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Dual-Use Solar Photovoltaics: Emerging Applications and Issues for Congress

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Dual-Use Solar Photovoltaics: Emerging Applications and Issues for Congress

SUMMARY

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Morgan Smith
Analyst in Energy Policy

Solar photovoltaics (PV) is one potential renewable energy technology that may help the United States achieve its carbon reduction goals and commitments. However, solar PV uses more land per megawatt of generation capacity than some other energy technologies. Thus, increasing deployment of solar PV has resulted in some land-use conflicts and is likely to result in more such conflicts in the future.

Dual-use solar PV is one potential way to generate carbon-free electricity without causing as many land-use conflicts as conventional solar PV deployment. Dual-use solar PV involves the co-location of electricity generation and a non-energy use on the same land at the same time—that is, generating electricity on the land while also using the land for another purpose. A common example of this is the use of rooftop solar or building-integrated solar on residential or commercial buildings or other structures. Emerging dual uses include agriculture (such as growing crops, grazing livestock, supporting biodiversity, providing ecological support services, and enhancing greenhouses), aquaculture, and water-based uses (including water that is being stored or transported for municipal use, water treatment, or irrigation). The terms *agrivoltaics*, *aquavoltaics*, and *solar-over-water* are often used to describe these emerging dual uses. Researchers are exploring the best practices, costs, and benefits associated with these emerging dual-use PV applications.

Dual-use solar PV offers potential opportunities. Compared with the standalone use of lands, dual use of land (or water) can potentially increase an area's overall productivity (as captured by a metric such as land use efficiency), while maintaining—or potentially improving—elements of both the energy and the non-energy uses. Dual-use solar PV can potentially increase agricultural and aquacultural yields; decrease water evaporation; increase the electricity generation efficiency of the solar panels; and decrease some solar PV development costs such as land acquisition, construction, and deconstruction costs.

Potential challenges associated with dual-use solar PV include the following: dual-use may negatively affect some agricultural or water operations (such as hydropower operations); planning for dual-use requires taking into account potentially complex interactions with the variety of crops and agricultural conditions in the United States; accommodating dual uses may increase the complexity of solar PV system designs, which may in turn increase system costs; and the cost of electricity, on a per kilowatt-hour basis, may be higher for dual-use solar PV than for standalone solar PV generation.

In 2022, the United States had 39.8 gigawatts (GW) of small-scale solar PV generation, most of which was dual-use rooftop solar installed on residential buildings, according to the National Renewable Energy Laboratory (NREL). NREL also identified 584 aquavoltaic installations with a total generation capacity of 10.064 gigawatts (GW) as of September 2024. For context, in 2023 total U.S. solar generation capacity from both utility-scale and small-scale development was 138 GW.

Recent Congresses have enacted or considered several bills that address dual-use solar PV. As part of the Water Resources Development Act of 2022 (P.L. 117-263), Congress directed the Secretary of the Army and the U.S. Army Corps of Engineers to report on floating solar PV opportunities under their purview. Section 50232 of P.L. 117-169 (commonly referred to as the Inflation Reduction Act) provided $25 million for solar panel installations over canals. The Pollinator Power Act of 2023 (S. 1555) would incentivize pollinator habitats surrounding new solar PV facilities. The Farm, Food, and National Security Act of 2024 (H.R. 8467) would require the U.S. Department of Agriculture and the Department of Energy to conduct a study on solar panel installations on farmland, including on "shared solar energy and agricultural production."

Topics for possible congressional consideration related to dual-use solar PV could include

- how federal farm, land, water, and resource management policy could affect development;
- how data collection and sharing could inform development and related resource management decisions;
- how federal R&D support and deployment incentives could affect development; and
- how federal actions could help state and local stakeholders develop dual-use solar PV standards and policies.

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Introduction

Dual-use solar photovoltaics (PV) involves the co-location of solar PV electricity generation and a non-energy use on the same land at the same time.[1] Deployment of dual-use solar PV could affect renewable electricity development, land use, food production, and the environment. This report discusses areas of dual-use solar PV development that might be affected by federal policy areas such as farm policy and land and resource management. It also discusses how federal legislation or policies could affect dual-use solar PV technologies, practices, or development.

Considerations for Congress could include how to coordinate with farm policy on permitting, land use definitions, and program eligibility requirements; and how dual-use solar PV applications might affect land and water management policies. Other potential considerations include federal requirements for the collection and use of solar PV data for resource identification and management, federal research and development (R&D) support for dual-use solar PV, and federal involvement in state and local dual-use solar PV development.

Congress has enacted statutes with provisions related to dual-use solar PV applications. One statute directed the Secretary of the Army and the U.S. Army Corps of Engineers to study floating solar PV opportunities on federal waters (P.L. 117-263). Another provided $25 million for solar panel installations over canals (Section 50232 of P.L. 117-169). Congress has also considered bills incentivizing pollinator habitats surrounding new solar PV facilities (S. 1555) and directing the U.S. Department of Agriculture (USDA) and the Department of Energy (DOE) to conduct a broad study on solar panel installations on farmland, including dual uses (H.R. 8467).

Scope of the Report

This report provides background and context for land use and other issues related to dual-use solar PV. Rooftop solar and building-integrated solar are mentioned briefly as established dual-use solar PV applications. Dual-use energy applications that incorporate other renewable energy (RE) technologies—such as wind and geothermal power—are outside the scope of this report. Handling and disposal of solar PV waste, and recycling and reuse of solar PV components, are also outside its scope (although the report mentions decommissioning planning as a generally required part of solar project permitting or energy contracting).

National Priorities for Electricity and the Carbon-Intensive Economy

Development of solar PV and other RE technologies is occurring in the context of federal policies seeking to reduce U.S. emissions of carbon dioxide, a greenhouse gas (GHG) that contributes to climate change. Although there is substantial disagreement among policymakers over how and how much to prioritize RE technologies and how to address issues related to carbon emissions, RE is increasingly important to the U.S. economy and the electric grid. From the first 1.1 megawatt (MW) solar PV plant in Hesperia, CA, in 1982, utility-scale solar PV generation has expanded to provide 3.9% of all the electricity in the United States.[2]

[1] Solar PV systems consist of panels made from silica and other materials that absorb sunlight and convert it to electricity. Another type of solar electricity generation is solar thermal (also known as *concentrated solar power*), which uses mirrors to reflect and concentrate sunlight to heat a material to create electricity.

[2] Solar Energy Industries Association (SEIA), "The Solar Century: Landmark Moments in the History of Solar Energy," April 29, 2024, https://www.seia.org/blog/solar-century-landmark-moments-history-solar-energy; U.S. (continued...)

The Biden Administration has established national commitments to carbon-free electricity and a net-zero economy.[3] Following its recommitment to the Paris Agreement, an international climate change agreement, on January 20, 2021, the Biden Administration set a U.S. target—a nationally determined contribution—to reduce net GHG emissions 50%-52% below 2005 levels by 2030.[4] To achieve these goals, the Biden Administration has set a target of 100% carbon-free electricity generation by 2035 and net-zero GHG emissions economy-wide by no later than 2050.[5] The Biden Administration has also committed to the electrification of carbon-intensive industries such as transportation, materials manufacturing (steel, chemicals, petroleum refining), energy production, and others to leverage low- to no-carbon electricity sources.[6]

The 117th Congress enacted P.L. 117-169, commonly known as the Inflation Reduction Act (IRA), which DOE has called "the single largest investment in climate and energy in American history" and which supports investments to advance many areas of climate and energy policy.[7] That law increased and broadened federal tax incentives for renewable and clean energy technologies.

Low- or no-carbon electricity generation will likely require significant amounts of land. One analysis using federal government data calculated that the United States uses 327,800 square kilometers (km^2), or 126,600 square miles (mi^2), of land to power the economy.[8] This is slightly larger than the area of the fifth-largest U.S. state, New Mexico, and about 3.3% of total U.S. territory.[9] Of this total area, 28,700 km^2 (11,100 mi^2) is used for solar and wind generation, and another 19,400 km^2 (7,500 mi^2) is used for power line easements (for both renewable and nonrenewable sources of electricity).

Other studies have estimated how much land the United States would likely need to dedicate to achieving a zero-carbon economy. Findings by Princeton University's Net-Zero America project,

Energy Information Administration (EIA), "Frequently Asked Questions: What Is U.S. Electricity Generation by Energy Source?" February 29, 2024, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[3] The U.S. Environmental Protection Agency (EPA) describes carbon-free electricity as "electrical energy produced from resources that generate no carbon emissions, including marine energy, solar, wind, hydrokinetic (including tidal, wave, current, and thermal), geothermal, hydroelectric, nuclear, renewably sourced hydrogen, and electrical energy generation from fossil resources to the extent there is active capture and storage." EPA, "Carbon Pollution-Free Electricity at EPA," last updated November 22, 2023, https://www.epa.gov/greeningepa/carbon-pollution-free-electricity-epa.

[4] The White House, "FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies," press release, April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

[5] U.S. Department of State and U.S. Executive Office of the President, *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*, November 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

[6] Ibid. Other approaches to achieving these emissions targets include transitioning to lower-emissions fuels and developing carbon-capture and storage applications.

[7] U.S. Department of Energy, "Inflation Reduction Act of 2022," last updated September 22, 2023, https://www.energy.gov/lpo/inflation-reduction-act-2022.

[8] This includes the land needed for energy used for the electric grid; for transportation; and in the residential, commercial, and industrial sectors. Dave Merrill, "The U.S. Will Need a Lot of Land for a Zero-Carbon Economy," *Bloomberg*, June 3, 2021, https://www.bloomberg.com/graphics/2021-energy-land-use-economy/.

[9] U.S. Census, "Profiles: United States," https://data.census.gov/profile?g=010XX00US.

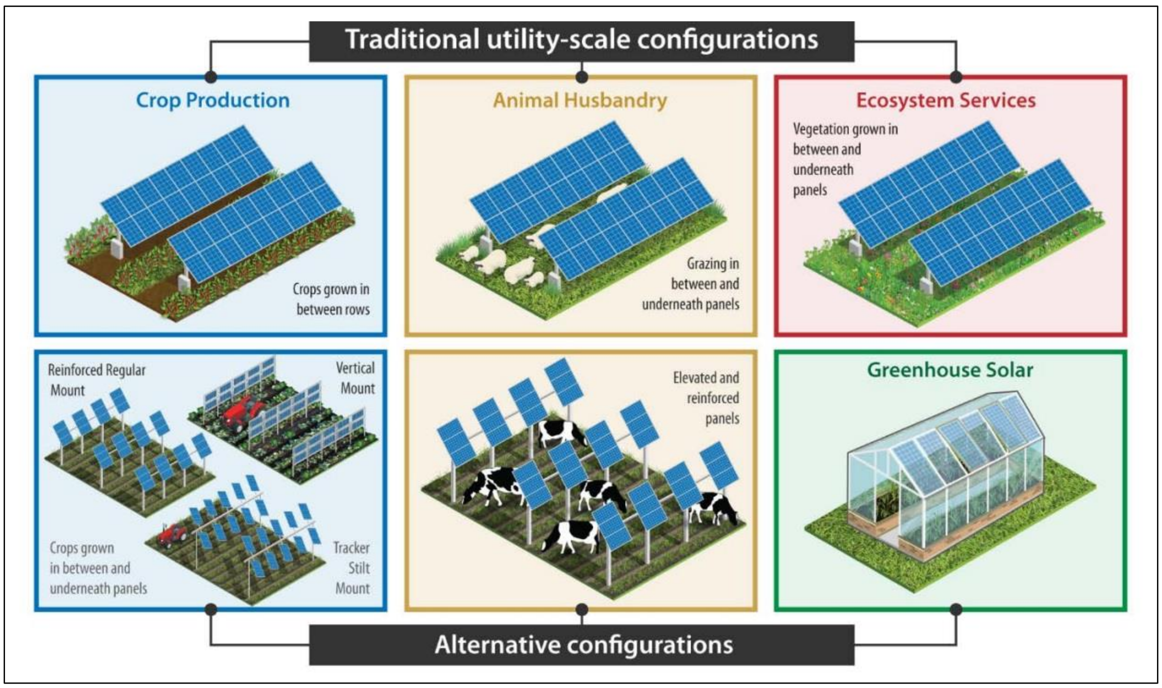
for example, estimate that the amount of land dedicated to carbon-free electricity production would need to increase between 889% and 3,920% over the current level.[10]

Dual-use solar PV is an alternative to having to set aside large swaths of land solely for the purpose of generating electricity.

What Is Dual-Use?

Dual-use for electricity generation is, in general, the co-location of electricity generators (e.g., solar PV arrays or wind turbines) and an additional application. Building-integrated solar panels, rooftop solar, and solar canopies are some common existing applications of dual-use; in these applications, the purpose of the building or the area covered by the canopy (e.g., a parking lot) is the second use. Additionally, some emerging applications integrate solar PV with agriculture, aquaculture, or water storage and transport (see examples in **Figure 1**).[11] The co-location of wind turbines with agriculture, including grazing land, is another common dual-use implementation.

Figure 1. Examples of Dual-Use Solar PV Configurations



Source: Jordan Macknick et al., *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study*, National Renewable Energy Laboratory, August 2022, https://www.nrel.gov/docs/fy22osti/83566.pdf.

Notes: Building-integrated solar panels or rooftop solar are other common types of dual-use configurations.

[10] The low and high numbers in this range are based on a low-land-use/low-renewables scenario and a high-land-use/high-renewables scenario, respectively.

[11] Individual solar panels can be grouped into large arrays to generate electricity for the grid. U.S. Department of Energy (DOE), "Dual-Use Photovoltaic Technologies," https://www.energy.gov/eere/solar/dual-use-photovoltaic-technologies; Jordan Macknick et al., *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study*, National Renewable Energy Laboratory (NREL), August 2022, https://www.nrel.gov/docs/fy22osti/83566.pdf.

Dual-use as a development approach has several purposes, including increasing the overall productivity of the land or water, alleviating some of the potential negative impacts of RE development, and providing some additional benefits to electricity generation or non-electricity-generation applications. For more information on the benefits and challenges, see "Benefits of Dual-Use Solar PV" and "Challenges for Dual-Use Solar PV."

Dual-Use Solar Photovoltaics—Current and Emerging Applications

Dual uses of land for solar PV include common uses, such as rooftop installations and parking lot canopies, and emerging applications, such as agrivoltaics and solar-over-water applications. In 2016, the National Renewable Energy Laboratory (NREL) estimated the United States had a total rooftop generation potential of more than 1 terawatt (TW), or 1,000 gigawatts (GW). By 2022, the United States had 39.8 GW of small-scale PV generation—most of which was rooftop solar installed on residential buildings.[12] The federal government has deployed some solar generation via solar canopies.[13] Several states, including Maryland and New York, and large commercial entities, such as Walmart and Ikea, are investigating greater deployment of solar canopies.[14]

While rooftop and parking lot canopy applications have been widely deployed, other applications are still emerging. Researchers are exploring the best practices, costs, and benefits associated with these emerging applications. Some of the applications—for example, agrivoltaics (described below) and solar-over-water—may have added costs and challenges related to additional panel infrastructure, design, and installation or maintenance. The dual-use structures might also limit or otherwise create challenges for some land or water applications and their operations. These challenges could affect dual-use project economics or create additional ecological impacts.

Research is ongoing at institutions such as USDA, DOE's Solar Energy Technologies Office, NREL, Sandia National Laboratories, and a number of universities. These organizations are developing tools, such as the AgriSolar Clearinghouse, to compile resources for researchers and project developers.[15] Additionally, state grants—such as the Solar Massachusetts Renewable Target (SMART) program, with its Agricultural Solar Tariff Generation Unit (ASTGU)

[12] Some commercial and industrial applications of small-scale solar PV are installed at ground level. EIA, "STEO Between the Lines: Small-Scale Solar Accounts for About One-Third of U.S. Solar Power Capacity," September 12, 2023, https://www.eia.gov/outlooks/steo/report/BTL/2023/09-smallscalesolar/article.php. For comparison, total large, utility-scale electric generating capacity in the United States was about 1.3 TW in January 2024. American Public Power Association, *America's Electricity Generating Capacity: 2024 Update*, https://www.publicpower.org/resource/americas-electricity-generating-capacity.

[13] The U.S. Department of Transportation (DOT) has installed some solar canopies, and the General Services Administration (GSA) has developed a variety of projects for federal facilities, including solar canopies over parking lots. DOT, "Solar Energy Use," https://www.fhwa.dot.gov/ipd/value_capture/defined/solar_energy_use.aspx; GSA Green Building Advisory Committee, "Advice Letter on Renewable Energy Outleasing," July 10, 2020, https://www.gsa.gov/system/files/FINAL_REO_TG_Advice_Ltr_7-9-20_-_508.pdf; Tom Harris et al., *On-Site PV Guidance*, GSA and NREL, September 2013, https://www.gsa.gov/system/files/On-SitePVGuidance_-_2013-09-25_Final_Draft2.pdf.

[14] New York State Energy Research and Development Authority, "Solar Canopies for Parking Lots," https://www.nyserda.ny.gov/All-Programs/Build-Ready-Program/Solar-Canopies-for-Parking-Lots; Maryland Energy Administration, "FY25 Solar Canopy and Dual Use Technology Grant Program," https://energy.maryland.gov/business/Pages/incentives/PVEVprogram.aspx; David Wagman, "Walmart Adds 6.5 MW of Rooftop and Canopy Parking Solar to California Stores," *PV Magazine*, April 19, 2021, https://www.pv-magazine.com/2021/04/19/walmart-adds-6-5-mw-of-rooftop-and-canopy-parking-solar-to-california-stores/; Michelle Lewis, "IKEA Is Kicking Off a Solar Car Park Push in the US," *Electrek*, September 12, 2023, https://electrek.co/2023/09/12/ikea-solar-us/.

[15] The Clearinghouse contains information for both agrivoltaics and aquavoltaics. See the AgriSolar Clearinghouse website at https://www.agrisolarclearinghouse.org/.

provision—are also available to support development, with the goal of incentivizing—and helping to reduce or offset the additional costs of—these types of dual-use systems.[16]

Dual-use solar PV facilities come in a range of sizes, from small-scale (less than 100 kilowatts [kW] of electricity generating capacity) to medium-scale (100-1,000 kW) to large-scale (also known as *utility-scale*; more than 1 MW).[17] Some applications, such as floating solar PV or solar-over-water, tend toward the larger end of this range because of their potential for higher-density configurations. But dual-use solar PV applications have the potential to support projects of most sizes, depending on the conditions of a given site. (For more information on these measurements, see "Dual-Use Metrics.")

Agrivoltaics

One emerging application of solar PV is its co-location with a range of agricultural land uses, including row crops, grazing animals, native or pollinator-friendly plants, and greenhouses. This dual use of land for agriculture and electricity generation is referred to as *agrivoltaics*.

Not all uses of agricultural land for solar are dual-use. For example, displacing agricultural production for solar use, or simply turning fallow land over to electricity generation, is generally not included in the concept.

Agrivoltaics has the potential to provide benefits for both the agricultural use and electricity generation use of the land. It also poses challenges. Agrivoltaics generally requires additional design considerations beyond those of standalone solar PV development. These include consideration of the spacing, height, and orientation of the rows of solar panels to coordinate with the agricultural operations (depending, for example, on whether large farm equipment is used). Some of the resulting solar PV structure designs also require deeper foundations or more support infrastructure for the panels.

Additionally, not all types of crops, animals, or climate conditions may benefit from or be compatible with dual-use solar PV structures and applications. The shading, irrigation, and other microclimate impacts from the solar PV structures can have significantly different effects on the yields and quality of different crops (even under the same panel configuration). Impacts can also vary depending on climate and weather conditions. For example, a type of crop might experience an increase in yield under solar panels during a hot, dry year due to shading compared with the same crop without the shade solar panels provide. However, the same type of crop might experience a *decrease* in yield in a wet year compared with unshaded crops.

Solar-over-Water

Another emerging application of dual-use solar PV is solar-over-water. Solar-over-water applications being developed include panels over various water supply infrastructure (such as irrigation canals, municipal water aqueducts, irrigation reservoirs, water treatment ponds, or

[16] Massachusetts Department of Energy Resources, "Solar Massachusetts Renewable Target (SMART)," Mass.gov, https://www.mass.gov/solar-massachusetts-renewable-target-smart. The SMART program aims to create a long-term solar incentive program in Massachusetts.

[17] Mohammad Abdullah Al Mamun et al., "A Review of Research on Agrivoltaic Systems," *Renewable and Sustainable Energy Reviews*, vol. 161 (June 2022), https://www.sciencedirect.com/science/article/abs/pii/S1364032122002635.

hydroelectric reservoirs), aquaculture facilities (including those in lakes, ponds, or tanks—termed *aquavoltaics*), or any other suitable body of water.[18]

The electricity generated by solar-over-water systems can be used in a variety of ways. The systems can be configured to supply the local energy needs of aquaculture farms or canals (such as for aerating the water or pumping) and can provide electricity for irrigation or other needs on adjacent lands. The systems can also be configured to supply electricity to the local utility grid.

Solar-over-water can have a variety of configurations. "Floatovoltaics" or "floating solar" are terms for solar panels on floats on the water's surface or suspended just under the water's surface (see **Figure 2**).[19] Aquavoltaics can include floating solar facilities in ponds or lakes or can be built into canopies or other structures over standalone aquaculture tanks (see **Figure 3**).[20] Similarly, solar over canals can be built as canopies supported by trusses and cables (see **Figure 4**).[21]

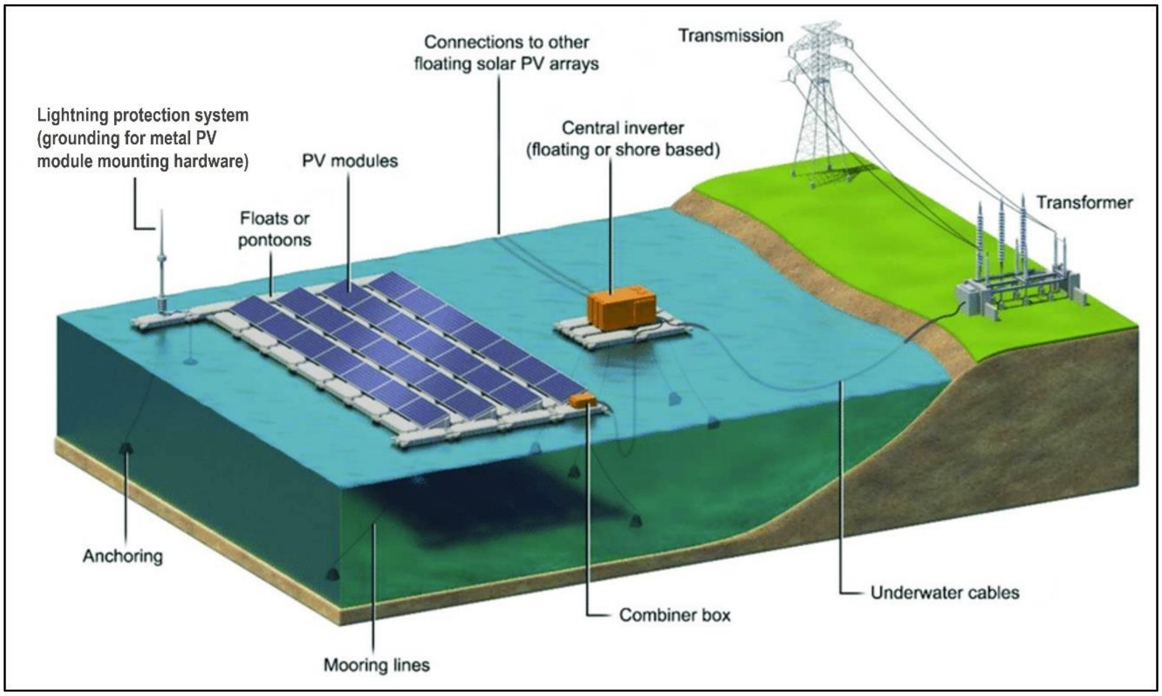
[18] U.S. aquaculture primarily takes place in enclosures in coastal waters or on land in tanks or manmade ponds. U.S. Geological Survey, "Aquaculture Water Use," June 7, 2018, https://www.usgs.gov/special-topics/water-science-school/science/aquaculture-water-use; Brandi McKuin et al., "Energy and Water Co-benefits from Covering Canals with Solar Panels," *Nature Sustainability*, vol. 4, March 18, 2021; Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304.

[19] Submerged floatovoltaics get additional efficiency benefits from reduced temperatures, consistent temperatures, and the prevention of dust buildup on their surfaces, as compared with surface systems. They can also have an anti-reflectivity benefit—water on the surface of the panel has a reduced index of refraction difference between the panel and water compared with the typical configuration of a panel and the air; this reduces how much light reflects off the surface of the panel. Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304; Sika Gadzanku et al., "Benefits and Critical Knowledge Gaps in Determining the Role of Floating Photovoltaics in the Energy-Water-Food Nexus," *Sustainability*, vol. 13 (April 2021), https://www.nrel.gov/docs/fy21osti/78427.pdf.

[20] Max Trommsdorff, "Aqua-PV: 'SHRIMPS' Project Combines Aquaculture and Photovoltaics," Fraunhofer ISE, August 28, 2019, https://www.ise.fraunhofer.de/en/press-media/news/2019/aqua-pv-project-shrimps-combines-aquaculture-and-photovoltaics.html.

[21] Brittany Peterson and Sibi Arasu, "Solar Panels on Water Canals Seem like a No-Brainer. So Why Aren't They Widespread?" *AP News*, July 20, 2023, https://apnews.com/article/solar-panels-irrigation-canals-climate-solution-c57cac43b71a0edf76e62c4adc0f3ff7#.

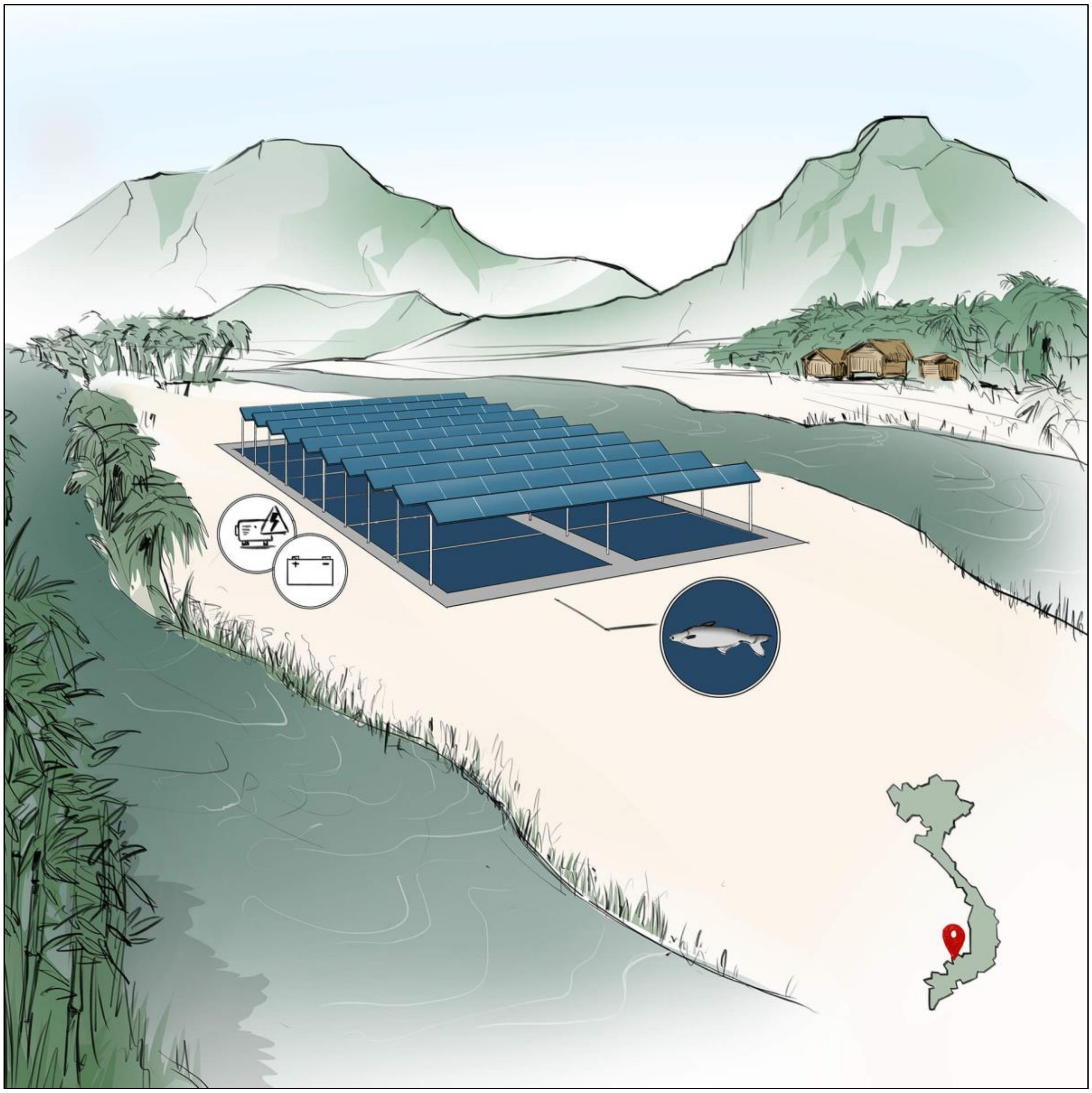
Figure 2. Diagram of a Floating Solar Photovoltaic System



Source: Sika Gadzanku et al., "Benefits and Critical Knowledge Gaps in Determining the Role of Floating Photovoltaics in the Energy-Water-Food Nexus," *Sustainability*, vol. 13 (April 2021), https://www.nrel.gov/docs/fy21osti/78427.pdf. Figure available via Creative Commons Attribution 4.0 International.

Notes: The figure illustrates a large-scale floating solar PV system on a hydroelectric reservoir. This is one of many possible floating solar configurations.

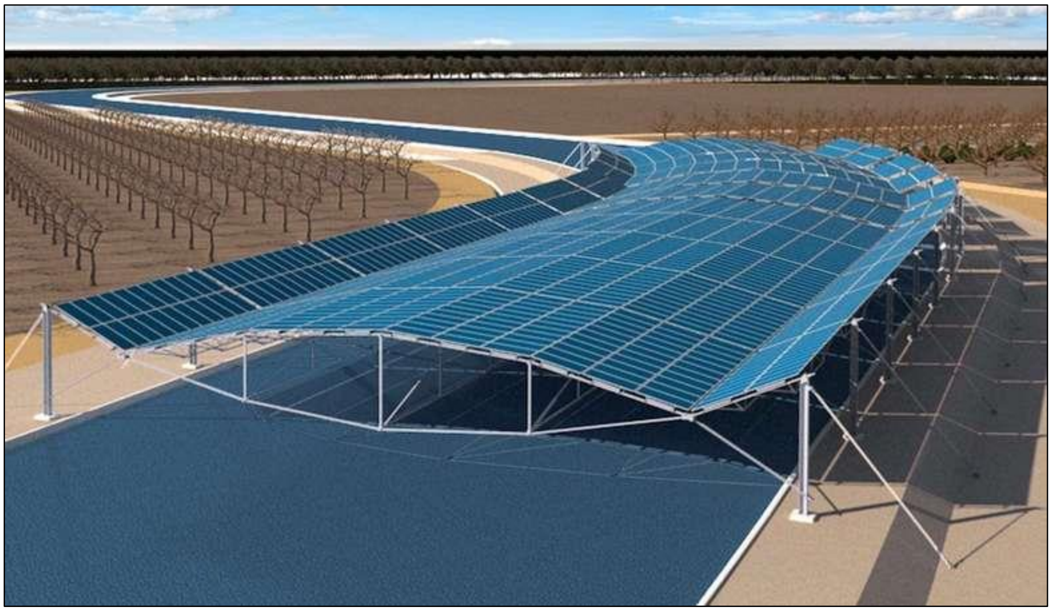
Figure 3. Rendering of an Aquavoltaic Facility over a Fish Farm



Source: Max Trommsdorff, "Aqua-PV: 'SHRIMPS' Project Combines Aquaculture and Photovoltaics," Fraunhofer ISE, August 28, 2019, https://www.ise.fraunhofer.de/en/press-media/news/2019/aqua-pv-project-shrimps-combines-aquaculture-and-photovoltaics.html.

Notes: The figure illustrates a self-sufficient fish farm aquavoltaic facility in An Giang, Vietnam. Circles with battery and generator symbols indicate the facility is a hybrid, off-grid system designed to limit the need to use typical diesel generators.

Figure 4. Rendering of a Solar PV Canopy over a Water-Supply Canal



Source: Brittany Peterson and Sibi Arasu, "Solar Panels on Water Canals Seem like a No-Brainer. So Why Aren't They Widespread?" *AP News*, July 20, 2023, https://apnews.com/article/solar-panels-irrigation-canals-climate-solution-c57cac43b71a0edf76e62c4adc0f3ff7#.

Notes: The figure is a rendering generated by Solar AquaGrid of a planned solar-PV-over-canal configuration in California's San Joaquin Valley Turlock Irrigation District.

Deployment of Emerging Applications of Dual-Use Solar PV

Federal agencies maintain several tools that report dual-use solar PV deployment in emerging applications. NREL and DOE created the Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) project, which reports on agrivoltaic deployment in the United States. As of September 2024, InSPIRE had identified 584 agrivoltaic installations with a combined generation capacity of 10.064 GW.[22] For context, in 2023, total U.S. solar generation capacity from both utility-scale and small-scale development was 138 GW.[23]

The U.S. Large Scale Solar Photovoltaics Database incorporates agrivoltaic data from InSPIRE. The database, created by Lawrence Berkeley National Laboratory and the U.S. Geological Survey, provides data on the more than 4,185 large-scale, ground-mounted solar PV facilities in the United States. Cumulatively, these facilities had more than 70 GW of capacity as of August 2024.[24]

CRS has not found an analogous database that tracks solar-over-water deployment. A report from 2021 identified 12 MW of deployment, with the three largest floatovoltaic projects being the Healdsburg Floating Solar Farm in California (4.8 MW), the Sayreville Floating Solar Farm in

[22] NREL, *Agrivoltaics Map*, InSPIRE, accessed September 26, 2024, https://openei.org/wiki/InSPIRE/Agrivoltaics_Map.

[23] EIA, Form EIA-860, "Annual Electric Generator Report," and Form EIA-860M, "Monthly Update to the Annual Electric Generator Report."

[24] Lawrence Berkeley National Laboratory, *The United States Large-Scale Solar Photovoltaic Database*, August 2024, https://eerscmap.usgs.gov/uspvdb/.

New Jersey (4.4 MW), and the Windsor Floating Solar Farm in California (1.8 MW).[25] The federal government is supporting some solar-over-water deployment—for example, a pilot project for solar panel installation over a canal being developed for the Gila River Indian Community in Arizona.[26]

Metrics for Dual-Use Solar PV

This section discusses metrics for solar PV and the additional challenges related to applying those metrics to dual-use solar PV applications. A set of standard metrics can be used to help measure the costs or impacts of solar PV technology and compare its value relative to other potential energy technologies (e.g., comparing a solar PV installation with a natural gas-fueled power plant), relative to alternative implementations of solar PV (i.e., comparing alternative project designs or sites), or relative to other potential uses of the land.

One important set of metrics for solar PV applies to land use. Given the estimates of how much additional solar PV generation could be needed to meet national carbon-free electricity goals, a key consideration is how much land might be used for future solar electricity generation. Since dual-use solar PV also incorporates applications beyond electricity generation, additional considerations may be taken into account to ensure that potential land use metrics are applicable to dual-use solar PV analyses.

Land Use Metrics

Land is required for the extraction and production of usable energy and for the generation, transmission, and distribution of electricity. Identifying a metric for land use can be helpful for the comparison between different energy technologies or installations.[27] *Power density* is one general land use metric that can be used when planning or evaluating electricity needs for long-term energy supply. Power density can be expressed as a unit of power per unit of area—for example, watts of electricity-generating capacity per square meter (W_e/m^2).[28]

One example of an analysis of average power density for solar PV comes from a review of 54 studies that examined the power density of electric power generation in the United States.[29] From

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[25] Vignesh Ramasamy and Robert Margolis, *Floating Photovoltaic System Cost Benchmark: Q1 2021 Installations on Artificial Water Bodies*, NREL, October 2021, https://www.nrel.gov/docs/fy22osti/80695.pdf.

[26] U.S. Department of the Interior, "Biden-Harris Administration Announces Nearly $6 Million for Innovative Solar Panel Installation over Canals in Gila River Indian Community," December 8, 2023, https://www.doi.gov/pressreleases/biden-harris-administration-announces-nearly-6-million-innovative-solar-panel.

[27] With the development of some energy technologies—including hydroelectric power, offshore wind, and floating solar—"land" use can also include water. Llorenç Milà i Canals et al., "Key Elements in a Framework for Land Use Impact Assessment Within LCA," *International Journal of Life Cycle Assessment*, vol. 12, no. 1 (2007), https://link.springer.com/article/10.1065/lca2006.05.250.

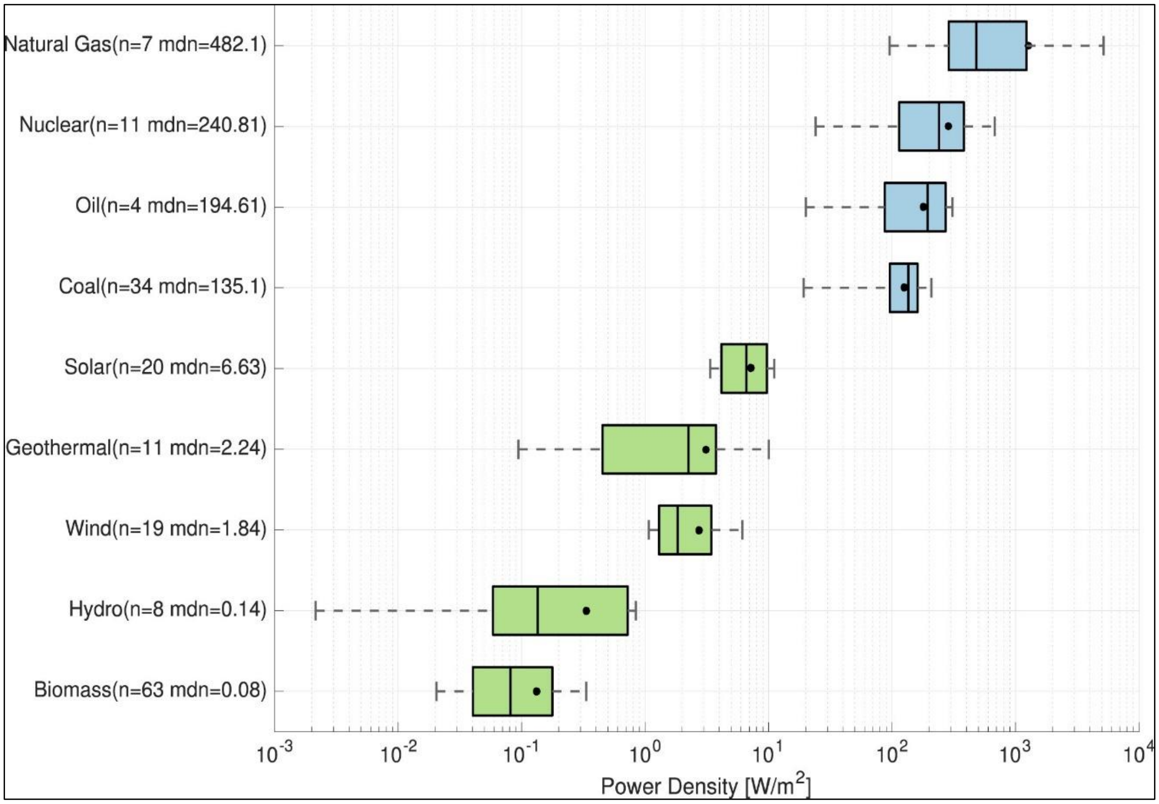
[28] There are alternative metrics of, and alternative formulations for, power density, and the calculations of power density can vary by study methodology and assumptions. Alternatives include the inverse metric—square meters per megawatt (m^2/MW)—often used when determining the land needed for a given amount of generation capacity, and the closely related *energy density*—for example, megawatt-hour per square meter (MWh/m^2)—which measures the actual amount of electricity generated per unit of land and accounts for the time-to-land-use equivalency of renewables versus fossil fuels. These and other related metrics supporting different analytical purposes are used in the literature covering solar PV and other renewables but are beyond the scope of this report. Alexander Cagle et al., "Standardized Metrics to Quantify Solar Energy-Land Relationships: A Global Systematic Review," *Frontiers in Sustainability*, February 27, 2023, https://www.frontiersin.org/articles/10.3389/frsus.2022.1035705/full.

[29] John van Zalk and Paul Behrens, "The Spatial Extent of Renewable and Non-Renewable Power Generation: A (continued...)

the 20 studies (n = 20) covering solar PV, the review calculated that solar PV has a lower power density than natural gas, nuclear power, oil, and coal but a higher power density than wind, hydropower, biomass, and most geothermal energy, as shown in **Figure 5**.

Figure 5. Power Density Values of Selected Energy Technologies in the United States

(aggregated from 54 studies)



Source: John van Zalk and Paul Behrens, "The Spatial Extent of Renewable and Non-Renewable Power Generation: A Review and Meta-analysis of Power Densities and Their Application in the U.S.," *Energy Policy*, vol. 123 (2018), pp. 83-91, https://www.sciencedirect.com/science/article/pii/S0301421518305512.

Notes: W/m^2 is watts per meter squared; *n* is the number of results identified for each energy technology type; and *mdn* is the median power density. *Hydro* is hydropower. The box plots indicate values within the second and third quartile of data points. Bars indicate the full range of data points.

The review accounted for energy conversion efficiencies, capacity factors, and infrastructure area, including infrastructure associated with energy production (e.g., mines for coal supply).[30] The review did not control for time, reporting that the earliest study included in the analysis was from 1974; however, the review concluded that, of the nine energy types evaluated, only solar had a statistically significant increase in power density over time.[31] The review found that published

Review and Meta-analysis of Power Densities and Their Application in the U.S.," *Energy Policy*, vol. 123 (2018), pp. 83-91, https://www.sciencedirect.com/science/article/pii/S0301421518305512 (hereinafter Van Zalk and Behrens, 2018). The review considered nine energy sources: biomass, coal, geothermal, hydro, natural gas, nuclear, oil, solar, and wind.

[30] *Conversion efficiency* is a measure of how much usable energy results from the technology relative to the input energy. *Capacity factor* is the ratio of electricity generated during a period of time to the maximum possible electricity that could be generated during the same period of time.

[31] Van Zalk and Behrens, 2018, reported *p*-values (statistical significance of the observed differences) and considered a (continued...)

values for power density for solar PV systems range from 1.5 to 19.6 W_e/m^2.[32] Generally, solar thermal and utility-scale solar PV were found to require more land area to produce the same amount of electricity than residential solar PV and concentrated solar power (CSP).[33]

Dual-Use Metrics

Dual-use introduces additional challenges to measuring solar power's impacts and comparing solar power with other energy types and other applications. Energy density might provide an accurate comparison between two applications of the same technology or between two energy technologies that use technologies or land in similar ways (for example, solar PV vs. CSP); however, dual-use installations have additional complications related to the second, co-located non-energy use. Measuring the energy density of only the electricity-generating portion of a dual-use installation will generally result in a value lower than that of an equivalent standalone electricity generation facility; thus, this measurement will tend to undervalue the land.

Trying to correct this undervaluation by calculating an energy density of the non-energy application will generally not be appropriate because the value of the non-energy application is not in energy production. Using an intermediate metric—such as dollar value—that could provide compatible values for both the energy and non-energy uses could be challenging if the dollar values of some applications (e.g., biodiversity) are difficult to determine or are not widely agreed upon.

Land equivalent ratio (LER)—or land use efficiency (LUE)—is a productivity metric that can help more properly measure the value of a dual-use installation and compare its value with alternatives. LER was originally developed to measure the efficacy of *intercropping*—growing two or more different kinds of plants in close proximity (e.g., in alternating rows). LER compares the productivity of each dual-use application to the productivity of the equivalent standalone application on the same land and then sums the productivity values for the two applications.[34] This results in a single overall productivity value, as illustrated in **Figure 6**. As an example, one recent study in Germany of agrivoltaics with four different crops found LER values between 1.56 and 1.7—that is, the total dual-use productivity of the land was between 1.56 and 1.7 times that of the land under the original standalone use.[35]

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p-value less than 0.05 to be significant. For solar PV, the *p*-value was found to be 0.001. According to the review, solar PV power density increased by an average of 0.42 W_e/m^2 per year. Wind had an average increase of 0.17 W_e/m^2 per year, but with a *p*-value of 0.17, indicating it was not a statistically significant result.

[32] Van Zalk and Behrens, 2018.

[33] While the underlying technology for residential solar PV and utility-scale solar PV is similar, sloped rooftops may allow more sunlight to reach otherwise flat panels for residential systems, and the spacing of panels at utility-scale facilities (regardless of tilt)—to provide for maintenance and to avoid shading—may lead to lower power densities. P. Denholm and R. Margolis, *The Regional Per-Capita Solar Electric Footprint for the United States*, NREL, Technical Report, NREL/TP-670-42463, December 2007, pp. 5-6, https://www.nrel.gov/docs/fy08osti/42463.pdf.

[34] A variety of metrics have been proposed and used in research. Alexander Cagle et al., "Standardized Metrics to Quantify Solar Energy-Land Relationships: A Global Systematic Review," *Frontiers in Sustainability*, vol. 3 (February 2023), https://www.frontiersin.org/articles/10.3389/frsus.2022.1035705/full.

[35] Max Trommsdorff et al., "Combining Food and Energy Production: Design of an Agrivoltaic System Applied in Arable and Vegetable Farming in Germany," *Renewable & Sustainable Energy Reviews*, vol. 140 (April 2021), https://www.sciencedirect.com/science/article/abs/pii/S1364032120309783?via%3Dihub; Christian Dupraz et al., "To Mix or Not to Mix: Evidences for the Unexpected High Productivity of New Complex Agrivoltaic and Agroforestry systems," conference paper, 5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, Brisbane, Australia, September 2011, https://www.researchgate.net/publication/230675951_To_mix_or_not_to_mix_evidences_for_the_unexpected_high_productivity_of_new_complex_agrivoltaic_and_agroforestry_systems.

Figure 6. Formula for Calculating Dual-Use Productivity

$$\frac{\text{Productivity of Dual-Use Application A}}{\text{Productivity of Standalone Application A}} + \frac{\text{Productivity of Dual-Use Application B}}{\text{Productivity of Standalone Application B}} = \text{Dual-Use Productivity}$$

Source: CRS.

Benefits of Dual-Use Solar PV

Dual-use solar PV has many potential benefits. It can allow agricultural production to continue rather than being supplanted by single-use solar PV; this has the added benefit of helping to maintain the rural character of communities where solar PV is sited. Dual-use solar PV may promote improved water quality and reduced evaporation. It can support aquaculture. It may provide opportunities for siting photovoltaic generation near major transmission lines and load centers. It can be designed for peak generation in the morning and evening to complement midday peaks from conventional photovoltaic generation. It could potentially reduce energy development costs.

Benefits for Non-electricity Uses

Dual-use solar PV can provide a variety of benefits for non-electricity-generation uses, including agriculture and solar-over-water. However, the types and degrees of the benefits are situationally dependent.

For agricultural production, erecting solar panels with space between rows or between panels (in the case of greenhouses, integrating semi-transparent solar panels into the roofs or walls) can provide several potential benefits. In a typical solar PV array configuration, the rows and panels are spaced to prevent self-shading, to maximize sunlight capture and electricity production. In an agrivoltaic arrangement, greater spacing between rows and panels allows sunlight for plants under or between the rows, while the shade reduces soil and air temperature under the panels, increases humidity under the panels, and reduces evaporation and related irrigation or watering needs.[36]

Initial studies show that dual-use can increase some crop yields.[37] The effect on yield varies depending on the crops being grown, the configuration of the solar panels, and the soil, weather, and climate conditions.[38] In general, dual-use solar works best with low-growing crops such as broccoli, Swiss chard, kale, peppers, common green beans, celery, winter wheat, clover, potatoes,

[36] Jordan Macknick et al., *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study*, NREL, August 2022, https://www.nrel.gov/docs/fy22osti/83566.pdf; DOE, “Farmer’s Guide to Going Solar,” https://www.energy.gov/eere/solar/farmers-guide-going-solar.

[37] In a survey of agrivoltaic applications, yields (by weight) for lettuce were found to vary from +87.6% to -50%, potatoes from +11% to -18%, cereals from +5.7% to -19%, sesame oilseeds from -7% to -53%, and berries and fruits from -2.6% to -20%. J. Widmer et al., “Agrivoltaics, A Promising New Tool for Electricity and Food Production: A Systematic Review,” *Renewable and Sustainable Energy Reviews*, vol. 192 (March 2024), https://doi.org/10.1016/j.rser.2023.114277.

[38] As discussed in the section on dual-use metrics, depending on the application, some negative impact on the primary land use could be acceptable to the operator if the total productivity of the land is higher—resulting in, for example, higher total revenue—than with standalone use.

and tomatoes.[39] The panels can also potentially reduce hail and frost damage to crops.[40] Agrivoltaics may boost food production overall relative to what it would have otherwise been during extreme weather or climate conditions. The revenue agrivoltaics provides may also allow farmers to expand or improve other agricultural operations, further boosting food production.[41]

Other configurations of agrivoltaics can provide general biodiversity support, which could benefit adjacent farmland. Instead of direct integration with crops or farm animals, solar PV panels can be installed with diverse, native, drought-resistant, and pollinator-friendly perennial plants underneath. The plants can support local wildlife populations, host pollinators that benefit adjacent farmland (which can increase agricultural yield), enhance biodiversity, prevent erosion, improve soil health, and sequester carbon.[42] The panel infrastructure can also allow the installation of birdhouses and bat boxes, or support bird and bat habitats, for additional biodiversity support or pest control.[43]

Non-crop plants can also potentially reduce maintenance costs for the solar PV facility. Typical standalone utility-scale solar PV facilities use crushed gravel or other weed control measures to limit interfering plant growth around foundations and under the panels. Gravel also provides erosion control. An agrivoltaic configuration with native plants grown under and around the panels can provide erosion control and prevent weeds, with less cost or effort than with those other measures.[44]

Solar PV facilities can also provide a number of benefits to aquaculture applications. Panels or canopies over the water can limit predation by birds and reduce impact of diseases carried by birds or their droppings.[45] If the solar PV system is configured for onsite use, the electricity can potentially support a variety of technologies used for maintaining clean water, providing and circulating nutrients, and maintaining water flow and oxygenation. Controlling aquaculture factors such as nutrient levels, water temperature, pH, salinity, turbidity, and lighting conditions—including the photoperiod (length of light), intensity of light, and frequency of

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[39] Srijana Neupane Bhandari et al., "Economic Feasibility of Agrivoltaic Systems in Food-Energy Nexus Context," *Agronomy*, vol. 11, no. 10 (2021), p. 1906, https://www.mdpi.com/2073-4395/11/10/1906; Hilary Sandler, Giverson Mupambi, and Peter Jeranyama, *Expectations for Cranberry Growth and Productivity Under Solar (Photovoltaic) Panels*, UMass Cranberry Station, May 2019, https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/shading_and_solar_panels_may_2019.pdf; NREL, "Benefits of Agrivoltaics Across the Food-Energy-Water Nexus," September 11, 2019, https://www.nrel.gov/news/program/2019/benefits-of-agrivoltaics-across-the-food-energy-water-nexus.html.

[40] The solar PV systems themselves may be damaged by hail, but solar PV panels are fairly robust and it takes very large hail to damage panels. Max Trommsdorff et al., "Can Synergies in Agriculture Through an Integration of Solar Energy Reduce the Cost of Agrivoltaics? An Economic Analysis in Apple Farming," *Applied Energy*, vol. 350 (November 15, 2023), https://www.sciencedirect.com/science/article/abs/pii/S0306261923009832; DOE, "Hail Damage Mitigation for Solar Photovoltaic Systems," https://www.energy.gov/femp/hail-damage-mitigation-solar-photovoltaic-systems.

[41] Michele Boyd, "The Potential of Agrivoltaics for the U.S. Solar Industry, Farmers, and Communities," DOE, Solar Energy Technologies Office, April 17, 2023, https://www.energy.gov/eere/solar/articles/potential-agrivoltaics-us-solar-industry-farmers-and-communities; Brooke DeCubellis, "Soaking Up the Sun: Agrivoltaics Build Resiliency into Producers' Operations in Rio Grande Valley," U.S. Department of Agriculture (USDA), July 17, 2024, https://www.farmers.gov/blog/soaking-up-sun-agrivoltaics-build-resiliency-into-producers-operations-in-rio-grande-valley.

[42] DOE, "Farmer's Guide to Going Solar," https://www.energy.gov/eere/solar/farmers-guide-going-solar.

[43] Stacie Peterson, "An Overview of Agrivoltaics," AgriSolar Clearinghouse, September 4, 2024, https://nmlegis.gov/handouts/IAC%20090424%20Item%203%20Agrivoltaics.pdf.

[44] Jordan Macknick et al., *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study*, NREL, August 2022, https://www.nrel.gov/docs/fy22osti/83566.pdf.

[45] Steve Hanley, "Shrimp, Fish, & Solar: A Recipe for Success," *CleanTechnica*, August 29, 2019, https://cleantechnica.com/2019/08/29/shrimp-fish-solar-a-recipe-for-success.

light—can potentially maintain or support greater aquacultural yield. For example, studies have shown that solar PV has prompted increased growth rates among shrimp, prawn, and fish.[46] Additionally, by managing these water conditions, solar PV facilities can potentially allow for aquaculture in environments that would not normally be suitable to support it.[47] Such on-site energy use can also support aquaculture operations at sites that did not previously have access to electricity or that relied on diesel generators.

Solar PV facilities can also have potential positive effects for other solar-over-water applications. Shading from the panels can reduce the growth of unwanted marine species (for example, algae or aquatic weeds). The growth of these unwanted marine species can impede water flow in a canal and can be expensive to manage.[48] The shading and reduced growth of these unwanted species can also improve water quality (including dissolved oxygen, nutrients, pH, and alkalinity concentrations) and reduce evaporation in aqueducts, irrigation canals, irrigation ponds, and other bodies of water.[49] One examination of a potential project over a canal in Arizona estimated evaporation could be reduced by as much as 50%.[50] A feasibility study for solar over a California canal estimated an increase in the project net present value (NPV) of 20%-50% compared with a standalone solar PV facility, with annual savings via reduced canal maintenance costs of $40,000 per mile of canal.[51]

Benefits for Electricity Generation

Dual-use solar PV deployment may make it easier to connect solar PV generation to the electrical grid. Some areas of the United States have strong solar resources but little existing electricity infrastructure.[52] For example, many areas of the desert Southwest—which has low frequency of cloud cover and high solar irradiance—are sparsely populated and largely undeveloped.[53] In contrast, land or water for dual-use applications—including farmland, aquaculture facilities, or other bodies of water—is often already adjacent to infrastructure such as roads and transmission lines and can be closer to demand (e.g., population centers). Dual-use solar PV applications in these areas could therefore generate electricity where there is already access to the transmission system.

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[46] Teng-Wei Wang et al., "Effects of Floating Photovoltaic Systems on Water Quality of Aquaculture Ponds," *Aquaculture Research*, vol. 53, no. 4 (March 2022), https://doi.org/10.1111/are.15665; Steve Hanley, "Shrimp, Fish, & Solar: A Recipe For Success," *CleanTechnica*, August 29, 2019, https://cleantechnica.com/2019/08/29/shrimp-fish-solar-a-recipe-for-success/.

[47] Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304.

[48] Steve Hanley, "California Plans to Add Solar Panels over Irrigation Canals," *CleanTechnica*, August 29, 2022, https://cleantechnica.com/2022/08/29/california-plans-to-add-solar-panels-over-irrigation-canals.

[49] Sherine El Baradei and Mai Al Sadeq, "Effect of Solar Canals on Evaporation, Water Quality, and Power Production: An Optimization Study," *Water*, vol. 12, no. 8 (July 2020), https://www.mdpi.com/2073-4441/12/8/2103/htm.

[50] U.S. Department of the Interior, Bureau of Reclamation, *Fundamental Considerations Associated with Placing Solar Generation Structures at Central Arizona Project Canal*, May 2016, https://www.usbr.gov/main/qoi/docs/09.27.2016%20Placing%20Solar%20Generation%20Structures%20Over%20the%20CAP%20Canal%20final%20.pdf.

[51] Brandi McKuin et al., "Energy and Water Co-benefits from Covering Canals with Solar Panels," *Nature Sustainability*, vol. 4 (March 2021), https://www.nature.com/articles/s41893-021-00693-8.

[52] Samantha Gross, *Renewables, Land Use, and Local Opposition in the United States*, Brookings Institution, January 2020, https://www.brookings.edu/wp-content/uploads/2020/01/FP_20200113_renewables_land_use_local_opposition_gross.pdf.

[53] *Solar irradiance* is the amount of solar energy that hits a given area over a given time period.

Bifacial solar panels standing vertically (like a wall or fence; see **Figure 7**), in rows running north-south, could provide a transmission-system-wide benefit by providing electricity generation that is complementary to other RE generation.[54] Typical U.S. solar PV array configurations feature panels that are placed largely parallel to the ground, with some southern tilt and potential east-west tracking capability. This configuration results in a pattern of high midday generation but decreased generation in the morning and evening.[55] In contrast, the vertical bifacial configuration can potentially increase electricity generation in the morning and evening, offsetting the decreased generation from other "typically configured" solar PV facilities.

Figure 7. Vertical, Dual-Faced Solar PV Configuration

Source: Next2Sun, "Next2Sun and iSun Build First Vertical Agrivoltaics System in the USA," press release, December 15, 2023, https://next2sun.com/en/next2sun-and-isun-build-first-vertical-agrivoltaics-system-in-the-usa/.

Dual-use solar PV can potentially provide on-site electricity generation to supply local applications, such as water aeration, water pumping for irrigation, or others. California is investigating installing solar PV over aqueducts and using the distributed electricity generation to supply pumping to reduce costs and emissions associated with existing diesel-powered pumping infrastructure.[56] On-site electricity generation can enable more locations to develop agricultural or aquacultural applications while reducing or eliminating the need to install additional electricity transmission capacity to support them. In 2009, the USDA Census of Agriculture, On-Farm Renewable Energy Production Survey, reported that 8,569 farms had on-farm RE generation

[54] Bifacial panels are capable of generating electricity from sunlight absorbed on both sides of the panel.

[55] For information on daily variability of electricity generation from solar panels, see CRS Report R46196, *Solar Energy: Frequently Asked Questions*, coordinated by Ashley J. Lawson; Cheryl Katz, "More Energy on Less Land: The Drive to Shrink Solar's Footprint," *Yale Environment 360*, July 28, 2022, https://e360.yale.edu/features/small-solar-agriculture-technology.

[56] Brandi McKuin et al., "Energy and Water Co-benefits from Covering Canals with Solar Panels," *Nature Sustainability*, vol. 4 (March 18, 2021), https://www.nature.com/articles/s41893-021-00693-8.

including solar, wind, or methane digesters. Of those farms that reported using renewable energy and saving on their utility bills, the average savings was $2,406 per farm.[57] On-site RE generation can replace the use of diesel-powered generators often used to provide off-grid or backup electricity supply. This use could avoid the costs and logistical challenges of fuel supplies for those generators and the associated emissions from their operation.[58]

Dual-use solar PV can increase electricity generation in several ways. First, solar PV panels experience an increase in electricity generation efficiency with lower temperatures—about 0.5% increase per degree Celsius in temperature drop.[59] A recent study by NREL showed solar PV panels in agrivoltaic facilities were approximately 9°C cooler during the day compared with standalone panel configurations, due to microclimate effects under the panels.[60] In aquavoltaic applications, panels similarly see efficiency gains from cooling due to microclimate effects or from direct contact with or submersion under the water. Second, the presence of crops, non-crop vegetation, or water underneath and around solar panels can reduce the levels of dust and soiling on panels, which helps maintain the panels' energy conversion efficiency.[61] Similarly, vertical panel configurations can also decrease soiling of the panels.

Different dual-use solar PV panel configurations can provide other benefits related to electricity generation. In the United States, a typical panel configuration for standalone utility-scale solar PV facilities might place panels in rows running east-to-west, with panels tilted to the south. These arrays of panels often incorporate tracking equipment allowing the panels to better face the sun as it moves overhead during the day. Agrivoltaic researchers have studied a variety of panel configurations—including primarily east-west- or north-south-oriented, as well as vertical panels—with a variety of tilts, row and panel spacings, and tracking options.[62] Researchers are developing configurations (based on various crops and environmental conditions) to optimize solar PV area and electricity generation while also maintaining or improving crop yield and thus maximizing LER.[63] In some markets, bifacial vertical system configurations can allow a dual-use solar PV facility to maximize electricity revenue by generating and selling electricity in the

[57] The released survey results do not indicate how many farms reported on-site renewable energy use. USDA, *On-Farm Renewable Energy Production Survey (2009)*, February 2011, https://agcensus.library.cornell.edu/wp-content/uploads/2007-On-Farm-Energy-Production-Survey-energy09.pdf.

[58] A. Mérida García et al., "Comparing the Environmental and Economic Impacts of On- or Off-Grid Solar Photovoltaics with Traditional Energy Sources for Rural Irrigation Systems," *Renewable Energy*, vol. 140 (September 2019), https://doi.org/10.1016/j.renene.2019.03.122.

[59] Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304.

[60] NREL, "Benefits of Agrivoltaics Across the Food-Energy-Water Nexus," September 11, 2019, https://www.nrel.gov/news/program/2019/benefits-of-agrivoltaics-across-the-food-energy-water-nexus.html.

[61] DOE, "Farmer's Guide to Going Solar," https://www.energy.gov/eere/solar/farmers-guide-going-solar.

[62] A typical agrivoltaic system configuration has panels elevated above the crops with spacing between rows or panels to control the amount of shading. Allison Perna et al., "Design Considerations for Agrophotovoltaic Systems: Maintaining PV Area with Increased Crop Yield," Purdue University, 2019, https://engineering.purdue.edu/NRT/wp-content/uploads/2019/10/PVSC-2019-210-Perna-Grubbs-Agrawal-Bermel.pdf; Kamran Ali Khan Niazi and Marta Victoria, "Comparative Analysis of Photovoltaic Configurations for Agrivoltaic Systems in Europe," *Progress in Photovoltaics*, July 13, 2023, https://onlinelibrary.wiley.com/doi/10.1002/pip.3727.

[63] Factors that affect crop yield include individual crop shade tolerance and the average precipitation, temperature, and solar incidence of the location. Allison Perna et al., "Design Considerations for Agrophotovoltaic Systems: Maintaining PV Area with Increased Crop Yield," Purdue University, 2019, https://engineering.purdue.edu/NRT/wp-content/uploads/2019/10/PVSC-2019-210-Perna-Grubbs-Agrawal-Bermel.pdf; Kamran Ali Khan Niazi and Marta Victoria, "Comparative Analysis of Photovoltaic Configurations for Agrivoltaic Systems in Europe," *Progress in Photovoltaics*, July 13, 2023, https://onlinelibrary.wiley.com/doi/10.1002/pip.3727.

morning and late day—since those can be times of otherwise low levels of solar electricity generation and resulting high electricity prices.[64]

Community Benefits

Other benefits of dual-use solar PV are that it does not eliminate the previous use of the land and may help to maintain the preexisting character of the land or area.

One of the challenges to utility-scale solar PV development is public opposition to the conversion of some land types, such as farmland, to solar development. This opposition can be because of expected impacts on food production, views, and adjacent property values. It can also stem, more generally, from concerns that solar development will affect the rural character of the region—in other words, that the area will shift from an agricultural focus to an industrial, power-production focus.[65]

Agrivoltaics maintains much of the preexisting land use, which could potentially reduce some of this opposition. Additionally, solar PV facilities are not intended to be permanent structures (compared with other land use conversions) and are generally designed and installed with decommissioning plans in mind; therefore, "solar farms do not pose the same level or type of risk to agricultural practices as does housing or commercial development."[66]

Agrivoltaics also supports the local economy. The additional revenue streams can support small-scale farmers—many of whom already rely on off-farm income—and help keep their farms operating. The revenue from solar PV facilities can allow farmers to focus more on their agricultural operations.[67] Additionally, some research indicates that successful small and midsize farmers tend to support the local economy more than other types of residents—for example, suburban residents in general.[68]

Development Advantages

Researchers have noted that dual-use solar applications can help mitigate some of the negative environmental impact of energy development. That's because these applications may target already disturbed land (including land that has previously been converted into human-made lakes

[64] This price dependency on solar is most noticeable typically where there is a lot of solar deployment (e.g., in California) and where there is market pricing for electricity.

[65] Lawrence Susskind et al., "Sources of Opposition to Renewable Energy Projects in the United States," *Energy Policy*, vol. 165 (June 2022), https://www.sciencedirect.com/science/article/pii/S0301421522001471; Alex Brown, "Locals Worry Wind and Solar Will Gobble Up Forests and Farms," *Stateline.org*, April 30, 2021, https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2021/04/30/locals-worry-wind-and-solar-will-gobble-up-forests-and-farms.

[66] Jesse Richardson, Peggy Kirk Hall, and Whitney Morgan, "Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses," WVU College of Law Research Paper No. 2022-004, April 6, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4042235.

[67] Brooke DeCubellis, "Soaking Up the Sun: Agrivoltaics Build Resiliency into Producers' Operations in Rio Grande Valley," USDA, July 17, 2024, https://www.farmers.gov/blog/soaking-up-sun-agrivoltaics-build-resiliency-into-producers-operations-in-rio-grande-valley.

[68] David Brown and Kai Schafft, *Rural People and Communities in the 21st Century: Resilience and Transformation* (Malden, MA: Polity Press, 2011); Charles Tolbert et al., "Civic Community in Small-Town America: How Civic Welfare Is Influenced by Local Capitalism and Civic Engagement," *Rural Sociology*, vol. 67, no. 1 (2002), pp. 90-113, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1549-0831.2002.tb00095.x.

or ponds).[69] Alternatively, in the case of some floatovoltaics applications, they can be built on natural bodies of water, with minimal disturbance to adjacent land.

Disturbed lands can include airport border land; landfills; former industrial sites, such as sand and gravel pits; former mine lands; decommissioned fossil fuel power plants; and infrastructure sites, such as dams (often in land-constrained locations, such as islands) or canals.[70] Land that has already been affected by human development will likely experience fewer or no additional impacts from solar development relative to undeveloped land. Projects on already developed land could also potentially require less development time than projects on undeveloped land.[71] These benefits also apply to floating solar applications built on water retention ponds, mine pit lakes, or other similar human-made or contaminated bodies of water.

Studies have also found that, compared with other electricity generation applications, solar facilities present relatively low risk of soil contamination from the sealed solar PV panels and other support equipment.[72] Floating solar facilities also have less risk than land-based facilities due to the lack of foundational structures and ground disturbance (outside of requiring some cable anchor points and on-shore locations for transformers or other support equipment).[73]

Reduced Costs

Dual-use development can provide a variety of monetary benefits or cost reductions compared with alternative solar power project development models. For example, the costs of developing farmland for dual-use solar PV may be lower than for other types of land. Farmland is typically flat, has already been cleared of obstructions, has a low risk for land subsidence, and is largely unshaded—all conditions preferred for solar PV development. In general, dual-use solar PV developed on already disturbed land, such as farmland, will have lower development costs compared with equivalent non-degraded facilities. Likewise, acquisition costs for floating solar facilities will generally be lower than acquisition costs for land-based facilities. Acquisition costs are lower because many water-based sites are underused or do not have competing commercial development interests. Further, like farmland, water bodies are flat and generally clear of obstructions and shading.[74] Dual-use solar PV facilities on these sites will generally be more productive—and can be developed less expensively—than facilities on more obstructed, shaded, and uneven land.[75]

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[69] *Disturbed land* is defined by the U.S. Geological Survey as land in an altered and often non-vegetated state due to human-induced or natural disturbances. Benjamin Sleeter, Tamara Wilson, and William Acevedo, eds. *Status and Trends of Land Change in the Western United States—1973 to 2000*, U.S. Geological Survey Professional Paper 1794–A, appendix 3, 2012, https://pubs.usgs.gov/pp/1794/a/sections/pp1794a_appendixes.pdf; Jordan Macknick et al., *Solar Development on Contaminated and Disturbed Lands*, NREL, December 2013, https://www.nrel.gov/docs/fy14osti/58485.pdf.

[70] Note that for some of these previously disturbed locations, *dual-use* refers to the location's former use, not an ongoing one.

[71] Jordan Macknick et al., *Solar Development on Contaminated and Disturbed Lands*, NREL, December 2013, https://www.nrel.gov/docs/fy14osti/58485.pdf.

[72] DOE, "Farmer's Guide to Going Solar," https://www.energy.gov/eere/solar/farmers-guide-going-solar.

[73] Hamid M. Pouran et al., "Environmental and Technical Impacts of Floating Photovoltaic Plants as an Emerging Clean Energy Technology," *iScience*, vol. 25, no. 11 (November 18, 2022), https://doi.org/10.1016/j.isci.2022.105253.

[74] Sika Gadzanku et al., "Benefits and Critical Knowledge Gaps in Determining the Role of Floating Photovoltaics in the Energy-Water-Food Nexus," *Sustainability*, vol. 13 (April 2021), https://www.nrel.gov/docs/fy21osti/78427.pdf.

[75] DOE, "Farmer's Guide to Going Solar," https://www.energy.gov/eere/solar/farmers-guide-going-solar; Jesse Richardson, Peggy Kirk Hall, and Whitney Morgan, "Land Use Conflicts Between Wind and Solar Renewable Energy (continued...)

Floating solar PV typically has lower construction and decommissioning costs than land-based solar because floating solar does not require buried foundations or large supporting truss structures.[76] Operational costs for floating solar can also be lower compared with land-based solar due to easier maintenance—which all occurs at ground level—and because less dust tends to collect on the panels compared with systems installed above land. Floating solar modules can be preassembled, and the floating structure can then be assembled on the shoreline and floated onto the body of water; this speeds up construction time and reduces installation costs compared with land-based solar. Finally, adding solar tracking to a floating solar installation can be easier and less expensive than for land-based solar; mechanisms to allow the panels to track the sun can be integrated into the floats or an installation can use alternative approaches, including reorienting the entire array to follow the sun during the day.[77]

Despite these advantages, however, total capital costs have tended to be higher for floating solar systems than for land-based systems. This is due in part to the costs to design and build the floats and in part because development and planning costs associated with floating solar are high due to it being a relatively new application area.

Vertical, bifacial panel configurations for agrivoltaics can potentially provide some cost advantages compared with other configurations. While the vertical panel alignment does not provide as much shading for crops as the typical horizontal arrangement, it does allow the panels to be installed closer to the ground, reducing the need for more foundation or structural supports and allowing for the use of large farm equipment between the rows. This configuration can reduce agrivoltaic construction and operational costs. It allows for a wider variety of crop types to be grown next to the panels, allows more uniform precipitation and shading, and potentially reduces the risk of damage to the solar PV system from weather events such as hailstorms. (See "System Costs" for more information on related challenges.)[78]

Challenges for Dual-Use Solar PV

Along with potential benefits, dual-use solar PV applications also face a number of challenges. Some challenges are specific to individual applications. These challenges include potential impacts on agricultural and aquacultural operations, wildlife, electricity production, and system costs.

Challenges for Non-electricity Uses

Agricultural Operations and Conditions

Research on the impacts of dual-use solar PV on crops is still fairly new and has not been proven across the full variety of solar PV system designs, climate, weather, and crop combinations in the

and Agriculture Uses," WVU College of Law Research Paper No. 2022-004, April 6, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4042235.

[76] Vignesh Ramasamy and Robert Margolis, *Floating Photovoltaic System Cost Benchmark: Q1 2021 Installations on Artificial Water Bodies*, NREL, October 2021, https://www.nrel.gov/docs/fy22osti/80695.pdf.

[77] Giuseppe Marco Tina and Fausto Bontempo Scavo, "Energy Performance Analysis of Tracking Floating Photovoltaic Systems," *Heliyon*, vol. 8, no. 8 (August 2022), https://www.sciencedirect.com/science/article/pii/S2405844022013767; Hongsub Jee et al., "Comparing the Performance of Pivotless Tracking and Fixed-Type Floating Solar Power Systems," *Applied Sciences*, vol. 12, no. 24 (December 16, 2022), https://www.mdpi.com/2076-3417/12/24/12926.

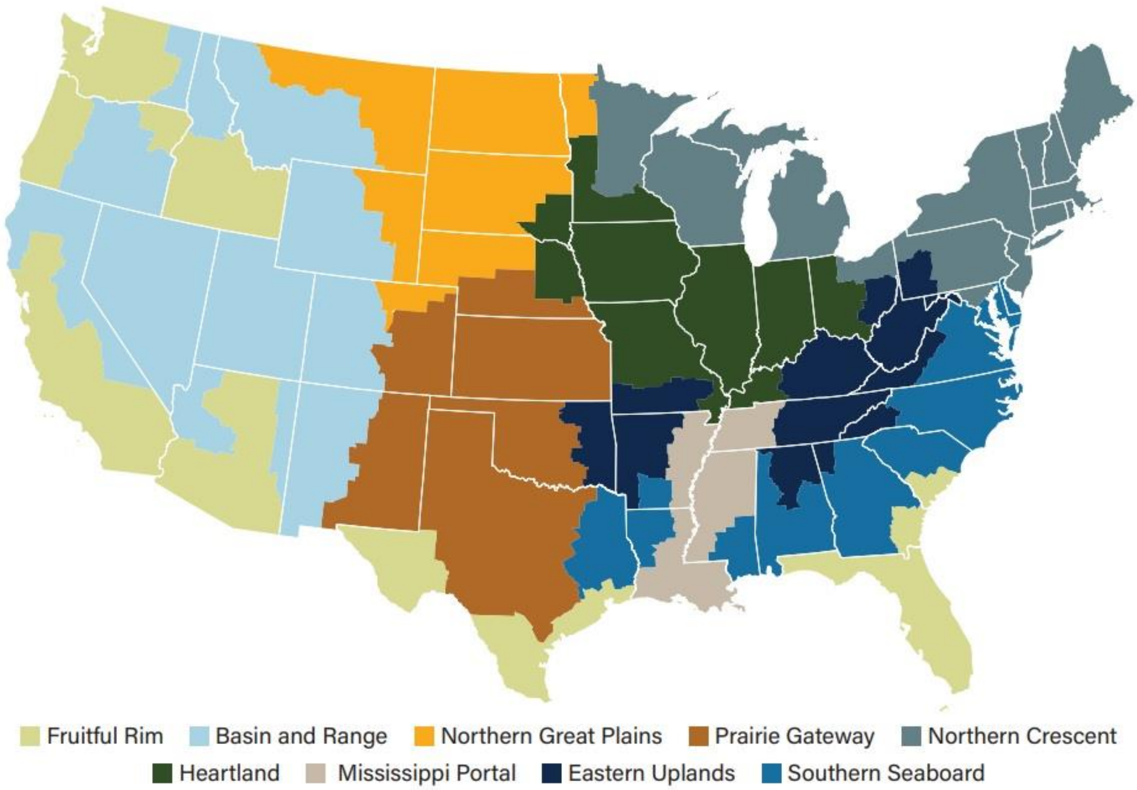
[78] Muhammad Hussnain Riaz et al., "The Optimization of Vertical Bifacial Photovoltaic Farms for Efficient Agrivoltaic Systems," *Solar Energy*, vol. 230 (December 2021), https://doi.org/10.1016/j.solener.2021.10.051.

United States.[79] However, experience to date suggests that dual-use solar PV projects may face a variety of potential challenges related to agricultural operations and conditions.

The United States has a variety of regional differences in farming conditions, each of which can introduce challenges to the development of dual-use solar PV on farmland. USDA ERS sometimes uses *farm resource regions* to organize and group agricultural conditions and practices, as shown in **Figure 8**.[80] Regions in the Northeast tend to have smaller-than-average farms, with fields potentially closer to infrastructure. Regions in the Midwest tend to have larger-than-average farms, with fields potentially farther from infrastructure. Also, all of the national regions have variations in their climate, weather, groundwater, and land conditions. These variations in conditions can affect the suitability of agricultural operations for dual-use solar PV development. Under different conditions, solar PV may have different effects on crops and yields.

Figure 8. USDA Farm Resource Regions

(in the contiguous United States)



Source: Kate Vaiknoras and Todd Hubbs, *Characteristics and Trends of U.S. Soybean Production Practices, Costs, and Returns Since 2002*, U.S. Department of Agriculture (USDA), Economic Research Service, June 2023, https://www.ers.usda.gov/webdocs/publications/106621/err-316.pdf?v=558.2.

[79] For example, one review of agrivoltaic impacts, led by researchers from Texas A&M University, concludes that a methodical understanding of the variety of conditions and impacts on crops and energy production is needed. Table 2 on page 15 of the article illustrates some of the yield impacts to date. Nuria Gomez-Casanovas et al., "Knowns, Uncertainties, and Challenges in Agrivoltaics to Sustainably Intensify Energy and Food Production," *Cell Reports Physical Science*, vol. 4, no. 8 (August 16, 2023), https://www.nrel.gov/docs/fy23osti/84669.pdf.

[80] For more information on the general characteristics of these regions, see USDA, Economic Research Service, *Farm Resource Regions*, September 2000, https://www.ers.usda.gov/webdocs/publications/42298/32489_aib-760_002.pdf?v=2860.7.

Note: Per USDA, Farm Resource Regions do not include Alaska and Hawaii because they are not included in ERS and USDA National Agricultural Statistics Service's Agricultural Management Resource Survey (AMRS).

To minimize negative impacts on agricultural operations and to minimize development costs, agrivoltaic projects often design and coordinate panel height, row and panel spacing, and orientation to accommodate crop choices, crop needs, and associated operations.[81] Some crops are less amenable to dual-use solar PV development than others. Taller crops might require higher panel infrastructure to allow for plant growth or for the use of farming equipment below or between the rows or panels. In some cases, the cost of these taller solar PV structures may be prohibitive—it may be more economically viable to limit crop types to lower-growing ones or to ones that do not require the use of large farm equipment. The presence of a solar PV system designed for certain crops could limit a farmer's ability to later switch crops—for crop rotation purposes or to adjust to market conditions. It might also otherwise change the use of that land during the solar PV system's lifetime.[82]

While individual research projects have examined the impacts of dual-use solar integration with specific crops under some growing conditions, not all crops of interest to U.S. farmers have data proven at commercial scale. For example, soybean, corn, hay, wheat, and cotton are the five largest crops in the United States—based on both acreage and value;[83] however, studies on the major row crops (corn, soybeans, and wheat) are limited.[84]

The integration of dual-use solar PV may pose significant risks to farm economic viability and long-term operations; risk management is a major consideration for agricultural operations.[85] While a relatively small decrease in crop yield (for example, 20%) might be acceptable under broad land use considerations (for example, if overall LER increased by 70%), such a decrease in yield could disproportionately affect agricultural operations. Agricultural yields and the percentage of revenue from agricultural operations are important considerations when farmers apply for loans, when they need to meet existing loan conditions, or if they wish to qualify for various governmental programs or agricultural tax exemptions or qualifications.[86] Some state or

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[81] AgriSolar Clearinghouse, "Getting Started with Agrisolar – A Tutorial," accessed July 2024, https://www.agrisolarclearinghouse.org/getting-started-w-agrisolar.

[82] American Clean Power, *Agrivoltaics: Considerations for Co-locating Solar and Agricultural Practices*, May 2024, https://cleanpower.org/wp-content/uploads/gateway/2024/05/ACP_Agrivoltaics-Considerations_Fact-Sheet-240507.pdf.

[83] University of Missouri, MU Extension, "Top 15 U.S. Crops Ranked by Area Harvested and Total Value," accessed July 25, 2024, https://extension.missouri.edu/programs/missouri-grain-crops/grain-crop-facts-and-figures#15uscrops; USDA, Economic Research Service, "Corn, Soybeans Accounted for More Than Half of the U.S. Crop Cash Receipts in 2023," last updated September 5, 2024, https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=76946.

[84] Purdue University is pursuing research into solar PV with corn and developing system models for corn, soybeans, and wheat. Rutgers University is researching soybeans. Steve Martin, "Purdue Agrivoltaic Farming Structures and Software Harvest Solar Power at Lower Cost and with Minimal Impact on Crop Yield," *Purdue News Weekly*, May 24, 2023, https://www.purdue.edu/newsroom/2023/Q2/purdue-agrivoltaic-farming-structures-and-software-harvest-solar-power-at-lower-cost-and-with-minimal-impact-on-crop-yield; Andy Wyenandt and Dan Ward, "Soybean Production Under Agrivoltaic Panels at RAREC in Southern New Jersey," Rutgers Agrivoltaics Program Blog, August 23, 2024, https://agrivoltaics.rutgers.edu/2024/08/23/soybean-production-under-agrivoltaic-panels-at-rarec-in-southern-new-jersey; Erik Dohlman et al., *Trends, Insights, and Future Prospects for Production in Controlled Environment Agriculture and Agrivoltaics Systems*, USDA, Economic Research Service, January 2024, https://www.ers.usda.gov/webdocs/publications/108221/eib-264.pdf?v=6749.4.

[85] USDA, Economic Research Service, "Risk Management," last updated May 23, 2024, https://www.ers.usda.gov/topics/farm-practices-management/risk-management/.

[86] Guido van der Hoeven, "Farm, Farming and Who's a Farmer for Tax Purposes," *Rural Tax Education*, February 2022, https://www.farmers.gov/sites/default/files/2022-03/whos-a-farmer.pdf.

federal agricultural or tax programs' definitions of farmland and agricultural uses may not accommodate energy development even if it is dual-use.[87]

Energy development can also present a number of challenges to farmers in the areas of contracts and agreements (including rights, duties, and other details for both farmers and energy developers) and related laws and regulations.[88] Solar development contracts can be long (i.e., have a high page count) compared with some other contracts—such as those for oil, gas, or mineral access under farmland—and the contracts can be highly specific to each individual development location and developer. Since solar energy leasing is relatively new and development contracts often require confidentiality agreements, there is less case law, there are fewer customs, and there is less available knowledge about what are the best practices and what are reasonable rates and terms for leasing land for solar energy development. The contract terms can be of relatively long duration (e.g., 20 years) and therefore may be an added risk for farmers who may need to vary their agricultural operations on a shorter time frame.

Solar PV structures are generally not intended to be permanent constructions; making farmland suitable for agricultural use again is often a regulatory requirement for energy development on farmland. However, reverting the land back to its original state introduces additional challenges. Contract agreements may need to include plans for decommissioning costs; these costs are often paid for by a bond from the developer. Contracts may need to specify what happens if the bond amount is insufficient to pay for the full price of decommissioning at the end of the project life. Contracts may include plans for what happens if the installation fails and the energy developer abandons the project during construction. Contracts may also address other changes that may affect the developer during the lifetime of the contract—including potential market changes or changes to state or local laws and regulations.

Development challenges can also include the need to consider how contract requirements might affect general agricultural operations or the farm owner's rights. These can include provisions that allow the developer access to the land (for construction, monitoring, maintenance, and decommissioning); that specify how the contract interacts with easements or tenant rights; that clarify whether the farm owner has the ability to sell land or transfer the contract; and that take into account restrictions on development due to property liens or other legal or financial conditions.

Because dual-use solar PV development on farmland involves greater integration with agricultural operations than projects that dedicate land to solely to energy production, additional challenges arise. Project designs may become complex. It may be challenging to integrate solar

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[87] Massachusetts and Colorado allow agrivoltaics to qualify for these programs; other states may not. Anuj Krishnamurthy and Oscar Serpell, *Harvesting the Sun: On-Farm Opportunities and Challenges for Solar Development*, Kleinman Center for Energy Policy, July 2021, https://kleinmanenergy.upenn.edu/wp-content/uploads/2021/07/KCEP-Harvesting-the-Sun.pdf; Michael T. Olexa and Christopher Hill, "Harvesting the Sun: A Sustainable Approach for Florida's Greenbelt Law," *Florida Bar Journal*, vol. 97, no. 5 (September/October 2023), https://www.floridabar.org/the-florida-bar-journal/harvesting-the-sun-a-sustainable-approach-for-floridas-greenbelt-law; Heidi Ricci et al., "Climate Change Challenges: Dual Use Solar, Food Production and Farmland Protection," presentation, Mass Land Conservation Conference, March 23, 2023, https://massland.org/sites/default/files/files/agrivoltaics_mltc_2023_complete_final.pdf; Becky Leis, "As Farmland Comes Under Threat from Development, 'Agrivoltaics' Is Emerging as a Potential Option," Council of State Governments – Midwest, September 20, 2023, https://csgmidwest.org/2023/09/20/as-farmland-comes-under-threat-from-development-agrivoltaics-is-emerging-as-a-potential-option.

[88] Shannon L. Ferrell, *Understanding Solar Energy Agreements*, National Agricultural Law Center, 2019, https://nationalaglawcenter.org/wp-content/uploads/assets/articles/ferrell-solar.pdf; University of Massachusetts Amherst, Center for Agriculture, Food, and the Environment, Clean Energy Extension, "Contract Negotiations for Solar PV Facility Agreements," last updated January 2024, https://ag.umass.edu/clean-energy/fact-sheets/contract-negotiations-for-solar-pv-facility-agreements.

PV system maintenance into agricultural operations—particularly for farmers who prefer to specialize only in agriculture.[89]

A final challenge to the broader development of agrivoltaics is the potential that integrated solar PV systems could affect the taste of the food grown underneath or nearby. Similar to studies showing impacts on crop yield, some studies have found an impact on taste. However, this research area is still developing, and results have varied by crop and conditions.[90]

Aquavoltaic Operations

For aquavoltaic facilities, the floating modules could increase the difficulty of tending to the aquaculture system. Periodically moving either the solar arrays or the marine animals could help reduce this interference. However, additional equipment, time, or financial resources might be required for these tasks. Further, moving the arrays or the animals could cause stress for the animals and affect their growth.[91]

Wildlife Impacts

Dual-use solar PV facilities have the potential to negatively affect wildlife. Solar panels over bodies of water might interfere with the ecological balance of the body of water. They might also cut off access for waterbirds or otherwise interfere with water access for wildlife.[92] The shade provided by solar PV facilities might also potentially favor certain unwanted species (e.g., invasive plants) or certain predators, shifting the balance of the local ecology.[93]

Mitigation measures such as elevating the systems further off the surface, leaving gaps in security fencing, creating animal crossing corridors, or otherwise providing for animal access may alleviate some of these challenges. However, these measures may impose additional costs or negative impacts on either the electricity generation capacity of the project or on its non-energy use.

[89] Cheryl Katz, "More Energy on Less Land: The Drive to Shrink Solar's Footprint," *Yale Environment 360*, July 28, 2022, https://e360.yale.edu/features/small-solar-agriculture-technology.

[90] Mariah Rogers, "Tasting the Fruits and Vegetables Grown Under Solar Panels," AgriSolar Clearinghouse, June 6, 2022, https://www.agrisolarclearinghouse.org/tasting-the-fruits-and-vegetables-grown-under-solar-panels; J. Widmer et al., "Agrivoltaics, a Promising New Tool for Electricity and Food Production: A Systematic Review," *Renewable and Sustainable Energy Reviews*, vol. 192 (March 2024), https://www.sciencedirect.com/science/article/pii/S1364032123011358; Jordan Macknick et al., *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study*, NREL, August 2022, https://www.nrel.gov/docs/fy22osti/83566.pdf.

[91] Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304.

[92] Hamid M. Pouran et al., "Environmental and Technical Impacts of Floating Photovoltaic Plants as an Emerging Clean Energy Technology," *iScience*, vol. 25, no. 11 (November 18, 2022), https://www.sciencedirect.com/science/article/pii/S2589004222015255.

[93] R.Y. Chock et al., "Evaluating Potential Effects of Solar Power Facilities on Wildlife from an Animal Behavior Perspective," *Conservation Science and Practice*, vol. 3, no. 2 (February 2021), https://doi.org/10.1111/csp2.319.

Challenges for Electricity Generation

Compared with standalone configurations, dual-use solar PV facilities may have reduced electricity generation capacity (or at least reduced capacity on a per-unit area basis). They may also increase risks to other co-located electricity generation or land use operations.[94]

Greater panel or row spacing—to accommodate agriculture or aquacultural operations—could reduce the electricity generation capacity of a dual-use solar PV facility. For floating solar, planning for the alternative uses of the body of water may reduce the size and potential electricity generation capacity of the solar PV facility compared with an equivalent area of land without those alternative uses. For example, solar-over-water development may be limited by the operations of a hydroelectric reservoir, the naturally occurring changes in water level in a lake, or competing uses of water such as recreation or transport. A floating solar PV facility on a hydroelectric reservoir could also further limit the operator's ability to maintain hydroelectric generation during low-water conditions—if continuing the hydropower operations would drop the reservoir's water level below the level necessary to support the solar array.

Also, floating solar could be a safety risk in a storm, during dam failure, or during other disruptive events. After such an event, even if the hydropower intake screens protect the hydropower facility from solar PV panel debris, the debris could otherwise interfere with operations of the hydropower facility or other activities on the surface of the water in general.

System Costs

Many dual-use solar PV configurations may have higher costs for infrastructure, installation, maintenance, or decommissioning compared with standalone configurations. Greater panel or row spacing and different panel or row orientations may be needed to accommodate agricultural requirements—for example, the use of farm equipment, the growth of taller crops, or allowing larger animals to graze.[95] These designs may require stronger foundations, more steel for structural materials, or the need for backup equipment (e.g., batteries or diesel generators) for associated equipment such as pumps.[96]

For floating solar, the system can have higher costs from additional engineering of the floats, electrical infrastructure, or cabling and anchoring, and from more frequent repairs. In floating solar applications, biofouling can interfere with power generation and increase maintenance costs, and aquatic organisms may slow or disrupt maintenance of the solar PV modules.[97]

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[94] As an added complication, reductions in electricity generation capacity of a dual-use solar PV facility could make it less likely that energy developers prioritizing project size would pursue its development.

[95] Sheep are the most often grazed animals in agrivoltaic applications, though cattle have also been tried. David McFeeters-Krone, "RUTE SunTracker Demonstrates Cattle-Grade Agrivoltaics in Oregon," AgriSolar Clearinghouse, February 7, 2023, https://www.agrisolarclearinghouse.org/rute-suntracker-demonstrates-cattle-grade-agrivoltaics-in-oregon.

[96] If the land is vulnerable to flooding, additional costs could apply. For example, associated electrical equipment might need to be raised above the projected level of flooding. Flood risk could also increase the cost of insurance. Cheryl Katz, "More Energy on Less Land: The Drive to Shrink Solar's Footprint," *Yale Environment 360*, July 28, 2022, https://e360.yale.edu/features/small-solar-agriculture-technology.

[97] *Biofouling* is the unintended accumulation or growth of aquatic organisms on surfaces exposed to water, which can cause corrosion of the structures or interfere with their operation. Pacific Northwest National Laboratory, "Marine Biofouling and Corrosion," https://www.pnnl.gov/marine-biofouling-and-corrosion; Adam Pringle, R.M. Handler, and J.M. Pearce, "Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture," *Renewable and Sustainable Energy Reviews*, vol. 80 (December 2017), https://www.sciencedirect.com/science/article/abs/pii/S1364032117308304.

Solar-over-canal applications potentially create a variety of challenges to canal operations and maintenance, leading to additional costs compared with conventional facilities.[98] Floating solar panels could be installed in canals, but this configuration can interfere with many canal operations (e.g., either water-based transportation or the control systems used to transport water). For this reason, solar PV canopies built over canals is the approach generally used. But canopies can still impact canal operations and maintenance: Canopies may make it more difficult or costly to control vegetation, mitigate subsidence of the canal, repair cracks, address embankment erosion, and remove sediment. Solar canopies over canals may also prevent airborne inspections and observations. The truss foundations on the canal banks can impede access for large mobile equipment for canal repairs and can complicate canal bank weed control or adjacent road maintenance.

Additionally, decommissioning costs for agrivoltaic or solar-over-canal facilities may be higher than for standalone solar power facilities if there are wider or taller truss structures or deeper foundations that need to be removed.[99] Also, there may be additional costs or bonding requirements for agrivoltaic facilities.[100]

Federal Support for Dual-Use Solar PV

Dual-Use Solar PV on Federal Lands

The Bureau of Land Management (BLM) anticipates future development of dual-use solar PV on federal lands as part of its mission to support multiple uses of federal lands and maximize sustained use of federal resources.[101] BLM states that co-located grazing opportunities are limited due to current solar PV designs but anticipates that new designs could make solar PV more compatible with grazing.[102] Solar-over-water potential for federally controlled bodies is currently

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98 U.S. Department of the Interior, Bureau of Reclamation, *Fundamental Considerations Associated with Placing Solar Generation Structures at Central Arizona Project Canal*, May 2016, https://www.usbr.gov/main/qoi/docs/09.27.2016%20Placing%20Solar%20Generation%20Structures%20Over%20the%20CAP%20Canal%20final%20.pdf.

99 Other agrivoltaic system conditions may contribute to a reduction in decommissioning costs—including less soil compaction, lack of gravel under the rows, and topsoil not being removed during construction. However, since few agrivoltaic facilities have reached their end of life, their impacts on agricultural conditions and the net effect on decommissioning costs are unknown. Samantha Levy and Ethan Winter, *Recommendations for State and Local Governments to Advance Smart Solar Policy*, American Farmland Trust, updated February 2024, https://farmland.org/wp-content/uploads/2023/12/AFT-Recommendations_for_State_and_Local_Governments_to_Advance_Smart_Solar_Policy.pdf; Ethan Beaulieu, "The Quick and Dirty on Agrivoltaics," *DSIRE Insight* (blog), NC Clean Energy Technology Center, January 25, 2022, https://www.dsireinsight.com/blog/2022/1/25/the-quick-and-dirty-on-agrivoltaics; Jessica Bozell, "When Green Energy Turns Brown: An Examination of the Insufficiencies in Louisiana's Current Solar Panel Decommissioning Regulations," *LSU Journal of Law and Resources*, vol. 11, no. 1 (February 6, 2023), https://digitalcommons.law.lsu.edu/cgi/viewcontent.cgi?article=1264&context=jelr.

100 Bonding requirements are often a condition for solar PV projects: regulations often require a decommissioning plan, and an accompanying amount of money (the "bond") as a guarantee, for returning the land to its pre-development state (e.g., agriculture-ready) for reuse. If the decommissioning is not completed by the solar developer, the bond amount is forfeited, typically to the regulating governmental authority or to the project insurer, investor, or lender.

101 U.S Bureau of Land Management (BLM), *Draft Programmatic Environmental Impact Statement for Utility-Scale Solar Energy Development*, vol. 1, January 2024, p. 1-1, https://eplanning.blm.gov/public_projects/2022371/200538533/20102762/251002762/2023%20Draft%20Solar%20PEIS%20Volume%201%201-10-2024_508compliant.pdf.

102 Other energy development is already co-located with grazing on federal lands. BLM notes that wind and geothermal energy facilities are "more dispersed" and more compatible with grazing. BLM, *Draft Programmatic Environmental*

(continued...)

being assessed by multiple federal agencies. These efforts, and other federal research and development activities, are discussed below.

Research and Development

The federal government currently supports research and development (R&D) for dual-use solar through several agencies. DOE's Solar Energy Technologies Office (SETO), USDA's National Institute of Food and Agriculture (NIFA), and others have dedicated funding to agrivoltaics. Following are some examples:

- DOE started funding agrivoltaics research in 2015. It had already invested more than $10 million (as of June 2021) when it announced the InSPIRE program round 3 with $3.7 million in funding.
- DOE also announced the Foundational Agrivoltaic Research for Megawatt Scale (FARMS) program with another $10 million in funding in 2022.[103]
- USDA funded NIFA's Agriculture and Food Research Initiative's (AFRI's) Sustainable Agricultural Systems. The funding includes $10 million for University of Illinois research into agrivoltaics.[104]

The federal government has also supported research on aquavoltaics, floatovoltaics, and other solar-over-water applications:

- DOE and NREL have funded and published research on floatovoltaics (including applicability for aquavoltaics).[105]

Impact Statement for Utility-Scale Solar Energy Development, vol. 1, January 2024, pp. 5-145, 5-148, https://eplanning.blm.gov/public_projects/2022371/200538533/20102762/251002762/2023%20Draft%20Solar%20PEIS%20Volume%201%201-10-2024_508compliant.pdf.

[103] Foundational Agrivoltaic Research for Megawatt Scale (FARMS) was funded under the Energy Policy Act of 2005, Section 931(a)(2)(A), and the Energy Act of 2020, Section 3004(b)(1)(B)(iii) and Section 3004(b)(2)(A)(i). Erik Dohlman et al., *Trends, Insights, and Future Prospects for Production in Controlled Environment Agriculture and Agrivoltaics Systems*, USDA, Economic Research Service, January 2024, https://www.ers.usda.gov/webdocs/publications/108221/eib-264.pdf?v=6749.4; U.S. Department of Energy, Solar Energy Technologies Office, *USDA-DOE Agrivoltaics Workshop*, presentation, January 2021, https://www.agrisolarclearinghouse.org/wp-content/uploads/2022/01/2022_USDA-SETO_Agrivoltaics_Workshop_-_Compiled-r.pdf; DOE, "DOE Announces $8 Million to Integrate Solar Energy Production with Farming," press release, December 8, 2022, https://www.energy.gov/articles/doe-announces-8-million-integrate-solar-energy-production-farming.

[104] Sustainable Agricultural Systems was funded under the Competitive, Special, and Facilities Research Grant Act, Section 2(b) (7 U.S.C. 3157). USDA, "USDA Announces More Than $146M Investment in Sustainable Agricultural Research," press release, October 6, 2021, https://www.usda.gov/media/press-releases/2021/10/06/usda-announces-more-146m-investment-sustainable-agricultural.

[105] Prateek Joshi, *Overview of NREL's Research on Floating Solar Photovoltaics (FPV), Including Technical Potential Assessments*, presentation, NREL, October 2023, https://www.nrel.gov/docs/fy24osti/87698.pdf; DOE, "Market Research Study: Floating Solar Photovoltaics," August 2022, https://science.osti.gov/-/media/sbir/pdf/Market-Research/SETO—Floating-Solar-Photovoltaics-August-2022-Public.pdf; Robert S. Spencer et al., "Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States," *Environmental Science and Technology*, vol. 53 (2019), https://pubs.acs.org/doi/pdf/10.1021/acs.est.8b04735; Sika Gadzanku et al., "Benefits and Critical Knowledge Gaps in Determining the Role of Floating Photovoltaics in the Energy-Water-Food Nexus," *Sustainability*, vol. 13 (April 2021), https://www.nrel.gov/docs/fy21osti/78427.pdf; Evan G. Rosenlieb, Marie Rivers, and Aaron Levine, "Floating Photovoltaic Technical Potential: A Novel Geospatial Approach on Federal Reservoirs in the United States," NREL, forthcoming 2024; Aaron Levine et al., *AquaPV: Regulatory and Environmental Considerations for Floating Photovoltaic Projects Located on Federally Controlled Reservoirs in the United States*, NREL, June 2024, https://www.nrel.gov/docs/fy24osti/86325.pdf.

- As part of the Water Resources Development Act of 2022 (P.L. 117-263), Congress directed the Secretary of the Army and the U.S. Army Corps of Engineers (USACE) to report on floating solar PV opportunities under their purview.
- Section 50232 of the IRA (P.L. 117-169) provided $25 million (available through FY2031) for solar panel installations over canals.[106] In December 2023, the Biden Administration announced that $6 million of this funding had been dedicated to a project to install solar panels over canals in the Gila River Indian Community in Arizona.[107]

Some public advocacy groups have urged the U.S. Bureau of Reclamation (BOR) to develop more projects like the Gila River installation.[108] Other stakeholders caution that solar-over-canals could interfere with public access and emergency access, or might interfere with canal operations in times of low water levels.[109] The POWER Our Reservoirs Act (H.R. 2731) would require BOR and USACE to examine and pilot the development of dual-use solar PV systems on BOR canals and USACE project sites. USACE does permit pilot projects for floatovoltaics on navigable waters of the United States (via Nationwide Permit 52).[110]

The federal government also supports R&D for aquaculture:

- The National Agricultural Research, Extension, and Teaching Policy Act (NARETPA), part of P.L. 95-113, established USDA as the lead federal agency for agricultural R&D, including aquaculture.
- The National Aquaculture Act of 1980 (P.L. 96-362) supports and maintains aquacultural production.

Though neither of these acts currently addresses aquavoltaics R&D, it is possible they could support such as part of aquaculture research or operations.

Selected Issues for Congress

Dual-use solar PV as an application is still in development. Much of the federal activity in this area has focused on R&D around the costs, benefits, and potential applicability of dual-use solar

[106] Additional information is available in CRS In Focus IF12437, *Bureau of Reclamation Funding in the Inflation Reduction Act (P.L. 117-169)*, by Charles V. Stern and Anna E. Normand.

[107] U.S. Department of the Interior, "Biden-Harris Administration Announces Nearly $6 Million for Innovative Solar Panel Installation over Canals in Gila River Indian Community," press release, December 8, 2023, https://www.doi.gov/pressreleases/biden-harris-administration-announces-nearly-6-million-innovative-solar-panel.

[108] Center for Biological Diversity, Letter from Interest Groups to Secretary Deb Haaland and Commissioner Camille Touton, July 19, 2023, https://www.courthousenews.com/wp-content/uploads/2023/07/Bureau-of-Reclamation-on-Solar-Canal-Initiative-Letter.pdf.

[109] Ryan Randazzo, "Arizona Utilities Have Long Rejected Covering Canals with Solar Panels. Here's Why That May Change," *AZCentral*, March 21, 2023, https://www.azcentral.com/story/money/business/energy/2023/03/21/should-solar-panels-cover-arizona-canals-srp-asu-looking-at-effects/70022804007/; Brad Hooker, "With Solar over Canals, Farmer Points to the Elephant in the Room," *AgriPulse*, April 8, 2024, https://www.agri-pulse.com/articles/20915-with-solar-over-canals-farmer-points-to-the-elephant-in-the-room.

[110] U.S. Army Corps of Engineers, "Nationwide Permit 52: Water-Based Renewable Energy Generation Pilot Projects," March 19, 2017, https://www.swf.usace.army.mil/Portals/47/docs/regulatory/Permitting/Nationwide/NWP52TX.pdf; U.S. Army Corps of Engineers, "Nationwide Permit 52: Water-Based Renewable Energy Generation Pilot Projects," March 15, 2021, https://saw-reg.usace.army.mil/NWP2021/NWP52.pdf.

PV. Beyond R&D activities, there are areas of potential overlap of dual-use solar PV with other federal activities and federal priorities.

Federal Policy Areas

Outside of energy policy, dual-use solar PV development could affect federal policy involving farm, land, and water management.

Farm Policy

Federal farm policy is one potential area of consideration for dual-use solar PV applications and development. The primary federal legislation on this issue is the omnibus farm bill, which is generally renewed about every five years.[111] The farm bill is concerned with impact on farmers, contracts, the food supply, and agricultural companies, but it also includes multiple titles covering policy areas that could be related to dual-use solar PV, including R&D for agriculture, aquaculture, and farm-based energy topics at USDA and other agencies.[112] The most recent farm bill was enacted in 2018 and was given an extension in 2023; the extension is set to expire at the end of 2024.[113]

The Farm, Food, and National Security Act of 2024 (H.R. 8467), introduced May 21, 2024, would require USDA and DOE to conduct a study on solar panel installations on farmland, including on "shared solar energy and agricultural production." A number of issues related to dual-use solar PV on agricultural lands or related agricultural, aquacultural, and energy goals could potentially be addressed in the farm bill, including

- what level of federal support (if any) to provide dual-use facilities and how to determine impacts to the agricultural uses of farmland;
- whether rural and farmland definitions can, or should, include or allow dual uses; and
- whether any distinction should be made between small-scale on-farm facilities and larger-scale facilities, especially as many smaller farms continue to rely on non-agricultural revenue sources.

Land and Water Management Policy

Many federal agencies have responsibilities for federal land and resource management.[114] Goals of federal land management policy are to manage federal lands and water and the resources associated with them for multiple uses, for the sustained yield of those resources, and to "sustain

[111] For more information on the farm bill, see CRS In Focus IF12047, *Farm Bill Primer: What Is the Farm Bill?*, by Renée Johnson and Jim Monke.

[112] Most of the energy-related provisions are contained within the Energy Title—Title IX. For more information on the Energy Title, see CRS In Focus IF10288, *Overview of the 2018 Farm Bill Energy Title Programs*, by Kelsi Bracmort, or CRS Report R45943, *The Farm Bill Energy Title: An Overview and Funding History*, by Kelsi Bracmort.

[113] For more information, see CRS Report R47659, *Expiration of the 2018 Farm Bill and Extension for 2024*, by Jim Monke, Randy Alison Aussenberg, and Megan Stubbs.

[114] Agencies include the USDA's Forest Service (FS); the Department of the Interior's Bureau of Land Management (BLM), Fish and Wildlife Service (FWS), and National Park Service (NPS); and the Department of Defense (DOD). The Bureau of Indian Affairs (BIA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (USACE), and the Environmental Protection Agency (EPA) also have responsibilities for tribal lands, marine commerce, bodies of water used for hydropower and related assets, and environmental protection of these resources, respectively. For more information on these agencies and their responsibilities, see CRS In Focus IF10585, *The Federal Land Management Agencies*, by Carol Hardy Vincent, Laura B. Comay, and Anne A. Riddle.

the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations."[115] Federal land management agencies could incorporate considerations of dual-use solar PV into their land and resource management decisions. A potential question for Congress could be whether dual-use considerations, by definition, help promote the goal of multiple uses and sustained yield.

Data Collection, Analysis, and Modeling

Dual-use solar PV development could benefit from data on various natural resources and conditions—data that could also inform any environmental reviews or land or resource planning. These could include data on soil quality, biodiversity, water quality and availability, and emissions, pollution, or other environmental impacts from before and after dual-use solar PV development. This data could support analysis and modeling of dual-use solar PV systems—including the power generation aspects and the land use impacts and associated economic and environmental aspects.

Some critics of current energy policy assert that energy policy and regulation—in seeking to maximize energy supply or minimize energy costs—sometimes give too little attention to the trade-offs. Collecting and analyzing data on the impacts of energy development on lost productivity (for example, of food production) and degraded ecosystem services (such as reductions in biodiversity or wildlife habitat) can help inform decisions about appropriate levels of support, development, and regulation and can help mitigate potential impacts.[116]

Congress could consider a number of options to address these concerns, if desired. For example, federal agencies—or development projects on federal lands or supported by federal actions—could be required to

- consider simultaneous uses of the land;
- collect data about the land before, during, and after development relevant to both the energy and non-energy purposes of the land;
- make the data, analysis, and system models available for use by government agencies or developers;
- use the data to identify lands where dual uses have the most potential versus lands that are most suitable to a single use (such as energy production); and
- require data collection and planning for the end-of-life and decommissioning of energy facilities for the restoration or sustainability of the land's long-term, non-energy uses.

Another option for Congress could be to expand federally supported data projects, such as the AgriSolar Clearinghouse and NREL's InSPIRE database, to include data, analysis, and modeling to support all types of dual-use solar PV projects (including agrivoltaic and solar-over-water uses).

[115] U.S. Department of the Interior, BLM, "Our Mission," https://www.blm.gov/about/our-mission.

[116] Brady W. Allred et al., "Ecosystem Services Lost to Oil and Gas in North America," *Science*, vol. 348, no. 6233 (April 24, 2015), https://www.science.org/doi/full/10.1126/science.aaa4785.

Federal Incentives for Dual-Use Solar PV Development

The 117th Congress enacted P.L. 117-169, which provides incentives for developing certain energy projects on some already disturbed lands.[117] Specifically, some energy projects located in areas associated with fossil fuel-related economic activity (e.g., near retired coal-fired power plants) are eligible for "bonus" tax credits. This policy aims to direct energy project development activities into certain areas. A similar approach could be used to direct development activities to dual-use applications.

The Pollinator Power Act of 2023 (S. 1555, 118th Congress) would incentivize pollinator habitats surrounding new solar PV facilities through USDA's Rural Energy for America Program (REAP). When considering this and other potential legislation relating to dual-use solar PV applications, Congress could consider whether dual-use solar PV facilities should be eligible for both agricultural- and energy-based incentives or funding. Options could include energy tax incentives or agricultural tax incentives and funding such as grant or loan programs for energy or agricultural projects.

Federal Support for R&D

The 118th Congress is considering several bills to support R&D on dual-use PV technologies. For example, the Agrivoltaics Research and Demonstration Act of 2023 (S. 1778) would require USDA to conduct R&D on agrivoltaics and to define agrivoltaic systems for integration with federal agricultural and energy policies and with the energy investment tax credit. As noted above, the POWER Our Reservoirs Act (H.R. 2731) would require BOR and USACE to examine and pilot the development of dual-use solar PV systems on BOR canals and USACE project sites (although USACE already permits pilot projects for floatovoltaics on navigable waters).

If Congress chose to expand federal investment in dual-use solar PV R&D, areas of interest could include

- assessing available land (and water); best land uses; cost trade-offs, including potential ecological impacts on biodiversity, pollution, and waste generation; comparison with impacts from equivalent fossil-fuel-based facilities; and impacts on the other uses of the land (including, for example, recreation, transportation, commerce, or conservation);
- assessing siting of dual-use solar PV generation—including proximity to infrastructure or demand and land acquisition and development costs—and the effect of dual-use solar PV development on the cost of electricity;
- assessing dual-use solar PV facilities' impacts on water quality and availability and their impacts on water runoff, erosion, and stormwater systems;
- developing an R&D roadmap for dual-use solar PV technologies;
- developing technologies and methods to improve the manufacturing, lifetime, maintenance, decommissioning, recycling, reuse, and sustainability of dual-use solar PV systems; and
- mapping inputs from legal, political, regulatory, environmental (e.g., soil and water conditions, topography and physical terrain, climate, solar incidence), and

[117] The IRA provided a bonus tax credit to projects located on brownfield sites and other "energy communities" (26 U.S.C. 45). Additional discussion is in the section "Tax Credit Policies for Businesses in Coal Communities" in CRS Report R47831, *Federal Economic Assistance for Coal Communities*, by Julie M. Lawhorn et al.

infrastructural data to identify best locations for dual-use solar PV applications nationwide.[118]

State and Local Development

Outside of federal lands, most electricity policy is created and implemented at the state level.[119] Permitting and environmental regulation is similarly handled primarily at the state and local levels. Land use is typically under local purview and is addressed through zoning laws and other regulations.[120] Some states have passed legislation to deal with the potential overlap between siting of renewables (largely solar and wind) and agricultural land. In some states, these decisions are left up to local governments or regulatory bodies—such as public utility commissions; in other states, state laws establish statewide controlling authorities. As of 2021, 21 states required state public utility commissions to review utility-scale solar projects, and 27 states left regulations to local governments. The remaining two states are Florida, which explicitly permits solar development in county agricultural zoning districts, and Ohio, which allows local governments to ban utility-scale solar development or to designate areas where it is prohibited.[121]

Approaches to supporting or allowing dual-use solar PV applications vary by state. Some states—for example, New York and Maine—advocate co-location of solar and agricultural uses and provide informational and technical assistance for farmers. Some states support advocacy and information sharing, including requiring consultation with the state's department of agriculture (e.g., Minnesota and Wisconsin) or consideration of the impacts of solar development on agriculture (including soil quality and sustainability; e.g., North Dakota). Some states encourage development and support of pollinator habitats (e.g., Missouri). At least one state allows for the creation of "agricultural security areas," which prevent the development of non-agricultural uses on agricultural land (excepting wind development, however; e.g., Ohio). Some states allow for dual energy-agricultural use of agricultural land based on soil quality assessments (e.g., Hawaii), impact mitigation agreements (e.g., Illinois), or environmental assessments (e.g., Tennessee).[122]

Congress could consider directing federal agencies to help coordinate state and local governments and other stakeholders to share best practices and other information on dual-use solar PV R&D, to develop relevant standards, and to coordinate policy.[123]

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[118] Researchers in Spain developed a methodology using GIS data to identify the best territory for the sustainable development of solar PV. Inmaculada Guaita-Pradas et al., "Analyzing Territory for the Sustainable Development of Solar Photovoltaic Power Using GIS Databases," *Environmental Monitoring and Assessment*, vol. 191, article no. 764 (2019), https://link.springer.com/article/10.1007/s10661-019-7871-8.

[119] Additional information is available in CRS Report R47521, *Electricity: Overview and Issues for Congress*, by Ashley J. Lawson.

[120] Jesse Richardson, Peggy Kirk Hall, and Whitney Morgan, "Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses," WVU College of Law Research Paper No. 2022-004, April 6, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4042235.

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

[122] Jesse Richardson, Peggy Kirk Hall, and Whitney Morgan, "Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses," WVU College of Law Research Paper No. 2022-004, April 6, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4042235.

[123] Jesse Richardson, Peggy Kirk Hall, and Whitney Morgan, "Land Use Conflicts Between Wind and Solar Renewable Energy and Agriculture Uses," WVU College of Law Research Paper No. 2022-004, April 6, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4042235.

Author Information

Morgan Smith
Analyst in Energy Policy

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