

A Review on Agrivoltaics and Recommendations for Alliant Energy's Customer-Hosted Renewables Program

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Introduction

Background on Project Site

The Kegonsa Solar and Agricultural Research Site is a dual effort between UW-Madison and Alliant Energy. The site is located at the UW Kegonsa Research Campus - Physical Sciences Lab, about 10 miles from campus in the Town of Dunn near Stoughton, Wisconsin [1]. UW-Madison is leasing the land to Alliant Energy who will build, own, and operate a 2.25 MW solar array at the site as a part of their Customer-Hosted Renewables program. The University will retire Renewable Energy Credits (RECs) from the project, and the electricity generated will go to the Alliant Energy distribution system to power local homes and businesses. The solar array, which will take up 15 of the 280 total acres of the research campus, is located in the interior parcel in order to shield views from neighboring property and roads. The land has a south-facing slope that is ideally suited for solar energy generation. The site will feature three different types of solar panels: regular fixed panels, single-axis tracking panels, and elevated fixed panels. UW -Madison students, faculty and staff will use the facility for multi-disciplinary education and research purposes. The site will be a demonstration to the public about the benefits of and opportunities for agrivoltaics in Wisconsin, and provide the UW-Madison and Alliant Energy a better understanding of best practices and community concerns about the co-location of solar energy and agriculture.

Problem Statement

In response to student and community advocacy for climate action and advancing renewable energy, the University and Alliant Energy are looking to develop and implement renewable sources of electricity to power Madison. In recent years, solar has been the forefront renewable energy option in Wisconsin, most of which has been developed on agricultural land. This has led to local tensions and public discourse over land use, particularly regarding Wisconsin's tradition of agricultural production. The growing field of "agrivoltaics" is a proposed solution, where agricultural production continues on the same plot as the solar arrays, thus maintaining agricultural productivity of the land while also using it to produce a renewable source of energy. Alliant Energy is currently developing a customer hosted solar PV project on active agricultural land at UW-Madison's Kegonsa Research Campus.

Our team was asked to research current applications of agrivoltaics, evaluate the landscape for agrivoltaics in Wisconsin, and develop recommendations to support the Kegonsa Research Campus Solar and Agricultural Research Pilot Project and further agrivoltaic opportunities in Wisconsin. Key project tasks include a literature review, market characterization research, and case study review. The team was also able to participate in an experiential spring break peer-exchange tour at the University of Arizona and Biosphere 2, to meet the researchers there and learn about the frontiers of agrivoltaics development. Final recommendations target key needs and concerns from Wisconsin rural communities, agricultural producers, and other Wisconsin-based stakeholders. Alliant Energy seeks to use our research agenda and recommendations of best practices to potentially pursue future agrivoltaic projects in Wisconsin.

Interdisciplinary Integration & Acknowledgements

Energy touches every aspect of life and we will maintain this viewpoint with our work. Our team came from different academic backgrounds (economic, engineering, environmental) and planned to bring the breadth of our experiences to this project. Our Energy Analysis & Policy (EAP) Capstone group has integrated a variety of perspectives to this project through consulting with Alliant Energy, UW-Madison Office of Sustainability, the Agroecology capstone group, and various UW researchers involved with the project. We'd like to thank all of these groups for contributing their time and brainpower to many discussions this semester. The team would like to personally thank Josh Arnold, Campus Energy Advisor, for his invaluable mentorship and guidance throughout the semester, along with Henry Hundt for all of his help. We also graciously thank Tracey Holloway, EAP program chair, for the generous funding that made our Arizona peer-exchange travel possible, as well as Scott Williams and Michael Kamp for their help. We thank those in Dr. Barron Gafford's group at the University of Arizona, specifically Kai Lepley, Nesrine Rouini, and Caleb Ortega for hosting our team and sharing about their work. Thank you to Amanda Thomas, Project Manager at Alliant Energy, for giving us the opportunity to research such an enriching and frontier topic for our capstone project. Lastly, we would like to thank our fellow EAP cohort, not only for the support and advice this semester, but also for the friendships over the last few years. On Wisconsin!

Literature Review

Agrivoltaics is defined as the use of land for both agriculture and solar photovoltaic energy generation [2]. The concept of agrivoltaics has emerged as a solution to reconcile conflicts between solar and agricultural activities, by creating mutual benefits and added value for each sector, though it was first established in academic literature in 1982 [3]. Various studies since have highlighted the potential co-benefits of agrivoltaics, such as increased land productivity, reduced plant and panel heat stress, and opportunities for reduced operation and maintenance costs [4],[5],[6].

Classification of Systems

To facilitate clear communication with stakeholders and policy makers, researchers in Belgium created a standardized classification of agrivoltaic systems [7]. As shown below in Figure 1, the first subcategory defines systems to be agrivoltaics if PV is combined with crops or rangevoltaics if PV is combined with livestock. Both types may be closed, like a greenhouse or fence with solar panels attached, or open, ground- or stilt-mounted arrays. Open agrivoltaics categorization separates into field or orchard crops, which have different height and economic value assumptions associated with them; orchard crops tend to sell for more but require taller, more expensive configurations. All open systems can be stilted or use increased spacing to provide the solar insolation necessary for agricultural production to reach the ground. The final filter defines the permanence of the installation. If the system is a typical ground mount that cannot be moved easily, it is static. If the panels are part of a less permanent system, like a solar pump system or a drink spot for cattle, it is dynamic.

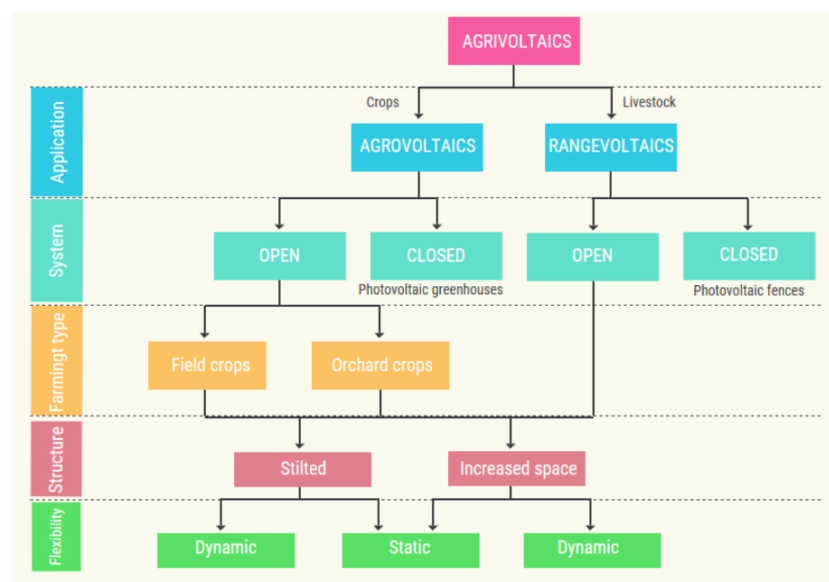


Figure 1. Flowchart for characterizations of solar colocated with other uses for land.

The U.S. Department of Energy (DOE) Agrivoltaics Market Research Study presents another classification system shown below in Figure 2 with similar separations based on open or closed system, and interspace or overhead (stilted) PV [8].

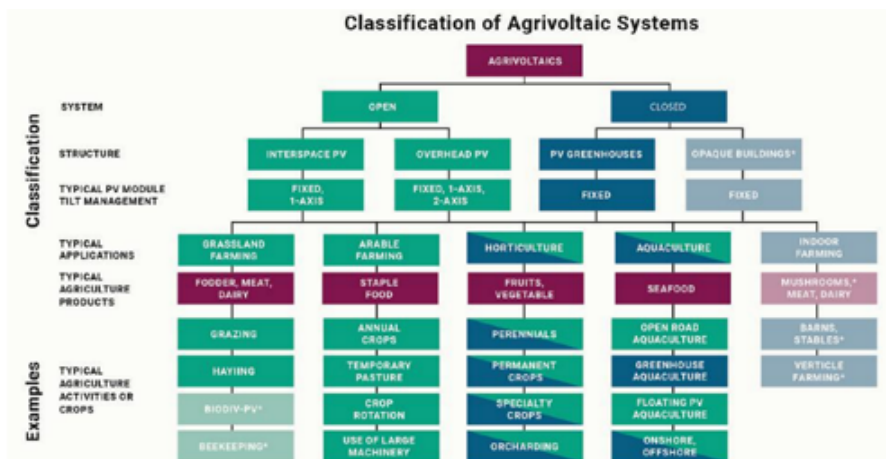


Figure 2. Flowchart by the U.S. DOE for classification of agrivoltaics systems.

Benefits of Agrivoltaics

(DOE section) One of the largest benefits of agrivoltaics is that it provides dual revenue streams for farmers. Landowners/land operators can generate a reliable income by producing electricity while continuing to grow and cultivate crops or graze livestock underneath the solar arrays. At the University of Arizona, researchers found that “growing crops in the shade from solar panels can yield two or three times more fruit and vegetables than conventional agriculture setups” [5].

Agrivoltaics installations also create a beneficial microclimate within the system. Growing plants underneath solar panels has proven to be beneficial for both the solar modules and plants. Research in Arizona has shown that the co-location of solar and agriculture creates a cooler environment that improves panel performance, while “the increased shade can improve water-use efficiency, soil moisture content, and crop yields” [5]. In open agrivoltaics system growing cherry tomatoes in Oregon, water-use efficiency was 65% greater than in normal growing conditions and production of the crop doubled [9]. Apart from the benefits to grazing animals, shade in an agricultural setting is also beneficial to human workers by improving working conditions and protecting against extreme weather.

Agrivoltaics systems bring many benefits to agricultural operations for landowners. There is potential for reduced operation and maintenance costs, typically involving mowing of vegetation. A native plant cover that serves as a pollinator habitat can reduce the need to mow between and under the panels, so long as the species chosen do not grow taller than the low edge of the panels. Sheep can also graze vegetation amongst the solar arrays, reducing the need for mowing and pesticides. An additional benefit is that bringing solar arrays to agricultural settings will improve the electricity infrastructure in rural areas. It can also increase the adoption of electric vehicles and equipment in rural areas and on farms by providing charging opportunities in the field [10]. Many of the operation and maintenance benefits are still being uncovered in the field, as agrivoltaics transitions from a research concept to real-world farm applications.

Current Agrivoltaics Market

The DOE found that in the U.S. there are about 2.8 GW of agrivoltaics sites, most of which involve pollinator habitats and/or sheep grazing [11].

The global market for agrivoltaics has increased in capacity from 5 MW in 2012 to over 14 GW in 2021 [12]. Figure 3 below shows the global demand for agrivoltaics over the last decade.????

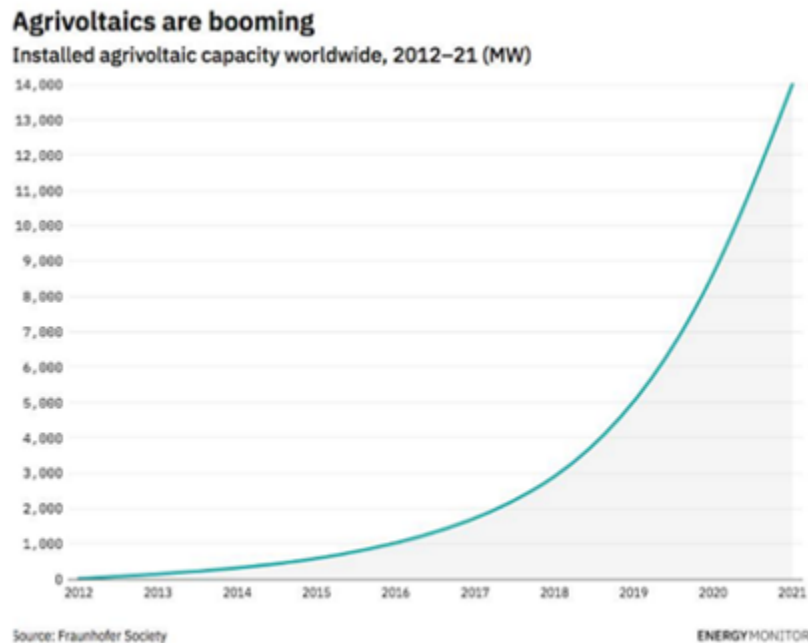


Figure 3. Global installed capacity for agrivoltaics.

Livestock grazing underneath solar panels is becoming more common in the U.S. There are currently over 100 MW of solar PV sites utilizing livestock grazing underneath the arrays, mostly involving sheep (though some sites utilize other animals like cattle or rabbits). The elevated solar arrays provide shade for grazing animals, reducing the amount of water that the livestock need. Growing crops underneath solar arrays is relatively behind compared to the rest of the dual-use solar movement. Globally, about 2.8 GW of solar + crop installations are in operation, and most of them are concentrated in China, Japan, South Korea, and Europe.

To investigate the current state of agrivoltaic research, we consulted a review of literature of agrivoltaics that was published in 2022 [13]. It indicates that agrivoltaics provides opportunities for improved water and land use efficiencies from plant-panel interaction and co-location. Installations can also provide diversification of income for landowning farmers. Though increased capital costs are realized for agrivoltaics compared with no growth beneath PV arrays, the installations provide owner-operator farmers with diversified incomes where energy production typically accounts for 80-90% of the revenue for the piece of land. This indicates opportunities for Wisconsin farmers to partner with solar installers to increase farm income, continue to agricultural production, provide ecosystem services, and increase the clean energy produced in Wisconsin. The review suggests future research on agrivoltaics aim to evaluate financial performance, assess crop suitability, develop best practices for working with stakeholders, and create clear recommendations for policy makers.

Pollinator Habitat Agrivoltaics

According to a study by NREL, the most common application of dual-use solar is pollinator habitat agrivoltaics, with over 1 GW of solar installations in the U.S. providing pollinator habitats (typically focused on bees and butterflies) [14].

Opportunities to combine PV with pollinator habitat is appealing for its low cost of implementation and environmental benefits. Agrisolar Clearinghouse produced an Overview of Pollinator-Friendly Solar, from which the following information comes [15]. Reasons to consider pollinator-friendly practices include requests from vendors and contractors due to customer expectations, potential cost savings on maintenance and adoption of business incentives by some states, and collateral ecological benefits. Some of the negative impacts of solar PV include disruption to pollinator habitat and biodiversity at the site. A common proxy to predict the impact is an estimation of the number of acres changed due to solar installations. Generally, for ground-mounted solar, 8-10 acres are disrupted per megawatt installed capacity installed. Additional impacts include loss of habitat, destruction of nesting sites, soil compaction that reduces access to pollinator nesting habitat, and an increase in invasive species that displace native flowering food resources. Some of these stem from siting and construction disruptions that fragment existing habitats or create barriers to movement. Studies have shown that isolated pollinator populations have reduced survival, reproduction, and gene flow. Considerations of damage to pollinators with design, construction and maintenance of solar sites should be made for any potential solar installations. Table 1 below summarizes construction and maintenance activities that support pollinators at sites.

Table 1. Solar PV site practices to support pollinators.

Siting and Construction	Maintenance Activities
Avoid critical pollinator habitat. Do not remove topsoil. Retain existing native vegetation. Do not overly grade the site. Avoid soil compaction.	Avoid mowing during blooming. Mow in late spring to avoid harming ground nesting overwintering pollinators. Avoid use of herbicides and insecticides. If needed, spot spray. Remove invasive species.

All stages of solar installations can consider pollinators, including design, construction, and maintenance. During the design process, panel height, shading, and spatial arrangement affect what can grow there. Since native plants tend to grow taller than solar panels, this poses problems. Rain can be diverted by the panels and cause variable soil moisture across the site. If irrigation is needed, the cost will increase. Shade from the panels causes variable shade across the site. There are ways to arrange panels and plants to complement each other, but this is site-specific. Additionally, consideration of planting types to use affects how pollinator-friendly a site is. Table 2 below shows elements of a pollinator-friendly plant community. Construction practices often include removing existing vegetation, stripping topsoil, and grading the site. Minimizing these, as mentioned in Table 1, can help pollinator populations. Regarding maintenance, when sites are seeded with native plants, there are commonly a few mowings per year to maintain sites, but more frequent mowing is needed in the first several years to help native plantings get established. Mowing in the spring rather than the fall can help butterflies and

moths that overwinter on native vegetation. Methods of maintaining site vegetation such as using grazing animals to mow vegetation can be used. Most commonly, sheep are used for grazing maintenance.

Table 2. Planting guidelines for pollinator-friendly vegetation.

Pollinator-Friendly Planting Specifics	
High flower diversity (20+ species), area, and flowering time (season long flowering)	Use native plants. Avoid ornamental species.
Range of flower colors and shapes. Select flowers with demonstrated attractiveness to pollinators.	Preserve nesting sites and larval host plants.

As mentioned above, supporting pollinator-friendly habitat provides other ecological benefits. These include preserving and providing food and nesting resources to grassland bird, bats, and small mammals, providing better pollination and natural pest suppression for land adjacent to the solar site, improved aesthetics of sites which increase public support for future projects, and benefits of planting native species because they are drought and fire adapted, and their deep roots reduce soil erosion and water runoff, which can be a stormwater management technique.

Though there is no published quantitative analysis for reduced costs for managing pollinator agrivoltaics sites as compared to the cost of managing traditional solar sites, often there are reduced costs in long-term operation and maintenance due to reduced mowing, fewer herbicide treatments, reduced stormwater and soil runoff, and reduced reseeding after erosion or drought dieback. Future research is necessary to better understand these pollinator-friendly solar opportunities. This includes cost-benefit analysis, vegetative design optimization plans, on-site species assessments to confirm pollinator benefits, and testing of electricity generation efficiency given plant shadowing and pollen residue effects on the panels. Overall, agrivoltaics have large potential to help with pollinator conservation and managing broader societal demands for renewable energy.

The anticipated value of these ecosystem services was assessed in EPRI's Pollinator-Friendly Solar Scorecards Comprehensive Analysis of Scorecard Attributes [16]. States and organizations have created various scorecards to rate and track the land used as pollinator habitat beneath solar panels that aim to provide environmental co-benefits at the PV production site. Fifteen state and one organization scorecards were evaluated to determine the overarching priorities across the country when evaluating these sites. Wisconsin's scoring system requires both initial siting and maintenance scorecards, whereas many states only require one for initial siting. The average passing score across cards was 56%; Wisconsin's is 65%. Across scorecards, categories of plant diversity and insecticide use were the categories weighted most, 49%-75% and -16%- -40% respectively. This indicates these categories are what is most important when siting an agrivoltaic array.

Assessing and Achieving Project Success

Planning

The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons From the InSPIRE Research Study presents the “5C s” - five success factors derived from lessons learned from the InSPIRE project [18]. The success factors are Climate (C1), Configurations (C2), Crop Selection and Cultivation Methods (C3), Compatibility (C4), and Collaboration (C5). This study builds upon the successes and failures of prior agrivoltaic projects to inform new innovations and agrivoltaic research. It presents a synthesis of lessons learned from the InSPIRE project research field sites, which include a diverse mix of geographies, agrivoltaic activities, and technological configurations. By taking the five success factors “5 Cs” into account, agrivoltaic practitioners and researchers can optimize the performance of existing systems and increase the chances of success.

The first success factor, *Climate, Soil, and Environmental Conditions (C1)*, includes the ambient conditions and factors of a specific location such as ambient climate, soil quality, and water access. While these factors are generally beyond the control of agrivoltaic practitioners and researchers, they can have a significant impact on the success of an agrivoltaic project. Given the diverse local climates, soils, and ecoregions across the United States, agrivoltaic systems must be tailored to suit the specific conditions of their location. As suggested in the study, additional research considerations are also needed, such as the “representativeness, research novelty and value,” and the “nearby land-use changes and crop rotation outside of the agrivoltaics array.”

The second success factor, *Configurations, Solar Technologies and Designs (C2)*, which indicates the choice of solar technology, the site layout, and other infrastructure that can affect light availability, microclimate, soil conditions, and solar generation. Specific C2 factors also include project capacity, panel height, racking system, inter-panel spacing, inter-row spacing, and PV module types. Each component of the configuration needs to be evaluated in the context of the entire system design. Importantly, because configuration designs are not generally able to change, decisions made during the design phase will be fixed for the duration of the project, which can be 20 to 30 years.

The third factor is *Crop Selection and Cultivation Methods, Seed and Vegetation Designs, and Management Approaches (C3)*, including the methods, vegetation, and agricultural approaches used for agrivoltaic activities and research. Besides basic vegetation selection, establishment, and associated market distribution, other determinants such as research plot size, research duration, modeling, validation, and control plot design, should also be considered for future agrivoltaic research designs. Figure 4 provides a summary of crop performance across multiple sites and locations, which could potentially serve as a reference for selecting crops at the Kegonsa site.

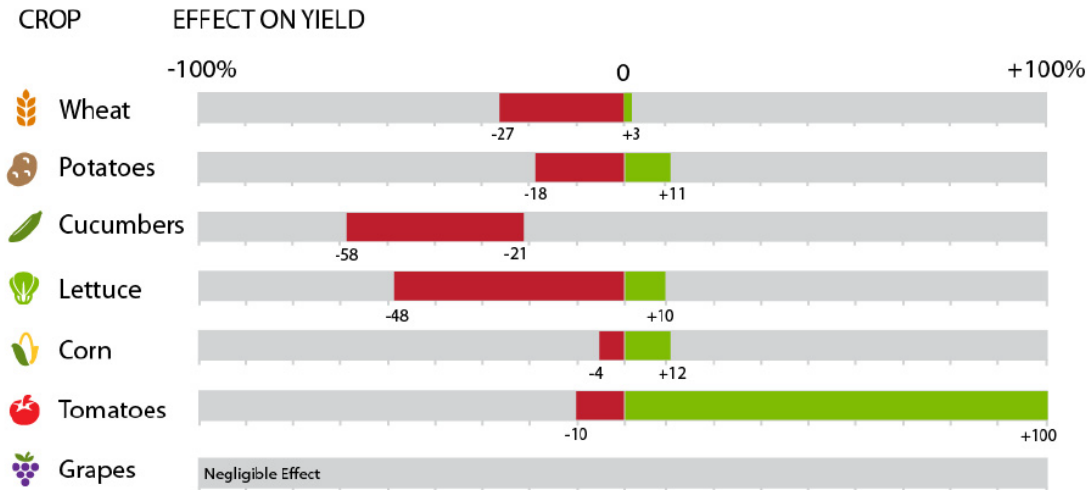


Figure 4. Summary of crop performance under solar PV installations.

The fourth factor, *Compatibility and Flexibility (C4)*, reflects the overall compatibility of an agrivoltaic system, which means that the solar technology design and configuration must be compatible with agricultural and research methods (C3) as well as with the competing needs of the solar owners, solar operators, agricultural practitioners, and researchers. Specific factors that could affect the success of an agrivoltaic system include farm practice compatibility, infrastructure placement, prescribed grazing plans, data collection compatibility, and crop rotation planning.

The fifth success factor, *Collaboration and Partnerships (C5)*, highlights the importance of understanding and agreements made across stakeholders and sectors to support agrivoltaic installations and research. The study discusses several detailed C5 topics, including understanding multiple priorities and establishing common goals, community engagement, long-term ownership and personnel consistency, information sharing, clear roles and responsibilities, planning, permitting, and zoning.

Future research activities have also been suggested in this study, offering valuable insights and recommendations for developing a specific research agenda for the Kegonssa site.

In addition to the 5Cs, researchers have considered other factors when considering the success of an agrivoltaic site.

It is important to understand the shadow effects of panels on the active agricultural land when planning plantings. As shown below in Figure 5, ground mounted solar panels produce three zones of light availability for plants in and around panels. Plants in Zone 3 have most access to sunlight and plants in Zone 1 have the least.

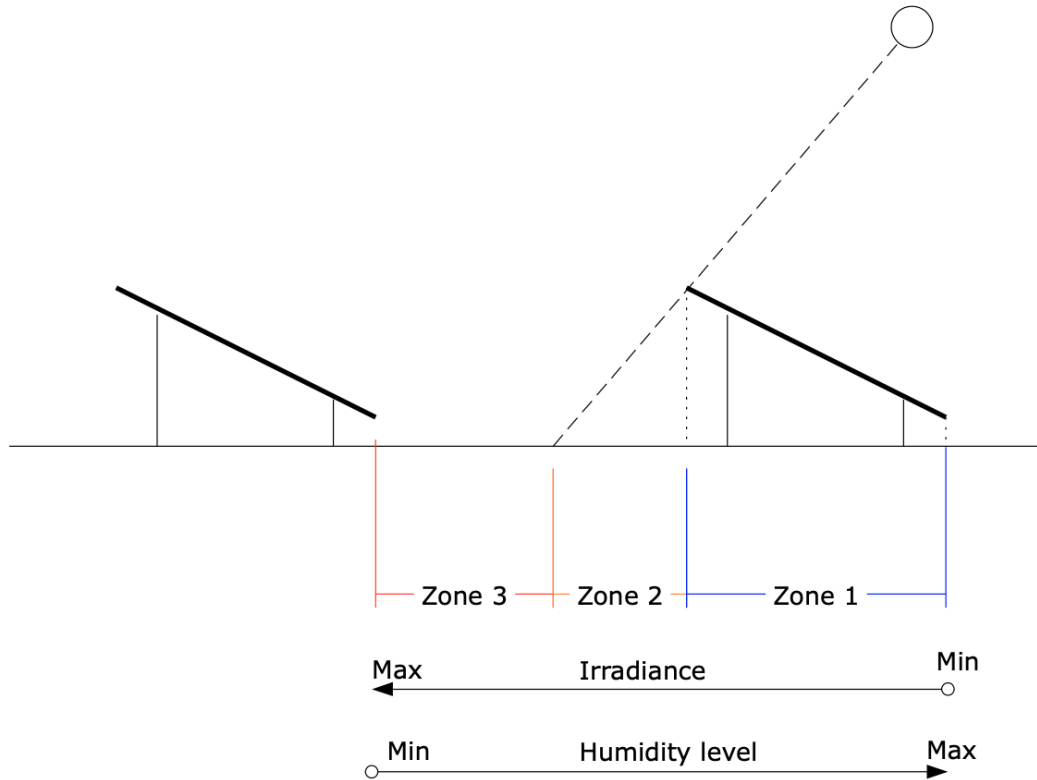


Figure 5. Light availability zones produced by ground-mounted solar panel configurations.

In consideration of increasing solar irradiance for agricultural production, researchers from Italy present a Trans-Disciplinary Cognitive Framework for the Design and Assessment of Agrivoltaic, which recommends assessing land use with a three-dimensional model [18]. The authors assess that module height is the most influential design parameter, and thus requires 3-dimensional analysis during the configuration planning phase. Figure 6 below, from the article, depicts how shading on the active agricultural plot is lessened with an increase in module height.

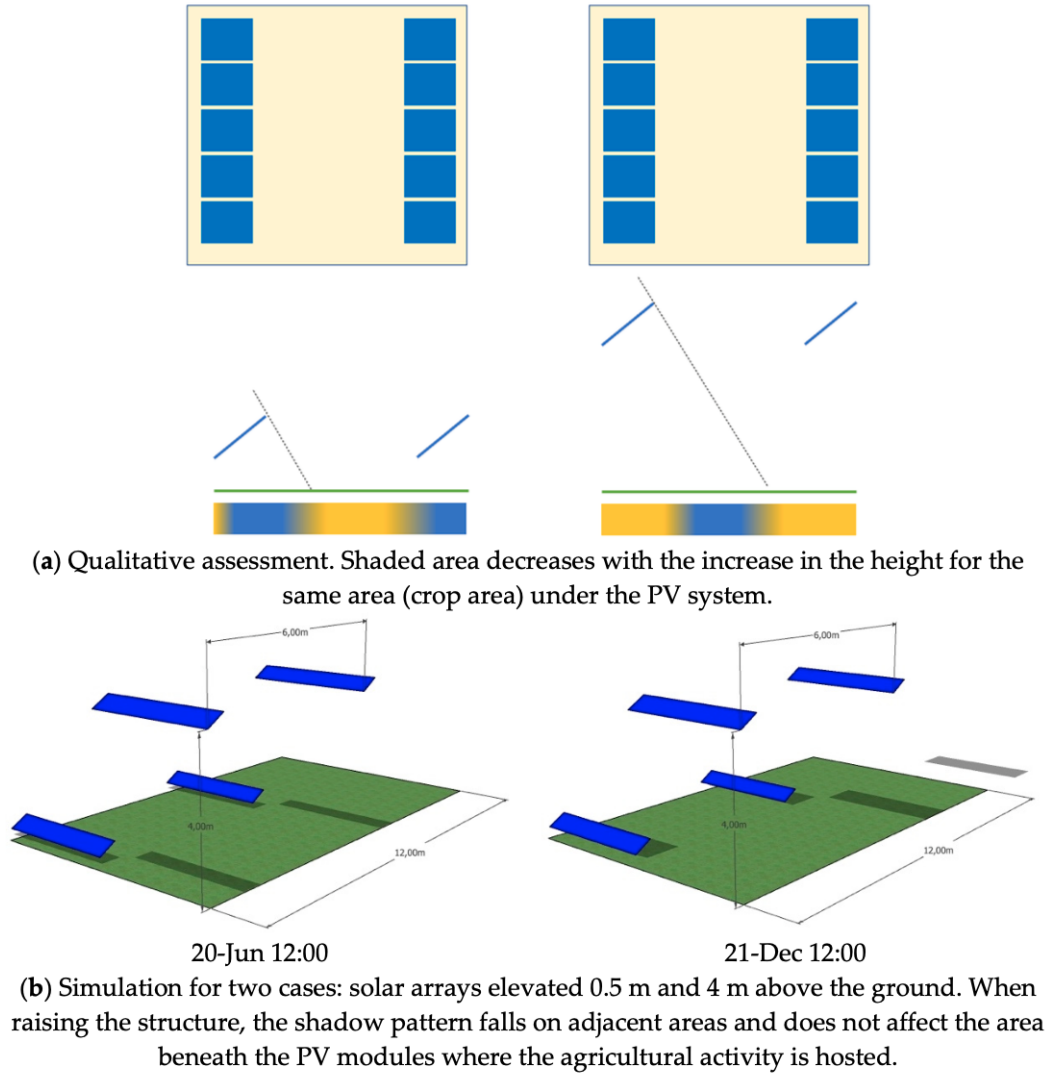


Figure 6. Shading changes as solar PV module height increases.

Assessment

The EU researchers who defined the classification system shown in Figure 1 also present seven performance indicators agrivoltaic research sites should track to facilitate comparison between sites: Ground Cover Ratio, Energy and Agricultural Yield, Agricultural Quality, Spatial efficiency, Water savings, Human comfort, and Economic indicators [7].

Ground cover ratio (GCR) is defined as the ratio of PV surface area to active agricultural surface area. A high GCR indicates high energy yield and low solar radiation penetration to the ground.

Yields of both energy per land unit and agricultural production should be tracked to assess profit potential.

Quality is difficult to assess, so using market prices is recommended at this stage.

Spatial efficiency is determined by Land Equivalent Ratio (LER) defined by the following formula:

$$LER = \frac{E(Y_{agri,AV})}{E(Y_{agri,N})} + \frac{Y_{el,AV}}{Y_{el,N}}$$

Where $E(Y_{agri,AV})$ is the economic value of agricultural production under agrivoltaic conditions, $E(Y_{agri,N})$ is the economic value of agricultural production under normal conditions, $Y_{el,AV}$ is electric production under agrivoltaic conditions, and $Y_{el,N}$ is electric production under normal conditions. When LER is greater than one, this indicates productivity of the combined agricultural and electricity production is greater than separate electric and agricultural production.

Water savings can be assessed using Water Use Efficiency (WUE) as defined as the unit of biomass produced per unit of water used. Use the following equation to compare WUE of agrivoltaic systems to control systems¹.

$$WUE = \frac{WUE_{PV} - WUE_{control}}{WUE_{control}}$$

Shade from panels can reduce heat stress for people working in the field. How much comfort is provided can be determined using Wet Bulb Globe Temperature.

To determine economic feasibility, agrivoltaic planners should have a price performance ratio defined by the below formula.

$$ppr = \frac{p}{pb}$$

where p is the annual extra cost for the agrivoltaic system compared to a conventional ground mounted array and pb represents the benefits from agricultural production, product quality, and ecosystem services provided by an agrivoltaic array. If the “ppr” is less than 1 it indicates the agrivoltaic installation provides more benefits than the extra cost compared to conventional PV. Levelized cost of electricity is another measure to consider when evaluating economic performance of agrivoltaic sites.

Challenges to Adoption

There are a few main challenges for adoption of agrivoltaics. A major question that has yet to be answered is if small research plots can be scaled to larger production-sized farms. The DOE Market Research Study found that most of the agrivoltaics installations in the U.S. are 2-15 acres, while data from the USDA National Agricultural Statistics Service (NASS) shows that the average size of farms in Wisconsin is 222 acres per operation [20]. Other challenges are outlined below.

¹ Toledo, C.; Scognamiglio, A. Agrivoltaic Systems Design and Assessment: A Critical Review, and a Descriptive Model towards a Sustainable Landscape Vision (Three-Dimensional Agrivoltaic Patterns). *Sustainability* **2021**, *13*, 6871. <https://doi.org/10.3390/su13126871>

Costs of Systems

One of the major reasons for the lack of large-scale applications of agrivoltaics is the cost of systems. Researchers in Germany identified several characteristics of agrivoltaics developments that may require increased costs, such as during the approval process, handling design constraints, and the use of special modules, racking systems, trackers, or other technology [21]. In 2020, NREL released an analysis of four dual-use solar installations comparing the capital costs of installing the systems in DC Watts. The study found an estimated installed cost premium of \$0.07/W_{DC} to \$0.80/W_{DC} for dual-use solar over traditional ground-mounted solar projects [22]. The study includes breakdowns of various agrivoltaics systems costs, including versions of solar + pollinator habitat, solar + grazing, and solar + crops. The costs are compared to a benchmark 500 kWdc, traditional ground-mounted system. The assumptions for each system can be found in Figure 7 below, and Figure 8 shows the detailed specifications for the mounting structure used in each system. Figure 9 shows a graphic depicting the ground coverage ratio, or the percent of the planting area that is shaded by the solar modules.

Table 1. Benchmark Model Assumptions for Each Scenario

	Conventional PV	PV + Pollinator Habitat (no grazing)	PV + Grazing	PV + Crops (Reinforced)	PV + Crops (Vertical)	PV + Crops (Stilt)
Groundcover type	Bare ground	Pollinator-friendly vegetation	Grass, other pollinator-friendly vegetation	Crops	Crops	Crops
Structure type	Conventional	Conventional	Conventional	Reinforced Regular Mount	Vertical	Tracker Stilt-Mount
Fixed tilt or tracker	Both	Both	Both	Fixed	Fixed	Tracker
Inter-panel spacing (ft)	0	0	0	2	0	2
Ground clearance (ft)	4.6	4.6	4.6	8.2	6.4	8.2
Inter-row spacing ^a (ft)	16.6	16.6	16.6	31.2	28.3	32.4
Ground Coverage Ratio (%) ^b	33% tracker, 44% fixed-tilt	33% tracker, 44% fixed-tilt	33% tracker, 44% fixed-tilt	28%	<1%	20%
Module Efficiency %	19%	19%	19%	19%	21%	21%
Power density (acre/MW)	5.9 tracker, 4.5 fixed-tilt	5.9 tracker, 4.5 fixed-tilt	5.9 tracker, 4.5 fixed-tilt	9.8	7.0	13.8

^a The inter-row spacing is calculated assuming a 44-degree tilt for all designs except for the vertical mount (which assumes a 90-degree tilt).

^b The GCR for vertical mount is negligible, as the solar panels are mounted at right angle to the ground.

Figure 7. Benchmark Model Assumptions for Each Scenario.

Mounting Structure	Regular	Regular	Vertical Mount	Reinforced Regular Mount	Tracker Stilt Mount
Fixed-Tilt/Tracker	Fixed	1-Axis-Tracker	Fixed	Fixed	2-Axis-Tracker
Acre/MW	4.5	5.9	7.0	9.8	13.8
Horizontal Tubing	4"x4"x0.137" Round	4"x4"x0.137" Round	2.4" x 1.8" Steel Channel tube	4" x 4" x 1/4" Round	4"x4"x0.137" Round
Horizontal Tubing lb/ft	7.2	7.2	3.6	12.2	7.2
Tubing \$/ft	\$3.7	\$3.7	\$2.1	\$6.3	\$3.7
Horizontal Tubing Ft	3961	3961	3740	3444	1840
Vertical Post	W6 x 15 Wide Flange	W6 x 15 Wide Flange	6.2" X 2.4" X 0.98" C Channel	8" Sch 40 Structural Pipe	W6 x 15 Wide Flange
Vertical Post lb/ft	15	15	7.5	28.5	15
Pipe \$/ft	\$6.3	\$6.3	\$7.5	\$23.9	\$6.3
Vertical Posts #	157	157	726	230	77

Figure 8. Details of Structural Assumptions for Each Mounting Structure.

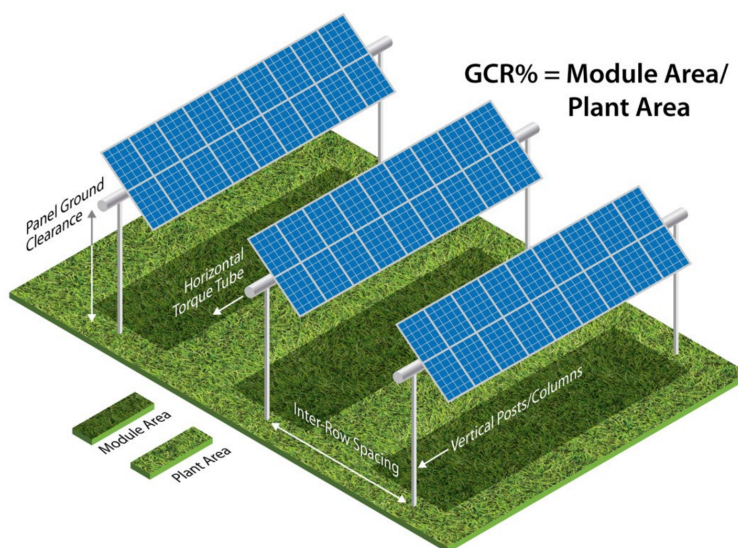


Figure 9. Graphic of ground coverage ratio.

NREL used their bottom-up modeling to account for costs in all steps in the installation process (labor, materials, equipment), as well as overhead costs and profits that are summed with the system design costs outlined above. The data on costs was collected from interviews with workers at solar developer and installer companies (seven from the U.S. and three from Europe) and standard construction cost guides. The PV installed system costs are averages from sites in states with one or more types of dual-use solar installations (Oregon, Arizona, Michigan, Massachusetts, New York, Connecticut, California, and Illinois). A breakdown of installed costs for each dual-use solar system with benchmark assumptions is shown in Figure 10 below.

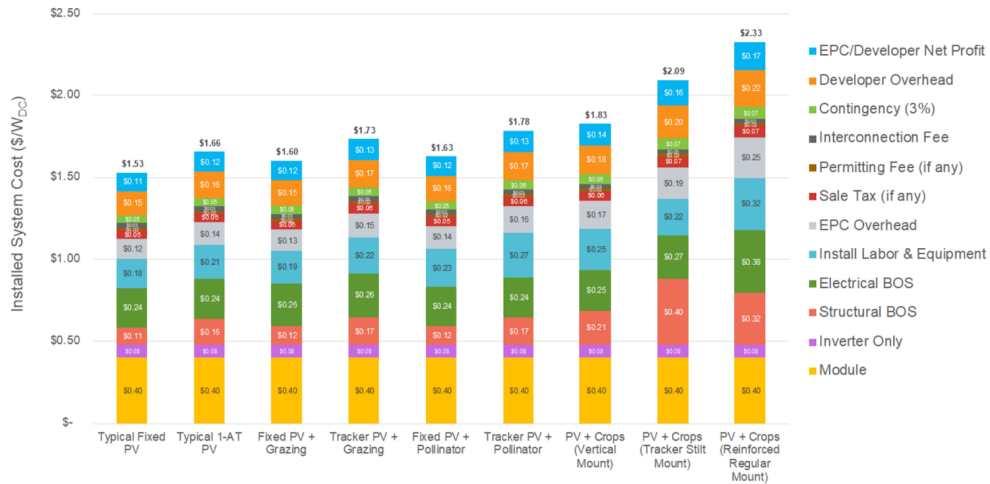


Figure 10. PV installed system costs for dual-use scenarios, adapted from NREL.

Each dual-use system showed higher installed capital costs than the traditional solar project installed on bare ground. Solar + grazing systems had the lowest price premium due to reduced site preparation and seeding needs, however the costs are based only on sites with sheep and therefore may increase if other livestock are considered (grazing with cattle would require higher panels and reinforcement of the racking structure). Systems with reinforced mounting structures had the highest installed costs due to the use of heavy-duty materials, necessary for maintaining the structural integrity of elevated panels in weather conditions like wind or snow. The study further examined the balance-of-system costs, breaking down the costs for labor and equipment for each type of dual-use solar system as shown in Figure 11.

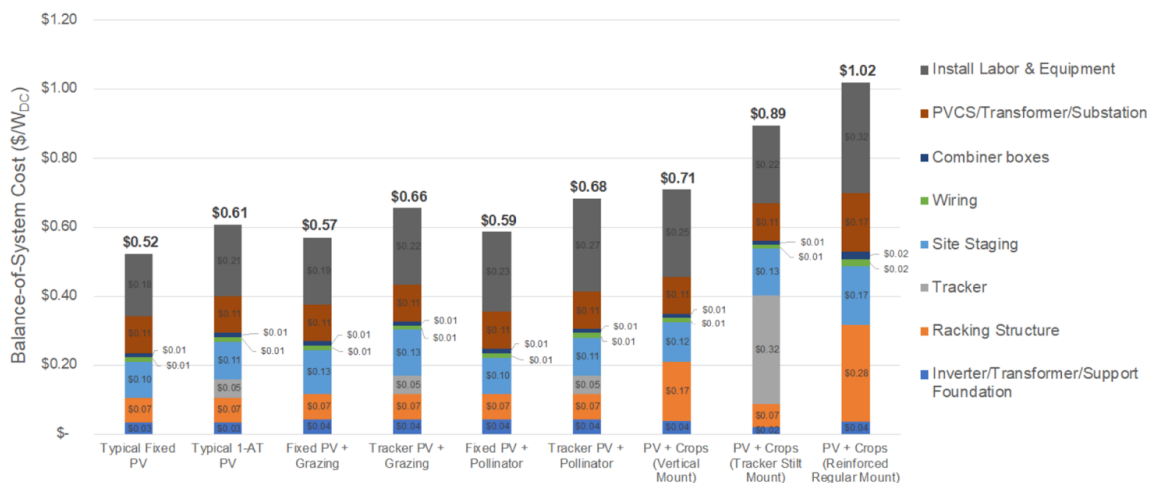


Figure 11. BOS cost breakdown for dual-use scenario, adapted from NREL.

The results show relatively equal costs for site staging, inverters/transformers, and wiring across all system types. The racking structure is a considerable portion of the high balance-of-system costs for reinforced mount installations, which are used with elevated panels above crops and for

cattle grazing applications. The “install labor and equipment” category includes site preparation, which is a large contributor to the difference in overall costs between systems. There are some additional site preparation costs associated with crops and grazing activities, such as fencing to protect crops/animals from predators and water wells for grazing animals or irrigation. However, these dual-use systems may also reduce some site preparation costs related to clearing vegetation and compacting soil. While solar + grazing and solar + pollinator installations require some grading in order to establish grasses or native plants and minimize soil erosion, solar + crop systems may see lower grading costs (assuming that the land was previously used as farmland). There is currently a lack of data and compilation of best practices to manage soil erosion and compaction during the construction and installation phases of solar developments. NREL also included site investigation and planning costs in the “install labor and equipment” category. All types of dual-use solar installations showed increased costs associated with planning, analysis, and coordination of site activities, such as selection of agricultural activities/crops, collaboration with developers, regulators, farmers, and the local community, selection of research studies, and applications for funding and incentive programs.

Social Acceptance

There has been some public resistance to solar energy projects in Wisconsin as the pace of utility-scale solar development has increased in recent years (see Case Study on Koshkonong Solar). Oftentimes the concerns are based on questions about the quantity of land that will be used for solar energy production in the future (see Solar Land Use in Wisconsin).

Agrivoltaics is an attractive solution to land use constraints or concerns. A 2021 survey by the Michigan Technological University found that “81.8% of respondents would be more likely to support solar development in their community if it combined the production of both energy and agriculture,” and the study concludes agrivoltaics “can increase local support for solar projects in areas where project developments could be perceived as a threat to agricultural practices.” [23]. The same group of researchers conducted a study of interviews with solar developers, engineers, policy experts, agrivoltaics experts, and land operators involved in grazing or pollinator solar installations. A key takeaway was the importance of local community involvement in a solar development’s success [24]. Retaining the agricultural interests of the community will not only ease the early stages of planning and permitting, but also provide benefits during the lifetime of the project as community members feel more comfortable with having the development nearby.

Finding willing farmers is another major aspect of the social acceptance of agrivoltaics. The DOE Market Research Study concludes that, in the case of solar + grazing, finding local shepherds to participate in solar grazing is more of a challenge than the technical aspects of the agrivoltaics installation. While the solar energy community has been progressive in seeking applications of grazing in developments, the grazing community may require additional education and support for the industry to expand.

Legislation, Policy, and Incentives

Related to the challenge of social acceptance, there is a lack of policy support for agrivoltaics installations that have delayed the speed of adoption. The DOE found the lack of regulatory guidance to support projects and incentives for landowners to participate as major challenges to

agrivoltaics development in the U.S. Few states have policies that specify standards for the dual-land use of renewable energy and agriculture, and there are no additional incentives for selling electricity from an agrivoltaics project compared to traditional solar developments. [25].

Some local municipalities in Wisconsin have moved to slow the pace of traditional solar developments, such as the Columbia County Board of Supervisors. The Board passed a resolution asking the Public Service Commission of Wisconsin to deny the final permitting for the High Noon Solar Energy Center, a 300 MW site being developed by Invenenergy located in the county (Appendix B). Most of the concerns outlined in the document were based around economic and environmental factors that were unwarranted, and although this resolution has no effect on the PSC's decision it shows the attitude of some local entities toward solar development. The Columbia County Corporation Counsel released a memorandum against the Board of Supervisors' resolution, providing economic and environmental evidence in support of solar energy and stating that no Wisconsin law provides a county "the authority to adopt a moratorium on solar energy facilities or their related permits" [26].

Technical Barriers

Since agrivoltaics has not been widely deployed in the Upper Midwest (or the U.S.), there is relatively little research on the impact of growing crops, planting native plants for a pollinator habitat, or growing grasses for sheep grazing on outcomes related to those activities (crop performance, soil conditions, water usage, working conditions, pollinator activity, animal biology, etc.).

All agrivoltaic systems should be designed to ensure that the solar panels cause the least interference with agricultural activities. Most of the agrivoltaic installations in the U.S. to date have focused on food production, so the solar PV systems installed have typically been suboptimal in terms of energy production. This is in part due to the concentration of agrivoltaic applications in hot and arid climates of the U.S., where the panels are tilted to shade the crops rather than maximize energy production. The mounting structures are typically taller than standard systems and modules may be spaced further apart to accommodate crops, allow equipment to pass through/under the arrays, and minimize the possibility of damage or injury [27]. One study that conducted a field trial on agrivoltaics maintenance found that operating mowing equipment within the solar arrays required some experience and the driver's increased attention to avoid any harm to the facility or worker [28]. The DOE Market Research Study identified a lack of research on the effects of solar panel longevity in connection to agricultural activities, such as dust spread by vehicles, fertilizers or herbicides used on the site, or damages from operations or maintenance.

Some of the technical challenges of agrivoltaics installations bring the opportunity for creative solutions. A research group in India installed a rain harvesting system at its 105 kW agrivoltaics site [29]. Researchers built troughs that were attached to the panels that allowed rainwater to collect in an underground reservoir, which can later be used for supplemental irrigation or cleaning the solar panels of dust. Of the 384 mm of annual rainfall at the site, about 72% could be collected by the system to total 180,000 liters of rainwater. This presents one example of a sustainable and creative solution to a technical challenge for agrivoltaics development.

A summary of a few major challenges to agrivoltaic development and their solutions are discussed in Table 3 below [18].

Table 3. Barriers and solutions to implementation of agrivoltaics in open-field systems.

Topic	Design Related Solution	Technology Related Solution
Minimizing shadows on crops (biomass yield)	Optimal design: Distance between the arrays of modules (the stripes)Distance of the modules from the ground	Sun-tracking systems Semi-transparent PV modules (by spacing PV cells) Light-selective PV devices
Maximizing electric energy generation	Optimal planning: Avoiding shading losses from surrounding elements (structures, buildings, trees, inter-row shading of the PV modules should be minimized) Optimal design: Azimuth facing equator and tilt close to latitude	Highly efficient systems (e.g., sun-tracking systems) Highly efficiency modules or technologies (e.g., bifacial module technology)
Social acceptance (landscape dimension)	Optimal landscape design: Pattern of PV arrays aligned to the parcel Natural fences and low height structures to minimize visual disturbance Use of marginal areas Removable systems Optimal design: Different tilt, azimuth and height to reproduces the orography of the land New business models: Higher economic efficiency per land unit (farmer perspective) Benefits for local economy and employment (tourism, local recreation, etc.)	New materials for structure

Market Characterization

Current State of Solar in Wisconsin

Solar energy has been the fastest growing renewable source in the state of Wisconsin, thanks to steady technological advancements that have lowered the cost to build, install, and maintain these systems. According to RENEW, Wisconsin has energized about 764 MW of solar PV since 2019 [30]. The following figure shows the rate of solar capacity development over the last 4 years.

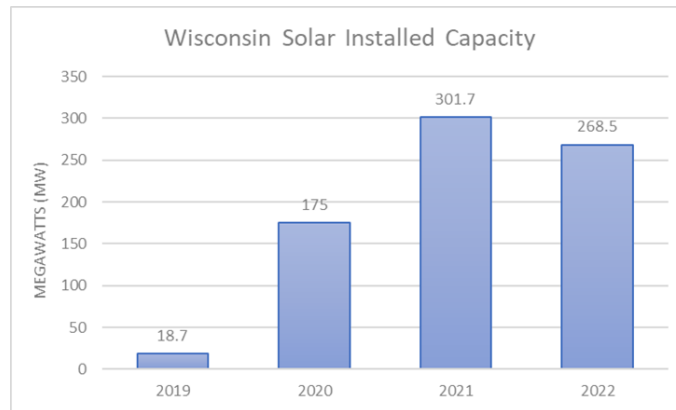


Figure 12. Wisconsin Solar Installed Capacity.

The figure above illustrates the fast rate of solar development in Wisconsin, though installed capacity was lower in 2022 than the previous year. Many projects were delayed in 2022 by disruptions affecting availability of solar panels and other important equipment, and are likely to come online sometime in 2023.

The MISO Generator Interconnection Queue (GIQ) lists 1164 MW of additional capacity scheduled to start service in WI in 2023 [31]. About 1000 MW of this capacity's requests are labeled as Done meaning these projects have cleared the application process to join the MISO grid and whose status is labeled as Under Construction or Not Started. The average 2023 Done project size is 111 MW and the average 2023 Active project size is 55 MW.

For comparison, the MISO GIQ lists about 1000 MW of planned solar generated capacity as Done scheduled to start service in 2022, of which only one project of 50 MW is listed as In Service. The average size for these projects is 142 MW.

The above information indicates the MISO GIQ is helpful to understand the appetite for building increased solar capacity, but less indicative of actual projects coming to fruition.

Figure 13 shows a map of major solar energy production project locations in Wisconsin as of March 2023 reported by Solar Energy Industries Association members [32].

Compare this with Figure 14, the map of Agrivoltaic Activities in Wisconsin from NREL's InSPIRE tool [33]. According to InSPIRE, Wisconsin has a total of 35 reported agrivoltaic sites, 1 grazing and 34 pollinator habitat. The sheep grazing site listed has a 3 MWdc capacity and sits on 19 acres. The average capacity of the pollinator habitat sites is 2.3 MWdc with an average footprint of 12.5 acres. Total agrivoltaic capacity in Wisconsin is 81.84 MWdc.

Compare these with Figure 15, the solar grazing map of Wisconsin from the American Solar Grazing Association [34]. There are five sites listed on this map, which indicates the InSPIRE tool may need updated data.

While no single resource provides a clear picture of the current state of solar production in Wisconsin, they all point to rapidly increasing development of both photovoltaic and agrivoltaic production.

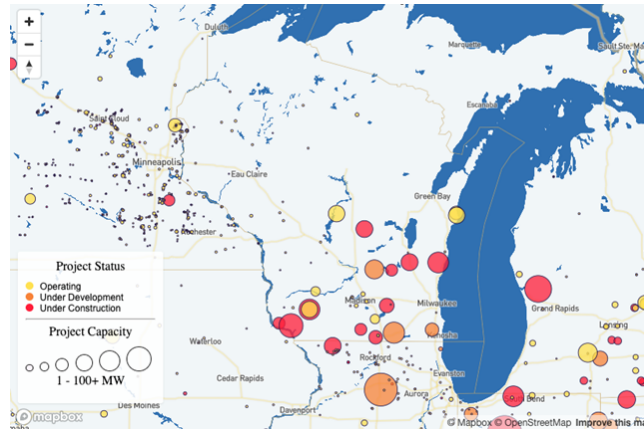


Figure 13. Map of major solar energy production project locations in Wisconsin.

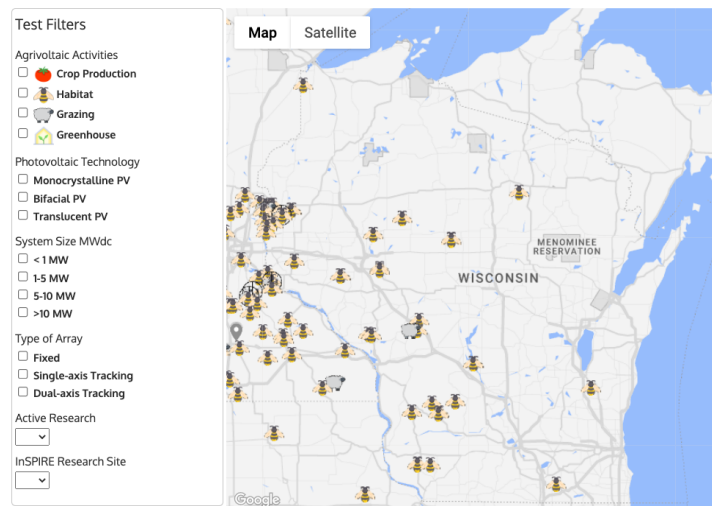


Figure 14. Map of Agrivoltaic Activities in Wisconsin from NREL's InSPIRE tool.

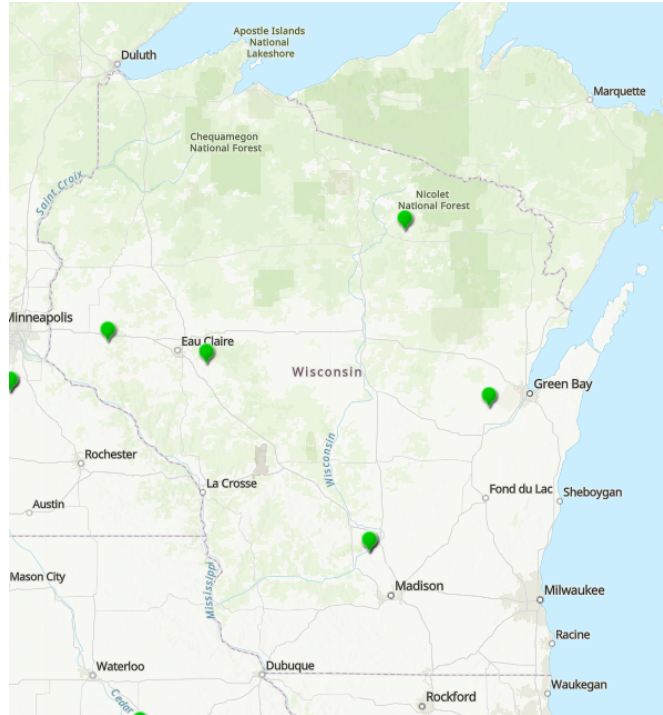


Figure 15. Solar grazing map of Wisconsin from the American Solar Grazing Association.

Solar Land Use in Wisconsin

Due to optimal siting characteristics, solar farms have predominantly been sited on agricultural land. According to the USDA NASS, Wisconsin has about 14.2 million acres of actively cultivated farmland [35]. Questions have surfaced regarding the quantity of farmland that could potentially be converted to solar fields, a topic that is analyzed fully in the Solar and Agricultural Land Use in Wisconsin report (Appendix B).

As one of the leading renewable resource technologies for the clean energy transition, solar panel design and installation layout will likely see improvements in the years to come, meaning solar fields will generate more electricity with fewer total inputs – including land. Put another way, as solar fields become more productive per square foot, they will occupy less land to generate the same amount of electricity [36]. With that in mind, we believe that a conversion factor of 7 acres per MW is a reasonable, if not conservative, assumption to use for current calculations and 2050 projections for solar energy land use.

Assuming that the land footprint for 1 MW of solar is 7 acres, the 764 MW of solar in Wisconsin uses about 5,348 acres of land. Using that conversion factor, solar generation occupies only 0.015% of Wisconsin’s total land area (34.7 million acres), or 0.038% of Wisconsin’s agricultural land (14.2 million acres).

RENEW Wisconsin’s collaborative report, titled “Achieving 100% Clean Energy in Wisconsin” (RENEW Zero Carbon Report), provides model results for various scenarios of an economy-wide transition to zero carbon by 2050 in Wisconsin [37]. The Net Zero Economy-wide (NZEW) scenario is the most cost-effective renewable energy deployment and transmission capacity development scenario modeled. In the NZEW scenario, widespread

decarbonization is achieved in our state’s electricity generation, transportation, building, and industrial sectors. In this scenario, Wisconsin’s annual demand for electricity in 2050 will increase by over 160% from today due to economy-wide electrification.

Based on the RENEW Zero Carbon Report modeling analysis, solar will continue to be the predominant source of new generation to meet the state’s electricity demand: about 31 GW of solar generation will be needed by 2050 in the NZEW scenario. Based on economic potential assumptions from a separate Cadmus study “2021 Rooftop Solar Potential Report” for Focus on Energy, 2.5 GW would come from rooftop solar PV in Wisconsin, resulting in about 28.3 GW of utility-scale solar in the state [38].

Assuming the land footprint for 1 MW of utility-scale solar is 7 acres, the 28.3 GW of solar required by 2050 would use about 198,000 acres of land. Using that conversion factor, utility-scale solar generation would only occupy about 0.57% of Wisconsin’s total land area, 1.4% of total agricultural land, and 2.4% of field crop land in Wisconsin by 2050 if this high solar penetration scenario comes to fruition.

Table 4. Summary of land use, land area and share of land needed.

Land use	Land Area (million acres)	Share of land needed for solar by 2050 (%)
Total WI land area	34.7	0.57%
Actively cultivated farmland	14.2	1.39%
Field crop land	8.4	2.35%
Total corn grain land	3.0	6.60%
Total ethanol land	1.1	17.84%

Case Studies

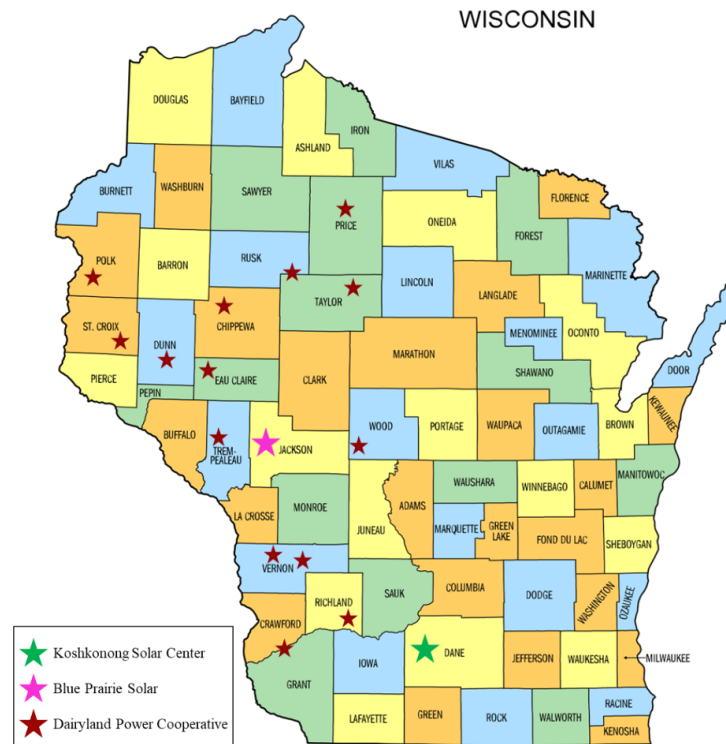


Figure 16. Map of Wisconsin with locations of case studies identified.

Koshkonong Solar Energy Center

The Koshkonong Solar Energy Center is a 300-megawatt alternating current (MWac) utility-scale solar powered-electric generation facility located in Christiana and Deerfield Townships in Dane County, WI. The project will be built within a 6,384-acre project area, among which 2,349 acres are proposed as primary array areas. The project will utilize PV panels installed on a single-axis tracking system and also include a 165 MWac battery energy storage system (BESS) [39]. The total project represents an investment of about \$649 million, and is currently being constructed to become operational in 2025. Koshkonong Solar is a wholly-owned subsidiary of Invenergy Solar Development North America LLC and an affiliate of Invenergy LLC [40].

The Koshkonong Solar project is not an actual “agrivoltaics” site by definition, it replaces current agricultural lands and other land cover types, mainly corn, soybean, prairie and grasslands with solar panels. The reasons we chose this case study are that the Koshkonong Solar Energy Center is a representative utility-scale solar project in Wisconsin; public opinions and comments could be derived from the WI PSC to better understand concerns regarding land-use conflicts, trade offs, and feasibility. The PSC docket 9811-CE-100 contains information surrounding the environmental review, public testimonies, and details of the development that were analyzed for this case study [41].

The Koshkonong Solar project conducted assessments and analysis of many aspects in their application file to the WI PSC, including the impacts of this project on soils (bedrock, topography etc.), crops and vegetation, land cover changes (agricultural lands, grasslands, wetlands), wildlife (white-tail deer, racoon, birds, endangered species, etc.), pre-construction noise tests, and pollution emission reductions. Their proposed environmental benefits include 60% reduction in stormwater runoff, 48% reduction in nitrogen flow, 53% reduction of phosphorus outflow, reappearance of deeply-rooted prairie grass, and establishment of a new habitat for insects, birds and other wildlife.

However, because all current agricultural activities will be eliminated once solar panels are installed in the area, there is strong public opposition and controversy towards this project. Comments and concerns include: 1) the project failed to be forthcoming with information necessary for public input; 2) project interferes with local land use plans and values; 3) private land owner rights and their interests; 4) safety, enrollment and funding concerns on local elementary school; 5) residents' health and safety concerns about the close proximity of convergence high-voltage lines and facilities; 6) loss of productive farmlands; 7) the disturbance of wildlife habitat and recreational paths; 8) the loss of property value for non-participating landowners; and 9) the impacts of disrupting drainage patterns in the Project area. The Town of Christiana has filed a lawsuit on May 26, 2022 in Dane County Circuit Court challenging the WI PSC's approval of the project, arguing that the state's largest renewable energy project violates the Wisconsin Constitution and the commission's own rules.

This case helps us to develop our research agenda recommendations from a social-acceptance perspective, and to present how the Kegonsa agrivoltaic site could avoid or address these concerns.

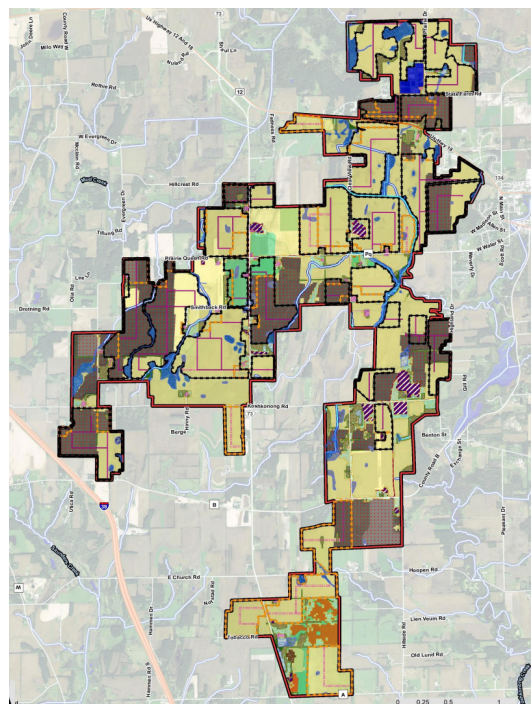


Figure 17. Project map of the Koshkonong Solar Energy Center.

Blue Prairie Solar

Blue Prairie Solar is a 3.1 MW solar farm developed by OneEnergy Renewables near Black River Falls, WI (Jackson County). Coming online in July 2021, the electricity generated by the solar farm is purchased by Jackson Electric Cooperative, a nonprofit cooperative utility in a Power Purchase Agreement lasting 25 years. The project's footprint is about 20 acres, uses single-axis tracking panels, and has an estimated annual output of 5,200 MWh [42].

The project was designed to integrate with the agricultural setting in which the site is located. Jackson County is in the northeastern portion of the Driftless Region, a topographical area that covers southwestern Wisconsin, northeastern Iowa, and southeastern Minnesota. Due to the natural hills and valleys of the region, grazing livestock is a common agricultural activity. At Blue Prairie Solar, sheep grazing is incorporated with the solar arrays. By planting a pasture mix underneath and around the arrays, sheep can move freely amongst the site to graze on the pasture grasses and enjoy the shade from the solar panels.



Figure 18. Pictures of the Blue Prairie Solar.

Blue Prairie Solar is a part of OneEnergy's Mastodon portfolio, which consists of 8 solar projects in western Wisconsin and southeast Minnesota. The electricity generated by these developments, which involves nine landowner hosts, is purchased by three nonprofit cooperative utility companies. OneEnergy estimates that the entire portfolio brings a \$30 million investment to the rural communities. Moreover, all of the projects (like Blue Prairie Solar) were designed to coexist in the agricultural landscape in which they are located, planted with either a deep-rooted perennial pollinator prairie or a pasture mix underneath the solar arrays [43].

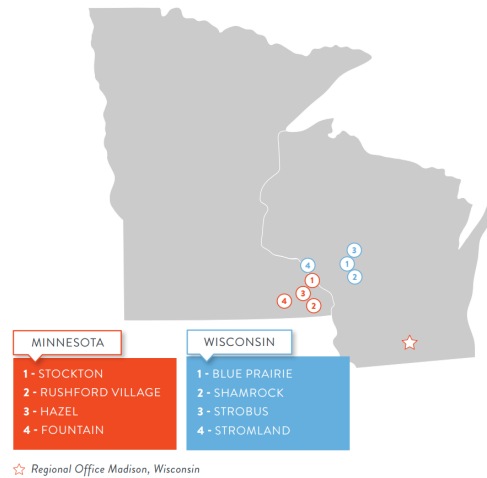


Figure 19. Locations of OneEnergy's Mastodon portfolio.

Dairyland Power Cooperative

Dairyland Power Cooperative has a system of community-hosted solar sites across the midwest, including WI, MN, IA, and IL. Currently, they support approximately 250 acres of pollinator habitat at 18 solar sites with a combined capacity of 25 MW. Fourteen of these sites are in Wisconsin and comprise 22 MW of the total capacity. Individual projects range in size from 0.5 – 3.7 MW. Their projects used Prairie Restoration, Inc. to design and install pollinator gardens of native grasses and flowering forbs at solar sites. Solar capacity comprises a very small part of their overall power capacity, which was 1,171 MW in 2021 [44].



Figure 20. One of Dairyland Power Cooperative's community-hosted solar sites colocated with pollinator gardens.

Jack's Solar Farm

Jack's Solar Garden is a 1.2 MW agrivoltaics farm in Boulder County, Colorado. The site was converted by the owner from his family hay and wheat farm into a 5-acre community solar garden in 2020 [45].

The site was foremost built to maximize electricity production, so the rows are spaced 17 feet apart. Jack's Solar Garden does feature two panel hub heights, 6 feet and 8 feet, in order to (1) study the effects of differences in shading, moisture, and other factors that may arise from higher solar panels, (2) allow for planting of taller crops, grasses, and other land covers to study how they grow under solar panels, and (3) provide a space for tours, educational visits, and outreach events amongst the arrays [46].

Jack's Solar Garden is a great model for a collaborative approach to an agrivoltaics site. It features production scale farming alongside research and outreach, with activities ranging from cultivating crops, studying pollinator and pasture grass environments, and hosting tours, visits, and classes. This involves the work from a variety of collaborators. Sprout City Farms is a nonprofit organization that runs the production farm section of the site, focusing on vegetable crop production that is distributed to the community. NREL is running a pollinator habitat test plot to develop better instrumentation for soil moisture and ecological microclimate sensing. Colorado State University is in charge of a few zones within the site, with the broad focus of studying ecosystem services, grassland ecology/physiology, and soil moisture/irrigation underneath the solar panels. The University of Arizona is also involved at this site, studying how crops behave and perform in the agrivoltaics setting. Finally, the Colorado Agrivoltaics Learning Center is another nonprofit group that organizes the tours, educational activities, and community outreach and events at Jack's Solar Garden.

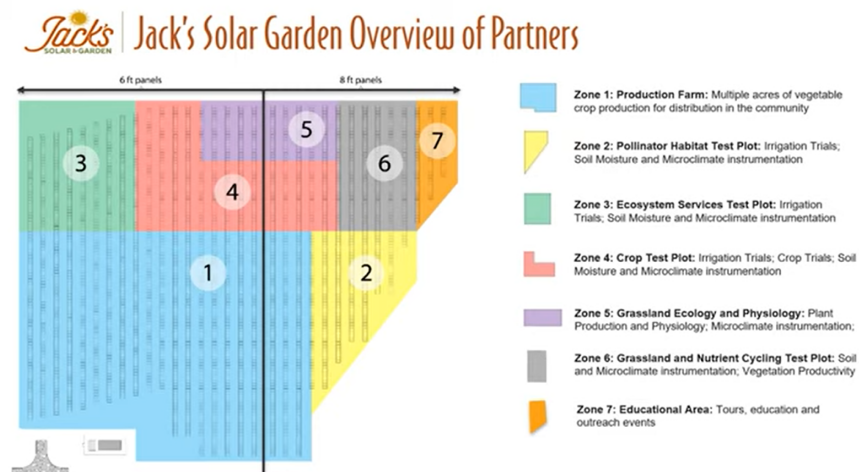


Figure 21. Jack's Solar Garden Zone Overview.

Recommendations for Agrivoltaics Research Agenda

These recommendations aim to guide the collaborative management at the Kegonsa Agrivoltaics research site by Alliant Energy and UW-Madison, and to help inform Alliant's. Recommendations 1 - 5 apply directly to the UW Kegonsa Research Campus, while recommendation 6 applies to future agrivoltaics development. Moreover, we believe that all of the recommendations can benefit future dual-use solar projects in Alliant Energy's Customer-Hosted Renewables Program.

1 – Promote Standardization for Agrivoltaic Research

To build a network of informed agrivoltaic advocates and enable pointed discussions, we recommend Alliant and UW-Madison researchers use the terms presented in the Standardized Classification and Performance Indicators shown in Figure 123 [7]. Clarity of language will aid clear communication amongst stakeholders and develop language structure for future specific policy interventions.

In addition to standardizing language, we recommend assessing the site using the seven performance indicators presented in the Standardized Classification and Performance Indicators. These are Ground Cover Ratio (GCR), Energy and Agricultural Yield, Agricultural Quality, Spatial Efficiency using Land Equivalent Ratio (LER), Water Savings using Water Use Efficiency (WUE), Human Comfort using Wet Bulb Globe Temperature, and Economic Indicators including price-performance ratio (PPR) and levelized cost of electricity (LCOE).

This will allow for comparison to other agrivoltaics sites across the world and, over time, establish standard performance of agrivoltaics at Kegonsa.

2 – Data Priorities and Research Recommendations

Below we provide an overview of research recommendations for the site including ideas for agricultural production research, what data to begin collecting immediately, and economic research tool recommendations.

2.1 - Choice of Agricultural Activities

While the scope of our project did not include research into ideal crops or plantings for agrivoltaics in Wisconsin, the complimentary Agroecology capstone project provides recommendations for ground covers and plantings at the site. We recommend further research into planting of Wisconsin-specific high value crops at the Kegonsa site. In Arizona, Chiltepin (Fig 22. below), a small pepper related to jalapeños and bell peppers, grew really well in the shade under solar panel installations. This crop is difficult for farmers to grow on a large scale due to the long time it takes for them to start producing (120+ days), but they are very lucrative and in demand. These characteristics make it a perfect plant to grow under panels on a community scale. Finding a Wisconsin specialty crop that performs exceptionally well under the

shade of solar panels will help promote the adoption of agrivoltaics in the state. Much of the research at the Kegonsa site will investigate this, though prior consulting with experts in agriculture, ecology, soil science, and other related fields will allow for better planning and selection of crops to research.



Figure 22. Chiltepin peppers growing on a bush.

In the future, we believe that incorporating the agricultural heritage of the local community will be critical for continuous public support of agrivoltaics projects. There have been questions raised about solar energy taking prime agricultural land out of production, leading to some public opposition to solar development. These concerns may be alleviated by the dual-land use opportunity that agrivoltaics presents in the first place, and incorporating agricultural activities that are common to the site area will help establish trust and support in the project. For example, sheep grazing is one form of agrivoltaics that has been adopted in Wisconsin already at the Blue Prairie Solar development. This activity is a good fit for the site location because of the existing sheep grazing industry that the area possesses. However, sheep grazing is not very common in central/southeastern Wisconsin, so the application of grazing livestock at the Kegonsa site should be considered further with discussion with those in the local agricultural community. For future projects that may be located in an area where grazing is more common, the American Solar Grazing Association is a comprehensive resource for best practices, case studies, and research about the grazing with livestock under solar panels [47]. A benefit of partnering with local farmers to graze under the solar arrays is that it increases the viability of their business by providing opportunities to contract for additional vegetation management at solar sites [48]. An example of a full legal contract for a “solar grazing” arrangement between a site operator and a farmer can be found on their website [49], and the first page is included in Appendix C.

2.2 – Soil Data

We recommend beginning soil data collection and research at the Kegonsa site as soon as possible. This is currently underway as several soil science researchers have visited the site with more visits planned for late spring 2023.

Soil health is critical for the plantings beneath the panels and environmental outcomes both near and far from the site. Soil health has implications for plant health and development, water availability to plants, water and nutrient runoff, and local water quality. With so many environmental impacts affected by soil health, tracking it should be a priority.

However, few PV or AV sites have made documenting soil health changes part of their research.

A study on soil property changes under ground-mounted PV panels published in 2022 asserts to be the “first time soil changes were assessed using an integrated methodological approach” [50]. Monitoring soil conditions throughout the construction and lifetime of solar energy production, especially at an agrivoltaic site, would make a meaningful contribution to the literature.

Research shows adding native plantings can help improve soil quality by creating channels for organisms that increase biodiversity, break up compacted soil plates, and cycle nutrients through the soil system [51]. This may aid in reestablishing healthy soil beneath solar panels where research in southern France showed soil quality was lower beneath large solar panel installations [52]. More research is necessary to determine ultimate impact from the combined plant and solar production.

We hypothesize the potential for reversal of soil degradation with implementing co-location of agriculture or native plantings beneath the panels, but much more research is needed. If co-location of agriculture beneath solar panels improves soil health, there may be increased opportunities to partner with environmental organizations for funding and support. These ecosystem services may also aid in cultivating community support for agrivoltaic installations.

The surrounding area farmed by the same producer as the site prior to Alliant’s takeover provides a quality control site to see what would have happened to the soil had agrivoltaics not been implemented.

Alliant has already shown a commitment to this field by hosting soil scientist visits. Wherever possible, we recommend Alliant support collection of data on soil compaction, biodiversity, moisture, and infiltration by UW soil scientists. This may look like writing letters in support of grants, allowing another PV site to serve as a control, or vocalizing the importance of this research goal. A variety of UW offices may have interest in supporting soil health research (e.g. Nelson Institute, CALS) so we recommend approaching many entities for funding opportunities. Prioritizing soil data collection at the Kegonsa site could propel UW-Madison as a leader in environmental impacts of solar panels, contribute to the nascent field of agrivoltaic research, and provide evidence of increased ecosystem services of agrivoltaics.

2.3 - Meteorological Data

We also recommend starting to collect meteorological data at the Kegonsa site, including land surface temperature, humidity, solar radiation, wind speed and directions, and precipitation, etc. This data will provide essential agrometeorological conditions for investigating and identifying which crops thrive best in the specific climate in Wisconsin.

Agrometeorology is an interdisciplinary science that draws on basic physical and biological sciences and deals with a complex system consisting of the atmosphere, soil, plant, and agricultural management [53]. By collecting and analyzing meteorological data, researchers can

enhance crop production, improve crop selection, and increase the efficiency of agricultural management practices.

The collected meteorological data at the Kegonssa site can serve as a comparison with the data collected at the Arizona agrivoltaics sites. Such a comparison could facilitate potential collaborations between researchers working at different sites, leading to a deeper understanding of how agrivoltaic systems can perform in various climates and environmental conditions. This collaboration could also advance research in the field, leading to more optimized and efficient agrivoltaic systems that are sustainable and beneficial for both the agricultural and solar energy sectors.

2.4 - Economic Research Model - FEADPLUS

We recommend Alliant provide the necessary economic and production data to researchers in order to develop an economic research tool similar to the German developed Framework to Assess the Economic Benefits and the Adoption Potential of Dual Land-Use Systems (FEADPLUS) [54]. This tool aims to assess the economic benefit from agrivoltaic implementation and what tariff the producer would need to receive to achieve positive economic benefit from implementing an agrivoltaic system. The details of this framework are presented in Figure 23.

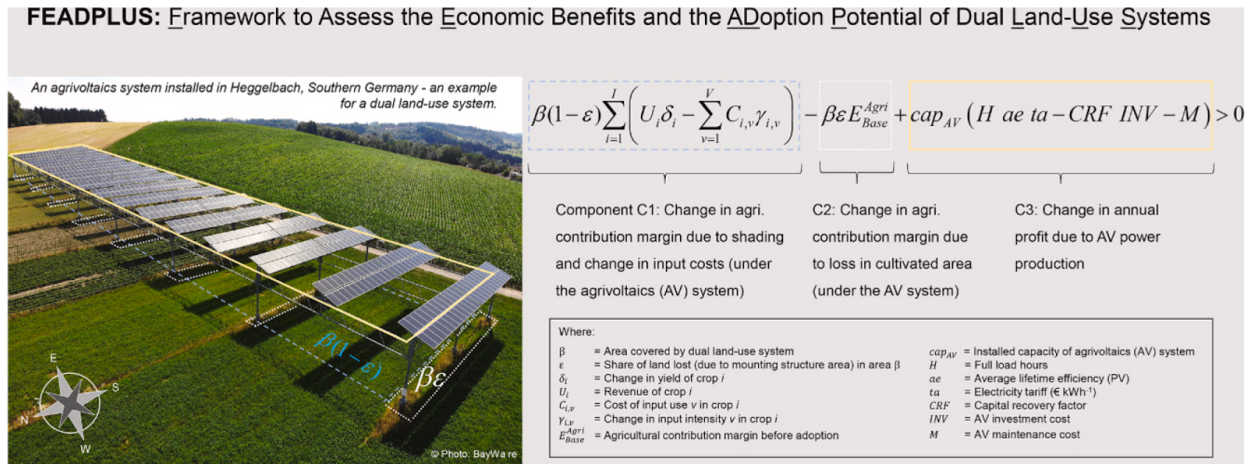


Figure 23. Framework of the FEADPLUS.

This framework was developed using data from an agrivoltaic site in Southern Germany. We recommend working with economists at UW-Madison to build on this German model using data from the Kegonssa site to build an economic tool applicable to Wisconsin farms. The output of this tool could help Alliant target future sites where farm qualities project positive benefits when implementing agrivoltaics.

3 – Data Transparency and Communication

We recommend trying to remain as transparent as possible with the Kegonsa site projects and additional agrivoltaics sites. Sharing solar generation data and annual (or more frequent) updates on the agriculture at the site will help build public awareness and trust in these types of partnerships for agrivoltaics projects [55]. To expand on the model that Alliant has already developed with its Madison office Energy Learning Lab, offering more comprehensive dashboards or monitoring systems of agrivoltaic installations can help educate and inform the public [56]. Madison Gas and Electric (MG&E) highlights solar in our community at locations around Madison, including links to several public sites where live and historic data for the production by the solar PV can be viewed [57]. Their Shared Solar Program is similar to Alliant Energy’s community-hosted solar and can be a model for showing consumers where their electricity is coming from in their community [58]. Local governments have been leaders in promoting renewable energy infrastructure to the public. The Dane County Clean Energy Map showcases clean energy and conservation projects, including solar installed in county facilities, local government buildings, and schools [59]. The city of Madison displays interactive maps showing where solar panels have been installed on city property, including access to detailed data about some of the solar array’s performance [60],[61]. This live data tracking is not only helpful and interesting to potential community members who might host a project but also facilitates further research into the site. Additionally, this type of data sharing could facilitate a community for agrivoltaics farmers where challenges and successes can be shared. The advancement of agrivoltaics depends on communications between the people farming that land, and this is a start to facilitating that. Having data publicly available means that people can look at what the goals for the site are and how closely aligned the actual production has been. It can open doors between Alliant Energy and people curious about these types of projects. In particular, for the Kegonsa site, a website can highlight the partnership between UW x Alliant Energy to show that both parties are leading this charge into agrivoltaics in Wisconsin that go beyond pollinator habitat colocated with solar PV.

4 – Community Involvement and Outreach

The Kegonsa site will serve as a demonstration to the public, showcasing the opportunities that agrivoltaics brings to agricultural and solar energy production in Wisconsin. Providing education and outreach opportunities will expand the impact of the Kegonsa site and help bring agrivoltaics (and solar energy) into the forefront for farmers. For future sites, proactive and continued communication with the local community can improve project success and provide additional benefits to project needs. The Town of Dunn prides itself on its agricultural heritage. The front page of the town’s official website states “Agriculture is by far the dominant land use, with 81% of the area being categorized as agriculture and undeveloped” [62].

Education and outreach will be vital to expand the impact that the Kegonsa site has on the community and agrivoltaics development. As indicated in the Dane County Legislative Information Center, Zoning & Land Regulation Committee filings, there has been some dissent within the local community (the Town of Dunn) about the project [63]. These include comments about dissatisfaction with the level of communication on development of the project, some misinformed concerns about environmental impacts to soil, wildlife, and wetlands, and questions over the impacts of taking prime agricultural land out of food crop production. Some of these

issues can be addressed, or at least appeased, by involving the community in the site through tours, educational events, and other outreach activities. The Kegonsa project team plans to share information about research and educational activities at the site with Town of Dunn staff and other interested stakeholders.

Communication with the local community can greatly improve the success of and support for agrivoltaics projects. While there is often the opportunity to comment during county or permitting meetings, there are typically few additional avenues for the community to provide input or ask questions about the project once it is underway. NREL's InSPIRE program found that "proactively engaging with community members can lead to greater understanding and less potential for conflict" and that neighbors of the project can provide "other assistance or support for the project if they are made aware of project needs and how the project can benefit them or their community" [17].

The University of Arizona runs a program called the School Garden Workshop that "connects students in public schools with Tucson's 4,000-year agricultural legacy by planting, maintaining, and engaging in school gardens" throughout the city [64]. As a relatively new addition, agrivoltaics are being introduced into the program where possible. At Manzo Elementary School, students learn hands-on about growing fruits and vegetables and take scientific measurements of the plant and soil. They make comparisons between the plants growing in the full sun and those growing under the solar panels, making conclusions about the effects of the shade on different ecological outcomes - astonishingly advanced for children of their age. The various crops that are grown at the school are distributed to the local community through a nonprofit, directly benefiting the families in the area. A program like this, or something similar, could provide numerous benefits and opportunities for Alliant Energy and UW-Madison in the Madison area and beyond. In the short term, developing programs to bring local students to the Kegonsa site to learn about solar energy, agrivoltaics, plant ecology, and more will be a rewarding way to connect with the community. Not only will students be enriched by the exposure to real world science, but the program will surely bring great public awareness to both institutions and to agrivoltaics in Wisconsin.

5 – Involve Collaborative Multi-Sector Research

We recommend involving collaborative multi-sector research at the Kegonsa site and hiring a research manager to manage research, education, and other collaborative activities there.

Collaboration among multiple sectors, including academia, industry, and government, can bring in diverse expertise and perspectives to tackle the challenges of designing, implementing, and promoting an agrivoltaic system. Collaborative research can lead to new innovations, best practices, and evidence-based solutions that can enhance the sustainability, productivity, and profitability of the agrivoltaic system.

The Kegonsa site has already received interest from many potential stakeholders. With the partnership between Alliant Energy and UW-Madison, enabling more comprehensive research from multiple partners can increase the practical and educational value of the site, and may also lead to advanced research outcomes which could help "advertise" future agrivoltaic projects.

Agrivoltaics could involve research from diverse disciplines, including soil science, social science, engineering, ecology, hydrology, agronomy, and energy. Research areas that could be explored at the Kegonsa site include crop performance, energy yield and economic optimization, social acceptance and adoption, and environmental impacts such as on soil quality, biodiversity, and water use, by engaging interested researchers from different departments at UW-Madison or other institutions.

Hiring a research manager can help ensure that the Kegonsa site is well managed using rigorous scientific methods and standards. There are many schools within UW-Madison that could host this position, though the College of Agricultural and Life Sciences (CALS) or the Nelson Institute for Environmental Studies seem most appropriate based on the research and faculty that are already in place. However, we believe that continuing the relationship with the Energy Analysis and Policy program will be beneficial due to the interdisciplinary aspect of the program. The UW Division of Extension - Agriculture could be another possible host for this position. Due to the lease agreement with UW-Madison, we advise Alliant Energy to consider partially funding or supporting the hiring of the research manager in order to maintain a close relationship to the research activities at the site. The research manager should be able to oversee data collection, analysis, reporting; and is also responsible for coordinating and communicating with various stakeholders, including local farmers, researchers, potential collaborators, and the public, to ensure that the research findings are disseminated effectively and translated into practical applications. Application process could start earlier than the Kegonsa site's completion date, and potential candidates should be qualified with communication skills, scientific experiences, and familiar with agrivoltaic terms and concepts.

6 – Target Future Work with Owner-Operator Farmers

We recommend targeting future work with owner-operator farmers at future agrivoltaics sites to establish more effective and mutually beneficial partnerships.

Developing agrivoltaic sites on existing agricultural lands where farmers do not own the land, but only rent and farm on that land, could potentially lead to tension and conflicts of interest. Because the landowners may possibly choose a more profitable option, in most cases, replacing agricultural activities with energy production by installing solar panels, original farmers, who have been farming on the certain lands for decades, may have no choice but to be dismissed.

To avoid such conflicts and promote mutual benefits for both sides, we suggest Alliant Energy to work with farmers who own and operate the land for future agrivoltaics sites. The involvement of owner-operator farmers in the design and implementation of agrivoltaic systems can ensure that the system meets the needs of both farmers and solar energy developers. Researchers can also work closely with the owner-operator farmers to design and conduct pilot projects that aim to address specific challenges, such as soil quality compaction, crop selection and yields, and irrigation systems. Such mutually beneficial partnerships may also lead to the generation of new business models that benefit both the agricultural and solar energy sectors, such as community solar programs that provide clean energy to local communities while supporting local farmers.

Targeting future work with owner-operator farmers at future agrivoltaic sites could involve conducting surveys and holding focus group discussions with farmers to learn about their concerns and perceptions about the integration of solar panels into their farmland.

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Columbia County Board of Supervisors resolution to PSC on High Noon Solar project

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Appendix B

RENEW Solar & Agricultural Land Use Factsheet

SOLAR AND AGRICULTURAL LAND USE

Wisconsin farmers have played a crucial role in providing food and energy to our communities for decades. Farmers now have a new opportunity to provide clean, renewable energy to the people of Wisconsin today and well into the future. Trends in conventional crop production have fostered ripe conditions for farmers to implement new ways to generate revenue. Thanks to rising crop yields, we are growing far more crops on less land, and commodity prices are low due to market conditions largely beyond farmers' control.

Solar farms offer energy independence and pump millions of dollars into rural communities. Solar-hosting farmers have reliable sources of revenue for years to come.



According to a recent report, in the most cost-effective economy-wide decarbonization scenario, solar would occupy under 200,000 acres in Wisconsin by 2050, which is about equal to land currently enrolled in the Conservation Reserve Program.

According to the report *Achieving 100% Clean Energy in Wisconsin* by Evolved Energy Research, 28.3 GW of utility-scale solar would be needed to achieve decarbonization economy-wide by 2050. Assuming 1 GW of solar uses 7,000 acres, the total land area needed for utility-scale solar under this scenario is 198,000 acres, or 1.39% of Wisconsin's actively cultivated farmland. The land required for these solar farms is about equal to that enrolled in the Conservation Reserve Program.

LAND AREA NEEDED FOR 198,000 ACRES / 28.3 GW OF SOLAR RELATIVE TO TOTAL ACTIVELY CULTIVATED FARMLAND



TOTAL WI ACTIVELY CULTIVATED FARMLAND
14,200,000 ACRES
1.39% SOLAR

I am a participating landowner [in High Noon Solar] and 4th generation farmer on a century-family farm. Since our family started farming in the 1800s, there have been a lot of changes to agriculture and ways to be profitable. This solar project is an opportunity for us to diversify our farm income. In my opinion, this is just another way to farm the sun, just as we have done to grow crops over the years. Our farmland in this project does not disappear. This is a temporary use of our land. There are many financial benefits from this project in all aspects, but the most important one is that this is good for our environment. We are doing our part to fight climate change for future generations.

—Larry Nelson

CROP PRODUCTION IN WISCONSIN

We are growing more crops today than we were 55 years ago and doing so on fewer harvested acres of land. Crop yields are expected to continue increasing, exacerbating an already oversaturated marketplace. Some crop producers are looking far and wide for new ways to generate revenue. Solar farms can offer a revenue solution.

FINANCING LAND CONSERVATION

Federal taxpayers are paying to take cropland out of production through the U.S. Conservation Reserve Program. Today in Wisconsin, nearly 200,000 acres are not in active cultivation to improve soil health, reduce the volume of crops produced, and manage oversupply. Utility-scale solar projects provide similar land conservation and restoration services but do not require taxpayer dollars. Solar farms inject money into local communities through host lease payments, Wisconsin's shared revenue formula, which provides funds to the host local governments, and increases local spending.

ENERGY PRODUCTION AND FARMLAND

Many farmers today are already in the energy production business. About 37% of the corn already grown in Wisconsin is used for ethanol, a common biofuel. Incorporating solar generation on farms is simply another form of Wisconsin-made energy that farmers can provide our state. Even if all the utility-scale solar PV needed by 2050 were placed on existing ethanol production land, solar farms would only use about 18% of that land. In addition, plantings under the solar arrays can be designed to advance sustainable agricultural practices such as increasing pollinators like bees and butterflies and rebuilding the soil to be more fertile when replanted.

Appendix C

American Solar Grazing Association Sheep Grazing Contract, page 1 & 2

AMERICAN SOLAR GRAZING ASSOCIATION, INC. SHEEP GRAZING MASTER SERVICES AGREEMENT TEMPLATE

This template was developed by student interns at the Food and Beverage Law Clinic in collaboration with the American Solar Grazing Association, Inc. The Food and Beverage Law Clinic is a part of John Jay Legal Services, Inc., a non-profit legal services organization housed at the Elisabeth Haub School of Law at Pace University. This document does not reflect or constitute legal advice. Your use of this document does not create an attorney-client relationship with the Clinic or any of its lawyers or students. This template was last updated on May 12, 2022.

INSTRUCTIONS FOR USING CONTRACT TEMPLATE:

This document is a template contract for a “solar grazing” arrangement, i.e. an arrangement in which sheep graze at a solar site for purposes of vegetation management. It is contemplated that the contract will be entered into between a sheep farmer and a solar site manager (which may be the site’s owner or a manager contracted by the site’s owner, as applicable).

This template contains three parts:

1. **Master Services Agreement (MSA)**, which sets forth the general agreements between the sheep farmer and solar site manager that apply to every site the farmer maintains for that solar site manager.
2. **Form of Statement of Work (SOW)**. Each SOW will contain the unique details (terms, payment, location etc.) for a specific solar grazing site. Thus, for every new solar grazing site between the sheep farmer and solar site manager, there must be a new SOW, but not a new MSA.
3. **Optional Riders** for provisions on fencing, signage, and security that may be added to the MSA if the parties so choose.

This contract is a template; it is not a one-size-fits-all contract. The following should be addressed by the parties in addition to any other changes the parties may negotiate:

- All provisions that are **[red, bolded, italicized, and bracketed]**
- All provisions with blank spaces (_____)
- All guidance footnotes
- All optional provisions in the Optional Provisions Exhibit B

Once the MSA and any corresponding SOW is complete, **DELETE** all footnotes throughout the documents, this instructional page, and any unused optional rider provisions.

SHEEP GRAZING MASTER SERVICES AGREEMENT

This Sheep Grazing Master Services Agreement (this “MSA”), dated as of *[date]* (the “Effective Date”), is entered into by and between *[sheep farmer name]* (“Sheep Farmer”) and *[solar site manager name]* (“Site Manager”). Sheep Farmer and Site Manager together constitute the “Parties”.

WHEREAS, the Parties desire and intend to enter into this MSA to facilitate the grazing of Sheep Farmer’s sheep on one or more solar sites managed by Site Manager for the purpose of vegetation maintenance;

NOW THEREFORE, in consideration of the mutual agreements made herein and for other good and valuable consideration, the Parties, intending to be legally bound, agree as follows:

Section 1. Statements of Work; Solar Grazing Services.

- (a) The Parties may, from time to time during the term of this MSA, enter into one or more statements of work, in substantially the form attached hereto as Exhibit A, to govern the specific terms applicable to a solar site where Sheep Farmer will provide solar grazing services (each, a “SOW”).
- (b) For each of Site Manager’s solar sites subject to a SOW with Sheep Farmer (each, a “Solar Site”), Sheep Manager shall provide sheep for the purpose of grazing for vegetation management in accordance with the terms and subject to the conditions set forth in the relevant SOW and this MSA (the “Services”).

Section 2. Fees. In consideration of the provision of the Services, Site Manager shall pay Sheep Farmer the fees set forth in each SOW, payable by check unless otherwise specified in the SOW.

Section 3. Vegetation Maintenance Standard.

- (a) For each Solar Site, Sheep Farmer shall cause the “Vegetation Maintenance Standard” set forth in the relevant SOW to be fulfilled.
- (b) In the event that the sheep alone will not effectively maintain the vegetation in accordance with the applicable Vegetation Maintenance Standard, Sheep Farmer shall fulfill the Vegetation Maintenance Standard through other means such as subcontracting a landscaping service or other service in accordance with Section 8 of this MSA.

Section 4. MSA Term.

- (a) The term of this MSA is *[three years]*¹, beginning on the Effective Date and ending on *[]* (the “Initial Term”); provided that if any SOWs are outstanding at the expiration of

¹ **Note to drafter:** Consider frequency and seasonality of work between Site Manager and Sheep Farmer. For example, a 3 year MSA term may be appropriate should Sheep Farmer work with Site Manager for non-consecutive years.