FACT SHEET

Agrivoltaics and Ecovoltaics

How Solar Power Can Deliver Water Savings, Farm Success, and a Healthier Environment

HIGHLIGHTS

Agrivoltaics and ecovoltaics are multibenefit land repurposing strategies that offer economic and ecological benefits. They can reduce groundwater pumping near disadvantaged communities, contribute to an equitable clean energy transition, and create job opportunities.

This fact sheet details benefits, key ideas for implementation—including a focus on costs, funding sources, and permitting—, and recommendations. Farmers, land managers, and others can use it to discuss land repurposing options with communities, conservation practitioners, project proponents, and block grantees participating in the Multibenefit Land Repurposing Program or other land repurposing programs.

Middle-Ground Solutions for Multibenefit Land Repurposing

Groundwater pumping limitations required by California's Sustainable Groundwater Management Act (SGMA), combined with climate change effects, are pushing water managers, farmers, and communities to reduce their water use while maintaining crop production and increasing social and environmental resilience.

Multibenefit land repurposing is a promising solution that involves transitioning irrigated agricultural land to uses that promote water savings, and it benefits communities and ecosystems. In some cases, farmers can be compensated to transition their farmland to alternative beneficial uses, such as parks, habitat corridors, new socioeconomic opportunities, non-irrigated rangeland, space for clean industries and renewable energy, and wildlife-friendly multibenefit recharge basins (EDF 2021; Fernandez-Bou et al. 2023).

Agrivoltaics and ecovoltaics demonstrate how clean energy can be integrated into multibenefit land repurposing projects, through the installation of solar panels, while moving toward other beneficial activities, such as transitioning to less-water-intensive crops, cover cropping, habitat restoration, and non-irrigated rangeland. Agrivoltaics and ecovoltaics contribute to clean energy production, energy resilience, and water conservation goals while providing additional revenue streams for landowners and farmers. As part of a holistic approach to land management, agrivoltaics and ecovoltaics represent innovative solutions that support the long-term sustainability and resilience of rural communities and preserve their agricultural heritage (Adeh, Selker, and Higgins 2018; Sturchio and Knapp 2023; Tölgyesi et al. 2023; Warmann, Jenerette, and Barron-Gafford 2024).

Eight Benefits for Farmers, Landowners, Communities, and the Environment

Agrivoltaics and ecovoltaics are compatible with sustainable agriculture, a healthy environment, economic benefits, and renewable energy production. They offer multiple benefits for disadvantaged communities, farmers, the environment, and society.

Agrivoltaics work best with crops that benefit from moderated temperatures and soil moisture, and crops that tolerate partial shade provided by solar panels. Multiple crops can thrive in agrivoltaic systems, including berries (e.g., blueberries, strawberries, raspberries), leafy greens (e.g., lettuce, bok choy, napa cabbage, kale,

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spinach), cover crops, herbs (e.g., basil, cilantro, dill, parsley), and native grasses. Ecovoltaics can be implemented in any traditional solar energy system.

Here are eight benefits of agrivoltaics and ecovoltaics:

1. Reduce Agricultural Water Use While Promoting Sustainable Agriculture

Agrivoltaics and ecovoltaics offer ecological benefits that promote sustainable agriculture and environmental health, including healthier soil and reduced water use. Also, because vegetation has a cooling effect on the solar panels and panels function better at lower temperatures, agrivoltaic systems tend to generate energy more efficiently than panels over bare ground (Williams et al. 2023).

There are multiple installation options for agrivoltaic systems, with different agronomic and energy advantages and trade-offs. A 2024 study in the southwestern United States showed that agrivoltaics can reduce water consumption by 30 to 40 percent, with minimal impacts on yields for shade-tolerant crops, although the results were less positive for crops that need direct sunlight (Warmann, Jenerette, and Barron-Gafford 2024).

Agrivoltaics reduce crop evapotranspiration (evaporation from the soil and transpiration by the plants during photosynthesis) by shading the soil beneath solar panels, resulting in significant water savings. When paired with soil health practices, agrivoltaics can boost long-term soil health and productivity. Reduced evaporation conserves water resources, while the moderated soil temperature and moisture levels can encourage microbial activity, enhance nutrient retention, and improve soil structure. Combined with other soil health principles (including US Department of Agriculture recommendations about increasing crop diversity, integrating livestock, maintaining soil cover, and minimizing soil disturbance), these conditions allow the cultivation of multiple crops and promote higher nutrient concentrations and resilience in agricultural systems (Stott and Moebius-Clune 2017).

BOX.

Definitions

Agrivoltaics: A system that integrates solar energy production and agriculture (i.e., crops or livestock) simultaneously on the same piece of land. Solar panels can be arranged between or above crops and can act as fences or windbreaks and provide shade for crops sensitive to sun exposure and animals like sheep.

Ecovoltaics: A system of solar energy production that fosters ecosystem functions (e.g., habitat, biodiversity, air quality control). Ecovoltaics use ecological knowledge to understand how solar panels affect components of ecosystems that are not biological (e.g., sunlight, water, air) and that involve living organisms (e.g., plants, animals, beneficial soil microorganisms). The goal is to make solar energy infrastructure contribute to ecosystems' health and sustainability (Sturchio and Knapp 2023).

2. Reduce On-Farm Electricity Costs and Diversify Income

Agrivoltaics can contribute to farms' economic resilience. For small-scale projects, agrivoltaics can reduce on-farm electricity costs generated from activities and infrastructure, such as water pumping, irrigation, heating, and refrigeration.

Pairing agrivoltaics with energy storage helps with production variability caused by day-night cycles and weather conditions, and it addresses the mismatch between generation and demand. Although energy storage can increase up-front investment costs, it can reduce energy bills and help during outages.

For large-scale systems, farmers may receive income through agreements (normally leasing the land use for solar energy) with energy buyers (off-takers) such as utilities, virtual power purchase agreements, or community choice aggregation. Community choice aggregation can include the provision of electricity to nearby disadvantaged communities.

Incentives to implement agrivoltaic systems can focus on small farmers, who often lack the financial resilience and the water access of larger agricultural corporations. While these systems may require some changes in equipment and techniques, agrivoltaics can increase economic resilience during drought periods and market fluctuations in crop prices, safeguarding the diverse fabric of California agriculture and its cultural richness.

3. Increase Potential Cropping Options with Shade and Moderated Temperatures

Agrivoltaic systems reduce exposure to direct sunlight and the risk of sunscald (sunburn), which can benefit some crops. The shading effect helps to moderate temperatures, decreasing risks from extreme heat and frosts. Conditions under agrivoltaic systems can provide farmers with more cropping choices and an opportunity to grow a broader range of plant species with varying sunlight requirements. Consequently, agrivoltaics can increase the potential yields of some crops and improve resilience to environmental and climate fluctuations. It also offers farmers cropping options that use less irrigation and that can have higher revenues.

4. Benefit Disadvantaged Communities

Agrivoltaics can play a significant role in reducing water pumping from farms near domestic and community wells, while preserving the agricultural identity of the region. Additionally, different ecovoltaic and agrivoltaic arrays can be designed with groundwater recharge projects to protect aquifers near disadvantaged communities.

Ecovoltaic projects, when combined with seasonal aquifer recharge, can enhance water security and water quality while providing habitat conservation and more secure water access to local farmers who depend on groundwater. Integrating ecovoltaics near communities vulnerable to water insecurity and other environmental issues can also lead to a healthier environment through improved ecosystem functions for both people and wildlife.

5. Create New and Diversified Job Opportunities

Agrivoltaics and ecovoltaics offer the potential to create new and diversified job opportunities, both during the construction phase of the solar infrastructure and throughout the system's life cycle for maintenance needs. Implementation, construction, and installation of solar panels on farmland require a skilled workforce that can be found in local communities if workers are given adequate incentives for workforce training. Habitat restoration combined with ecovoltaics can provide local job opportunities, as can maintenance tasks, such as panel cleaning or habitat management. These systems' contribution to local tax revenue can also help the region's economy.

6. Integrate Renewable Energy and Environmental Conservation

Ecovoltaics offer a sustainable solution to the negative impacts of conventional solar energy projects on local communities and ecosystems, such as dust and heat islands. Well-planned ecovoltaic systems can generate clean energy while contributing to ecological and societal well-being. Ecovoltaics can create habitat for pollinators and endangered species, provide microclimates to alleviate the impacts of extreme weather events exacerbated by climate change, and control dust accumulation that impairs energy generation and affects local residents' health.

Cover crops and native plants can be integrated into ecovoltaic systems to enhance biodiversity, promote soil health, and reduce erosion while maintaining a functional relationship between renewable energy infrastructure and the surrounding environment. The income generated from ecovoltaic installations can also finance habitat maintenance, contributing to connectivity projects and the long-term sustainability of restoration plans.

7. Contribute to an Equitable Clean Energy Transition

Agrivoltaics present a significant opportunity for farmers to keep land in production during the transition to clean energy by integrating solar energy generation with agricultural production. This solution contributes to an equitable transition to clean energy while addressing land use, water use, and economic feasibility. Agrivoltaics demonstrate the compatibility of agriculture and renewable energy production. They maximize renewable energy and environmental benefits while supporting a healthy agricultural economy.

Ecovoltaics can help with the clean energy transition and address ecological and environmental issues on the same land. If ecovoltaics is the standard for new solar panel installations, the increase in solar energy can also increase environmental resilience and ecosystem functions, providing multiple benefits for everyone.

8. Create New Infrastructure That Can Help with Precision Farming and Automation

Agrivoltaic systems have synergies with smart agriculture and automation technologies that can help farmers integrate new and future advanced equipment. The infrastructure can accommodate and power automation technologies, such as communication devices, robotics devices, and sensors, enhancing farming efficiency, precision, and sustainability. For instance, the solar panel infrastructure can incorporate precision farming and automation elements, such as internet connection and electronic devices to measure and collect data (e.g., evapotranspiration), facilitating data-driven decisionmaking through monitoring and automated mechanics.

Four Recommendations to Incentivize Agrivoltaics and Ecovoltaics

1. Incentivize Access to Financing for Agrivoltaic Systems

The financial benefits of agrivoltaics are the biggest factor influencing the decision to invest in the systems, but the cost of agrivoltaics is the biggest obstacle, according to surveys and interviews with farmers in the United States and abroad (Cuppari et al. 2024). Incentives for agrivoltaics should consider both reducing installation costs and guaranteeing revenues or savings related to electricity.

Financing, either via low-interest loans or grants, can make agrivoltaics more affordable, especially for small and disadvantaged farmers with limited access to capital. Agrivoltaics can be compatible with other economic incentives focused on environmental conservation, smart agriculture, and sustainable practices. Conservation-, community-, or farmer-led projects can form partnerships with private solar developers. These partnerships can collaboratively design the projects, outline the benefits provided, and establish cost-revenue agreements.

2. Fund Pilot and Demonstration Projects

Because agrivoltaics implementation in California remains limited, pilot projects are important to showing the feasibility of these systems. Pilot projects also provide more data to inform the most effective ways to implement different agrivoltaic system designs, such as panel spacing and crop selection for different California subregions. As the agrivoltaics field grows, demonstration projects can help farmers learn about agrivoltaic system implementation and management.

3. Design Farmer-centric Systems with Outreach and Technical Assistance

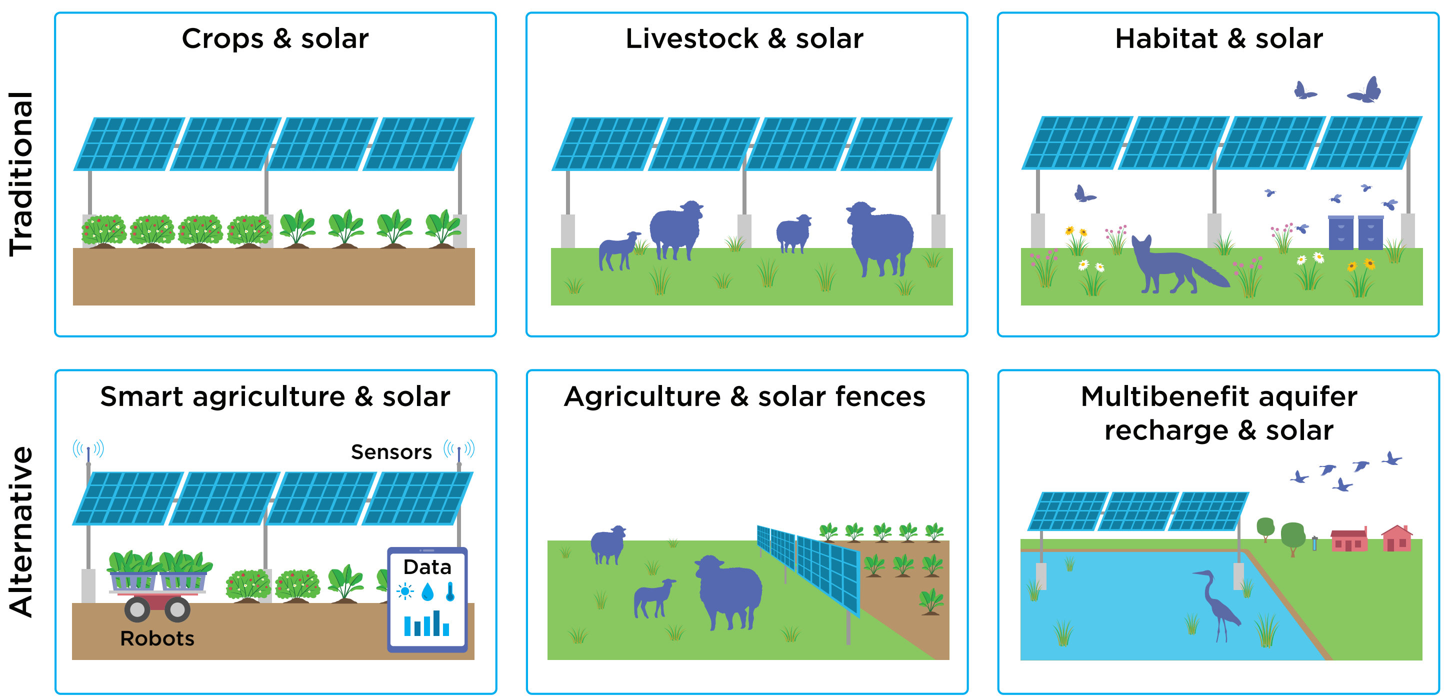
Farmers have many logistical and technical considerations when installing agrivoltaic systems, including the crops grown, equipment needed, panel layout, relations with nearby communities, and the relationship between solar developer and landowner. Assistance in navigating these decisions will be critical to increasing the adoption of agrivoltaic systems and ensuring they are well-designed to maximize multiple benefits while being economically feasible. Educational organizations and extension specialists familiar with the technology and community needs can facilitate technical assistance and outreach.

Demonstration projects and peer-to-peer learning can help farmers overcome challenges in transitioning to agrivoltaic systems, and they are often preferred methods of learning for farmers. The support of well-established community members provides role models for other farmers, and farmers' peers are an important factor in making future decisions.

4. Incentivize the Adoption of Ecovoltaic Systems Instead of Traditional Solar Projects

Ecovoltaic systems can become the standard for solar energy projects, since they create multiple benefits by using the soil in more than one way. One interesting and novel option can be ecovoltaics and aquifer recharge (see the figure). Such projects can create a win-win situation for farmers, landowners, renewable energy, and nearby communities. Aquifer recharge fosters water security for local people and farmers, supporting a natural habitat that can improve local air quality. In addition, society can benefit from clean energies and habitat restoration.

FIGURE. Agrivoltaic and Ecovoltaic Systems



Agrivoltaic and ecovoltaic systems and their different implementation options are presented. The top images show traditional uses of agrivoltaics for crops and livestock, and ecovoltaics for habitat conservation. The bottom images show alternative ideas that allow multiple uses of the soil and of the infrastructure, to obtain even more benefits than received with traditional uses.

Easements could encourage the implementation of ecovoltaic systems that guarantee ecosystem functions (such as habitat, improving environmental health, and increasing flood and drought resilience) and better environmental health for nearby communities. Community benefit agreements between nearby communities and ecovoltaic project developers can help implementers avoid delays or legal challenges, while supporting the needs and perspectives of communities.

> ***Ecovoltaic systems can become the standard for solar energy projects to maximize multiple benefits.***

Three Considerations for Implementing Agrivoltaics and Ecovoltaics

1. Costs

Agrivoltaic systems often have higher capital costs than traditional ground-mounted solar photovoltaic systems (e.g., panels may need to be raised higher), and farmers may need new equipment and training. The increased capital cost of agrivoltaics ranges between \$0.07/watts of direct current (WDC) and \$0.80/WDC more than regular photovoltaic installations, depending on the design and farming practices.

Ecovoltaic systems are designed and managed to reflect and encourage ecosystem functions. For example, solar panel trackers can be set to provide shade at specific times, and panels spaced closer together can reduce evaporation from the soil. Some designs may require higher capital costs. However, there are opportunities to incorporate ecovoltaics management practices into existing solar arrays at little cost. For example, native plant species or pollinator-friendly species can be grown under panels with little to no additional changes to solar array design.

2. Permitting

Attaining permits for clean energy projects has become an increasingly lengthy process in California. However, agrivoltaic systems are arguably better positioned for permitting than traditional solar systems. Local governments have limited authority to prohibit solar development for on-site use, allowing farmers to attain permits more easily. On-site use of electricity generated from agrivoltaic systems can have significant financial benefits for farms, particularly farms that are energy intensive.

One of the major barriers to clean energy permitting has been opposition by local communities, leading to delays and litigation. These delays are often warranted when developers fail to consider the impact of clean energy infrastructure on local communities. Agrivoltaics leaders can improve the process for clean energy development by involving community partners, such as farmers who will manage the land.

However, agrivoltaic systems involve other issues that could complicate permitting procedures. For example, some easements or tax incentives for agriculture and conservation may not be clear about whether agrivoltaics qualify, which may lead to delays in permitting. Uncertainties such as these can make developers hesitant to pursue projects. Clarifying these policies is an important step to encouraging the transition of certain agricultural land to agrivoltaics.

3. Funding

Potential federal and state funding sources, including rebates, can be used for implementation, construction, planning, and technical assistance for solar energy projects. Consider the following:

- **US Department of Agriculture:** Rural Energy for America Program (REAP) and Rural Utilities Service
- **US Department of Energy:** State Energy Program and Solar Energy Technologies Office (SETO)
- **California Department of Food and Agriculture:** Pollinator Habitat Program
- **North Carolina State University:** Database of State Incentives for Renewables and Efficiency

Authors

Angel S. Fernandez-Bou is a western states senior climate scientist in the Union of Concerned Scientists (UCS) Climate and Energy Program. **José M. Rodríguez-Flores** is a senior analyst at Environmental Defense Fund. **Rosa Isabella Cuppari** is a doctoral student at University of North Carolina, Chapel Hill. **Vivian Yang** is a western states energy analyst in the UCS Climate and Energy Program.

Acknowledgments

This work was made possible by the Statewide Support Entity Award (Self-Help Enterprises and Environmental Defense Fund) from the Multibenefit Land Repurposing Program of the California Department of Conservation and the generous support of UCS members. The authors would like to thank Sonia Sanchez and Stephanie Mercado from Self-Help Enterprises, Gopal Penny from Environmental Defense Fund, and Molly Daniels and Katie Riley from Environmental Incentives for their contributions and support. We also thank the expert reviewers who helped us improve this fact sheet and prefer to remain anonymous.

Organizational affiliations are listed for identification purposes only. The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The authors bear sole responsibility for the report's content.

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NATIONAL HEADQUARTERS
Two Brattle Square
Cambridge, MA 02138-3780
(617) 547-5552

https://doi.org/10.47923/2024.15501