grazing and agrivoltaics gaining popularity, site developers can,and should, place emphasis on creating a livestock-friendly array. Areas of consideration include site preparation and vegetation establishment, costs, and creating a safe environment for the animals and graziers.

Site Preparation and Vegetation Establishment

When preparing a site for solar development with the intention of grazing, it is important to involve multiple stakeholders, including O&M producers, graziers, environmental scientists, and the community. Conversations with these stakeholders should focus on Macknick et al.'s 5 Cs of success: collaboration, compatibility, solar panel configuration, climate, and crop selection and cultivation (Macknick, 2022).

Establishing permanent pastures prior to site construction can improve soil health (Makhijani, 2021). Soil health can be monitored with soil testing over the project's lifespan to ensure it is being properly managed. Diverse seed mixtures can provide optimal benefits for both site and animal health. For example, when grasses and legumes are sown together, the quality of forage and soil fertility is improved, with the higher-quality forage promoting animal health (Mamun et al., 2022; Andrew et al., 2024). Native and pollinator-friendly groundcover can also be considered, providing benefits for pollinators, the soil, and nearby agricultural land (Horowitz et al., 2020; Makhijani, 2021). No matter the approach to seeding a site, special care should be taken to avoid toxic or invasive species on-site and in perimeter areas.

Cost Considerations for Grazing-Intended Solar Sites

When establishing a solar site with the intention of including grazing animals, there are some additional considerations that can make a site easier to graze. These include providing water on-site, adjusting site layout to assist with rotational grazing, including permanent interior fencing, and in some cases—such as with grazing cows—raising the height of the panels. However, compared with the cost of photovoltaics over bare ground, solar grazing can reduce some site preparation costs related to clearing and grubbing, soil compaction, soil stripping, and stockpiling (Horowitz et al., 2020). Profits and costs are variable depending on the size and location of installations (Makhijani, 2021).

Graziers also need to consider O&M costs that may be different from a traditional grazing system, such as the cost of travel to and from the site, hauling water to sites without water access, and potentially purchasing additional equipment to perform vegetation maintenance. Many of these costs can help graziers negotiate their grazing fees and will vary from site to site. Additional budgets can be accessed from ASGA. Even with additional considerations, a survey by Kochendoerfer found grazing sheep on solar to be a cost-effective method to control on-site vegetation, benefiting the site owners and operators, as well as the graziers (2019).

Safety

Graziers and solar developers must ensure there will be no risk to the livestock, graziers, or solar operators. For example, all wiring, inverters, CAB systems, and other equipment should be inaccessible to the livestock. Proper fencing, signage, and security should also be in place. This involves ensuring fences used for livestock are predator-proof. Signs should be posted on gates informing workers when animals are present and that gates should remain closed, and providing contact information in case of emergencies. Additional safety concerns include avoiding contact with electricity, personal protective equipment, and specifying who may enter the site (Owens, 2023).

ANIMAL MANAGEMENT CONSIDERATIONS

In addition to O&M considerations, there are different ways to use livestock to manage the site. Site management can involve different methods of grazing and different breeds of livestock. It is important to choose the proper breed of livestock that is most compatible with the site's features, such as vegetation type and panel height.

Livestock Considerations

Sheep grazing is the most common form of solar grazing, though cattle, rabbits, poultry, honey bees, pigs, and other animal operations are possible (Horowitz et al., 2020; Macknick et al., 2022). One reason that sheep are most common is that they fit in sites with little to no modification of conventional structures. Additionally, they are not known to stand or jump on equipment, do not chew wiring, and do not cause damage if they rub against the equipment (MRSEC, 2020). There are projects that incorporate cattle, but this can require a higher panel height or different site design (Makhijani, 2021). Despite the added cost, the solar panels can provide shade benefits for cows and could be feasible for areas where sheep are less common (Sharpe et al., 2021). Lytle et al. (2021) found rabbits to be viable for agrivoltaics, providing a high-value agricultural product that increased site revenue by 2.5 to 24.0% with less environmental impact than that from cattle (Makhijani, 2021). Rabbits on solar sites would require additional considerations, such as ensuring the interior fencing extends below the ground and providing lightweight portable shelters to protect against aerial predators. Regardless of which livestock is selected for solar grazing, the grazier will need to consider management styles that benefit both the animals and the solar site.

Management Considerations

While grazing animals on a solar site, factors such as grazing management style, stocking density, and timing should be considered. A prescribed grazing plan (PGP) can create the framework for graziers to follow during the solar facility's operation and includes gauging stocking rates, timing of grazing and rest periods, vegetation standards, soil conditions, and other similar details (Macknick et al., 2022). Forage testing can be used to ensure forage quality is being maintained. Rotational grazing has clear environmental benefits and is often used on solar sites. This method is known to improve soil health and forage yield compared to continuous grazing or mechanical mowing, further supporting stocking rates and economic returns to farmers (MRSEC, 2020). Other management styles, including mob grazing, low-impact grazing, or intensive grazing can be used, depending on forage availability and vegetation management goals. ASGA has released resources pertaining to the mechanics of solar grazing that can help determine the proper protocol for a site. Furthermore, combining solar grazing with pollinators demonstrates the potential for solar sites to include many ecosystem services, as shown by MNL.

Case Study: Jake Janski, MNL Pollinator Friendly Conservation Grazing

MNL is an organization with a mission to "Heal the Earth," through ecological restoration and native species landscaping. As the organization progressed, they established projects on solar sites, including conservation grazing and prioritizing native seeds and plants that provide pollinator benefits. Jake Janski, who's been with MNL for over 20 years, is one of the leading players for MNL's conservation grazing projects. Janski, Senior Ecologist and the Director of Strategic Planning with MNL, contributes to the organization's pollinator-friendly solar projects. As he continued his work, he began to see more need for prairie management on solar sites than what mowers could successfully provide. In typical situations, prescribed burns are often used to create a disturbance event, further promoting the health of the prairie. However, prescribed burns could not be used at the solar sites, requiring an alternative method.

Pollinator plants with solar. Photo: Jake Janski

After meeting a sheep farmer in 2017 who lived near one of MNL's pollinator-friendly solar sites, MNL decided to try sheep grazing to reinvigorate vegetation and remove dead thatch. With the timing falling at the beginning of the solar grazing industry's development, and with Minnesota not having a large sheep industry, Janski focused on using sheep solely to help with the pollinator habitat. In other words, they used sheep as another tool for vegetation management and chose not to place the larger focus on sheep production. Janski started seeing surprisingly good results from this method and has built up from there, expanding MNL's solar grazing projects.

MNL currently has about 60 Minnesota sites that incorporate solar grazing, with the average site being 20- to 00 acres and 2 to 10 kW. To date, they use 2,500 sheep, and they hope to expand their collaboration with other graziers to increase that number.

The sheep graze the sites for two to four weeks to maintain the vegetation and account for stocking density. Since the sheep are used as a tool to promote pollinator habitat, there is some variability in animal management. There is an ideal time each year to graze the sites, but grazing at the same time each year would negatively interfere with the botanical species composition. To avoid this interference, MNL rotates the timing of grazing between years.

Occasionally, the site will be grazed at a prime time for pollinators; however, Janski identified benefits for pollinators resulting from carefully managed solar grazing. For example, grazing allows for more gradual blooming periods. Staggering or delaying blooming extends the flowering season and will provide different food sources at different times. Grazing is also less aggressive, with plants rebounding faster than they would following a mowing event. This method promotes wildlife such as songbirds, rodents, and reptiles.

Broadly speaking, Janski believes that grazing is far easier on all habitats. MNL has secured research funding to continue an on-going study investigating the grazing impacts on vegetation and plant communities at solar sites. The results from this study should further support the benefits of solar grazing.

Despite the benefits that Janski has observed over time, there are some challenges associated with promoting a healthy trifecta of solar energy production, pollinator habitat, and animal welfare and production. One of his greatest challenges is getting the price points that are needed to build a robust program. He is competing with some low-cost mowing companies, while also dealing with overwintering costs and expenses of hauling water to sites. Janski and the team at MNL had to learn new information at a quick pace about animal health, especially on a landscape with variable conditions. Over time, they've been able to create better systems and know what to plan for.

Bringing sheep on-site has made some aspects of site management easier. They are dealing with less equipment damage and healthier soil. The sheep have helped with weed control, and while they have not completely eliminated the need for spot spraying, they are creating healthier plants with more competition that should make weed infestations less likely over time.

Sheep grazing amongst flowers at a solar site.
Photo: AgriSolar Clearinghouse

Janski shared that there was a time when an electric short started a fire on a site; however, the sheep removed the majority of the fire fuel load, resulting in a low-intensity fire that did not get hot enough to cause any damage to the panels. This is in direct contrast to mowing, which leaves a lot of material on the ground, creating a thick dense layer of fuel for fires.

With such clear advantages, it is no wonder that solar grazing has helped ease the majority of public discomfort regarding solar.

Janski recognizes that agrivoltaics (solar grazing and solar pollinator habitat) can be an important, multi-purpose system that benefits communities. He reports that every group that interacts with MNL wants to hear about solar grazing and that they enjoy seeing livestock on the land. This positive support is also helping to get policymakers on board. MNL is in discussions with the state of Minnesota about pollinator scorecards and updated policy-level incentives. Furthermore, the Minnesota Department of Agriculture is beginning to push solar grazing from an agricultural perspective, giving others the confidence to get behind it. With an increase in community support, Janski recommends creating and maintaining good partnerships with solar companies. The solar industry is a much faster moving market than agriculture in general, so forming these relationships can provide valuable updates on developments within the solar industry.

This ties in with what Janski identified as MNL's future goal: to get as far ahead of development as possible. They want to build sites that serve as a solar site and as a farm, with structures and paddocks pre-built. The sites will also promote pollinator habitat. To accomplish this, more market analysis is needed to show the importance of investing in agrivoltaic modifications at the start of site planning. Janski and MNL want to expand their reach to other states that are not yet as solar-heavy. This can be accomplished by serving as consultants to provide and share evidence and examples of sites that have seen beneficial progress during the development and operation of an agrivoltaic site to large audiences through marketing.

Goals and Benefits of Solar Grazing

The goals and management considerations will vary from site to site. Thus, there are certain goals that remain consistent across all sites (MRSEC, 2020), including preventing vegetation from shading solar panels, controlling invasive plant species, maintaining a diverse plant community, controlling erosion, and maximizing the opportunity for soil carbon sequestration by increasing topsoil and root mass. When managed correctly, grazing can satisfy all five soil health principles: "soil armor, minimizing soil disturbance, plant diversity, continual live plant/root, and livestock integration" (USDA NRCS, no date). In addition to improving soil health, water efficiency and biomass yield can be increased (Horowitz et al., 2020). To improve water quality, the vegetative quality of pastures should be promoted, soil health should be maintained, and grazing should be actively managed (MacDonald, 2021). Benefits of solar grazing are further supported by research from Handler and Pearce, who determined the global warming potential of agrivoltaics involving sheep is 3.9% better than conventional photovoltaics and grazing sheep separately (2022). These benefits further support the need for best management practices in solar grazing.

CONCLUSION

The goal of this section was to provide an overview of solar grazing and explain best management practices that provide optimal benefits for graziers, solar developers, and the environment. When done correctly, this growing industry has the potential to improve the solar and agricultural industries while promoting shared-use systems. The American Solar Grazing Association is working to publish a more in-depth review of solar grazing best management practices as part of a grant funded by the National Renewable Energy Laboratory's InSPIRE Project.

Monarch caterpillar and solar. Photo: Jake Janski

Chapter 5

Ecosystem Services of Habitat-Friendly Solar Energy

Leroy J. Walston, Heidi Hartmann, Laura Fox, Michael Ricketts, Ben Campbell, and Indraneel Bhandari, Argonne National Laboratory

This section highlights several types of agrivoltaic options related to ecosystem services that include siting considerations, ecological impacts of dual-use sites, construction methods and habitat restoration strategies. One type focuses on ecologically focused siting, construction, and vegetation management principles in an effort to make photovoltaic (PV) solar energy more ecologically compatible. This includes minimizing ecological impacts associated with siting and construction and improving the ecological value of the site through habitat enhancement. Given its ecological focus, this form of agrivoltaics design is often referred to as *ecovoltaics* (Sturchio and Knapp, 2023; Tölgyesi et al., 2023).

What are Ecosystem Services?

Ecosystem services represent the benefits that people and human society obtains from ecosystems. There are four classes of ecosystem services (MEA, 2005):

- Provisioning services—the production of goods such as food, water, and energy
- Regulating services—such as climate stabilization, carbon sequestration, and flooding and erosion control
- Cultural services—such as recreation, aesthetics, education, and spiritual opportunities
- Supporting services—services that underpin all the other benefits, including soil formation, photosynthesis, and nutrient cycling

The co-location of solar energy and habitat restoration (i.e., *habitat-friendly solar* or *solar-pollinator habitat*) has become the most popular ecovoltaics strategy to safeguard biodiversity and improve the site's ecosystem services output. Habitat-friendly solar designs typically focus on the planting and establishment of deep-rooted and regionally appropriate native grasses, wildflowers, and other non-invasive naturalized flowering plant species. The habitat created at these sites could support insect pollinators and other wildlife and improve other ecosystem services of the site (Figure 1).

But what ecosystem service benefits might be realized at solar facilities managed for habitat? Agrivoltaics can broadly improve the output of all classes of ecosystem services (Figure 2). Conceptually, solar-pollinator habitat has the potential to improve the outputs of all classes of ecosystem services (Table 1).

The pairing of solar energy and habitat enhancement sounds like a logical win-win for clean energy and biodiversity. However, several factors can influence the feasibility and ecological effectiveness of solar-pollinator habitat, such as geography, seed availability and cost, previous land use, soil type, and solar size and design (e.g., PV panel height and spacing). Several scientific studies have been conducted in recent years to examine different solar-pollinator habitat configurations and management options. Two studies in particular are the Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) and Pollinator Habitat Aligned with Solar Energy (PHASE). Both projects are funded by the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) and include a focus on the ecological and economic implications of solar-pollinator habitat. Results from these studies have shed light on which vegetation establishes at solar sites based on their unique management needs and the amount of time required for vegetation to establish and for biodiversity responses to be measured. These studies incorporate the research findings into guidelines and toolkits to assist the site-specific selection of seed mixes and management strategies to optimize the performance of solar-pollinator habitat based on ecological and economic (budget) objectives.

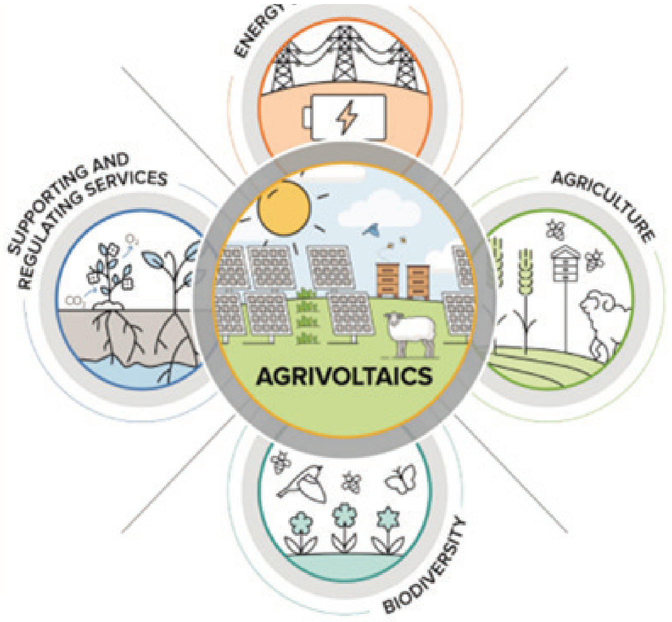


Figure 2. Ecosystem services of agrivoltaic systems (from Walston et al., 2022). Agrivoltaic systems produce electricity and thus contribute directly to energy and economy (top circle). Agrivoltaic systems also support food provisioning through on-site crop production and livestock grazing (right circle). Finally, on-site habitat management systems can support plant and animal biodiversity to help achieve conservation goals (bottom circle) and improve supporting and regulating services, including net primary production, carbon sequestration and water and soil conservation (left circle).

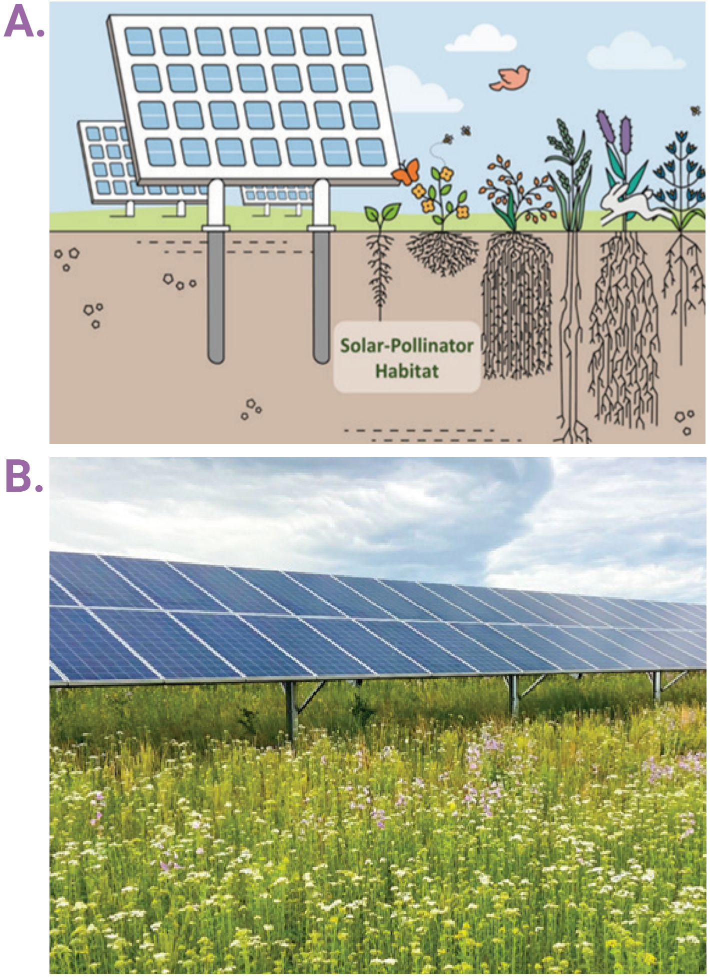


Figure 1. A) Illustration of the theoretical ecosystem services of solar-pollinator habitat. Compared to conventional groundcover, such as turfgrass, solar-pollinator habitat can provide higher-quality habitat for biodiversity. B) Example image of solar-pollinator habitat at a solar site in Minnesota. Images: Argonne National Laboratory

WHAT ARE BEST PRACTICES FOR ESTABLISHING SOLAR-POLLINATOR HABITAT?

There is growing science-based evidence on the ecological effectiveness of solar-pollinator habitat. Most of this research focuses on two main aspects: 1) vegetation establishment and management; and 2) biodiversity responses (Figure 2). One critical need for the solar industry has been assistance in selecting the seed mix design and vegetation management tools that would optimize the establishment of solar-pollinator habitat for (Continued on pg 41)

Table 1. Potential Ecosystem Services of Solar-Pollinator Habitat.

Ecosystem Service	Benefit
Biodiversity conservation (broadly linked to all ecosystem service classes)	Solar-pollinator habitat can safeguard biodiversity by supporting a larger diversity of organisms and communities. This could benefit several ecosystem services, such as food production (provisioning), recreation (cultural), water conservation (regulating), and nutrient cycling (supporting) (Walston et al., 2021, 2022, 2024; Blaydes et al., 2024).
Energy production (provisioning service)	Solar-pollinator vegetation can create favorable microclimates to improve PV panel performance (Choi et al., 2023).
Food production (provisioning service)	Solar-pollinator habitat can improve populations of insect pollinators and predators, which can benefit nearby agricultural production (Walston et al., 2024).
Carbon sequestration and soil health (regulating services)	The establishment of solar-pollinator habitat typically involves soil and vegetation management practices that allow for greater soil carbon sequestration over time, compared to other land uses (Walston et al., 2021).
Stormwater and erosion control (regulating service)	Deep-rooted solar-pollinator habitat can help stabilize soil and minimize runoff (Walston et al., 2021).
Nutrient cycling and air quality (supporting services)	Solar-pollinator habitat can improve nutrient cycling and air quality (Wratten et al. 2012; Agostini et al., 2021).
Aesthetics and recreation (cultural services)	Solar-pollinator habitat can improve human perception public acceptance of the solar site (Moore et al., 2021).

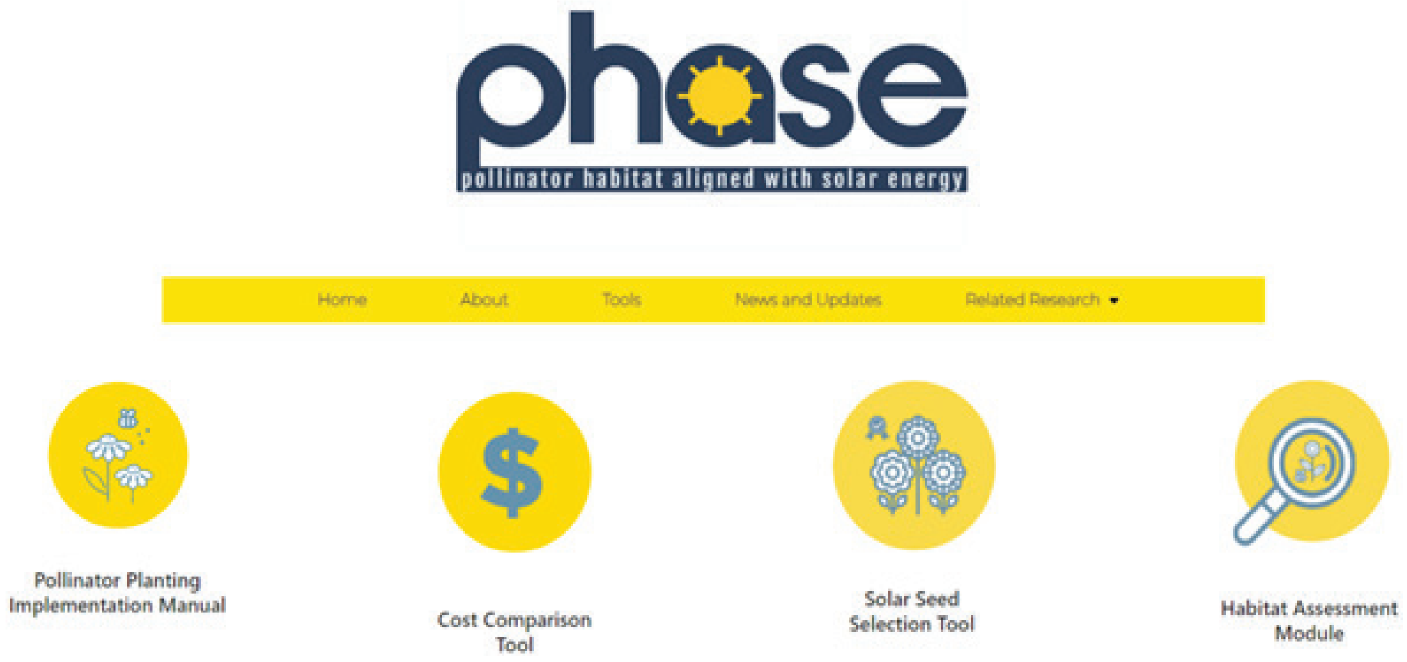


Figure 3. Solar-pollinator habitat decision support toolkits developed through the DOE PHASE project. Source: rightofway.erc.uic.edu/phase-toolkits/rightofway.erc.uic.edu/phase-toolkits/

(Continued from page 39) a site's specific physical characteristics (e.g., geographic region, soil type), PV site design (e.g., plant height restrictions), and budget. To help guide these decisions, the DOE PHASE project has produced a series of tools to inform solar-pollinator habitat planting implementation, seed selection, cost comparisons, and habitat assessment (Figure 3).

WHAT DO WE KNOW ABOUT THE EFFECTIVENESS OF SOLAR-POLLINATOR HABITAT?

This section highlights objectives and outcomes from field research projects funded by DOE to understand the ecosystem services of solar-pollinator habitat. Two case studies are presented: 1) potential biodiversity benefits of solar-pollinator habitat; and 2) potential benefits of solar-pollinator habitat for soil health.

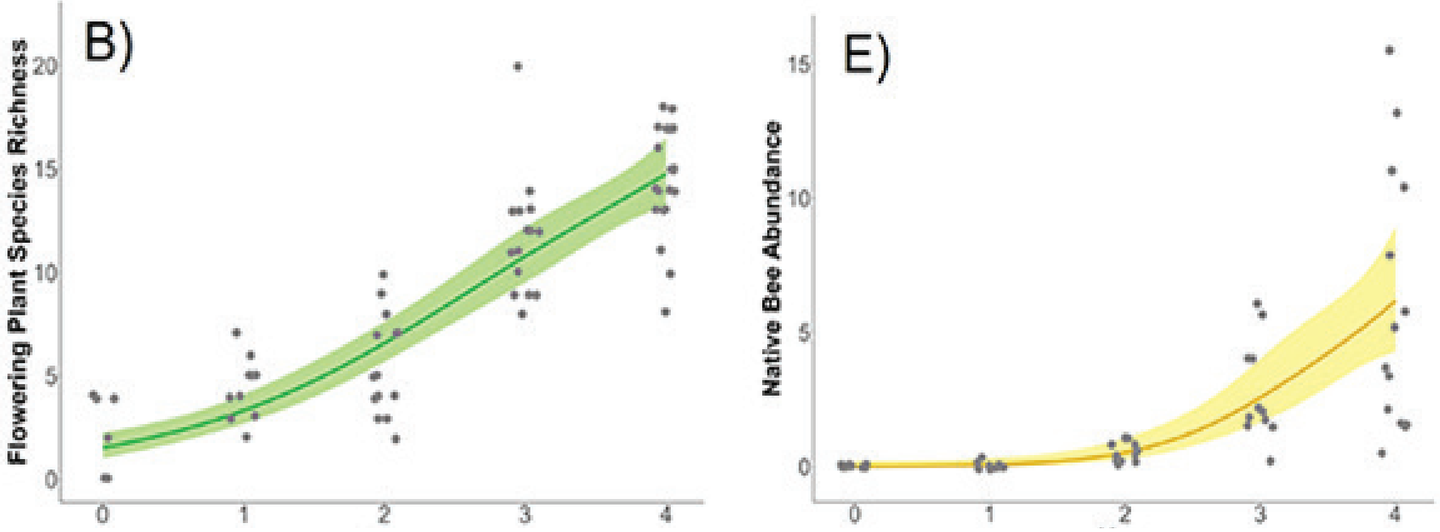


Figure 4. Observed and predicted measures of (A) flowering plant species richness and (B) native bee abundance recorded over time at two PV solar facilities planted with pollinator-friendly habitat in Minnesota. (Walston et al., 2024).

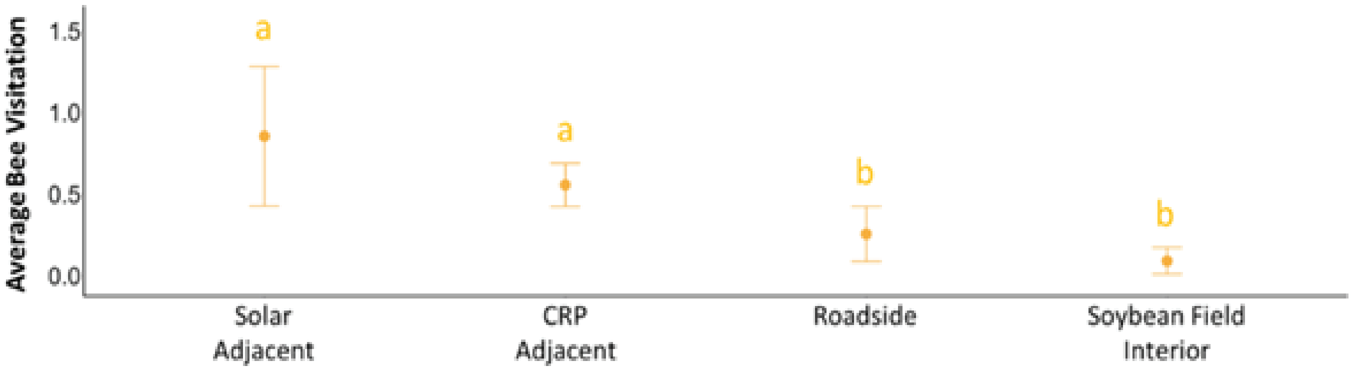


Figure 5. Observed bee visitation to soybean flowers at different field locations in Minnesota. Different letters indicate statistically different groups at the p = 0.05 level (Walston et al., 2024).

Case Study 1: If You Build It, They Will Come

A recent study from the DOE InSPIRE project examined the biodiversity responses for five years following the establishment of solar-pollinator habitat (Walston et al., 2024). The research was conducted at two Minnesota PV solar facilities owned and operated by Enel Green Power. The research team from Argonne National Laboratory, National Renewable Energy Laboratory, and Minnesota Native Landscapes conducted a longitudinal field study over five years (2018 to 2022) to understand how insect communities responded to newly established habitat on solar energy facilities in agricultural landscapes. Specifically, they investigated: 1) temporal changes in flowering plant abundance and diversity; 2) temporal changes in insect abundance and diversity; and 3) pollination services of solar-pollinator habitat to nearby agricultural fields. The team found increases over time for all habitat and biodiversity metrics. For example, by 2022, the researchers observed a sevenfold increase in flowering plant species richness, and native abundance increased by over 20 times the numbers initially observed in 2018 (Figure 4). The research team also found positive effects of proximity to solar-pollinator habitat on bee visitation to nearby soybean (*Glycine max*) fields. Bee visitation to soybean flowers adjacent to solar-pollinator habitat were greater than bee visitation to soybean field interior and roadside soybean flowers (Figure 5). These observations highlight the relatively rapid (less than four years) insect community

Figure 6. Solar-pollinator habitat and insects observed at solar facilities in Minnesota. Top: solar-pollinator habitat dominated by purple prairie clover and black-eyed Susan flowers, with a honeybee visiting a flower (inset). Bottom: solar-pollinator habitat dominated by yellow coneflower. Photos: Argonne National Laboratory

responses to solar-pollinator habitat. This study also demonstrates that, if properly sited and managed, solar-pollinator habitat can be a feasible way to safeguard biodiversity and increase food security in agricultural landscapes. Photos of solar-pollinator habitat insects visiting the on-site vegetation at these sites are shown in Figure 6.

Case Study 2: Soil Health Benefits of Solar-Pollinator Habitat

As PV solar energy sites become increasingly common, there is growing interest in identifying potential co-benefits, in addition to energy production, that could be provided using the same land area (Choi et al., 2023). These co-benefits include a variety of both economic and ecosystem services, many of which rely greatly on preserving, restoring, and/or maintaining a healthy soil environment, which is itself a valuable ecosystem service. Healthy soils are key to supporting and nurturing plant growth, and solar facilities offer a unique opportunity to improve soils that are either naturally low-quality or have been degraded from decades of agriculture. This can be accomplished through a variety of strategic planning initiatives and land management practices that focus on minimizing soil and vegetation disturbances and encouraging the establishment of ecologically friendly and sustainable ecosystems. By understanding the relationships and interactions that exist between plants and the soil environment, we can gain valuable insights into how to maximize land-use efficiency and increase sustainable land management practices over the large areas of land that will be required for utility-scale solar facility development needed to achieve the renewable energy goals of the United States by 2050.

Just as healthy soil is necessary to support plant growth, plants can help improve soil health through various mechanisms (Figure 7). Soil health is characterized by a combination of physical, chemical, and biological properties, including bulk soil density, water infiltration and holding capacity, soil organic carbon and available nutrient contents, soil pH and cation exchange capacity, and microbial activity and diversity. Plant roots, especially those from deep-rooting perennial species (such as are found in many pollinator seed mixes), help reduce soil erosion and improve soil structure by providing a supportive network of course and fine roots that stabilize soil particles and aggregates while simultaneously improving water infiltration. Plants also supply organic matter, carbon, and other nutrients to the soil environment viasurface leaf litter, root exudates, and root litter. These organic matter inputs serve as nutrient pools for micro- and macro-organisms in the soil, and to increase soil water-holding capacity. Additionally, a portion of the carbon from plant organic matter inputs and microbial necromass will end up becoming associated with soil minerals to form mineral-associated organic matter (MAOM), which can have very long residence times in soil and serve as a carbon sink for atmospheric CO2 (Bai and Cotrufo, 2022).

There are many ways that vegetation can be used at solar facility sites to provide additional benefits beyond increasing soil health. While there is much research that has shown the positive effects of vegetation on soil health, research that specifically addresses how soil health indicators are affected by land management practices at solar facilities is lacking. Given what is known, it is reasonable to expect that sustainable vegetation management at solar facilities will result in improved soil health over time. However, this is likely dependent on the degree of disturbance sustained during site construction, and possibly any number of other controlling factors, such as local climate, native vegetation, and/or soil type. For example, Choi et al. (2020) found that even after seven years of revegetation at a solar facility site in Colorado, carbon and nitrogen concentrations had not recovered to comparable levels of adjacent reference grasslands. The authors attributed this to the significant amount of topsoil removal and grading that occurred during site construction, which significantly

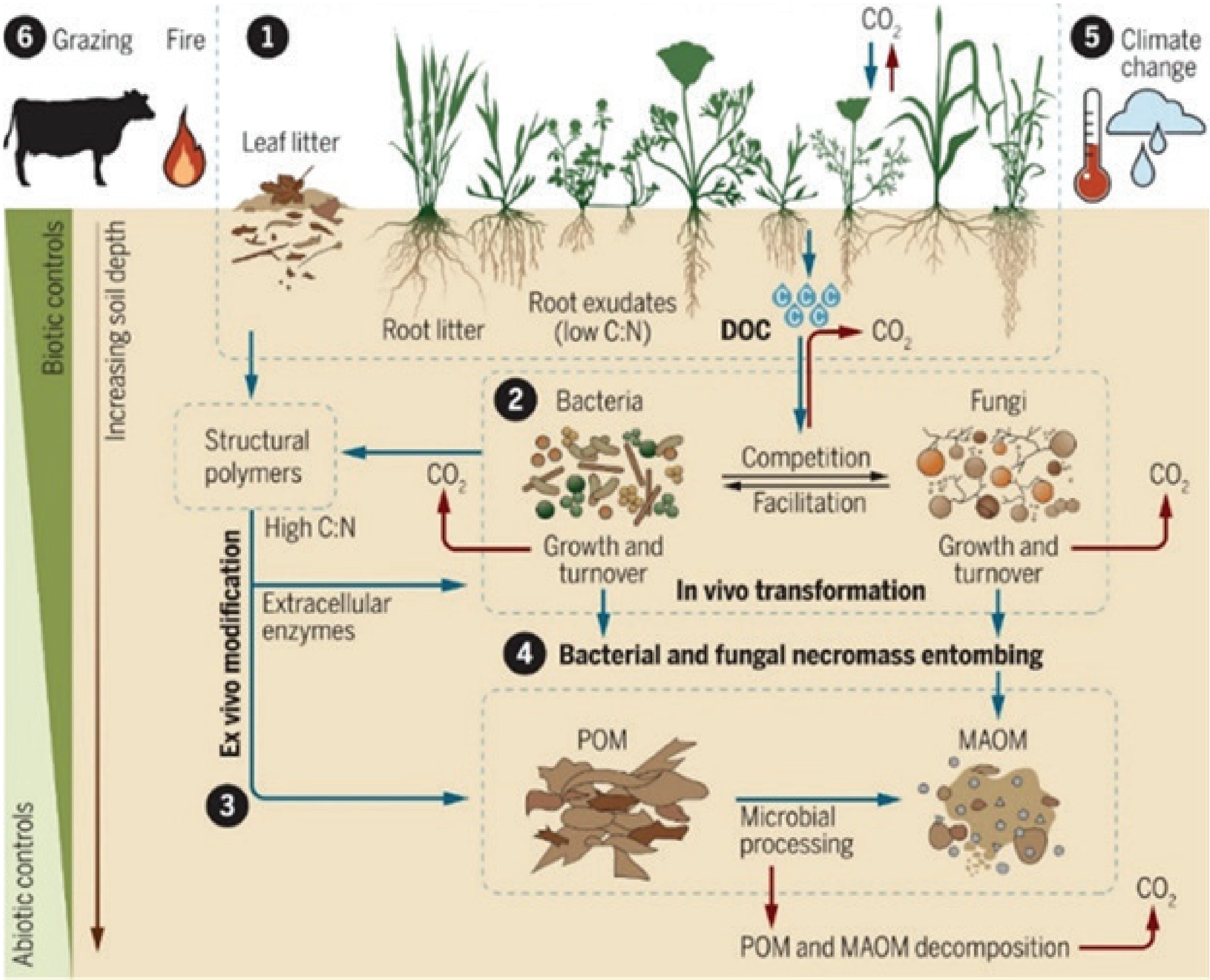


Figure 7. Conceptual framework for soil organic matter and carbon cycling. Source: Bai and Cotrufo, 2022).

disturbed and mixed the soil profile, resulting in severely reduced surface carbon and nitrogen levels. However, this study did not compare vegetated areas to non-vegetated areas within the site. Another study by Choi et al. (2023) did make this comparison at a site in Minnesota where topsoil removal and grading were avoided. The researchers found that revegetated areas had significantly more carbon, nitrogen, and other nutrients levels relative to the areas that were left bare and were ultimately similar to adjacent control plots (Figure 8). This disparity in results and lack of clear data presents a challenge to understanding soil health dynamics as it relates to land management practices at solar facilities.

Fortunately, DOE SETO has sponsored a project whose sole focus is to gather soil data from solar facilities across a wide range of environments in the United States that can hopefully address this question. This project, Ground-mounted Solar and Soil Ecosystem Services, is being led by Argonne National Laboratory and will provide standardized guidance on measuring and analyzing soil parameters central to soil health at solar facilities, and establish a national database of solar facility soil data that will hopefully shed light on how vegetation and land management at solar facilities can impact soil health over time.

Chapter 6

Power, Plants: Seed Mixes and Sweet Treats that Increase Public Support for Solar

Rob Davis, M-RETS

ENGIE project in Vermont. Photo: Rob Davis

It is exciting to see all the advancements and innovations that enable photovoltaic solar farms to provide co-benefits and dual uses. With large-scale solar farm growth accelerating globally, now is a good time for companies to review and implement a programmatic approach to ensure that their sites address both the climate and ecological emergencies, as well as strengthen public support for producing more clean energy. Global energy companies are actively moving forward with plans to combine solar farms with additional land uses to provide ecological and community benefits. Dual-use solar farms, particularly solar co-located with pollinator habitat, are seeing an increase in development around the world.

AFFORDABLE COST OF BENEFICIAL PUBLIC ATTITUDES

The practice of co-locating solar farms and pollinators, including both honeybee apiaries and wild pollinators, through the management of sites known as *species-rich grasslands*, occurs across the world. These practices resonated well among U.S. pollinator, solar, and agriculture advocates alike, many of whom came together in Minnesota to establish the nation's first statewide standard for vegetation on solar farms.

The results of a six-year longitudinal study of three solar projects meeting Minnesota's habitat-friendly solar standard are presented across three studies, showing the cost of designing and planting a seed mix for the vegetation cost to be less than 0.1% of the overall project construction budget (Choi et al. 2023; Walston, 2024; McCall et al., 2024).

A study by Lawrence Berkely National Laboratory focused on neighbors' perceptions of large-scale solar projects and revealed that projects incorporating co-benefits and/or dual uses for agriculture (e.g., pollinator habitat, grazing sheep, or cultivating crops) result in both more positive attitudes and fewer negative attitudes for large-scale solar (Rand et al., 2024). Embracing innovation and committing to use the design of ecological/agricultural landscapes to stack additional benefits into solar development is a positive sign that solar industry leaders are working to strengthen public support for solar.

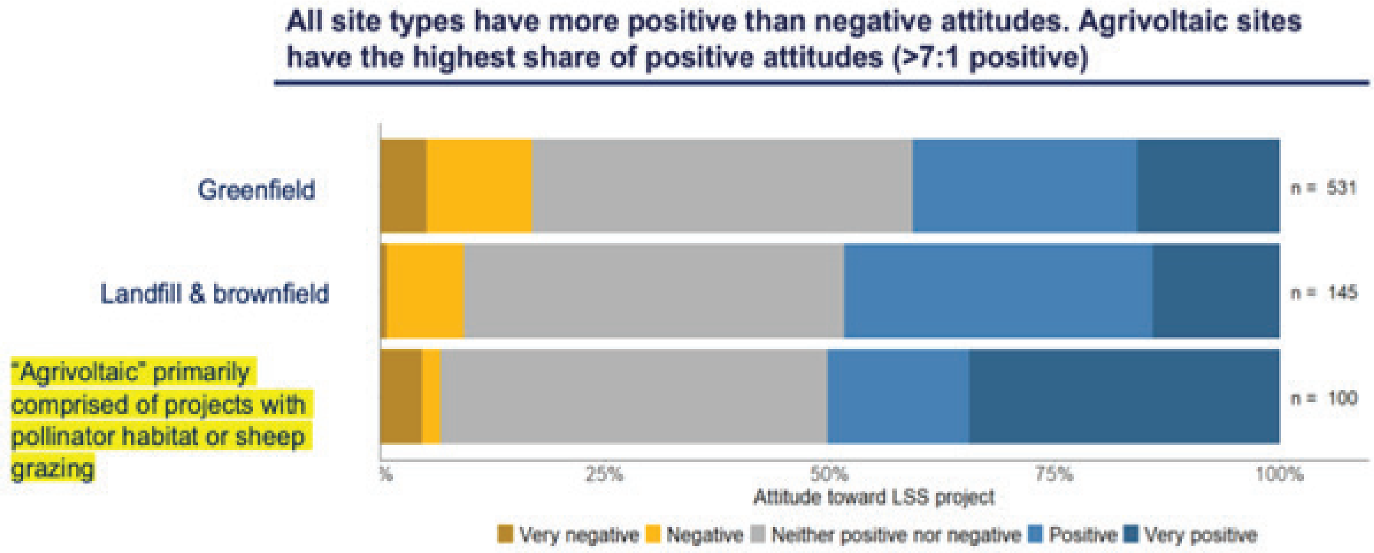


Figure 1. Attitudes toward large-scale solar projects. Source: Rand et al., 2024

Other states have published standards and best practice guidance to determine, for their state, what incremental seed mix changes qualify as pollinator-friendly and are appropriate for the managed landscapes of solar arrays. Tech-forward clean energy registries with the accounting systems of the clean energy transition that are responsible for the tracking, issuance, transfer, and retirement of renewable energy certificates can use these lists, adding information about pollinator-friendly ground cover to solar renewable energy certificates (RECs). In 2023, Midwest Renewable Energy Tracking System (M-RETS) was the first registry to start doing this, enabling transactions on pollinator-friendly RECs.

Pollinator-friendly designs are enjoyed by both bees and beekeepers. Beekeepers at Bare Honey in Minnesota, Old Sol Apiaries in Oregon, and Bee the Change in Vermont partner with solar developers and operators to provide partners, county commissioners, and planning board members with honey sticks and small jars of honey harvested from solar arrays. The simple, familiar, and sweet reminder that something so delicious is produced on solar sites makes a positive impression.

Beekeepers have consistently highlighted the risk to food systems from lack of healthy forage available to pollinators. Producing a single market-ready blueberry requires a pollinator to visit a flower two to four times. This may sound simple, but there are 3 to 5 million flowers per acre of blueberries, and all 64,000 acres grown in the U.S. are blooming around the same time. This situation is similar for other crops. Each raspberry flower requires five to six pollinator visits to produce a marketable fruit. Each strawberry requires 20 to 60 visits. Crops across the country produce hundreds of billions of individual flowers, requiring trillions and trillions

Honeybee pollinating blooming raspberries. Photo: Rob Davis

Solar honeybee hives and solar-grown honey. Photos: Rob Davis

of visits by managed and native pollinators each year. To sustain these pollinators throughout the year, they need acres of healthy habitat for the times when the crops are not blooming.

POLLINATOR BEST PRACTICES FOR SOLAR FARM OPERATORS

Mind the Land

Continued public support for pro-solar policies and subsidies depends on broad coalitions and demonstration of beneficial land stewardship. Here are 10 evidence-based recommendations developed by Lancaster University (Blaydes et al., 2021):

1. Provide a diverse mix of flowering plant species.
2. Plant or maintain hedgerows at the site boundary.
3. Ensure season-long access to foraging resources.
4. Provide a range of nesting, breeding, and reproductive resources.
5. Graze, cut, or mow at low intensity and late in the season.
6. Create or maintain variation in vegetation structure.
7. Minimize the use of agrochemicals.
8. Target management for agrivoltaic pollinators located in agricultural landscapes.
9. Promote connectivity to natural habitat.
10. Generate a range of microclimates.

It is important to establish a low-growing perennial ground cover that includes plants that flower throughout the season and remember that incremental changes to seed mixtures can make a meaningful difference.

Depending on the soil and site design, a solar array area can include low-growing clover and other species, with open areas banked with diverse communities of flowers, sedges, and grasses. Wherever possible, avoid agrochemical use and promote landscape connectivity.

Communicate Clearly about Biodiversity

Having a flock of chickens will not save the eagles, and hosting honeybee hives won't save the bees or provide biodiversity benefits in the absence of other measures. As Dr. Sheila Colla of York University reminds us, livestock can't replace native biodiversity. Making bold claims without proper ecological understanding or evidence could cause the industry more harm than good, attracting accusations of greenwashing.

Place Matters

Every site is different, with greater or lesser potential, depending on the characteristics and the surrounding land. Consequently, implementing practices that are suitable for your site considering climate, ecosystem, site history, and current management (perhaps advised by a local ecologist) will deliver the best returns.

BEEKEEPING TOP TIPS FOR SOLAR FARM OPERATORS

As co-location of beekeeping and large-scale solar continues to spread across the globe and more companies adopt the practice, the following are important lessons to keep in mind:

Remember that honeybees poop

Particularly in arid regions, it's important to keep honeybee hives 20 feet (6 meters) or more from PV panels. Over time, honeybee droppings accumulate and are notoriously difficult to remove.

Safety first

Ensure placement of honeybee hives includes at least one or more empty bee boxes. As honeybee hives grow, it's natural for a new queen to emerge and a portion of the hive to look for a new home. If one is available they won't go looking at inverter boxes or leave altogether. Additionally, make sure that the honey is cleaned through a food-safe, licensed, and insured facility. While the risk is incredibly low, nobody needs food-borne illness.

Apiary owned and managed by Bare Honey.
Photo: Dennis Schroeder/NREL InSPIRE

Apiary owned and managed by Bare Honey.
Photo: Dennis Schroeder/NREL InSPIRE

Open communication between teams

Facility operators, vegetation contractors, beekeepers, and/or shepherds should all have one another's contact information to help ensure open communication.

Pay your beekeeping partners

The only way to become a beekeeper is to be willing to be stung in the nose. Solar asset owners/operators should pay beekeepers for professional hive placement and management and guarantee a purchase of a portion of the honey. Professional agreements, contracts, and management help ensure honeybee hives remain disease-free and healthy.

Consider improving habitats for wild pollinators, too

If project operators can design and manage the vegetation to provide incremental benefits for wild pollinators, this will return even more benefits by providing additional food sources for the honeybees. It will boost pollination services to nearby crops and positively contribute to the biodiversity of the ecosystem.

Chapter 7

Solar Thermal Energy

By Stacie Peterson and
Chris Lent, National Center for
Appropriate Technology

Winston Cone Optics Solar Thermal System. Photo: Winston Cone Optics

Agrivoltaics is a practice defined as the co-location of crops and grazing under and adjacent to solar photovoltaic panels. The concept of agrisolar co-location goes beyond photovoltaic solar and includes other solar energy production that is not photovoltaic, such as *solar thermal*. Solar thermal is a term used to describe a technology, such as a crop dryer or solar water heater, that converts the energy from the sun into thermal energy. This thermal energy can be used to heat, dry, and distribute air, water, or heat transfer fluids. Solar thermal principles can be employed in crop drying, processing, and storage, and in water-intensive operations like dairies.

In addition to solar photovoltaic energy production systems, solar thermal energy production is a great way to collect and utilize solar energy. In *concentrated solar thermal* (CST) production, energy from the sun is concentrated by mirrors, lenses, and parabolic dishes or troughs that reflect the heat energy to a collection point called a *receiver*. The accumulated energy is then used to power an electric generator. CST systems are often associated with utility-scale electric production; however, CST also has potential applications in commercial water heating, water desalination, and manufacturing. In agriculture, smaller-scale solar thermal systems can be used for crop and grain drying, food processing and drying, greenhouses, and to heat process water for dairies, such as the Winston Cone Optics system shown in in the photo above and described later in this publication.

SOLAR THERMAL CROP DRYING OVERVIEW

The sun has been used to dry crops for preservation for millennia. This natural drying process exposes agricultural products to the sun and wind and continues to be used in certain regions to preserve crops because of its low cost and simplicity. It is limited by natural conditions that affect drying, including hours of sunshine and precipitation, which can lead to inconsistent and low-quality results. Sun drying can also be a lengthy process, leaving the crop susceptible to insects, animals, and birds.

Solar thermal drying is a method of dehydrating food crops and grains using solar energy. It's an environmentally friendly and energy-efficient

Direct solar thermal crop drying of coffee beans. Photo: AgriSolar Clearinghouse

technique that harnesses heat from the sun to remove moisture from agricultural products and preserve them for periods of storage. Grains, fruits, vegetables, herbs, meat, and fish are some of the agricultural products that are dried to preserve their quality and for use in a variety of value-added products.

Crop dryers can be distinguished by the source of energy used to operate them. Three types are *fossil fuel dryers*, *electric dryers*, and *solar energy dryers*. It takes 2.4 megajoules of energy to evaporate 1 liter of water, and most dryers operate at less than 50% efficiency, therefore requiring large energy inputs (Dhumne et al., 2015). Because of the cost to operate fossil-fuel powered and electric crop dryers, solar crop dryers have gained attention as a cost-saving alternative. Small-scale solar dryers have been used around the world, especially in areas where fuel and electricity are scarce and there are favorable sun and weather conditions.

Solar dryers are further categorized as either *passive* (using natural convection) or *active* (using powered convection). Within these two main types, there are three different designs for solar dryers: *direct, indirect*, and *mixed-mode*. All these systems have a solar collector component often made of glass or plastic, but it can also be a metal surface painted black to optimize solar energy collection. The solar collector absorbs sunlight and converts it into heat energy, which is then transferred to a drying chamber where food crops are spread in a thin layer to maximize exposure to the heated air.

One option for direct solar thermal crop drying is a greenhouse or high-tunnel structure with natural ventilation and screened tables and shelves inside to lay the product to be dried, as shown in the photo at left. It is a best practice to add a solar-powered fan to force the circulation of air through the greenhouse or high tunnel.

A basic indirect solar dryer design, shown in Figure 1, includes an insulated box with a glass window that allows light in, a dark surface that absorbs light and radiates heat, an air inlet that allows cold air in, and an air outlet at a higher point in the dryer box that allows hot air, which naturally rises, out (Muhammad K., 2003). The heat of the sun, which is magnified in the solar

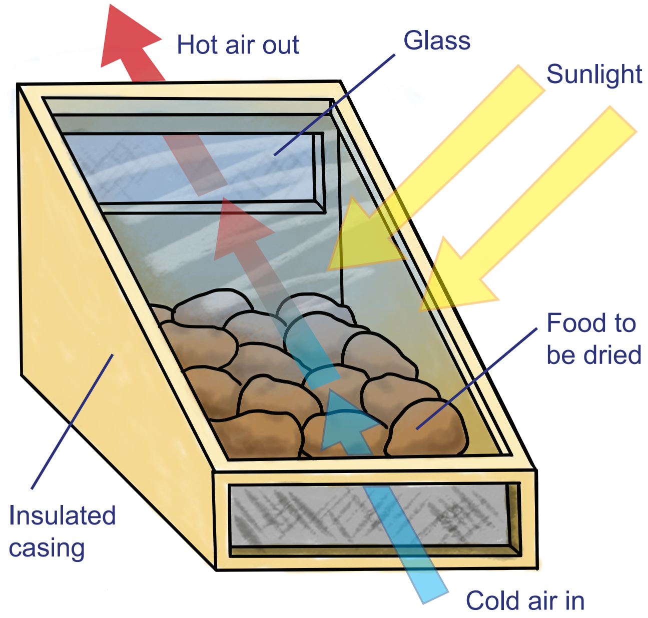


Figure 1. Schematic of a Solar Air Dryer. Graphic: AgriSolar Clearinghouse

dryer, and the natural movement of the air through the dryer work to dehydrate the crops placed in the dryer chamber. To avoid mold, a best practice is to clean the dryer chamber and remove condensation regularly. A solar-powered fan can also be incorporated into the design to lessen condensation and increase dehydration. A variation on this design includes the incorporation of a fan, which can be solar-powered, and a drying chamber with crop trays that is separate from the solar collector (Figure 2).

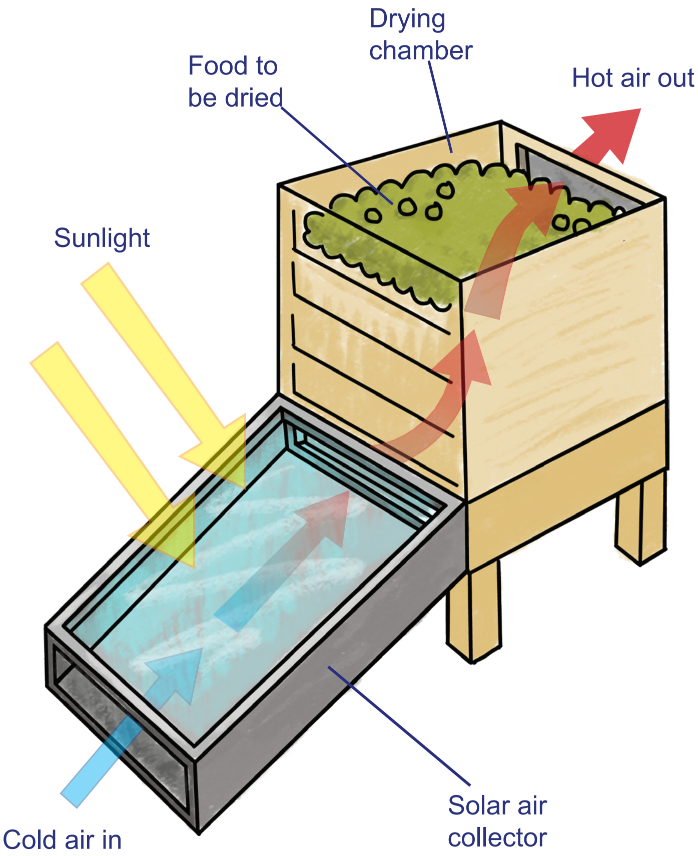


Figure 2. Schematic of Solar Air Dryer with Separate Drying Chamber. Graphic: AgriSolar Clearinghouse

GRAIN DRYING

Grains such as rice, soybeans, corn, and wheat are almost always harvested at a moisture content that is too high for safe storage of the crop. High moisture levels in stored grain lead to spoilage and mold-induced aflatoxins that can ruin the crop and be harmful to animals and humans (NTP, 2021). To prevent this, grain is sometimes dried through natural air drying where air is forced through the perforated bottom of a grain bin and up through the stored grain by a fan. This can work well when the ambient air conditions are dry enough to allow for moisture to be removed from the grain. When the ambient conditions don't allow for effective natural air drying, a heater is used to help dry the grain. Most stored grain in the U.S. is dried this way.

SOLAR THERMAL BUILDINGS AND GRAIN BINS

The metal roof and side walls of an existing or new building can be converted into a solar thermal collector. In this application, the existing metal on the south-facing side of a building is painted black, and wooden purlins are attached to accept a second layer of metal or a clear covering. A metal covering creates what is called a *bare-plate solar collector* and a clear covering creates a *covered-plate solar collector* (Figure 3). The solar-heated air is then ducted to an adjacent grain bin. In a similar manner, the bin

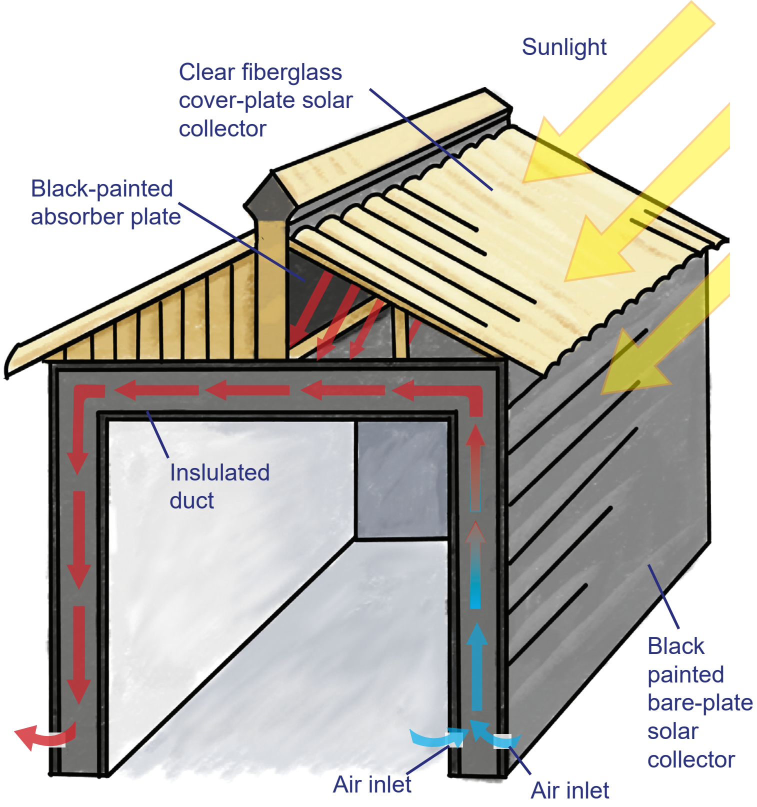


Figure 3. Solar Thermal Building. Graphic: AgriSolar Clearinghouse

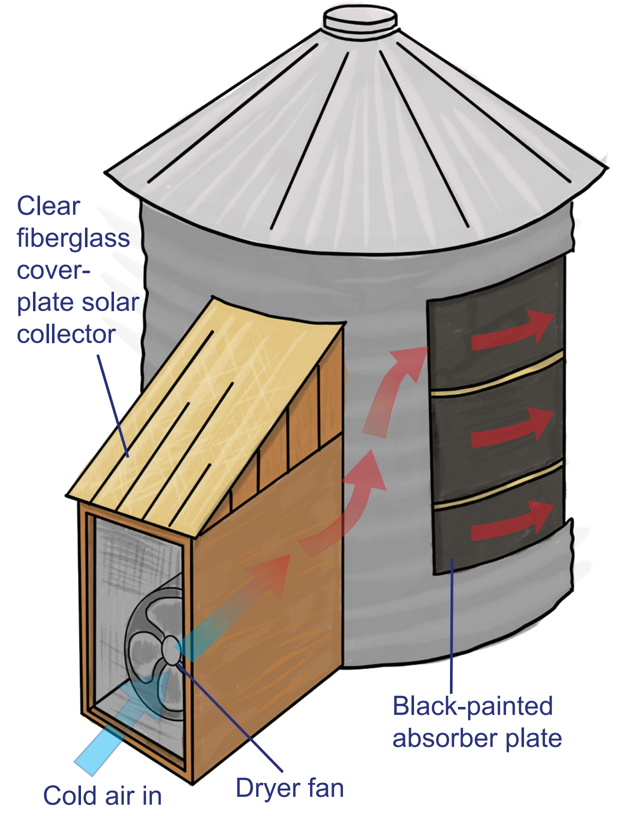


Figure 4. Solar Thermal Grain Bin. Graphic: AgriSolar Clearinghouse

where the grain is being dried and stored can be converted to a solar thermal collector (Figure 4).

SOLAR THERMAL FOR PROCESS WATER

In agricultural operations that require a lot of hot water, like dairy farms, heating water can account for as much as 40% of energy costs. On farms like these, solar thermal water heating can be used to reduce energy costs. Solar water heaters, much like the crop and grain dryers described above, require a solar collector to capture the sun's energy. Depending on the design, this energy is transferred directly to the water being heated or to a heat transferring fluid, like glycol, that is pumped through a heat exchanger to heat water.

Designs vary for solar water-heating systems, but the basic components are a collector, a heat exchanger, and a hot-water storage tank. A basic schematic of a simple solar hot-water collector, as shown in Figures 5 and 6, illustrates the principles of solar hot water heat collection and storage. Like solar dryers, the heat from the sun is transferred through a transparent or semi-transparent medium, like glass, and reservoirs of water behind the medium collect and store the solar heat. This hot water is then used in farm processes.

As shown in Figure 5, solar thermal water systems often include a flat-plate collector. In this type of system, a flat metal plate is attached to metal tubes, which contain a heat transfer fluid that is used to heat water in a storage tank. This type of systems works best for water that does not need to be heated higher than 200°F (U.S. Energy Information Administration, 2024). The main components of a flat-plate solar collector are:

1. Black or dark surface that absorbs solar energy.
2. Transparent cover that transmits solar radiation to the dark surface but prevents heat loss from the dark surface.
3. Tubes containing heat transfer fluid connected to the dark surface. These are often called *evacuated tubes* because they are designed as a set of two glass tubes, with the air between the tubes removed, or evacuated. This vacuum is created to reduce heat loss.

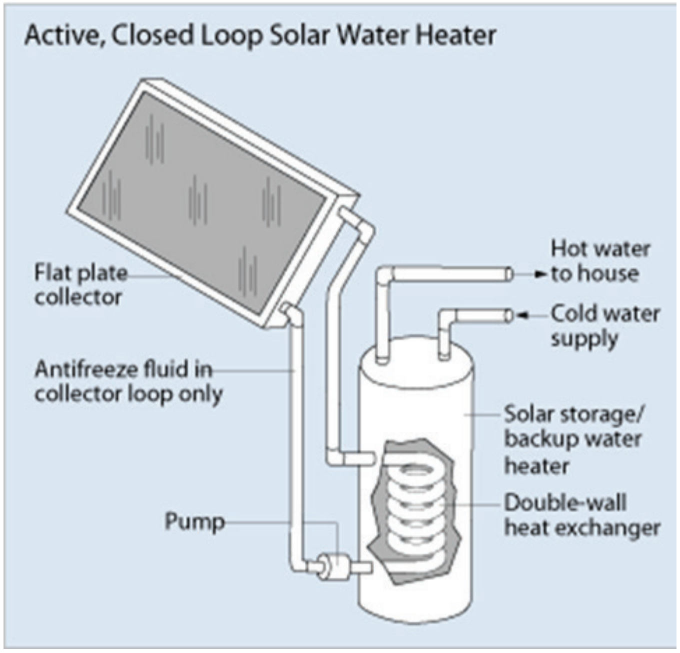


Figure 5. Simple Solar Thermal Water System (U.S. DOE, 2024)

It is common to build a support structure with insulation around the plate and tubes. Figure 6 is a schematic of a basic flat-plate system.
The solar radiation is absorbed by the black plate and transfers heat to the fluid in the tubes. The thermal insulation prevents heat loss during fluid transfer; the screens reduce the heat loss due to convection and radiation to the atmosphere.
In the case of Winston Cone Optics, the

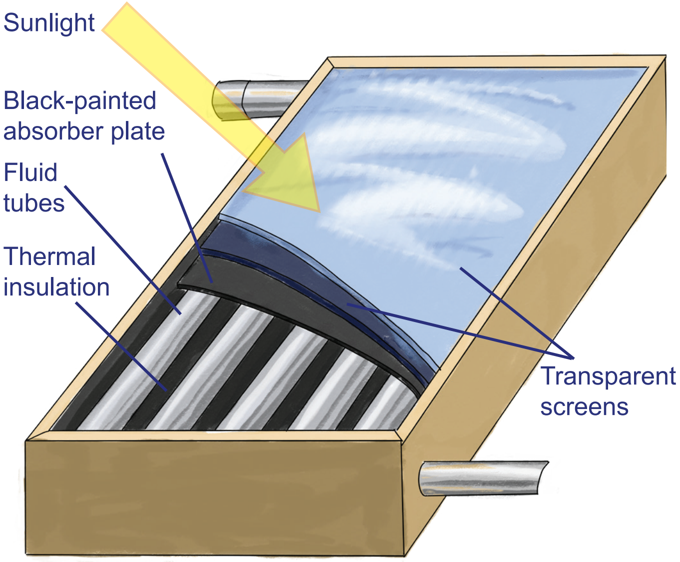


Figure 6. Schematic of a flat-plate solar collector with liquid transport medium. Graphic: AgriSolar Clearinghouse

Winston Cone Optics solar reflectors and evacuated tubes. Photo: Winston Cone Optics

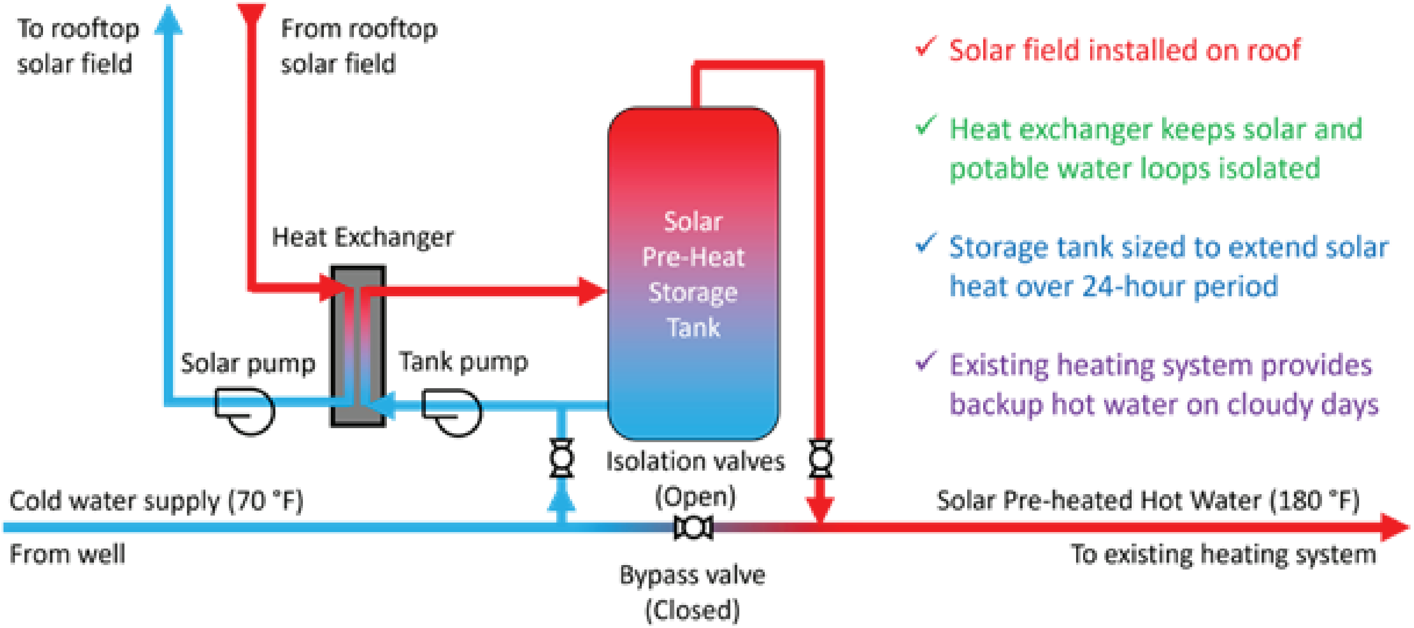


Figure 7. Schematic of Winston Cone Optics. Graphic: Winston Cone Optics

evacuated tubes are paired with solar reflectors, as shown in the photo above. A schematic of their process is shown in Figure 7. They can heat water, create steam, and deliver process heat up to 350°F with this system.

The photo below shows a solar thermal flat-plate collector array coupled with a high tunnel. In this system, the collectors provide heat for an in-ground hydronic heating system in a 30 X 96-foot-high tunnel. Inside the high tunnel, an insulated 500-gallon, in-ground solar storage tank is heated with the heat transfer fluid circulating through the collector panels. Water circulating through PEX tubing buried under the growing beds is heated from the storage tank via a heat exchanger delivering heat to the root zone of the crops. A back-up heater is used to heat the water for cloudy days when solar can't be used.

CONCLUSION

Solar thermal provides an opportunity to harvest sunlight and use the energy in crop drying, processing, and storage. Solar thermal works by collecting sunlight, converting sunlight to heat, and transferring heat via airflow or heat transfer fluids. Projects can be as simple as a solar air dryer, or as complex as a concentrated solar heating system for a dairy. By working with the sun, thermal energy can help make farm processes more efficient and environmentally friendly while saving significant energy costs.

Solar thermal flat-plate collectors heating a high tunnel. Photo: AgriSolar Clearinghouse

Chapter 8

Stakeholder Engagement in Agrisolar: Co-producing Optimal Outcomes

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This publication intends to inspire critical thinking about the importance of social aspects in agrisolar projects. We highlight considerations related to cultural landscapes, social acceptance, and participatory planning and offer lessons learned from case studies and a *Stakeholder Engagement Plan* to empower project planners and stakeholders. The intended audience for this chapter includes project planners, community developers, solar developers, researchers, landowners, and community members. While broad, the intent is to provide background, context, and considerations for these different audiences and an approach to meaningful engagement.

Farm-to-table event at Jack's Solar Garden in Longmont, Colorado. Photo: AgriSolar Clearinghouse

Agrisolar projects have the potential to benefit communities and ecosystems and contribute to our global sustainable development goals. Stakeholder engagement is required to advance socially acceptable, economically viable, and technically sound agrisolar development practices. A stakeholder can be an individual or organization that has interest in or is impacted by an agrisolar project. This can include but is not limited to landowners, farmers, ranchers, developers, community members, local officials, advocacy groups, and local organizations. In this publication, the term *stakeholder engagement* is used to broadly address engagement of these actors, which is a critical component of developing equitable, inclusive, and sustainable agrisolar projects. The goal of stakeholder engagement is to build relationships, trust, and conditions that create mutually beneficial outcomes, such as diversified revenue streams for agricultural producers and host communities and the social license to operate in rural America for solar developers. When done well, stakeholder engagement can position agrisolar solutions for high social acceptance levels, build resilience in host communities, and maximize value for all involved parties.

> *"This might sound fuzzy, but real-world shovels in the ground (or not) can hinge on how [stakeholder engagement] is approached"* (DOE, 2022).

Community engagement in Phoenix, Arizona. Photo: AgriSolar Clearinghouse

A cultural landscape framework can be used to better understand the interaction between people and place, particularly highlighting spaces where community members derive a part of their cultural identity (King, 2003), as well as reflecting how a community perceives, modifies, and interacts with their environment (Altschul, 2005). Cultural landscapes include historic designated landscapes; historic vernacular landscapes, including farm complexes; and ethnographic landscapes, which contain a variety of natural and cultural resources that associated people define as heritage resources (National Park Service, 2024). A cultural landscape includes the physical landscape and the history, heritage, sense of place, and cultural practices associated with that landscape over time (Smith, 2006).

The sense of place associated with a community can include the construction of community members' position in both the physical and social world (Smith, 2006). In addition to providing a physical anchor in a geological space, it also allows for the negotiation of social value and cultural identity. Designations such as prime farmland serve as an authentication of significance to cultural landscapes (Little, 2003). These designations shape public perception of the place, including the people that live within it. During periods of conflict, cultural identity, sense of place, and cultural features can become more valuable to a community (Brown, 2003).

THE IMPORTANCE OF CULTURAL LANDSCAPES

In this section, we discuss why it's important to incorporate cultural landscape considerations into development decision-making. Cultural landscapes illustrate the relationship of people and communities with the land over time and are valuable to communities and cultures because they provide a source of identity and sense of place. When making changes to a landscape, it is important to understand whether this change could impact the sense of place, historical importance, or cultural identity associated with the landscape.

One way to approach this in decision-making is to use a cultural landscape framework. By understanding how the project could impact the cultural landscape and engaging with the community, developer, and landowner to address concerns, the project will have a greater chance of meaningful stakeholder engagement and community acceptance.

American farmlands and rural areas often contain cultural landscapes that are described in terms of the pastoral ideal (Marx, 2000). Industrial systems, such as a solar array, can pose a threat to the pastoral nature of a rural landscape and the cultural identity of the community. Agrisolar can serve as a potential solution by keeping the land in agricultural production or, if there is not a current agricultural practice, by incorporating agriculture into the project design. The solar array design can also incorporate low-impact design elements, follow the undulation of the landscape, and potentially incorporate innovative strategies, such as vertical panels, elevated or mobile racking, or semi-transparent panels.

THE IMPORTANCE OF INCLUSIVITY IN SOLAR ENERGY RESEARCH AND DEVELOPMENT

In this section, we highlight considerations for inclusive research and development to demonstrate the importance of stakeholder engagement in this process. Lessons learned from agrisolar research and design experiences demonstrate how stakeholder engagement and participatory planning improves social acceptance, builds trust, and maximizes positive project outcomes.

Despite generally positive public perspectives on solar energy, abstract acceptance does not directly translate to concrete, local acceptance (Sütterlin and Siegrist, 2017). Continued solar development will require bridging this gap between general and local acceptance. Past experiences show how stakeholder engagement in research and design can address this gap and improve project outcomes (Schelly et al., 2019; Bessette et al., 2024). Researcher-led engagement can identify priority interests, values, and needs and enable generalization of key priorities to similar contexts to inform improved development practices across the United States. Developer-led engagement during the project process can translate stakeholder input into locally relevant benefits. Both types of engagement provide distinct value to current and future development efforts. Examples of engagement in research and design are provided in the "Community Engagement Examples" section on page 8.

Stakeholder engagement, or lack thereof, directly impacts social perspectives of solar development, including agrisolar development. Opposition to solar stems from concerns with development processes and outcomes and is particularly correlated with the community's participation in the project design, trust in the type of information provided by developers, and perceived project impacts (Bessette et al., 2024; Carlisle et al., 2016). Local opposition is among the leading causes of solar project cancellation in the United States and is becoming more frequent and expensive to address (Bessette et al., 2024). Local opposition, and its impacts on solar deployment efforts, may best be ameliorated through stakeholder engagement at all phases of a project and more social science aimed at understanding the varying causes of community opposition.

AgriSolar stakeholders in Massachusetts. Photo: AgriSolar Clearinghouse

The positive influence of participatory planning and local ownership on social acceptance is consistent with other forms of renewable energy (Schreuer and Weismeier-Sammer, 2010), underscoring the importance of using stakeholder engagement to build trust and improve justice aspects of projects, which are often a concern (Banerjee et al., 2017). Increasing in-person interactions, discussing project tradeoffs openly, and creating local economic benefits and employment opportunities have been identified as the most effective community engagement strategies for solar development (Bessette et al., 2024).

By leading strong engagement efforts, solar developers establish credibility, include stakeholders in the strategic vision of a project, and ensure that development outcomes represent local interests and concerns, all of which maintain the social license to operate in a community. The concept of social license to operate was originally employed to describe social acceptability of mining operations and is now applied broadly to energy, agriculture, forestry, and other operations that impact natural resources (Moffatt et al., 2016). The demonstrated willingness of developers to be transparent and responsive creates proper conditions for sustainable solar development and increases the social license to operate. This is true for solar development broadly but is particularly important for agrisolar projects that involve a diverse set of stakeholders, land use practices, regulatory factors, and design considerations.

Community engagement at Connexus Energy in Minnesota. Photo: AgriSolar Clearinghouse

SUSTAINABLE AGRISOLAR REQUIRES DEEP COLLABORATION

Stakeholder engagement is especially vital for agrisolar developments. The cross-sector nature of projects requires balancing diverse priorities to achieve common goals. Mutual learning, aimed at combining local agricultural knowledge with technical energy expertise, empowers agrarian communities to align projects with their needs and enables solar developers to deliver locally relevant solutions (Moore et al., 2022; Pascaris et al., 2023a, 2023b). This deep collaboration is the fabric of good agrisolar work, and clear understandings and agreements set the foundation for just outcomes, farm viability, and long-term project sustainability (Macknick et al., 2022). Because the potential loss of farmland is a main community concern with solar development (Bessette et al., 2024), thoughtful approaches are needed to protect agricultural heritage and create positive impacts on agricultural economies.

Agrisolar can improve development by retaining local agricultural interests and value. A public survey study found an increase in social acceptance of solar when it is co-located with agriculture (Pascaris et al., 2022). Similarly, in a survey of community members who live near large-scale solar developments in the United States, researchers at Lawrence Berkely National Laboratory found that projects incorporating agriculture or agrisolar were more favorable

AgriSolar Clearinghouse stakeholders touring Biosphere 2 agrivoltaic project in Oracle, Arizona.
Photo: AgriSolar Clearinghouse

(Rand et al., 2024). While social acceptance is highly place-based, the potential for agrisolar to maintain agricultural community interests and reinvigorate public perspectives towards solar is appreciable. Solar developers, who are sensitive to community sentiment, also see value in agrisolar's potential to foster favorable local conditions and improve their relationships with communities (Pascaris et al., 2021, 2023a). Higher levels of agrisolar acceptance can be expected if local actors play a determining role in project development, especially if projects are community owned (Ketzer et al., 2019; Torma and Aschemann-Witzel, 2023).

Co-developing agrisolar projects with stakeholders not only stimulates greater social acceptance but also ensures farm operation compatibility and viable business models. Farmer engagement is critically important to the agrisolar development process; projects designed with long-term operational flexibility, and business models that feature fair distribution of benefits, is a requisite for farmer adoption of agrisolar (Pascaris et al., 2020; Torma and Aschemann-Witzel, 2023). Lessons learned from agrisolar efforts in the United States suggest that establishing clear roles and responsibilities, ownership agreements, and long-term plans for persistence of agricultural activities are key components of project success (Macknick et al., 2022).

When engaging with agricultural stakeholders, it's essential to understand the mindset of farmers and landowners who are considering adopting agrisolar. Importantly, many farmers feel passionate about leaving a positive legacy and want to ensure land they've worked hard to steward continues to serve their community and support their families for years to come. The decisions to lease land to solar developers are often long, complicated, and stressful conversations for farm families to navigate. Outreach and engagement to farmers should be approached with empathy and understanding to frame conversations for success.

KEY CONSIDERATIONS FOR AN EFFECTIVE STAKEHOLDER ENGAGEMENT PLAN

A stakeholder engagement plan is a framework that includes considerations for communication, participatory planning, feedback strategies, and target outcomes. The plan sets forth a process to identify, listen to, and collaborate with project stakeholders. A good plan features clear objectives, roles, resources, timelines, and actions and has dedicated the proper internal capacity to be managed over the lifetime of a project.

A range of responsible parties can lead a stakeholder engagement plan, including a solar development company, farmer, or landowner. Solar developers are typically responsible for the broad, multi-stakeholder engagement associated with the development process, whereas a farmer or landowner may lead an engagement effort to socialize a prospective project with their neighbors, solicit community feedback, and encourage local buy-in. The following outline of a stakeholder engagement plan suggests key considerations for responsible parties, namely solar developers, and is intended to promote agrisolar development that is more equitable, inclusive, and sustainable. Figure 1 provides a graphic representation of the process.

Define Goals and Outcomes

1. *Determine the intended goals and outcomes of the stakeholder engagement effort.* Effective engagement is objective-driven and is directly used to inform development decisions.
2. *Consider conducting impact assessments.* Environmental and social impact assessments can identify project-related challenges, risks, and opportunities. The insights derived through a project developer-led impact assessment can inform a risk mitigation plan.
3. *Co-produce a Community Benefit Agreement.* A key outcome of the stakeholder engagement effort could be an agreement between the responsible parties and host community that specifies benefits to be delivered in exchange for the social license to operate.

Figure 1: Example Stakeholder Engagement Plan. Graphic: NCAT

Get Acquainted and Determine the Scope of Stakeholders

1. *Perform community discovery.* This helps a solar company understand if there has been a history of development in the area. If so, who was involved and what were the outcomes? What is the general community sentiment towards solar development?
2. *Conduct a stakeholder analysis.* Project developers can consider how engagement strategies may vary across stakeholders deemed to have high interests and high

influence versus others with lesser interest and influence. Available community engagement software tools can help with stakeholder mapping at this stage, such as [A Quick Guide to Effective Stakeholder Mapping](#) (Athuraliya, 2023).

3. *Include traditionally excluded stakeholders and anyone who may be affected by the development.* This could involve targeted efforts to build relationships and remove barriers to participation, such as inviting leaders of cultural groups to represent broader group interests in meetings or expanding accessibility through multilingual materials that broaden awareness.
4. *Educate yourself about the issues facing farmers and landowners in the community.* Understanding local issues, such as drought or loss of agriculture infrastructure, can help project developers better appreciate the farmer and landowner decision-making factors involved in agrisolar adoption.

Decide the Methods of Engagement

1. *Develop an engagement strategy.* Local meetings, presentations, and open houses are the most common and effective strategies led by solar companies (Bessette et al., 2024). Public hearings, town halls, one-on-one meetings, meditated discussions, and virtual information sessions are additional modes of engagement. Agrisolar-specific strategies can include farm-to-table events, tours, open forums, and educational workshops.
2. *Consider sponsoring or attending events.* Solar company presence where the agricultural community regularly gathers, such as state farm shows, farmers markets, trade shows, etc., can help build relationships. Farmers have little free time, so meeting them where they already are is an effective way to engage this important stakeholder group.
3. *Use a combination of methods, tailored to the various stakeholder groups.* Active stakeholders (i.e., high interest, high influence) should receive greater in-person engagement, whereas passive stakeholders require different communication strategies, such as media tools.
4. *Prepare a timeline for implementation.* Track the various engagement efforts and assign roles and responsibilities to the team.

Establish a Transparent Feedback Strategy

1. *Determine what type of stakeholder feedback is needed and relevant.* Participatory planning can be focused on informing acceptable project design (e.g., height, spacing, vegetation, and setbacks), or it can be focused on appropriate siting that avoids sites of cultural significance. Be clear about the bounds of input you intend to gather.
2. *Create a plan for how stakeholder feedback will be used.* Co-generation of outcomes and shared decision-making are hallmarks of effective stakeholder engagement (Prehoda et al., 2019; Kliskey et al., 2021), yet many developers prefer to solicit input rather than share decision-making power (Bessette et al., 2024; Nilson et al., 2024). Determine what is right for you, educate the community about what type of feedback is most valuable and can be acted upon, and be transparent about your plan.
3. *Acknowledge that good feedback strategies are "two-way,"* in that project developers not only solicit stakeholder input, but also actively respond to concerns and use them to inform decisions (DOE, 2022). Consider that some factors are outside of the project developer's influence, such as hard costs and interconnection timelines, and cannot be directly shaped by community input.

Maintain Long-term Engagement

1. *Explore post-construction engagement*

opportunities. Continue efforts to reach stakeholders who are new to the community or were not reached during the pre-construction engagement efforts by maintaining a presence in the community and facilitating gatherings.

2. *Sustain stakeholder relationships*. Solar companies can maintain strong community relations through ongoing listening sessions, community events, and continuous project improvements.
3. *Use the project as a demonstration and learning opportunity*. Organize community events, develop research partnerships, leverage insights for education and information dissemination, and provide workforce-development training opportunities.
4. *Don't miss storytelling opportunities*. Both responsible and interested parties can follow up with farmers and landowners after projects are built to capture their stories. Compensating their participation in storytelling and elevating their voices is a great way to honor their lived experience, share lessons learned, and inspire the next generation of agrisolar projects.

COMMUNITY ENGAGEMENT EXAMPLES

The following examples demonstrate how stakeholder engagement has been used in agrisolar research and development in the United States.

American Farmland Trust's Smart Solar in Connecticut Project

Recognizing the importance of stakeholder engagement in agrisolar research, the American Farmland Trust led a project effort aimed at capturing farmer, farm landowner, solar developer, land trust, environmental organization, and government official perspectives about solar on farmland in Connecticut. The interests and concerns identified in farmland solar were translated into state-level recommendations for appropriate strategies to minimize negative impacts and maximize benefits at the agriculture-energy nexus. The project's multifaceted engagement methods, including the convening of an advisory committee, administration of a state-level farmer survey, facilitation of solar industry interviews and roundtable, and organization of agency briefings, is an exemplary approach to producing stakeholder-informed solutions. Through strategic coordination of stakeholders and co-developed research protocols, the American Farmland Trust, in partnership with AgriSolar Consulting, was able to deliver recommendations for agrisolar that reflect Connecticut stakeholder values to the Connecticut Department of Agriculture, Connecticut Department of Energy and Environmental Protection, and the Public Utilities Regulatory Authority. This project effort exhibits how robust stakeholder engagement in research can promote cross-sector collaboration and participatory processes that promote optimal agrisolar outcomes. This type of engagement is related to, but distinct from, project-specific engagement that should occur prior to development.

AgriSolar Clearinghouse

The AgriSolar Clearinghouse serves as a center for technical assistance, best practices, information sharing, and community engagement relevant to the co-location of agriculture and solar. The clearinghouse bases its stakeholder engagement work upon the tenets of connection, cooperation, and celebration. These tenets translate easily into any stakeholder engagement plan.

The following information details the five elements of a stakeholder engagement plan implemented by the AgriSolar Clearinghouse.

1. Establish Goals and Objectives

- The first step of the stakeholder engagement process included setting goals and objectives of the project, including resources to develop, technical assistance to offer, target audience, deliverables, project timelines, and project

AgriSolar Clearinghouse Farm to Table Community Engagement Event at Biosphere 2 in Oracle, Arizona. Photo: AgriSolar Clearinghouse

budgets. This work was performed with the U.S. Department of Energy's Solar Energy Technology Office.

- The second step included envisioning a diverse stakeholder group and the perspectives the stakeholder group would provide.
- The third step included recruitment of a diverse stakeholder group that could represent solar grazing, crop co-location, solar beekeeping, pollinator advocates, researchers, farmland preservation groups, and rural community members.

2. Get Acquainted with Stakeholders and Define Their Scope

- Monthly meetings with stakeholders during development of the clearinghouse website and its resources included presentations and discussion with stakeholders. This allowed ample time to learn stakeholder motivations, scope group objectives, and provide opportunity for stakeholders to connect and develop relationships.
- Regular drafts of the website, statement of project objectives, and resources were provided to the stakeholders and discussed in monthly meetings. Feedback, such as additions to the information library, was incorporated before the next meeting.
- Regular meetings, individual phone calls and video meetings, and an email group helped shape the scope of the website and the common definitions, goals, and community benefits of the clearinghouse.

3. Determine Methods of Engagement

- The AgriSolar Clearinghouse was developed at the height of the COVID-19 pandemic, and in-person meetings were not possible. Additionally, stakeholder group members reside throughout the country, and virtual meetings worked well from a practical standpoint. Engagement methods included virtual meetings, an email group, a forum within the website, and individual phone and video meetings.
- As pandemic travel restrictions lifted, field trips and farm-to-table events provided excellent opportunities to connect, support agrisolar projects throughout the country, and collect stories from farmers, graziers, landowners, community members, and solar developers. Because food and food sharing are the basis of culture, they are an integral part of community engagement and important methods of engagement.
- Virtual engagement pieces, such as short films, professional photographs, blogs, and case studies developed during the field trips, served to engage stakeholders who could not attend. Stakeholders helped identify the field trip sites and many traveled to attend the field trips, showing a high level of engagement.
- Surveys are regularly offered to stakeholders and tour attendees and are available to the general public via the website. Feedback from surveys influenced website design and functionality.
- To have a broad engagement reach, the AgriSolar Clearinghouse developed a wide array of technical assistance materials, such as a webinar and podcast series (both featured stakeholders), a short-film series, a case-study atlas, fact sheets, financial information, an abstracted library of peer-reviewed research, and a choose-your-own adventure guide for co-locating agriculture and solar.

4. Establish a Feedback Strategy

- The feedback strategy for the AgriSolar Clearinghouse was developed around the stakeholder meetings. During the meetings, staff members kept a list of suggestions and feedback, and this feedback was incorporated before the next stakeholder meeting, where the action was discussed.
- Stakeholders can see changes made to the website, resources, and events by reviewing the website and its resources and by attending the events.

5. Maintain a Long-Term Engagement Strategy

- The long-term engagement strategy includes expanding the stakeholder group to include more members with more diverse perspectives, strengthening the existing stakeholder relationships, and asking for feedback and input regularly.
- Field trips, farm-to-table events, webinars, and the creation of resources such as this *Best Practices Guide* provide excellent opportunities for substantial engagement and for learning vital stakeholder perspectives and knowledge.

CONCLUSION

Meaningful stakeholder engagement can increase community acceptance, build resilience in rural communities, and address cultural and community concerns early in the project planning process. By first working to understand the community, cultural landscape, and project goals, a stakeholder engagement plan can help stakeholders to shape the project and engagement methods in a way that is tailored to the community and the project goals. A transparent feedback strategy and long-term engagement plan will help create lasting local relationships and networks of support for an agrisolar project.

Chapter 9

Low-Impact Solar Design

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Photovoltaic (PV) solar energy is projected to continue playing the leading role in energy development in the United States (U.S.) in the coming years. Solar energy has accounted for the largest share of new electricity-generating capacity in the U.S. since 2019 and accounted for 54% of total new electricity-generating capacity in the first quarter of 2023 (Wood Mackenzie/SEIA US Solar Market Insight, 2023). The majority of this new electricity-generating capacity has been in the form of utility-scale projects, and this trend is expected to continue, while residential and non-residential projects are expected to continue growing in capacity, as well. Utility and community-scale solar projects tend to be ground-mounted PV systems requiring three to 10 acres of land per megawatt of DC (MWdc) energy (Bolinger and Bolinger, 2022). The U.S. is expected to need to develop more than 10 million acres of land for utility-scale solar by 2050 (Ardani et al., 2021). While this is less than 1% of the total U.S. surface area, the land that is technically suitable for utility-scale PV development often coincides with natural ecosystems and agricultural lands (Hernandez et al., 2015).

Photovoltaic power plants, or solar arrays, are primarily designed to reduce the cost of electricity generation, making solar power competitive with other energy sources, such as fossil fuels. Developers achieve this by optimizing energy production per unit of land area and minimizing capital expenditures. Historically, the emphasis on cost reduction and efficiency has led to development practices that may not always prioritize environmental considerations.

Elements of Low-Impact Solar Design

Siting – the geographic location of a solar site and the location's environmental, cultural, and social characteristics.

Development – preparation and construction of the solar site to be energized and operational.

Operations and Maintenance – ongoing activities to keep the solar site producing energy and staying safe and compliant with regulations.

Agricultural Co-location – integration of agriculture and solar energy production on the same land.

The construction and operation of solar facilities can alter the land's natural characteristics. These changes may include soil disturbance, vegetation removal, and creation of impervious surfaces. Depending on the previous land use and its ecological context, such alterations could affect the land's agricultural productivity, ecological health, and hydrological functions. For example, changes to soil structure or vegetation cover can disrupt local water-flow patterns, impact biodiversity, or interfere with agricultural practices.

Agrivoltaic project at University of Massachusetts Crop and Animal Research and Education Farm. Photo: AgriSolar Clearinghouse

This chapter explores low-impact solar design strategies that aim to mitigate these environmental impacts. It provides best practices for minimizing land disturbance, preserving natural ecosystems, and enhancing the sustainability of solar installations. Additionally, it examines the potential benefits of integrating agrivoltaic and ecovoltaic systems, which combine solar energy production with agricultural or ecological activities, offering opportunities to balance energy generation with land stewardship.

WHAT IS LOW-IMPACT SOLAR DESIGN?

Low-impact solar design practices are a development strategy focused on reducing the environmental footprint of solar energy projects during both the construction and operational phases. Unlike traditional solar development, which gives more consideration to energy production than environmental impacts, low-impact solar design seeks to minimize land disturbances, enhance ecological resilience, and support sustainable land use.

This approach is particularly relevant for ground-mounted PV systems, where site preparation and ongoing land management can have significant environmental implications. Low-impact solar design practices encompass a range of strategies, including the use of native vegetation, minimal land grading, and thoughtful integration with other land uses. These strategies aim to reduce soil erosion, enhance water retention, support biodiversity, and maintain or improve the health of the local ecosystem.

Although low-impact solar development can apply to a wide range of configurations, this chapter primarily focuses on ground-mounted solar systems. It outlines four key elements of low-impact solar design: site selection, development practices, operations and maintenance, and agricultural co-location. The goal is to identify ways to reduce environmental impacts, improve project sustainability, and enhance the potential for long-term benefits to local communities through ecosystem services.

Opportunities

Low-impact solar design offers potential opportunities to integrate solar energy generation with other land uses and environmental goals. As solar developers have faced increased opposition to solar development in recent years, adopting low-impact solar design practices is seen as an opportunity to improve community acceptance (Pascaris et al., 2021). Low-impact solar design practices can be grouped into three broad categories:

1. **Solar-centric design**: This configuration focuses on optimizing solar energy production while minimizing land disturbance. It typically involves the use of low-growing vegetation, such as native grasses or groundcovers, for habitat and soil stabilization. Solar-centric designs prioritize energy production but incorporate ecological elements to reduce environmental impact. Example: Pollinator-friendly solar projects, which use native plant species to support pollinator health while maximizing energy generation, have gained traction in the U.S. (Walston et al., 2024)
2. **Vegetation-centric design**: In this approach, minimal changes are made to the land's vegetation, and solar installations are configured with larger spacing between panels to allow for more significant vegetation growth. This design aims to enhance soil health, promote biodiversity, and reduce stormwater runoff. Example: Vegetation-centric designs may include large, open spaces between solar arrays that allow for the cultivation of food crops or grazing of livestock, or that support native vegetation for wildlife habitat.
3. **Co-location and co-optimization**: This design approach seeks to optimize both energy production and land use for other purposes; for example, agriculture or ecological restoration. In these systems, solar panels are integrated with agricultural activities, such as crop cultivation or livestock grazing, to achieve dual outputs. Example: Agrivoltaic systems, where crops are grown under solar arrays, can increase land productivity and create additional revenue streams while reducing the land use impact of solar development (Macknick et al., 2022).

By adopting these design configurations, developers can create solar projects that are not only efficient in terms of energy production but also contribute positively to the local ecosystem and agricultural productivity. Tradeoffs associated with the potential added cost and complexity of adopting these alternative design configurations may be balanced by the other co-benefits they provide, which developers and communities value (Pascaris et al., 2023).

Benefits

The potential environmental, economic, and social benefits of low-impact solar design are project-specific and depend on the characteristics of the site, the design goals, and the stakeholders involved. Early and ongoing collaboration among stakeholders, including solar developers, landowners, environmental groups, and local communities, is crucial to realize the full range of benefits. For this chapter, we focus on potential benefits for two groups of stakeholders: landowners and producers, and solar developers.

Potential Benefits to Landowners and Producers:

- **Self-generation of electricity**: Landowners can benefit from reduced energy bills through the generation of their own electricity, providing financial stability and independence.
- **Additional income streams**: By integrating agriculture or livestock grazing with solar

installations, landowners, and producers may have the opportunity to diversify income sources and increase long-term revenue security.

- **Erosion control**: Low-impact practices can help control wind and soil erosion by maintaining soil integrity and promoting vegetation growth.
- **Agricultural compatibility**: Landowners and producers can continue farming or grazing activities, using the land for both energy production and agricultural purposes. Solar arrays can provide shade for livestock, conserve water, and protect crops from extreme weather.
- **Protection of natural habita**t: Low-impact design can help preserve or restore natural habitats, enhancing biodiversity and ecosystem services on the site.
- **Improved soil health**: Soil health can be preserved or enhanced using native vegetation and careful site management practices that reduce soil compaction and erosion.

Potential Benefits to Solar Developers:

- **Cost reductions**: Low-impact solar design can reduce site preparation, installation, and long-term O&M costs, particularly by minimizing land grading, vegetation management, and erosion control measures.
- **Improved efficiency**: Properly designed systems can reduce the need for dust suppression and other maintenance activities, increasing operational efficiency.
- **Reduced permitting and compliance risks**: Low-impact solar designs may be less likely to face opposition from local communities or regulators, leading to shorter permitting times and reduced risk of litigation.
- **Increased energy production**: Designs that reduce soil temperature through vegetation and airflow can create cooler microclimates beneath the panels, which decrease cell operating temperatures and increase solar panel efficiency.
- **Lower environmental mitigation costs**: Developers may incur lower environmental mitigation costs by implementing sustainable practices that reduce the overall ecological footprint of the project.

Although the benefits of low-impact solar design can vary depending on the specific project and stakeholders, the potential to create projects that are more environmentally sustainable, economically viable, and socially beneficial makes low-impact solar an attractive option for many developers, landowners, and producers.

SOIL HEALTH PRINCIPLES

Safeguarding soil health is a common theme across the low-impact solar design strategies outlined in this chapter. The USDA Natural Resources Conservation Service defines soil health as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans” (NRCS, 2024). Healthy soils support plant growth that feeds humans and animals and provide various ecosystem services, such as carbon sequestration, erosion control, nutrient recycling, water infiltration, water filtration, and water storage.

Soil-health management practices are generally guided by four core principles of soil health:

1. **Minimize disturbance**: Minimize tillage, grading, soil compaction, and chemical inputs.
2. **Maximize soil cover**: Protect the soil surface by maximizing vegetative cover and limiting bare soil.
3. **Maximize biodiversity**: Support a biodiverse ecosystem that contains as many different living species per land unit as possible.
4. **Maximize days in living roots**: Maintain robust vegetation that retains living roots in the soil for as much time as possible

throughout the year.

These principles are crucial to protecting the function and productivity of ecosystems and agricultural soils, though the specific practices implemented may vary depending on land use, climate, site design, and soil types.

Siting

Selecting the optimal location for a solar project is one of the most important steps in its development. A range of factors, from environmental sensitivity to land ownership and local community support, will influence this decision. Considerations such as solar resource quality, proximity to transmission infrastructure, previous land use, and environmental or cultural sensitivities all play a role in determining the best site for a solar facility. Low-impact solar design focuses on minimizing the ecological, social, and economic costs associated with project siting, helping developers reduce upfront and operational costs, avoid delays, and ensure long-term sustainability. A thoughtful and comprehensive siting process that balances cost, community needs, and environmental considerations can help facilitate successful solar project development. This section provides an overview of best practices in solar siting, highlighting how proper site selection and screening can reduce risks and create opportunities for both developers and local communities.

SITE SELECTION AND SCREENING

The process of selecting a site for a solar project involves more than just identifying areas with favorable solar resource conditions. It requires a detailed analysis of factors such as access to transmission lines, the cost of land acquisition, and site suitability for construction. Developers must consider not only the technical and economic feasibility but also the potential environmental, social, and regulatory challenges that may arise. Proper screening of potential sites can help avoid issues that may lead to project delays, unanticipated costs, or legal complications. Key elements of the site selection process from a low-impact solar design perspective tend to fit into two categories: environmental and cultural considerations.

Potential Benefits of Thoughtful Site Selection

- **Cost savings:** Proper siting reduces the need for expensive land grading and environmental mitigation measures. Minimizing construction-related impacts can also help avoid costly permitting delays.
- **Regulatory compliance:** Thorough environmental assessments and early engagement with stakeholders can streamline the permitting process, potentially reducing the time required for approval and mitigating the risk of litigation.
- **Community acceptance:** Projects that are sited with community input and consideration of local concerns are more likely to gain public support, reducing opposition and fostering a positive relationship with residents and stakeholders.

Effective site selection for a solar project requires a thorough assessment of both technical and non-technical factors to ensure project feasibility and minimize risks. By evaluating environmental considerations, such as ecosystems, soil quality, and water resources, alongside cultural factors like community sentiment and the protection of indigenous lands, developers can reduce potential challenges and costs. A careful site-selection process supports regulatory compliance, minimizes construction impacts, and can improve project outcomes, contributing to the long-term success and sustainability of the solar installation.

Prior Land Use Considerations

The history of land use at a potential site plays a crucial role in determining the suitability and feasibility of developing a solar project. Land that has previously been disturbed or used for other purposes may offer advantages in terms of cost, permitting, and environmental impact, but it can also present risks and challenges. Understanding the type of land and the potential issues associated with its previous use helps developers make informed decisions. Solar development projects are typically classified according to the following land-use categories:

Contaminated Lands

Contaminated lands include sites that have been classified as polluted due to previous industrial or commercial activities. Examples include capped landfills, Superfund sites, and other brownfields with a history of contamination. Although these sites may require remediation, they offer significant potential for repurposing underutilized land for solar development.

Benefits:

- **Environmental and economic benefits:** Redeveloping contaminated land can provide substantial benefits to

Table 1. Site Selection and Screening Considerations

Environmental	
Ecosystem and Habitat	Assessing the presence of important ecosystems or habitats for protected or endangered species. Avoiding areas that support critical wildlife habitats or wetlands can reduce risks of environmental harm and regulatory scrutiny.
Soil Quality and Topography	Understanding soil types, erosion risks, and the suitability of the land for construction activities is essential. Site preparation, including grading and clearing, can account for a significant portion of the project's capital costs, and minimizing these activities can lower both financial and environmental costs.
Water Resources	Identifying nearby water bodies (lakes, rivers, streams) is crucial, as solar projects can impact water quality and local hydrology, necessitating measures to prevent runoff and pollution.
Cultural	
Community Sentiment	Engaging with local communities to gauge public opinion on the project is vital for ensuring acceptance and addressing concerns. Collaborative engagement with environmental groups, local stakeholders, and adjacent landowners can help identify potential issues early in the planning process.
Indigenous Lands and Cultural Heritage	Solar projects near or on indigenous lands or cultural heritage sites must respect local customs, practices, and legal frameworks. Open consultation with indigenous communities and careful consideration of cultural resources can help avoid conflicts and ensure that the project is developed responsibly.
Aesthetic Considerations	The visual impact of solar arrays on the surrounding landscape is an important factor, especially in scenic or rural areas. Developers should consider design strategies that minimize visual disruption and promote integration with the existing landscape.

communities, including job creation, increased tax revenue, and the revitalization of blighted areas.

- **Cost savings:** Solar projects on contaminated lands may be eligible for tax incentives and other financial mechanisms that help offset cleanup costs. The infrastructure already present (e.g., roads, grid connections) may also reduce development costs.

Challenges:

- **Remediation costs and risks:** Some contaminated sites require significant cleanup before they can be developed safely, which may involve costly environmental assessments and remediation efforts. In addition, health risks to workers and the local community may necessitate additional safety protocols.
- **Permitting complexity:** The permitting process for contaminated lands is often more complex and time-consuming, involving multiple regulatory agencies and compliance with strict environmental standards.
- **Insurance and financing costs:** Solar projects sited on contaminated lands may incur higher insurance premiums and costs of capital from financiers, due to potential liabilities, health risks, and environmental risks associated with construction and operations.

Brownfield Sites

Brownfield sites refer to lands that have been used for commercial or industrial purposes in the past but are not necessarily contaminated. These sites are typically underutilized and may offer an opportunity for redevelopment without the environmental concerns associated with fully contaminated lands.

Benefits:

- **Economic revitalization:** Developing solar projects on brownfield sites can provide economic opportunities, including additional revenue streams for landowners and local municipalities, as well as the potential for job creation in construction and operations.
- **Reduced environmental impact:** By utilizing previously developed land, brownfield site development helps avoid further disruption to natural ecosystems, agricultural land, or critical habitats.

Challenges:

- **Geotechnical and infrastructure challenges:** Previous uses of brownfield sites may have left the land with unstable soil conditions or remaining structures that complicate development. Geotechnical surveys and additional site preparation may be required, adding to project costs.
- **Land title and access Issues:** Ownership and access rights may be complex, with multiple stakeholders involved in the site's history, requiring additional negotiations and legal work to secure project development.

Previously Tilled Agricultural Land

Previously tilled agricultural land includes sites that were once used for farming but may no longer be suitable for agricultural use due to soil degradation, salt accumulation, or other factors. These lands may offer a practical solution for solar development, particularly when co-located with agricultural activities.

Benefits:

- **Simple development:** Agricultural lands typically have uniform topography and geotechnical conditions that make them well-suited for solar installation. There may also be fewer environmental barriers to development compared to greenfield sites.
- **Dual land use:** Solar systems can be co-located with farming activities, offering farmers additional revenue while

maintaining agricultural production. This can be particularly beneficial in areas affected by drought or other challenges that reduce crop yields or otherwise negatively impact the viability of agricultural operations.

Challenges:

- **Land-use conflicts:** In some cases, farmers may be reluctant to lease land for solar development due to concerns over losing future farming opportunities or the need to commit to long-term leases (typically 20-25 years).
- **Vegetation management:** Agricultural lands may have latent seed banks or soil conditions that require careful management to prevent invasive species and ensure proper vegetation growth under the solar modules.

Greenfield Sites

Greenfield sites are undisturbed lands that have never been developed or used for agricultural purposes. These sites may seem appealing due to their pristine condition and lack of prior development, but they come with significant risks.

Benefits:

- **Fewer site-preparation issues:** Greenfield sites typically have fewer obstacles in terms of existing infrastructure or contamination, making them easier to develop from a logistical perspective.

Challenges:

- **Environmental sensitivity:** Greenfield lands may support sensitive ecosystems or endangered species, which can lead to costly delays or even project rejection. Sites like forests, prairies, or wetlands may require extensive environmental assessments and mitigation strategies.
- **Higher costs:** Greenfield sites tend to be more expensive to acquire, and the development process may involve more complex and time-consuming permitting, especially if the land is seen as valuable for conservation or preservation purposes.

In summary, proper siting and land-use considerations are critical to ensuring the success of a solar project. By carefully evaluating environmental and cultural factors, engaging with local communities, and choosing sites based on their previous land use, developers can minimize risks, reduce costs, and ensure that their projects are sustainable over the long term. By avoiding environmentally sensitive areas, working with local stakeholders, and considering the full range of land-use options, solar developers can maximize the potential benefits while minimizing the potential negative impacts of their projects.

DEVELOPMENT

Developing solar arrays, particularly large-scale, ground-mounted photovoltaic (PV) systems, involves land modification that can have significant environmental impacts if not managed thoughtfully. Site preparation for solar installations typically includes land clearing, re-grading, and installing infrastructure like racking systems, roads, and power electronics. These activities can lead to soil disturbance, removal of native vegetation, and alterations in the landscape, all of which can impact local ecosystems, contribute to erosion, and promote the spread of invasive species.

Site preparation is often a precursor to the construction phase and can be quite intensive. On conventional solar sites, mass grading may be used to standardize the slope and surface conditions, making it easier to install the array, provide access for construction, and support ongoing operations and maintenance (O&M). However, these practices may strip fertile soils from the site, reduce the land's ability to support agriculture in the future, and degrade wildlife habitat. Additionally, land clearing can lead to the complete removal of existing vegetation, often followed by gravel application and herbicide use, which further disrupt local ecosystems. The impervious surface of the solar panels also plays a role by concentrating rainfall and runoff, further elevating erosion risks: researchers found an increase of three to 10 times in runoff under the drip-edge of solar panels compared to open ground (Mulla et al., 2024). These processes are interconnected, and their cumulative effects can significantly degrade the land's environmental quality.

Cost modeling by the National Renewable Energy Laboratory (NREL) has shown that site preparation can account for a significant portion (up to 20%) of the total cost of utility-scale solar projects, with grading alone potentially comprising 3% to 6% of total capital costs. As such, integrating low-impact site development strategies is crucial not only for environmental protection but also for cost management and permitting efficiency.

Maintaining Existing Vegetation and Reducing Soil Disturbance

Land is one of the most valuable resources in solar development, and effective management of the land under and around a solar array is key to ensuring long-term sustainability. When solar developers minimize soil disturbance and preserve existing vegetation, they help maintain essential ecosystem services such as erosion control, stormwater management, and carbon sequestration (Sturchio and Knapp, 2023). These services not only benefit the environment but also contribute to reducing operational and maintenance costs.

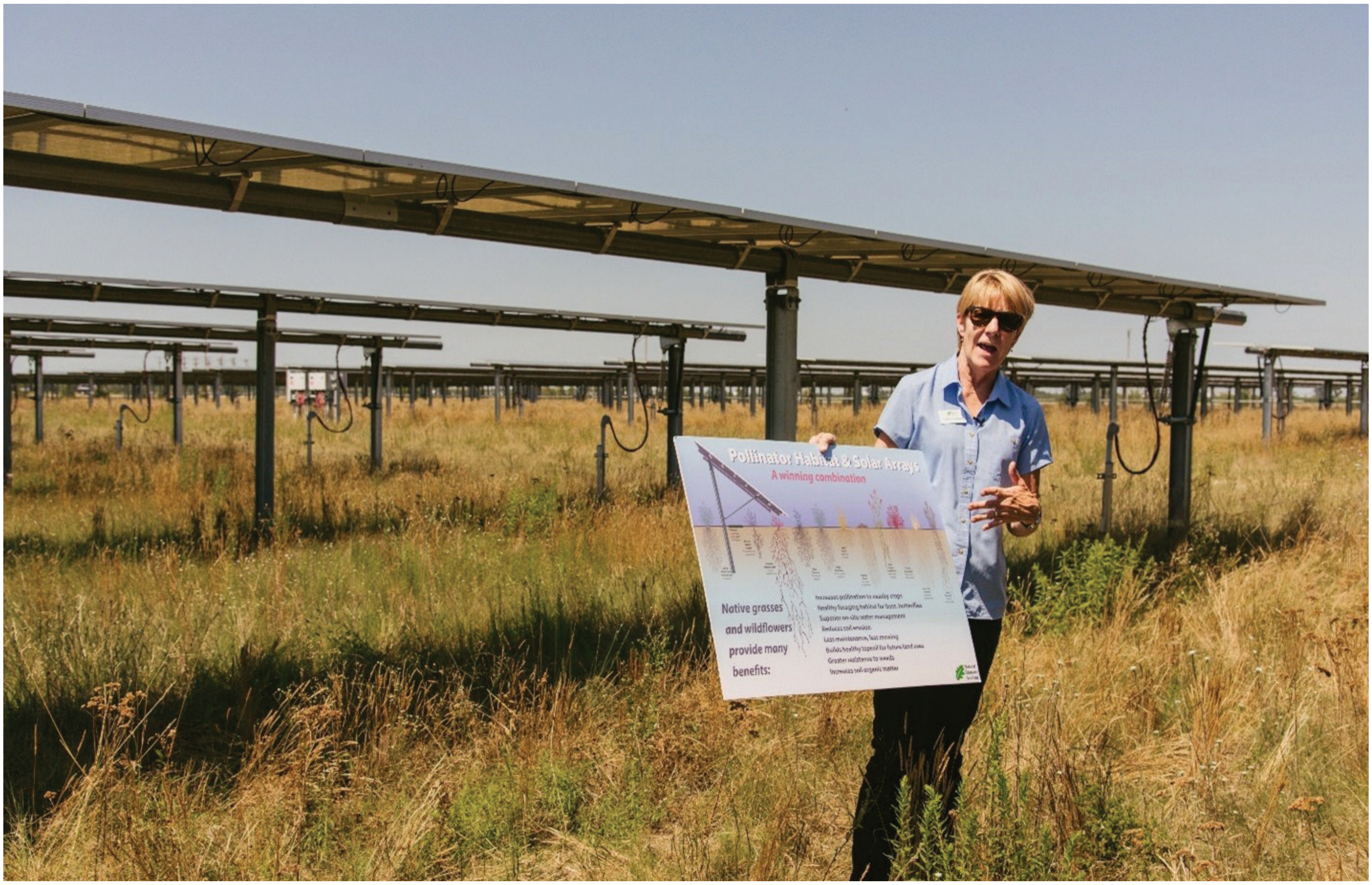
For low-impact solar development, maintaining and protecting existing vegetation should be prioritized. Vegetation helps stabilize the soil, reduce runoff, and support biodiversity. In particular, preserving or restoring pollinator habitats beneath the solar array can provide vital support for local ecosystems and surrounding agricultural areas, potentially leading to increased agricultural yields. Moreover, maintaining natural vegetation can reduce the need for herbicides and excessive land management activities, which lowers O&M costs over time.

The challenge, however, is to strike a balance between meeting the technical requirements of solar installations and maintaining ecological health. Excessive grading and land disturbance can prevent establishment of desirable vegetation and increase the likelihood of soil erosion. Conversely, reducing grading and working with the existing topography can preserve natural systems, reduce soil disturbance, and mitigate risks like invasive species encroachment.

Groundcovers and Working with Native Vegetation

Groundcover selection plays a central role in low-impact solar development, particularly with regard to vegetation and pollinator habitat. The appropriate groundcover type can help prevent erosion, reduce stormwater runoff, support biodiversity, and enhance the overall aesthetic and ecological value of the site. For instance, native vegetation is highly suited to solar projects because it is adapted to the local climate, requires minimal water and fertilization, and supports local wildlife, including pollinators such as bees and butterflies.

The type of ground cover chosen can vary depending on the site conditions, such as climate, previous land use, and topography. In arid regions, such as deserts, developers may choose to leave the ground bare or cover it with gravel, as the dry climate reduces the likelihood of invasive species and the need for irrigation. However, this approach may increase the need for regular panel cleaning, as dust accumulation can affect panel efficiency. In contrast, temperate climates may present greater challenges with invasive species, which require careful management that may involve seeding



Colleen Hollinger of Natural Resource Conservation Service speaking about solar pollinator habitat in Minnesota. Photo: AgriSolar Clearinghouse

with native, low-growth vegetation to restore the ecosystem.

Benefits of establishing native or low-growth vegetation include reduced stormwater runoff, improved habitat for local wildlife, and reduced O&M costs. Native vegetation can also replenish nutrients in soils previously used for agriculture, improving the long-term viability of the land for future uses. Furthermore, promoting pollinator-friendly ground covers has been shown to enhance the yield of nearby pollinator-dependent crops, which can support both environmental and agricultural goals.

Common ground-cover strategies include the following:

- **Bare ground:** Often used in arid regions where vegetation establishment is difficult or unnecessary.
- **Gravel cover:** Used in some desert climates but can increase the need for regular panel cleaning.
- **Low-growth or native vegetation:** Helps stabilize the soil, reduce erosion, and provide pollinator habitat.
- **Impervious mat or herbicide:** Commonly used for minimizing vegetation growth, but may have long-term environmental trade-offs, such as preventing future land use.

It is essential for developers to choose groundcover strategies that are appropriate for the site's climate, local vegetation, and long-term goals.

System Design and Racking Considerations

The design and installation of the solar array, including the racking system, are critical to

Single-axis tracking system at Jack's Solar Garden. Photo: AgriSolar Clearinghouse

achieving low-impact development goals. The racking system's structure and installation methods can affect soil disturbance, vegetation growth, and local hydrology. A well-designed system will reduce the need for heavy grading, minimize soil compaction, and allow for the healthy establishment of vegetation underneath the panels.

New racking systems and techniques can reduce the need for mass grading and better accommodate sites with natural topography. For example, some fixed PV systems can handle a more varied landscape without significant grading, and the use of variable racking post lengths can adapt to slopes in a way that avoids soil disruption. Single-axis tracking systems, on the other hand, often require relatively flat terrain, typically within a 3% to 6% slope range, to ensure that the panels are optimally oriented. Although newer systems can accommodate slopes of up to 15%, these solutions may increase the initial cost of the racking system due to the need for longer posts or additional materials.

For fixed systems, where topography allows, racking systems that adapt to local conditions can minimize the need for excavation and reduce soil disturbance. However, in areas with significant terrain variation, additional grading may be necessary, especially for tracking systems. In these cases, reduced grading can still be achieved by selecting marginal lands, such as non-productive agricultural land or areas with minimal ecological value, reducing the overall cost of site preparation.

Minimizing grading and working with existing topography can help maintain ecological health, reduce invasive species, and protect valuable vegetation. Additionally, sites that require less grading may experience faster and smoother permitting processes, as environmental permits are often granted more readily for projects that involve fewer land disturbances.

Re-vegetation and Pollinator Habitat Restoration

After construction, solar developers should prioritize the re-vegetation of disturbed areas to restore ecological functions and protect local habitats. Appropriate groundcover and vegetation choices can help stabilize the soil, reduce erosion, and enhance biodiversity. Pollinator-friendly seed mixes can be particularly beneficial, providing essential habitats for pollinators and enhancing the local agricultural ecosystem.

Re-vegetation efforts should focus on low-growth, native species that are suited to the site's climate and soil conditions. Depending on the location, this could involve planting short grasses, wildflowers, or low-growing forbs. Pollinator-friendly plants, such as wildflowers, should be prioritized in areas where pollinators are important for nearby agricultural crops.

The re-vegetation process should be completed after construction cleanup, using techniques such as broadcast seeding or mechanical planting. Timing is crucial to ensure that seeds are planted during the growing season and that the site is prepared adequately to allow for proper seed establishment. In some cases, temporary cover crops may be used to help stabilize the soil and suppress noxious weeds until the permanent vegetation becomes established.

Low-impact strategies for re-vegetation can include these:

- Selecting locally adapted, native seed mixes that are suitable for the specific site conditions.
- Working with regional vegetation experts to tailor seed mixes to local soil types, hydrology, and ecological conditions.
- Using erosion control mats or mulch to help retain moisture and protect seeds during establishment.

Considerations for Seed Mixes and Local Adaptation

The choice of seed mix is critical for ensuring the success of re-vegetation efforts. Developers should collaborate with local experts to design seed mixes that are tailored to specific site conditions, such as wetland areas, upland zones, or areas with poor soil fertility. Additionally, using native seeds that are adapted to local conditions will help ensure long-term establishment and ecosystem health.

Seed mixes should be locally sourced to avoid introducing non-native species and to ensure compatibility with local wildlife and pollinator populations. Seed should be purchased on a Pure Live Seed (PLS) basis, ensuring that the seed meets quality standards for germination and purity.

> By integrating practices like minimizing grading, preserving native vegetation, and restoring pollinator habitats, developers can create solar installations that are environmentally beneficial and economically efficient. These strategies not only help meet energy production goals but also support broader ecological and community objectives, making solar energy development a more integrated part of the landscape.

OPERATIONS AND MAINTENANCE

Operations and maintenance (O&M) for low-impact solar development primarily involves managing vegetation on-site, including both desired vegetation seeded after construction and non-desired species, such as invasive plants that may colonize disturbed areas. Effective vegetation management is crucial to ensure optimal system performance and can account for 3% to 8% of annual O&M expenditures. However, these costs vary widely depending on a project's location and vegetation management plan and contract (McCall et al., 2023). Common O&M activities for vegetation management include mowing, herbicide application, and hand-weeding at certain sites.

The long-term maintenance of ground cover and drainage should be considered during the design, civil engineering, and construction phases of ground-mounted systems to reduce O&M risks and costs. In climates with high rainfall, for example, vegetation control and grass cutting can sometimes equal or exceed the costs associated with maintaining the solar equipment itself. Upfront site selection, design, and choice of ground cover significantly influence the types of O&M practices required. For instance, siting a solar facility in a desert region to maximize solar resource potential may lead to higher costs for dust and dirt removal from modules, while using gravel as a ground cover could necessitate more intensive vegetation-control methods, such as herbicide application and hand-pulling weeds to prevent rocks from damaging equipment during mowing events. Such practices often result in specialized O&M strategies that increase costs for the operator.

Managing Vegetation and Soil Health

Vegetation management is essential for maintaining both the surrounding ecosystem and the solar array's efficiency. Unmanaged or excessive vegetation can reduce solar generation by casting shadows on panels or obstructing access for maintenance activities. Vegetation-management practices include mowing, weed management, and, in some cases, tree or sapling removal.

Mowing is commonly used to control vegetation height and prevent shading of the solar panels. Tall vegetation can cause significant degradation of photovoltaic (PV) cells by generating high temperatures in shaded areas, accelerating cell deterioration. However, mowing comes with risks, such as the potential for projectiles when large equipment is used. To mitigate this risk, operators may try to reduce the frequency of mowing events but, instead, may find it necessary to mow more frequently for effective vegetation control. Researchers found that median mowing costs were $113/acre/year for sheep grazing sites, $121/acre/year for native vegetation sites, and $203/acre/year for turf grass sites (McCall et al., 2023). When mowing pollinator-friendly habitats, take care to avoid disrupting seasonal blooming periods. Additionally, mowing events should be scheduled to avoid harming ground-nesting species, with mowing typically occurring in late spring or early fall. In many cases, mowed material should be bagged and removed from the site to prevent smothering the groundcover.

Weed management can be a significant component of vegetation control, particularly in areas where invasive species pose a threat to the health of the ecosystem. While herbicides may be a cost-effective and efficient tool for managing weeds, there are concerns regarding their impact on soil health, safety considerations, and regulatory restrictions. Targeted application of herbicides (spot-spraying) is often recommended to minimize damage to non-target plants. Herbicide use is especially common in arid regions, where persistent weeds with deep root systems are difficult to manage with mowing alone. When managing vegetation on gravel-covered sites, herbicides or hand-weeding are often the only practical options, as mowing poses the risk of throwing debris that could damage solar equipment.

Industry feedback suggests that operators aim to reduce herbicide use due to both cost and environmental concerns. Many sites with native vegetation find that the native plants outcompete invasive species, reducing the need for herbicides. Proper ground cover selection, choosing native grasses or other resilient plants, can also minimize the frequency of herbicide application, creating a more sustainable long-term management approach.

Solar Grazing Benefits

Solar grazing—the practice of integrating livestock, particularly sheep, with solar installations—can help manage vegetation and reduce reliance on mowing and herbicides, while providing additional revenue streams for landowners. Research showed that current utility-scale PV capacity could be quadrupled to accommodate existing U.S. sheep flocks (Handler and Pearce, 2022). Sheep are often preferred for grazing because they are docile and well-suited to grazing under solar panels. However, to prevent damage to the solar infrastructure and promote animal welfare, design adjustments are necessary, including raising the panels, improving cable management to prevent livestock entanglement, and ensuring adequate access to water for the animals.

Sheep grazing can be effective at controlling weeds and promoting the establishment of native vegetation. The hooves of grazing sheep can help disturb the soil, encouraging germination of latent seeds and facilitating growth of native plants. However, careful management of grazing is essential to avoid overgrazing, which can damage vegetation and soil health. Grazing must also be timed appropriately to avoid impacting pollinator-friendly plants during flowering periods.

Other animals, such as cows, buffalo, and goats, may have potential for grazing on solar sites. However, they present challenges due to their size and behavior. Cows and buffalo can damage equipment by rubbing against panels or fencing, while goats may chew on electrical wires or jump on solar panels, risking both damage to infrastructure and shading of the panels.

In regions where grazing is viable, it can reduce the environmental footprint of solar operations and support biodiversity. However, planning for animal welfare, soil health, and solar infrastructure is critical to ensuring the success of solar grazing programs.

Single-axis tracking system at Jack’s Solar Garden. Photo: AgriSolar Clearinghouse

VEGETATION MANAGEMENT PLANS

A Vegetation Management Plan (VMP), also referred to as an Integrated Vegetation Management (IVM) program, becomes of key importance for operations and maintenance of community- and utility-scale solar sites. An effective VMP prevents vegetation from negatively impacting the technical performance of solar assets, operational safety, and regulatory compliance. A VMP that includes pollinator habitat will provide ecosystem services to the surrounding community (EPRI, 2020). VMPs that utilize sheep grazing and/or planting native vegetation have comparable yearly costs to gravel and turf grass (McCall et al., 2023). If the site is to be grazed, develop a Prescribed Grazing Plan (PGP) in the planning phase that includes stock rates, time of grazing, class of animals, and vegetation standards. This will allow for planning and feedback that will result in healthier soils and plant communities and reduce erosion and overgrazing (Macknick et al., 2022). Agrisolar practices utilized in a system's VMP for a community- or utility-scale solar power-generation site will keep land in agricultural production while also generating electricity and providing an alternative revenue opportunity for landowners.

What are VMPs?

The core requirements of the vegetation at ground-mounted solar facilities are that it supports safe operations of the energy facility and stabilize the soil (University of Illinois Energy Resources Center, 2024). Other requirements for the vegetation may vary by site and often include compliance with local viewshed or aesthetic ordinances, prevention of invasive species, and support of co-location ecosystem services, such as pollinator-friendly habitat, grazing, or crop production. To meet these requirements, solar facilities have vegetation management plans (VMPs), which contain all the information necessary for the vegetation management of the site, from site preparation through construction and operation for the expected duration of the facility. The vegetation present at a solar facility, whether it existed prior to construction, was planted during construction, or was planted as a retrofit long after construction, greatly affects what the management should be (Macknick et al., 2015). Common components of a VMP include the following (University of Illinois Energy Resources Center, 2024):

- Summary of site characteristics and conditions
- Vegetation goals and objectives
- Planting plan design and site layout
- Planned seed mixes
- Site preparation and installation provisions
- Establishment provisions
- Anticipated maintenance provisions
- Integrated vegetation management
- Associated inspections and monitoring

Why VMPs Are Necessary

VMPs are critical to the success of a solar facility because they lay the foundation for the vegetation of the site to meet the site's goals. Most solar facilities could not be approved for permitting or constructed without a VMP, as most land-use approvals and permitting for adherence to the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) requires a VMP.

NPDES Permits

The Clean Water Act's NPDES applies to all construction activities on one acre or more of land, and thus applies to the development of most ground-mounted solar facilities (US EPA, 2015). In most cases, the NPDES is regulated through state or local stormwater permits, which require each project to have and follow a Stormwater Pollution Prevention Plan (SWPPP). Two main requirements of the NPDES are soil stabilization on site as soon as possible and permanent vegetation establishment in disturbed areas. The federal NPDES specifies that at least 70% of the disturbed area, not including paved areas or areas occupied by a structure, must achieve permanent perennial vegetative cover. Some localities may have higher percentage thresholds for permanent vegetive cover and may require native vegetation ("Developing Your Stormwater Pollution Prevention Plan," n.d.). A VMP is often used with a SWPPP to show how the project plans to establish permanent vegetation and what erosion control and stormwater best management practices (BMPs) will be implemented.

Land-Use Approvals

VMPs are also often required in land-use approval applications. Land-use approvals can make or break a solar energy project. Through a VMP, the developer can show the regulators how they plan to plant and manage the vegetation at the solar facility. Depending on the locality, regulators may want the vegetation on site to reflect the character and aesthetics of the surrounding area. One way for solar facilities to reflect the character and aesthetic of agricultural areas is by incorporating agrivoltaic activities such as grazing, crop production, or pollinator-friendly habitat and apiaries. Vegetative screening is also an important part of the site design. This heavily affects how the surrounding community sees the facility, and it is something that can be included in the VMP.

Not only do VMPs show regulators what will be planted at the facility, but also how the vegetation will be managed. Local regulators may have concerns about invasive plant species populations in the facilities spreading to the surrounding landscape or having a negative effect on the community aesthetic. Invasive plant species management, as well as the mowing or grazing plan, would be detailed in the VMP, thus showing regulators how the site operator will prevent any negative aesthetic effects and deal with them if problems arise.

Vegetative Success at Solar Facilities

Solar facilities without proper vegetation management can suffer in many ways, such as being unable to close out their stormwater permit, facing fines from local government, having decreased energy production due to shading, increasing the risk of fire occurring on-site, incurring stormwater problems that require costly repair, or having failed vegetation establishment that forces reseeding of the entire facility (SolSmart, 2020). One major hurdle to vegetative success at solar facilities is controlling invasive and/or noxious plant species' populations on site. Whether or not a plant species is considered invasive and/or noxious varies by locality. This can cause confusion for many developers, because a plant species may be acceptable at one of their solar sites, but, at a different site, that same plant species may be considered a noxious weed. The presence of noxious weed populations can prevent developers from closing out their stormwater permits and may even cause the local regulators to fine a project. To avoid confusion around invasive and/or noxious plant species, the VMP should include a list of designated invasive and/or noxious plant species for that locality that may be found on site. Surveys of the site prior to construction, such as wetland delineations, can provide data on any invasive and/or noxious plant species that may already be present on site.

Another way vegetation can prevent a solar facility's success is by shading out the panels, thus negatively affecting energy generation. To prevent shading, the system design needs to be compatible with the vegetation. This means that the expected vegetation growth remains below the minimum height of the solar panels. This includes vegetation such as grasses, forbs, shrubs, and trees that many grow near the solar panels. To prevent shading, the VMP should incorporate maintenance plans, including trimming or mowing or grazing to control the vegetation from growing too tall or spreading into unwanted areas.

Maintenance crews will need to carry out the maintenance plan carefully throughout the life of the project, in order to achieve the project's vegetation goals and prevent shading (Kiatreungwattana, et. al., 2016). At dual-use solar facilities, where the vegetation maintenance is more likely to vary across the entire site, it is important for the developers to communicate clearly to the maintenance crews how the maintenance should differ across the site. For example, maintenance might include only frequently mowing the perimeter areas and areas directly under the panels and not where the crops or pollinator-friendly vegetation are planted. Regarding vegetation management, a project's VMP should consider how the vegetation management will change throughout the lifetime of the project. Considering only the short-term costs of vegetation implementation and management during decision-making can result in inappropriate vegetation for the project's vegetation goals and higher long-term costs to achieve those goals (University of Illinois Energy Resources Center, 2024).

Design Considerations to Minimize O&M Costs

Design decisions made during the initial planning phases of a ground-mounted solar system can significantly influence O&M costs over the system's lifetime. To minimize long-term maintenance costs, it is important to mount panels with adequate clearance from the ground and space racking systems appropriately to allow for easy access by mowing and cleaning equipment. Uniform panel height and row spacing further facilitate efficient vegetation management and reduce the risk of damage from equipment.

Panels mounted too close to the ground can make access difficult, requiring more labor-intensive approaches to vegetation management. Proper planning during the design phase can prevent such issues and help keep operation and maintenance costs under control. For instance, ensuring that the racking system allows for easy maneuverability of equipment can lower labor costs and reduce the risk of damaging solar panels.

In addition to panel design, the choice of ground cover has a significant impact on O&M requirements. Native vegetation, for example, often requires less frequent mowing and herbicide application compared to non-native grass or gravel covers. Selecting appropriate ground covers that suit the local climate and ecosystem can help mitigate soil erosion, manage stormwater runoff, and reduce the need for costly vegetation-management interventions.

> Ultimately, thoughtful design, early planning, and proper ground cover selection play a key role in minimizing O&M costs and ensuring the long-term functionality of a low-impact solar facility. Integrating practices such as solar grazing or carefully timed mowing can further reduce costs and environmental impact, while maintaining the ecological health of the site.

PLANNING FOR AGRIVOLTAIC CO-LOCATION

Agrivoltaics involves the co-location of agricultural activities with photovoltaic (PV) systems on the same land. This chapter specifically refers to agricultural activities conducted beneath or between rows of solar panels, including crop cultivation, livestock grazing, forage production, and the management of pollinator habitats (e.g., apiaries). As solar development expands, agrivoltaic systems offer a way to increase land-use efficiency by simultaneously generating renewable energy and supporting agricultural production.

While the low-impact solar design strategies outlined earlier are relevant for agrivoltaic projects, agriculture introduces additional land-use intensity and considerations. Agricultural activities often have specific needs related to soil quality, water use, and sunlight exposure. Therefore, developers of agrivoltaic systems must carefully tailor a project to the needs of both the energy and agricultural components. Successful agrivoltaic projects frequently involve close collaboration with farmers, ranchers, and other land users, resulting in designs that meet both energy and agricultural goals. For example, Jack's Solar Garden in Longmont, Colorado, demonstrates the benefits of such collaboration. The farmer played a central role in designing a community solar project that effectively supports agricultural activities while meeting energy production targets.

Two major success factors of agrivoltaic projects relate to the compatibility between solar infrastructure and agricultural operations, as well as stakeholder collaboration (Macknick et al., 2022). This includes understanding how shade from solar panels, changes in microclimate, and new infrastructure (e.g., access roads, wiring) may impact crop yields, grazing conditions, or livestock management. Additionally, it includes early stakeholder engagement and participatory planning practices to ensure that agrivoltaic systems provide co-benefits for all involved stakeholders, including producers, landowners,

Jack's Solar Garden farmer Byron Kominek speaking to a tour group. Photo: AgriSolar Clearinghouse

community members, local organizations, research institutes, and more. Understanding multiple priorities and establishing common goals across a wide range of actors is central to the agrivoltaic development process (Macknick et al., 2022).

Site Preparation and Design Considerations

The site-preparation phase for agrivoltaic projects requires careful consideration to minimize land disturbance and support agricultural productivity. Traditional solar-site preparation often involves extensive grading, which can result in significant impacts to soil quality, vegetation, and local ecosystems. For agrivoltaic systems, however, it is critical to minimize grading and work with existing topography to maintain soil health and preserve land suitability for agricultural use.

Low-Impact Solar Development Strategies

Mass grading, which is commonly used in large-scale ground-mounted solar installations, can strip fertile soil, destroy native vegetation, and disrupt local habitats. Agricultural co-location requires efforts to minimize soil compaction and preserve existing soil structure. Excessive grading can also introduce invasive species, increase weed growth, and necessitate the use of herbicides, which can further degrade soil and water quality.

To reduce these impacts, low-impact site preparation strategies should focus on the following:

- **Reduced grading:** Wherever possible, reduce grading activities to preserve soil integrity and maintain the natural topography. This can involve using variable racking systems that accommodate slopes and contours, rather than leveling the site completely.
- **Minimal soil disturbance:** Use techniques that minimize soil disturbance, such as avoiding the removal of topsoil and preserving existing vegetation where feasible. Stockpiling productive topsoil for later use can help re-establish healthy soil conditions post-installation.
- **Topography adaptation:** New racking systems can accommodate slopes up to 15%, which allows for greater flexibility in site selection. Fixed PV systems are also more adaptable to uneven terrain, reducing the need for large-scale grading and helping to preserve the natural landscape.

Research indicates that reduced grading can lower project costs, expedite permitting processes, and reduce environmental impacts. Minimizing grading could significantly reduce civil engineering costs and mitigate the risk of cost overruns and environmental concerns (Goodrich, James, Woodhouse, 2012). Furthermore, such approaches improve community acceptance, as they are less disruptive to local ecosystems and agricultural activities.

Agricultural Compatibility

When selecting sites for agrivoltaic projects, it is essential to consider the land's suitability for both energy generation and agriculture. Ideal sites often include these types:

- **Marginal or degraded agricultural land:** Sites that are no longer productive or have been previously degraded by intensive farming can be ideal for agrivoltaic development, as they reduce the need for land transformation.
- **Low-impact sites:** Prioritize locations that require minimal grading or disturbance, such as areas with natural topographic variations.
- **Water management:** Given the potential for increased soil moisture under solar panels, give careful consideration to water-management practices. This can include optimizing irrigation systems and ensuring that water does not accumulate in areas prone to flooding or wetland conditions.

By selecting suitable sites and using low-impact site preparation methods, agrivoltaic projects can significantly reduce construction costs and environmental impacts while supporting sustainable agricultural practices.

Different solar configurations can support agricultural activity underneath, between, or around the solar arrays. Important design considerations include:

- **Location of agricultural activity:** Agricultural activities can take place directly under the solar panels or in the open spaces between the rows of panels. The key is to ensure the shade is appropriate for the crops while minimizing interference with solar-panel performance. Plant taller crops between rows, while shorter crops can grow underneath panels without interfering with solar production.
- **Access for workers and equipment:** Design the height of the panels, the spacing between rows, and access pathways to accommodate workers and agricultural equipment. For example, taller panels or wider spacing may be necessary for mechanized harvesting or frequent maintenance.
- **Access to water:** On irrigated sites, solar design must allow for effective water distribution without contacting sensitive solar components. Drip or sprinkler irrigation systems can be integrated into the design of the solar farm, either below or above the panels.
- **Panel height and spacing:** Increasing panel height and spacing between rows can improve light penetration and reduce shading, which benefits crop production. However, higher panels increase the initial installation cost due to the need for taller racking systems. Spacing adjustments must also account for local environmental conditions and agricultural practices.

Racking and Construction Considerations

Low-impact construction practices aim to minimize grading and site disturbance while ensuring the project's structural integrity. Common methods include the following:

- Concrete sleepers: These are concrete blocks used as foundations, but they require a level surface and are limited to fixed-tilt systems. This method may increase grading and is less adaptable to uneven terrain.
- Rammed posts: A more flexible and cost-

Agrivoltaic crop co-location. Photo: AgriSolar Clearinghouse

effective option, rammed posts involve driving posts into the ground, which reduces grading and adapts well to varied topographies. They are suitable for both fixed and tracking systems and are an industry standard.

Other best practices include minimizing soil compaction by restricting construction activities to dry conditions and using defined pathways for machinery.

Agricultural Activities

Agricultural activities under solar arrays depend on a range of factors, including local climate, crop type, and farm management practices. In general, most agricultural activities that are feasible in a specific region can also be integrated with agrivoltaic systems, given appropriate design and management strategies. However, agricultural co-location might not be the ideal solution in every case, so consider other low-impact design strategies during the initial planning process.

Agricultural Crops

The partial shade provided by solar panels can benefit certain crops by reducing heat stress, extending the growing season, and improving water retention in the soil. Crops such as leafy greens, herbs, and root vegetables often thrive under solar arrays, as they are sensitive to extreme heat and benefit from moderated temperatures. However, the success of crops depends on factors such as panel spacing, the height of the arrays, and local climate conditions.

- **Microclimate effects:** The area beneath solar panels is generally cooler during the day but warmer at night, which can reduce heat stress and frost-damage risks. The change in microclimate can also influence humidity and wind patterns, which may affect crop performance.

- **Water management:** Increased soil moisture under solar panels may reduce irrigation needs, benefiting crops in dry regions. However, in areas with high rainfall or wetland conditions, excess moisture could pose a challenge.

Ongoing research aims to better understand the relative performance of crops under solar arrays, with some studies indicating higher yields and reduced water use in arid environments, while other regions show more complex interactions between panel configuration and crop types.

Livestock Grazing

Livestock grazing, particularly with animals like sheep, can be an effective method for vegetation management beneath solar panels. Grazing reduces the need for mechanical mowing and herbicide use, and the presence of animals can provide additional income streams for farmers. However, certain precautions are necessary, such as raising equipment to prevent damage and ensuring access to water sources for livestock.

- **Grazing with sheep:** Sheep are often preferred for solar-farm grazing due to their docile nature and smaller size compared to other livestock. Grazing with sheep can also help establish native plant species by allowing them to take over weed-dominated areas.
- **Considerations for other livestock:** Cattle and bison are less suitable for agrivoltaic systems due to their size and tendency to damage solar infrastructure. Goats are also discouraged, as they are known to chew on electrical wiring and modules.

Pollinator Habitat and Apiaries

Solar arrays can provide excellent opportunities for growing pollinator-friendly vegetation beneath the panels. Integrating native plants and flowering species can enhance local biodiversity, improve soil health, and support pollinators like bees, which are essential for many agricultural systems. Apiaries can be incorporated into agrivoltaic systems to support pollinator populations, with honeybees benefiting from the forage provided by solar installations.

By incorporating a variety of agricultural activities—ranging from crop cultivation to livestock grazing, pollinator habitat, and apiaries—agrivoltaic projects can create a multi-benefit approach to land use, supporting both renewable energy generation and sustainable agriculture.

Agrivoltaic systems represent a promising opportunity to simultaneously produce renewable energy and support agricultural activities, offering environmental and economic co-benefits. By integrating low-impact site preparation practices and carefully selecting suitable agricultural activities, developers can optimize the potential of these projects while minimizing risks and costs. Collaboration between energy developers, farmers, and other stakeholders is crucial to ensure the success of agrivoltaic projects, ensuring that they benefit both the agricultural sector and the growing renewable energy market.

Chapter 10

Agrisolar Ownership

Carl Berntsen, NCAT
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This section discusses ownership options for small-scale, single-user systems in the 5kW to 50kW range, medium-scale solar projects in the 50kW and larger range, and utility-scale solar sites that are larger than 1MW. Utility and community solar power generation involves complex ownership structures where the solar site, solar power generating array, and power distribution network may be owned by different entities. For landowners looking to allow a developer to construct and operate a solar installation on a portion of their land, breakdown of common utility-scale land-lease components is also discussed. Finally, using nationwide average statistics on production and cost, this section offers a financial snapshot of a utility-scale solar installation.

TYPICALLY INVOLVED PARTIES

As system size increases, so does the complexity and the number of involved parties. In a typical small-scale solar system, the owner and solar contractor develop and construct the system. Community- and utility-scale systems typically involve a landowner, a solar developer who plans and owns the solar system, a solar contractor who installs the system, and an electric utility or cooperative that distributes the power. There does not need to be a combination of separate parties; any party can take on the tasks of another. For example, a landowner may choose to develop a solar site and retain ownership of the solar system, a solar developer may also purchase land to construct their own solar installation, or a utility may lease land from a landowner and develop a community-scale solar array. Large-scale system planning is more complex and includes community involvement, permitting, lawyers, financiers, insurers, land surveyors, civil engineers, and vegetation management specialists.

Planting in progress at the NCAT solar array. Photo: AgriSolar Clearinghouse

SMALL-SCALE SOLAR SYSTEMS

Small-scale systems are designed to generate power for onsite use and are commonly referred to as “behind the meter” installations, as the power generation and usage take place on the customer side of the utility power supply meter. In some states, it is possible for a customer to enter into a Power Purchase Agreement (PPA) with a solar developer. The developer will install a solar system on a landowner's property and sell the power to the landowner at a rate that is lower than the utility's rate, thus saving the landowner money. The solar array will be owned, maintained, and eventually removed by the solar developer. The PPA rate will be high enough to eventually provide the developer with a return on investment (ROI) and generate a profit from the array.

Otherwise, landowners can own their solar systems and have the array sized to offset all, or part of, their electricity usage. When an electric utility provides net metering, it will buy back any excess generated power, generally at the full retail rate, and credit a landowner for providing power for the grid. The savings provided by the solar installation will eventually pay for the up-front construction costs and provide an ROI.

Alternatively, an electric utility may provide net billing and will buy back excess generated power at a reduced rate. The rate varies by state and utility. Solar systems are then typically sized to offset baseline usage during peak consumption, thereby avoiding grid-storage as much as possible as the excess power is worth significantly less. In both metering instances, in the event of a grid power outage, a solar array is disconnected for safety reasons and will not generate power. This will result in the site experiencing a power outage. Some utilities don't offer net metering or net billing, and all power generated must be used onsite and the excess power is lost. Adding a battery storage system to a solar system will allow for excess generated power to be stored and used later.

MEDIUM-SCALE SYSTEMS AND COMMUNITY SOLAR SYSTEMS

Medium-scale solar systems include commercial and small community-scale systems in the 100kW to 1MW range. While commercial systems are typically behind the meter and generate power for use onsite, community solar refers to systems that distribute power to a community of users. Community solar provides access to solar for individuals whose personal site lacks solar access due to shading, roof condition, roof orientation, or building ownership/rental status. For these reasons, community solar provides an opportunity for communities—especially low- and mid-income communities—to access solar technologies.

University of Illinois at Urbana-Champaign. Photo: AgriSolar Clearinghouse

As of December 2021, 39 states and Washington, D.C., have enacted policies to create a regulatory pathway for utilities and solar developers to develop community solar projects (NREL, no date). As a result, it is possible for landowners to install a solar system on their property and sell the generated electricity to their local communities. The landowner owns the system, sells the electricity, and benefits from any other solar incentives that are in place. An alternative approach is to pursue a solar developer who will lease the land from a landowner and build, own, and operate a community-scale solar system to distribute power to the community of users.

There are two models for community solar programs: ownership-based and subscription-based. An ownership-based model is where an individual buys individual solar panels or modules that are installed on a community solar array, and the power generated by those specific panels is credited to the owner's electric bill. Subscription-based models are similar, but instead of buying panels up-front, the subscriber pays periodically to realize savings on their electric bill, which can vary from 5% to as much as 25% (EERE, no date).

UTILITY-SCALE SOLAR SYSTEMS

Landowner Lease to a Solar Developer

Utility-scale solar sites are typically 2MW or greater and occupy 20-plus acres for many years. It is common for a solar developer to research locations and reach out to landowners to discuss the possibility of leasing land to install an array. Solar leases take on many different forms. A developer may draft a Letter of Intent (LOI) to initiate the agreement, or approach with an option-to-lease agreement followed by a lease agreement, or a lease agreement with due diligence, construction, operations, and decommissioning phases. It is important for a landowner to know which terms of the document are negotiable and must be addressed for the benefit and protection of the landowner (Kiessling, 2022). Solar leases often range from 25 to 40 years; therefore, multiple generations may be affected, and landowners should thoroughly consider all aspects of leasing their property for these extensive timeframes (Hannum et al., 2022). The AgriSolar Clearinghouse strongly recommends landowners discuss this opportunity with an attorney, financial planner, accountant, and insurer who are familiar with solar leasing before entering into any agreement with a developer. Many landowners, regardless of location, may find American Farmland Trust's *Solar Leasing: A Guide for Agricultural Landowners in the Pacific Northwest* useful in navigating the process, as it takes a deeper dive into many of the following topics (Hannum et al., 2022).

Options/Due Diligence Phase

The Options or Due Diligence Phase typically lasts one to three years. During this period, the developer demonstrates uninterrupted control of the site, which is often a requirement by utilities, obtains a Power Purchase Agreement (PPA) price from the utility, and applies for all the necessary permits. Depending on local rules, there may be a public review of the project where any interested party can make comments. Other existing agreements such as joint ownerships, existing mortgages, plans to leverage equity, farmland leases, hunting leases, mineral rights, and water rights must all be examined for potential conflicts. The local zoning rules may also inhibit solar development; however, it is common for a state to disallow a local authority from regulating a public utility, which may include utility-scale solar energy production. For these reasons, it is important for the landowner to enlist the help of an attorney familiar with solar lease agreements.

During this phase, the landowner will be locked into negotiations, bound by confidentiality agreements to not discuss negotiations with others, and non-compete agreements to not work with other solar developers. There are limitations on what actions a landowner can take regarding their land. Often selling, leasing, or refinancing are limited or completely disallowed. The landowner will typically have the same physical access to the land to continue routine operations and will be paid an amount by the developer to offset legal expenses (Kiessling, 2022). Another payment structure involves periodic payments of increasing value (Branan, 2022). This type of payment structure may prevent the options phase from proceeding long after a project has been abandoned and will lift the restrictions from the landowner.

Defining the Lease Land

It is common for a solar developer to only lease a portion of the landowner's land. Initially, the developer may approach the owner to lease a large amount of acreage needed for the installation, but then decide to lease a much smaller portion of land. It may be necessary to define a minimum acreage requirement, to ensure that, in the event a developer leases less land than originally proposed, the landowner is still compensated a worthwhile amount. There have been occurrences of solar developers proposing large land leases to gain access to beneficial easements and then not actually leasing any land at all but instead utilizing the easements for free.

Easements

Easements can be extremely valuable to developers looking to develop neighboring lands that need to access the grid through a landowner's land. Therefore, easements should be defined in detail. Exclusivity rights, where the solar developer will have the only access, can result in common property used by the landowner becoming off limits. Certain easements should co-terminate with the lease agreement so that the easements cease to exist once the array is decommissioned. Compensation for easements should also be discussed. Rates for easements can vary widely, depending on the developer's need.

Non-Interference Clauses

The solar developer will also have non-interference provisions in place to limit development outside of the leased area to protect the solar array from permanent sources of shade, such as buildings. Clearly defining this provision is necessary so that it cannot be used to limit development on the landowner's land that would not have any impact on the performance of the solar arrays. Additionally, the landowner should be compensated for land that becomes landlocked by leased land and inaccessible to the landowner. Any land unaffected by the lease should be noted as excluded land and thereby unaffected by lease.

Vegetation Management Plan and Prescribed Grazing Plan

A Vegetation Management Plan (VMP), also referred to as an Integrated Vegetation Management (IVM) program, becomes of key importance for operations and maintenance of community- and utility-scale solar sites. An effective VMP prevents vegetation from negatively impacting the technical performance of solar assets, operational safety, and regulatory compliance. A VMP that includes pollinator habitat will provide ecosystem services to the surrounding community (EPRI, 2020). VMPs that utilize sheep grazing and/or planting native vegetation have comparable yearly costs to gravel and turf grass (McCall et al., 2023).

If the site is to be grazed, a Prescribed Grazing Plan (PGP) should be developed in the planning phase to include stock rates, time of grazing, class of animals, and vegetation standards. This will allow for planning and feedback that will result in healthier soils and plant communities and reduce erosion and overgrazing (Macknick et al., 2022). Agrisolar practices utilized in a system's VMP for a community- or utility-scale solar power-generation site will keep land in agricultural production while also generating electricity and providing an alternative revenue opportunity for landowners.

CONSTRUCTION

The duration of the construction phase often depends on the size of the installation and site specifics, such as soil type and terrain. It is in the developer's best interest to complete this phase as quickly as possible, and they often will do so in less than one year. The large equipment used at these sites can compact soils and alter water drainage causing increased runoff and erosion. Soil compaction negatively impacts plant growth that is detailed in the array's vegetation management plan, and when returning the land back to agricultural purposes after decommissioning. If construction affects large areas of land, vegetation, and wildlife may also be negatively impacted. By utilizing

Sheep grazing on a solar site. Photo: AgriSolar Clearinghouse

low-impact construction techniques and de-compacting soils after construction, the negative impacts of construction can be greatly reduced (Macknick et al., 2022).

OPERATIONS AND MAINTENANCE

The lease enters the operation phase once arrays are fully constructed, and the developer begins selling energy to the grid. This phase lasts as long as the panels are generating an acceptable amount of energy for the developer, typically around 25 years. During the operations phase, very few personnel are on-site at any given time. The developer will remotely monitor the performance of the power plant. There will be routine groundskeeping, equipment cleaning and maintenance, troubleshooting, and repair/replacement of malfunctioning components. Part of the maintenance operations include vegetation management, which is a crucial maintenance process to prevent shading of the panels. A detailed vegetation management and/or prescribed grazing plan must be in place during the permitting phase (McCall et al., 2023).

REPOWERING OR DECOMMISSIONING

The expected lifespan of a solar array is typically 25 to 30 years. At the end of the lifespan, the solar panels' production has degraded to the point where either they must be repowered, or the site must be decommissioned. For the facility to be fully decommissioned, the land must be returned to its original state and developers often create reclamation bonds or escrow accounts to ensure final decommissioning. A repowering event is when the developer will replace malfunctioning equipment with new panels and repair or refurbish any equipment that is no longer working optimally. This is a very attractive option as the permits and lease agreements can be easily extended, land improvements and existing infrastructure can be reused, and the existing racking systems often has enough life left for another 25 to 30 years, depending on materials and maintenance. Often, repowering arrays will also increase the generation capacity of the installation because the newer technology is more productive. The operation lease rate can be renegotiated due to the increased solar income.

CONCLUSION

There are many ownership options for small-scale, single-user solar installations, community solar installations that distribute power throughout a community, and utility-scale installations that sell power to the utility to distribute to customers. When working with a solar developer to lease land for a utility-scale installation, there are important lease topics that a landowner must consider when allowing a developer to construct, own, and operate a solar installation on a portion of their land.

Chapter 11

Existing Solar as Farmland Access for Emerging Farmers

Rob Davis, M-RETS

"Growing Farmers, Growing Foods" is the mission at Minnesota-based Big River Farms, a program of 501(c)3 nonprofit The Food Group. They recently won the North American Agrivoltaics Award for Best Solar Farm in 2024. Big River Farms teaches farmers to farm organically, sustainably, and regeneratively while also enhancing the level of understanding of the environmental impact that can result from properly implementing these types of farming practices. Specialty crop farmers are the backbone of our food system and are major contributors to local economies. However, land access is a major barrier for many emerging farmers, including farmers of color, in both rural and urban communities.

In 2022, the Minnesota Department of Agriculture established the nation's first Emerging Farmers Office, with the intention of helping to remove barriers that emerging farmers face when getting started in farming. This includes new Americans and first-generation farmers who lack access to land or capital. Farmland access has been identified by the Emerging Farmers Office as the most common challenge for these farmers.

Big River Farms works with farmers who are in constant need of land to farm on. Last year in Big River Farms' incubator program, several farmers stated that they are ready to leave the incubator farm if they can buy land or access land elsewhere so that they can scale up independently. Expanding their program to solar sites will enable Big River Farms to build leadership and capacity in the immigrant community, diversify and enhance local food production, improve access for low-income households to healthy food, and build cultural bridges between emerging farmers and the larger community.

Big River Farms program manager KaZoua Berry.
Photo: AgriSolar Clearinghouse

"With thoughtful planning and procurement, the community benefits of multi-acre solar projects can be numerous," said Brian Ross, vice president of Renewable Energy for Great Plains Institute. "It's important that we are stacking solutions to local food production and access into the clean energy transition."

With this project, the visibility of the dual-use solar will create new connections to the host communities for the solar arrays and build Big River Farms' success and enhance its mission.

Winners of the North American Agrivoltaics Award for Best Solar Farm in 2024: The Food Group, Big River Farms, US Solar, NREL, Great Plains Institute, and Connexus Energy. Photo: AgriSolar Clearinghouse

Association of the solar facilities with the Big River Farms' equity goals will help resolve concerns about loss of agricultural capacity in communities hosting solar development and can contribute to accelerated deployment of solar sites on arable soils.

"A quarter of an acre between rows can become an incredibly productive plot of land that right now isn't necessarily in use," said Sophia Lenarz-Coy, executive director of The Food Group.

The Solar Farmland Access for Emerging Farmers project seeks to increase land access to BIPOC and immigrant farmers through the utilization of spaces around solar farms, while concurrently documenting the safe and scalable practices that solar asset owners and insurers can implement as prerequisites of site utilization. Big River Farms, Great Plains Institute, US Solar, and Connexus have worked together to implement best practices from the National Renewable Energy Lab that have created replicable guidance for others seeking to collaborate and enable solar facility access for farming activities.

Community opposition to multi-acre solar development is driven in part by communities misunderstanding the local benefits of agrivoltaics and thinking that farmland is being taken out of production. Developing solar does not mean farmland is being destroyed or taken out of production. LBNL's recent research and NREL's latest publications from the InSPIRE study show that utilities and solar developers need to maintain and improve what is known as "solar's social license" in communities nationwide. To avoid the worst effects of climate change, more than 3 million additional acres of solar arrays need to be built by 2030.

While incorporating agriculture into solar designs has been shown to increase public acceptance of solar, some approaches are looking at elevating solar panels 10 feet to grow commodity corn and continue status-quo farming approaches. However, hand-harvested crops commonly sold in farmers markets nationwide can readily be grown in abundance with existing solar facility designs, such as one or two panels on single-axis trackers and torque-tube height of six feet.

Through the Big River Farms program, farmers learn to scale up their food production while implementing sustainable and regenerative farming practices that improve water quality and usage. Having land access to get started as a specialty crop farmer fills a critical niche in helping address the larger challenges related to land ownership and sustainable, specialty farm operations. Building skills, network, and resources, especially in the agrivoltaics community, helps prepare specialty crop farmers for the next stages of their success.

Abundant crops grown by Big River Farms between rows of solar panels.
Photo: AgriSolar Clearinghouse

Moving Forward: Growing Farmers, Growing Crops

Moving forward, Big River Farms and Great Plains Institute have been identifying barriers, challenges, and successes of utilizing solar spaces and gathering feedback from farmers, utilities, solar facility owners, and host communities. This project will build capacity and enhance the possibility of success for emerging farmers among immigrant and BIPOC farmers. It will also diversify local agricultural and food-production markets. Most important, it will help enhance the communities' understanding of agrivoltaics systems and diminish the misunderstood concept that solar is taking over valuable agricultural lands.

With these concepts and practices in place, it will help the organization achieve and sustain the mission of "Growing Farmers, Growing Foods." Through education, the emerging farmers will succeed and prosper, and through sustainable and regenerative agrivoltaics farming practices, the foods will grow as well.

Chapter 12

Agrisolar Policy Overview

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Any discussion of agrisolar policy is challenging because the main policy realm for agrisolar development is usually local. Local decisions about land use are typically left to county and municipal governments, and state and federal governments are less involved. Due to a wide range of community identities, economic development goals, and geographical variations, there is no uniform policy that will apply across the 3,142 counties and county equivalents in the United States. For this reason, this policy section will examine how different governments, at various levels of authority, have addressed agrivoltaics and provide examples of what producers and agrisolar supporters consider to be best practices in agrisolar development.

While siting and local land-use decisions are important considerations a producer must consider in the development of an agrisolar project, the electric generation itself is a policy matter that may be regulated – not only by governmental authorities, but also by utilities purchasing the power. The size and scope of a solar project will be important, especially if it affects the primary use of the land. For example, a small solar-powered water-pumping project that produces on-site power for stock watering and irrigation will likely be subject to few, if any, regulatory hurdles. On the other hand, a large solar farm that supplies the grid and affects a view shed could be subject to many regulatory laws at each level of government and by the utility purchasing the power.

While the many policy questions surrounding agrisolar development may seem daunting, this section will help simplify and explain the maze of policies that a producer may encounter and provide a realistic expectation of what you may encounter when designing and permitting a new agrisolar project.

Flower growing at the NCAT solar array. Photo: AgriSolar Clearinghouse

POLICY LEVELS

1. Local

Local policies often create the biggest challenges for a potential agrisolar producer. For example, the University of Illinois Urbana-Champaign, as detailed in its publication, *Agrivoltaics in Illinois: A Regulatory and Policy Guide*, surveyed local ordinances enacted in

Illinois and found a wide variety of purpose statements that offer insight into "…how various localities throughout Illinois view land-use interactions between renewable energy and agricultural uses" (Guarino and Swanson, 2023). The various counties that had policies in place cited purposes such as safety; preserving public health; promoting economic development while maintaining order in construction, installation, and operation; avoiding adverse impacts to agricultural, endangered species habitats, conservation, or other sensitive lands; orderly development, etc. (Guarino and Swanson, 2023). No purpose statement overtly encouraged or discouraged solar development, but the list of concerns in these statements will inform the producer of the information they will need to gather and the concerns that will need to be addressed before receiving local approval for project construction. One county noted in the study, however, had passed a moratorium on any new solar projects. The study also found that of 102 counties, only 30 had enacted ordinances regulating the construction of solar projects.

The local restrictions documented in the study are indicative of what producers may encounter from their local governments while planning a startup agrisolar project. Ideally, the location of an agrisolar project will not have any restrictions; however, more practically, a producer must consider local land-use planning board decisions, as well as zoning regulations, building codes, and local land-conservation restrictions. For this reason, local land-use planning boards, building permits departments, and local legislative bodies will serve as valuable sources of information regarding regulations that affect an agrisolar project.

Local governments wanting to encourage local development of agrisolar projects should consider the following recommended best practices.

Land-Use Planning

Counties and municipalities often use comprehensive land-use plans to help guide development. It is common for these plans to reflect the values of the local community, and they frequently include language relating to the preservation of agricultural heritage and farmland. Agrisolar provides an alternative to the either/or mindset often found at the crossroads of agriculture and renewable energy development and can help foster preservation of agricultural roots in rural areas. Counties can also benefit economically from renewable energy development through increased tax revenues, lease payments to local landowners, job creation, and dual revenue streams for local farmers.

Currently, many local governments' land-use policies are murky and confusing when it comes to agrisolar project development. For example, counties in the Pacific Northwest have policies in place to encourage adoption of renewable energy but also to preserve farmland. In Oregon, local governments are required to zone agricultural land exclusively for farm use, with smaller solar projects under a certain acreage allowed pending county approval. If a farmer wants to develop a solar project on their land, they must go through an exceptions process with the county, regardless of whether the project will be dual-use or not. Furthermore, Oregon has a soil classification system in place that considers certain land to be high-value, prime, or unique farmland and no ground-mounted solar development of any kind is allowed on these prime locations without an exception from the local government. However, dual-use projects are allowed on lower-quality soils if they are under 20 acres (Marieb, 2019).

Some local governments have started incorporating dual-use projects into their land-use plans. The town of Montgomery, New York, has a soil classification system similar to Oregon's that also prohibits utility-scale solar development on land classified as having the highest agricultural value. However, the county's solar policies specifically state that a solar system considered dual-use shall not fall under this restriction (Pascaris and Jackson, 2023). While a farmer would still need to apply for special-use permits and go through a site review with the planning board, having clear language allowing for dual-use projects makes the process much more straightforward for town officials reviewing the applications.

Zoning Regulations

Where land-use policies help communities guide growth and development, zoning regulations dictate how land can or cannot be used. A community's land-use plan frequently cites its zoning ordinances to provide decision-makers with guidelines for determining what type of development is appropriate in which areas. When it comes to agrisolar development, especially large-scale projects, the lines between what counts as agricultural versus industrial use quickly become blurred.

Agricultural production in and around solar arrays is a relatively new form of land use, and many current local zoning regulations are not clear on how these types of projects should be classified. Local policymakers interested in supporting dual-use projects should take a proactive approach in the ordinance development process and consider updating regulations before projects are submitted for consideration. This approach also allows stakeholders within the community to provide input before these projects are even proposed, potentially mitigating future conflicts between project developers and their neighbors.

The town of Florence, Arizona, provides a helpful example of proactive agrivoltaic ordinance development, having recently added a definition of agrivoltaics and acceptable use zones to its zoning code. The policy allows agrivoltaics as a permitted use in all rural zoning districts and as a conditional use in industrial zoning districts. This alteration to the town's zoning code was made to preserve agriculture amid a rise in utility-scale solar development and allows farmers to easily add agrivoltaics to their operation without needing to apply for a special or conditional-use permit (Town of Florence, 2024).

Creating zoning schemes that allow for mixed land use is one strategy for local governments to support agrisolar development. For example, through overlay districts, decision-makers to be strategic about where solar development occurs because they require any proposed solar construction within certain zones to undergo a special permitting process (Pascaris, 2021). Development could also be restricted to parties who agree to certain land-use standards, such as planting a pollinator habitat on a percentage of the site (Kolbeck-Urlacher, 2023). Explicitly identifying agrisolar projects as acceptable use of land within agricultural zones should be considered, as well. Shifting away from strict language on zoning allows localities to embrace the concept of mixed land use to whatever extent is comfortable to each unique community.

Definitions

It is important to provide clear definitions for terms found in zoning regulations to ensure they do not prevent opportunities for dual-use solar. While the first step may be to consider redefining terms such as farmland or solar generation, it is equally important to specify what activities will be considered dual-use. For example, pollinator habitats and wildlife conservation sites can be integrated with solar facilities but may unintentionally be restricted if a locality's dual-use definition is limited to agricultural production only (Kolbeck-Urlacher, 2023).

Alternatively, local land-use planners should be careful not to make definitions of agrivoltaics too broad, as this can create the potential for "greenwashing," the use of misleading claims by a person or organization to present something as environmentally friendly. New Jersey's Farmland Assessment Program provides a useful example of defining agrisolar to be both encompassing of various agrisolar designs while also preventing greenwashing. The program allows solar, wind, and biomass energy generation to be considered agricultural use as long as the ratio of land used for energy and

Gold Tree solar grazing site in California. Photo: AgriSolar Clearinghouse

land used for agriculture is maintained at 1:5 and agriculture is practiced under solar panels to the extent practicable. While the New Jersey dual-use definition is broader than just solar, and it is statewide in scope, it is still applicable to local land-use policy (New Jersey Department of Agriculture, 2015).

Interaction of Dual-Use Goals

Even with the best of intentions, setting overly strict guidance could restrict beneficial practices or deter development entirely. For example, a solar site can host a pollinator habitat and support solar grazing activities. However, plants must be allowed to bloom in order to benefit local pollinators, which means graziers must account for bloom times in their schedules (CFRA, 2021). Guidelines in place for vegetation management plans must consider both activities and strive not to be so inflexible that the two goals cannot work in tandem.

Alternatives to Land-Use Restrictions – Smart Solar Principles

As the number of solar energy facilities continues to expand rapidly across the nation, there has also been a rise in moratoriums, bans, and restrictions on renewable energy projects from local governments (Eisenson, 2023). Many of these oppositions reflect localities' concerns about shrinking agricultural lands and the desire to maintain traditionally rural communities. In 2022, American Farmland Trust introduced its Smart Solar principles, which aim to "accelerate solar energy development, strengthen farm viability, and safeguard land well-suited for farming and ranching" (Sallet, 2022). To this end, these principles encourage solar development on buildings and land not suited for agricultural activities, promote integration of dual-use agrisolar practices when solar is placed on farmland, and advocate for practices that will help ensure the land can return to agricultural use in the future. Adopting these guidelines or establishing similar recommendations for solar expansion is one way that local governments can help shape solar deployment in their area without implementing harsh restrictions.

Property Tax Exemptions

Property taxes are most often levied at the local level and are based on the value and use of the property. Often, counties encourage the preservation of agricultural land by taxing agricultural lands at reduced rates. A local government wanting to encourage agrisolar development could ensure in its policies that, at a minimum, the addition of solar production in a dual-use situation does not reclassify the land use from agricultural.

2. State

States have a wide range of policy tools available to encourage agrisolar development. From providing statewide limitations on local land-use decisions to funding research studies, state legislatures and regulatory agencies have wide latitude in encouraging or discouraging agrisolar development. Listed below are just a few examples.

Net Metering

State regulation of solar projects is traditionally more limited to regulations on utilities themselves since utilities are monopolistic by their nature. The best example of this is net metering. Net metering allows customers who generate their own electricity to sell their excess electricity back to the grid. A state may require utilities operating in their jurisdictions to offer net metering to their customers. According to the Solar Energy Industries Association, 34 states plus Washington, D.C., and Puerto Rico require net metering (SEIA, no date-a). In effect, net metering allows a private electricity generator to use the grid as a battery to store excess electricity. In the case of agrisolar installations, the purpose may be to supplement the grid with all the electricity generated, and producers will need to consider net metering and the extent of its use for their particular situation.

Net metering laws are not uniform across the states in which they are enacted. Caps on the amount of electricity generated are common, along with rates or fees that the utilities are allowed to assess to the customer to cover the cost of managing this source of electricity on the grid. Producers should work closely with the utility that will receive electricity during the design phase of the project to understand all the financial implications of net metering.

Sales Tax Exemptions

A common way policymakers can support solar development in their state is by approving sales tax exemptions for the purchase of solar systems. The Solar Energy Industries Association reports that 25 states currently have sales tax exemptions in place (SEIA, no date-b). For example, any purchases of building supplies or production equipment in North Dakota are exempt from sales and use taxes, but only for commercial generation facilities greater than or equal to 100 kW (North Dakota Office of State Tax Commissioner, 2022). The specific details are different in every state, but the overarching goal is to reduce the upfront costs of building a solar installation from the ground up.

Examples for Policymakers: Innovative State Incentives

Beyond net metering and state tax incentives, there are a wide array of policies that a state may implement to encourage dual-use agrisolar development. The following four examples highlight the various ways programs in different states are supporting agrisolar development.

Minnesota Habitat Friendly Solar

Minnesota statute 216B.1642 creates the designation that a solar project is “beneficial to pollinators, songbirds, or game birds” for solar producers who implement the dual-use practice of implementing a native prairie habitat in conjunction with solar panels. The statute requires that “an owner of a solar site implementing solar site management practices may claim that the site provides benefits to gamebirds, songbirds and pollinators only if

Grafton solar array in Grafton, Massachusetts. Photo: AgriSolar Clearinghouse

the site adheres to guidance set forth by the pollinator plan provided by the Board of Water and Soil Resources." The statute further states that "to the extent practicable, when establishing perennial vegetation and beneficial foraging habitat, a solar site owner shall use native plant species and seed mixes under Department of Natural Resources *Prairie Establishment & Maintenance Technical Guidance for Solar Projects*. Producers participating in this program receive from the Minnesota Department of Natural Resources a combination of technical resources, collaboration with conservation partners, and project assessment forms. As of August 2023, 59 projects ranging from 1.2 to 1,500 acres have been awarded the designation (Minnesota Habitat Friendly Solar Program, 2024). More information on the technical requirements of this program can be found in the online publication *Prairie Establishment & Maintenance Technical Guidance for Solar Projects*, from the Minnesota Department of Natural Resources.

Illinois Shines Program

The Illinois Shines Program is a state-administered solar incentive program created to facilitate development of new photovoltaic distributed generation and community solar projects through the issuance of *renewable energy credit* (REC) delivery contracts. RECs are certificates that represent the environmental benefits of electricity generated from renewable energy generation. An REC is created when one megawatt-hour of electricity is produced by a renewable energy project. This REC can then be sold to a utility or trading firm to help a utility to meet its statutory sustainability requirements. Appendix C of the *Program Guidebook* for the Illinois Shines Program defines and sets requirements for agrivoltaic program participants.

Massachusetts SMART Program

In 2018, Massachusetts launched the Solar Massachusetts Renewable Target (SMART) program, a declining block incentive program designed to support solar energy development in the state (UMass Amherst Clean Energy Extension, 2024). The SMART program supports up to 3,200 megawatts of solar energy generation, with the capacity divided between three utility companies (Commonwealth of Massachusetts, no date). Each utility provider then splits their total allocated capacity into different blocks. As projects are admitted into the program, the blocks are filled, and future approved projects will move on to the next block. Each project receives a base compensation rate per kilowatt-hour of energy that they produce directly from their utility company. The base compensation rate depends on what block the utility is currently filling, with each block having a lower incentive rate than its predecessor.

Solar systems do not have to be dual-use to qualify for the SMART program, but those that do incorporate agricultural activities are known as *Agricultural Solar Tariff Generation Units* (ASTGUs). ASTGUs receive an additional $0.06 per kilowatt-hour of energy produced, but they do have to follow additional parameters, provide certain documentation, and submit reports (Commonwealth of Massachusetts, no date). The SMART program has seen success in encouraging agrisolar development within the state. The AgriSolar Clearinghouse's case study atlas highlights several successful operations, including Grafton Solar: Knowlton Farms, Joe Czajkowski Farm, and Million Little Sunbeams.

New Jersey Dual-Use Solar Energy Pilot Program

In 2021, the New Jersey legislature passed the Dual-Use Solar Act, which established the Dual-Use Solar Energy Pilot Program. This program allows a limited number of farmers to build dual-use agrisolar systems on their farms in order for the systems to be tested, observed, and refined. The legislature's goal in creating this pilot program is to gather data and develop techniques and best practices design criteria that will help future projects develop and support sustainable systems that work best in the state's unique situation.

To support the data-gathering project, the New Jersey Agricultural Experiment Station received $2 million in the 2022 state budget specifically for building research and demonstration agrivoltaic systems on their research farms. These systems will allow for detailed experimentation and engineering that would not be possible in a commercial setting.

3. Federal

Investment in agrisolar at the federal level primarily centers on creating a supportive environment for agrisolar advancement, rather than dictating nationwide policies. Because successful agrisolar projects look different across the country, research sites and pilot projects are vital for the development of regional best practices. Smaller agricultural operations that receive federal grant assistance may serve as pioneers for agrisolar practices in their region, proving the feasibility of such projects and demonstrating the economic benefits for farmers along the way. Federal funding also opens the door for universities and organizations to conduct large-scale analysis and solar system design work, which can translate into more successful deployment techniques for future sites. Both the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) have demonstrated their commitment to agrisolar development with the following programs.

Rural Energy for America Program (REAP)

The Rural Energy for America Program (REAP) is funded through USDA and helps agricultural producers and rural small businesses "make energy efficiency improvements and renewable energy investments" (USDA RD, no date). The program provides guaranteed loan financing and grant funding for solar energy systems in a competitive application process. Historically, the federal cost share for an awarded solar project was capped at 25%. With the increase in funding from the Inflation Reduction Act, that percentage was bumped up to 50%. There are no requirements in place that limit a producer's ability to design their system specifically for agrisolar production, making this program an attractive option for funding a project that might otherwise present a financial roadblock.

Foundational Agrivoltaic Research for Megawatt Scale (FARMS)

In May 2022, the U.S. DOE Solar Energy Technologies Office (SETO) announced an $8 million funding opportunity called Foundational Agrivoltaic Research for Megawatt Scale (FARMS). The overarching goal of the FARMS program is to "examine how agrivoltaics can scale up to provide new economic opportunities to farmers, rural communities, and the solar industry" (EERE, no date). Six projects covering a wide range of research topics, including soil health, livestock grazing, crop production, and community perceptions, were awarded funding in December 2023. FARMS represents a significant investment in agrisolar research by the U.S. government, which may offer state and local governments reassurance that agrisolar is a worthwhile pursuit in their areas of responsibility, as well.

EXAMPLE CASE STUDIES FOR FARMERS: AGRISOLAR POLICY IN ILLINOIS

Solar energy policy in Illinois supports pollinator-friendly, crop, and livestock agrivoltaics through several policies. This section will elaborate on the policies supporting each type of agrivoltaics, with advice on how to get started with agrivoltaics within the Illinois policy framework.

Pollinator-Friendly Solar

Hypothetical Case Study

Barbara the Beekeeper owns a small apiary in Illinois. Wanting to expand the size of her operation but lacking the land necessary to do so, she considers partnering with a local solar energy facility to host her expanded bee colonies on the facility. First, Barbara should be aware that in 2018 Illinois passed the Pollinator-Friendly Solar Site Act, which allows an owner or manager of a solar site to claim the facility is "pollinator-friendly or provides benefits to game birds, songbirds, and pollinators only if the site adheres to guidance set forth by the pollinator-friendly scorecard." Barbara should also be aware that county governments can require that solar developers adhere to the Pollinator-Friendly Solar Site Act as a condition of receiving project approval. Finally, Barbara should note that the Illinois Shines Adjustable Block Program provides a scoresheet for traditional community solar project applications, and including pollinator-friendly habitat in site design plans increases an applicant's score and can move them higher up on the project waitlist. With all these policies in mind, Barbara knows that not only is pollinator-friendly solar allowed in Illinois, but it is also actively encouraged by the state government. Now, all Barbara has to do is find a local solar site adhering to pollinator-friendly habitat standards and ask about bringing her apiary to the site!

Crops growing among solar panels. Photo: AgriSolar Clearinghouse

Policy-Heavy Discussion

In 2023, the Illinois legislature passed HB 4412, a law that established a uniform zoning code for wind and solar energy in unincorporated county land across the state. As a result of this law, all county governments are required to accept the proposal of any solar or wind energy project that meets the requirements of HB 4412. Overall, this legislation repeals any overly stringent restrictions or moratoriums on the construction of wind or solar in Illinois, allowing these renewable energy projects to be built in any county's unincorporated land. While HB 4412 does not explicitly require the use of pollinator-friendly solar or any other form of agrivoltaics on Illinois solar projects, the bill does allow county governments to "require a commercial solar energy facility owner to plant, establish, and maintain for the life of the facility vegetative ground cover, consistent with the goals of the Pollinator-Friendly Solar Site Act and require the submittal of a vegetation management plan in the application to construct and operate a commercial solar energy facility in the county." The Pollinator Friendly Solar Site Act is a 2018 law enacted in Illinois that allows an owner or manager of a solar site to claim the facility is "'Pollinator Friendly' or provides benefits to game birds, songbirds, and pollinators only if the site adheres to guidance set forth by the pollinator-friendly scorecard." Instructions for certifying a solar facility as pollinator-friendly are listed on the Illinois Department of Natural Resources website. The Illinois state government provides further incentive for solar developers to incorporate pollinator-friendly vegetation management into their project designs by including a commitment to pollinator-friendly habitat on the traditional community solar project scoresheet included as part of the Illinois Shines Adjustable Block Program. This policy is discussed further in the following section.

While the Pollinator-Friendly Solar Site Act does not require that an apiary be hosted at a solar facility, it ensures that there are a number of pollinator-friendly solar sites that may be suitable for apiculture. The National Renewable Energy Laboratory's Agrivoltaics Map lists over 30 pollinator-friendly solar sites in Illinois. To get started with practicing apiculture on a pollinator-friendly solar site, identify the owner of the site you wish to partner with and contact them to inquire about using the land.

Solar Grazing

Hypothetical Case Study

Sam the Shepherd owns a small flock of sheep in Illinois. To increase the income he earns from his sheep, Sam decides he wants to try solar grazing. He is aware that in 2023 Illinois enacted HB 4412, a state law that sets the maximum stringency requirements a wind or solar energy facility can be subject to, and which prohibits any county from banning solar or wind development on unincorporated land. While doing his research on energy land-use policy, Sam finds the Renewable Energy Facilities Agricultural Impact Mitigation (REFAIM) Act enacted in 2018. The law requires that the owner of a renewable energy facility in Illinois not only be responsible for decommissioning and remediation of the land at the end of the facility's life cycle, but also be responsible for weed and vegetation control throughout the life of the facility. Reading further, Sam sees that the REFAIM Act expressly includes livestock as a valid vegetation control method as long as the landowner agrees. Unfortunately, since Sam has a small flock of sheep and may not be able to adequately manage a utility-scale solar facility, he decides to research what other policies may help him get started in the solar grazing business.

In addition to HB 4412 and the REFAIM Act, Sam learns about the Illinois Shines Adjustable Block Program for Traditional Community Solar Projects. In this project, solar developers apply for a limited amount of capacity allotted for Traditional Community Solar in Illinois, and those who apply after all the capacity is filled are waitlisted with the opportunity to fill out a project scoresheet to improve their priority on the waitlist. Looking at the program and the scoresheet, Sam finds that solar developers can earn a point for incorporating agrivoltaics into project design and that livestock grazing is included as permissible agricultural use. Now all Sam has to do is find a solar developer to partner with!

Policy-Heavy Discussion

In addition to pollinator-friendly solar, Illinois has two policies favorable to solar grazing: the Renewable Energy Facilities Agricultural Impact Mitigation (REFAIM) Act, and Illinois Shines Adjustable Block Program. The REFAIM Act addresses concerns surrounding the maintenance and decommissioning of wind and solar energy facilities. While REFAIM is intended to ensure that renewable energy facilities are properly maintained, the act also supports agrivoltaics by expressly enumerating livestock as a valid method for vegetation control with the agreement of the landowner (Guarino and Swanson, 2023). As a result, a farmer interested in practicing solar grazing in Illinois needs only to find a solar company to partner with and the approval of the landowner to utilize livestock for the provision of vegetation maintenance.

The Illinois Shines Adjustable Block Program supports distributed generation and community solar in Illinois by allocating a set amount of capacity for these projects each application period. Applications for the Traditional Community Solar block are in high demand, with many applications waitlisted once capacity is reached. To better organize the project waitlist and improve the quality of traditional community solar in Illinois, project applicants are required to fill out a 16-point scorecard based on the details of the site and project design. This way, when the capacity limit is reached and additional projects are waitlisted, they can be ranked by the score they receive on the scorecard. Solar developers can earn one point on the scorecard for incorporating agrivoltaics into project design and meeting set requirements, and an additional point can be earned if the site is pollinator-friendly in compliance with the pollinator-friendly solar scorecard administered by the Illinois Department of Natural Resources.

Crop-Based Agrisolar

Hypothetical Case Study

Fran the Farmer owns a small farm in Illinois where he grows specialty crops for local farmers markets. Fran has heard about agrivoltaics and thinks it could be a good way to get some additional acreage for his farm and bring more crops to market. A look at state and local laws around zoning doesn't provide Fran with any information about agrivoltaics, but he finds what he is looking for with the Illinois Shines Adjustable Block Program. Since Traditional Community Solar Projects are limited to a maximum of 5 MW of capacity, Fran won't be overwhelmed by the scale of a utility-scale solar project. Additionally, Fran sees that only 50% of the project's land must be under agricultural production to qualify for agrivoltaics status, and he is certain he can use that land for his crop production. Determined to get started, Fran begins looking for a solar developer who will work with him.

Policy-Heavy Discussion

The Illinois Shines Adjustable Block Program may be the only incentive for crop-based agrivoltaics in Illinois, but the program requirements are rigorous in ensuring that agriculture is practiced in good faith. Requirements for agrivoltaic systems in the Illinois Shines Adjustable Block Program are informed by stakeholder feedback from the American Farmland Trust and the standards set by the aforementioned Massachusetts SMART Program. Agrivoltaic system designs must be able to accommodate labor and/or machinery and must include provisions for site decommissioning that preserve the land's agricultural resources and utility. While agrivoltaics is only a small part of the scoresheet in the Illinois Shines Adjustable Program, the requirements' basis in stakeholder feedback and existing agrivoltaics make it a strong example of agrivoltaics policy while giving farmers the opportunity to expand into agrivoltaic production systems.

Chapter 13
Land Use Tax Policy Considerations for Agrisolar

Heidi Kolbeck-Urlacher, Center for Rural Affairs

INTRODUCTION

Utility-scale solar energy projects require considerable land. The U.S. Department of Energy has forecasted that to meet national decarbonization goals, solar projects may require an estimated 5.7 million acres of land by 2035 (NREL, 2021). Because solar projects have similar land requirements as crop production (flat, clear land with necessary sunlight), farmland may be considered for solar development (Goldberg, 2023). With demand for solar energy continuing to grow, it is wise to consider how land use might be maximized to allow agriculture and solar to coexist. Dual-use land practices can provide opportunities to keep land in agricultural use while at the same time meeting clean-energy goals.

State land-use policies significantly impact where solar development can occur and whether dual-use land practices can be meaningfully implemented at project sites. For example, some states have placed restrictions on developing solar on prime farmland or have created land areas where only agricultural production is allowed. Alternatively, other states have developed policies that allow solar development on farmlands if certain management practices are maintained that keep the land in agricultural use while it is also being used for energy development (Kolbeck-Urlacher, 2023).

One tool that policy-level states can use to incentivize dual-use is their land-use tax structure. For example, allowing landowners to integrate solar development into their farming operation without a land-use tax change is financially beneficial to landowners, providing them with an additional income stream while keeping their land in agricultural production.

CURRENT USE TAXATION

Current use taxation programs are designed to provide an incentive to landowners to keep their land in a certain use, such as for agricultural purposes. These programs are designed to reduce property tax burden by allowing farmers to pay taxes on the way the land is used (currently in agriculture) rather than its assessed value for another use. In areas with increasing property values, this can reduce the need for farmers to sell land to pay for rising taxes. Due to the crucial role of agriculture and farmland in relation to the nation's economy, all U.S. states have developed current-use taxation programs (Phelps, 2021).

Current-use taxation benefits can become unavailable when a landowner chooses to lease their land for solar development. The change from farming activities to energy production may constitute what is called a *land-use conversion,* disqualifying the land from enrollment in the program and, in some cases, resulting in financial penalties (Farm and Energy Initiative, 2019).

Some states have enacted policies or programs that allow land being used for solar energy to continue to be taxed at a lower agricultural use rate and avoid land conversion penalties if certain conditions are met. These types of programs can increase farm viability by allowing farmers to take advantage of new income streams from clean energy development while maintaining land in agricultural use (Farm and Energy Initiative, 2019).

AGRISOLAR AND CURRENT USE CONSIDERATIONS

Without specific rules for solar development on farmland, states must interpret existing definitions to determine whether dual-use land practices qualify as *agricultural use*.

For example, according to the Farm and Energy Initiative's publication, Understanding Current Use Taxation, current use programs may:

- Have strict definitions of the terms *farm, farmer, farming, or agricultural use*
- Have strict acreage requirements
- Have land income requirements

Dugan Marieb, in Dual-use Solar in the Pacific Northwest, suggested that one practice state and local governments can employ to help facilitate dual-use at solar sites is to review land-use definitions of *solar generation, farmland,* and *farm uses* to ensure compatibility with desired dual-use practice.

It is also important to define the applications and practices that will be considered dual-use. For example, in Oregon a rule was adopted allowing for dual-use practices on high-value soils. However, the rule only identifies agrivoltaics and grazing as qualifying practices, meaning pollinator habitats or other conservation dual-uses do not qualify (Marieb, 2019).

In 2024, Illinois Congressman Eric Sorenson announced in an official press release that the SUNRAY Act (HR7391) had been introduced in Congress to require the U.S. Department of Agriculture (USDA) to define the term ***agrivoltaic system***. This clarity would provide a standardized definition of agrivoltaic practices that would be applied to all USDA programs.

AGRISOLAR CURRENT USE TAXATION POLICY EXAMPLES

Land-use tax policies are most often enacted at the state level, although local governments also have the ability to create tax incentives (Griffith, 2023). Some examples of agrisolar current use taxation policies or programs include:

Rhode Island

Rhode Island's Farm, Forest, and Open Space Act outlines farmland current-use designation and taxation. If land classified as farmland is withdrawn from this program, it is subject to a land use change tax. This tax is 10% of fair market value during the first six years of classification and decreases by 1% per year until the 10th year (State of Rhode Island, 2022).

Under this law, enrolled farmland is not subject to a land use change tax if no more than 20% of enrolled acreage is converted to renewable energy use.

In 2017, Rhode Island amended the law to allow landowners who convert more than 20% of the enrolled acreage to renewable energy to be exempt from a land use change tax if they integrate dual-use practices into the renewable energy generation system.

According to Rhode Island statute, a ***dual-use generation unit*** is defined as a raised generation unit that allows for agricultural production to continue on the land beneath the solar photovoltaic modules or wind turbine structure under normally acceptable practices.

For farmland to be taxed as Renewable on Farmland/Dual-Use Generation, the following conditions must be met:

- The generation unit will not interfere with continued use of the land beneath the unit or around the structure for agricultural purposes.
- The generation unit will be designed to optimize a balance between electricity generation and the agricultural productivity of the soil.
- The generation unit must allow for the continuous growth of crops underneath the system, with enough height for labor, machinery, and grazing animals.

- The unit must be in compliance with fire safety codes and must include a vegetation management plan to be developed with the local fire official in order for a fire permit to be issued.
- A conservation plan must be submitted that ensures continued viability of the farmland during and after the life of the energy project.
- An annual report will be made to the Division of Agriculture on productivity. This includes identifying:
    - The type of dual-use being utilized (solar or wind)
    - Total acres of open farmland integrated with the project
    - Types of crops, including grazing crops
    - Pounds of crops to be grown, harvested, or grazed
    - Animals to be grazed and herd size

New Jersey

In 2021, New Jersey enacted a Dual-Use Solar Law that provides an incentive for keeping land at solar sites in agricultural production. The law established a pilot program allowing unpreserved farmland that is used for dual-use solar projects to be eligible for farmland assessment under certain conditions.

Under this law, *dual-use solar energy project* means that the energy-generation facilities, structures, and equipment for the production of less than 10 megawatts of electric power is sourced from solar projects that allow land below the panels to be simultaneously used for both agricultural and horticultural production.

This law allows land being used for dual-use solar projects to qualify for a farmland assessment, if certain conditions are met, including:

- Land must be unpreserved farmland that is continuing to operate as a farm in the tax year of valuation, assessment, and taxation.
- Land must have been valued, assessed, and taxed as agricultural or horticultural use in the year preceding construction and installation of the dual-use solar energy project.
- Land must continue to be actively devoted to agricultural and horticultural use and meet income requirements.
- A conservation plan must be filed with and approved by the soil conservation district.
- The project must be approved by the state Department of Agriculture.

In 2023, the New Jersey Board of Public Utilities approved an agreement with the Rutgers University Agrivoltaics Program to develop and implement a pilot program. This program will allow for the installation and operation of 200 megawatts (MW) of solar capacity over three years, with the option to expand to 300 MW over five years. The program will then be evaluated and considered for permanent adoption.

Massachusetts

In 2018, a section was added to Massachusetts General Law 61A, which outlines the assessment and taxation of agricultural and horticultural land. Under Chapter 61A Section 2A, land in agricultural and horticultural use "may, in addition to being used primarily and directly for agriculture or horticulture, be used to site a renewable energy generating source," which includes solar and wind. The renewable energy generating source must meet the following requirements:

- It must produce energy for the exclusive use of the land and farm on which it is located.
- It cannot produce more than 125% of the annual energy needs of the farm and land on which it is located.
- The land and farm on which the source is located includes contiguous or non-contiguous land that is owned or leased by the owner of the land and the farm, or in which the owner holds an interest.

SMART Program

Chapter 61A also allows for energy projects that "qualify in accordance with a solar incentive program for agriculture or horticulture sectors developed by the Massachusetts Department of Energy Resources, if such renewable energy generating source does not impede the continued use of the land for agricultural or horticultural purposes pursuant to this chapter."

Under the Massachusetts Department of Energy Resource's Solar Massachusetts Renewable Target (SMART) program, specific types of dual-use solar systems, known as "*Agricultural Solar Tariff Generation Units*, can qualify for a financial contract modification or incentive to the base rate of electricity produced through the system. To be eligible for the SMART program, land must be currently taxed as, or have the ability to be taxed as, "agricultural" as defined under Massachusetts General Law 61A. However, energy projects that meet the requirements of Chapter 61A Section 2A are not required to be enrolled in the SMART program to qualify for a farmland assessment.

SMART program guidelines allow for projects on agricultural land supporting up to 200% of on-farm use, or dual-use systems up to 2 MW AC, but these values differ from Chapter 61A size requirements. Participants with projects that will exceed 125% of on-farm demand should contact the tax assessor's office to determine the future status of the property.

When a property is removed from the Chapter 61 program, penalties could include payment of property tax arrears for up to the previous five years. If the land is to be leased or sold to a solar developer, the town may have the right of first refusal on that lease or sale.

KEY TAKE-AWAYS

- Current use taxation programs are designed to decrease the tax burden for farmland owners.
- Farmland that is removed from current use taxation programs for solar energy development may be subject to financial penalties.
- State current use taxation programs can be structured to incentivize dual-use and agrisolar practices by allowing land to stay in farmland assessment if it is maintained in agricultural use while also producing solar energy.
- Dual-use tax incentives may increase the adoption and acceptance of energy development.
- Agrisolar current use taxation programs can increase financial stability for farmers by allowing them to take advantage of new income streams through solar development while maintaining agricultural use on farmland.

Conclusions

Co-locating solar and agriculture is possible. It works differently across the country, in accordance with local climate, community engagement, policy, incentives, and tax considerations. Local innovations, pioneering agrivoltaic projects, and national research are driving and defining best practices for co-location sites.

Collaboration is at the heart of all co-location work. By its nature, agriculture and solar must collaborate to share the same land, risks, and benefits. Producers work in partnership with solar developers, graziers cooperate with the solar grazing community, and beekeepers coordinate with solar pollinator experts.

When done well, the different branches of agrivoltaics can collaborate, too. Solar grazing can synchronize with pollinator habitats and apiaries. Site design can include areas for crops, grazing, beekeeping, and pollinator habitat. But, it is important to understand the impacts, tradeoffs, and synergies of each branch. Some pollinators can be toxic to grazing animals, and grazing at different stages of growth can harm pollinator plants. Pollinator habitat and honey hives around crops can increase crop production, and grazing can increase improve soil health. As with all collaboration, clear and consistent communication is the key to success. In any co-location project, it is important to remember the 5 Cs developed by the NREL InSPIRE project: context, collaboration, communication, compatibility, and capacity.

Partnership with the local community and project stakeholders is vital to the success of co-location projects. The stakeholder engagement framework described in this guide provides a starting point that can be customized for any project. By determining goals and outcomes, conducting an impact assessment, co-producing a community benefits agreement, developing an engagement strategy, and then maintaining long-term engagement, stakeholders will have an opportunity for meaningful collaboration and long-lasting support.

It is a best practice to incorporate low-impact solar design into any co-location project. This design strategy includes minimal soil disturbance, minimal land forming and grading, maximizing biodiversity, conservation of native vegetation, enhancinged ecosystem services, careful site selection, intentional site development, and consistent low-impact operations and maintenance, with long-term benefits to the producer and local community. In co-location site selection, it is important to consider environmental, cultural, and future land impact. The site plan should not limit potential future farming or grazing. Avoid areas that support critical wildlife habitats, wetlands, or traditional cultural properties. The local community can help identify cultural heritage sites, indigenous lands, aesthetic concerns, and it can assist in low-impact siting through stakeholder engagement.

There are many ownership structures for co-location, from farmer-owned solar, to solar providing farmland access for emerging farmers, to community solar, and solar leases. Lawyers and policy experts that specialize in tax law, easements, water rights, decommissioning, and repowering are imperative in the planning process.

Co-location is a relatively new practice, and best practices are rapidly evolving. The AgriSolar Clearinghouse looks forward to the evolution of agrisolar and what comes next.

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