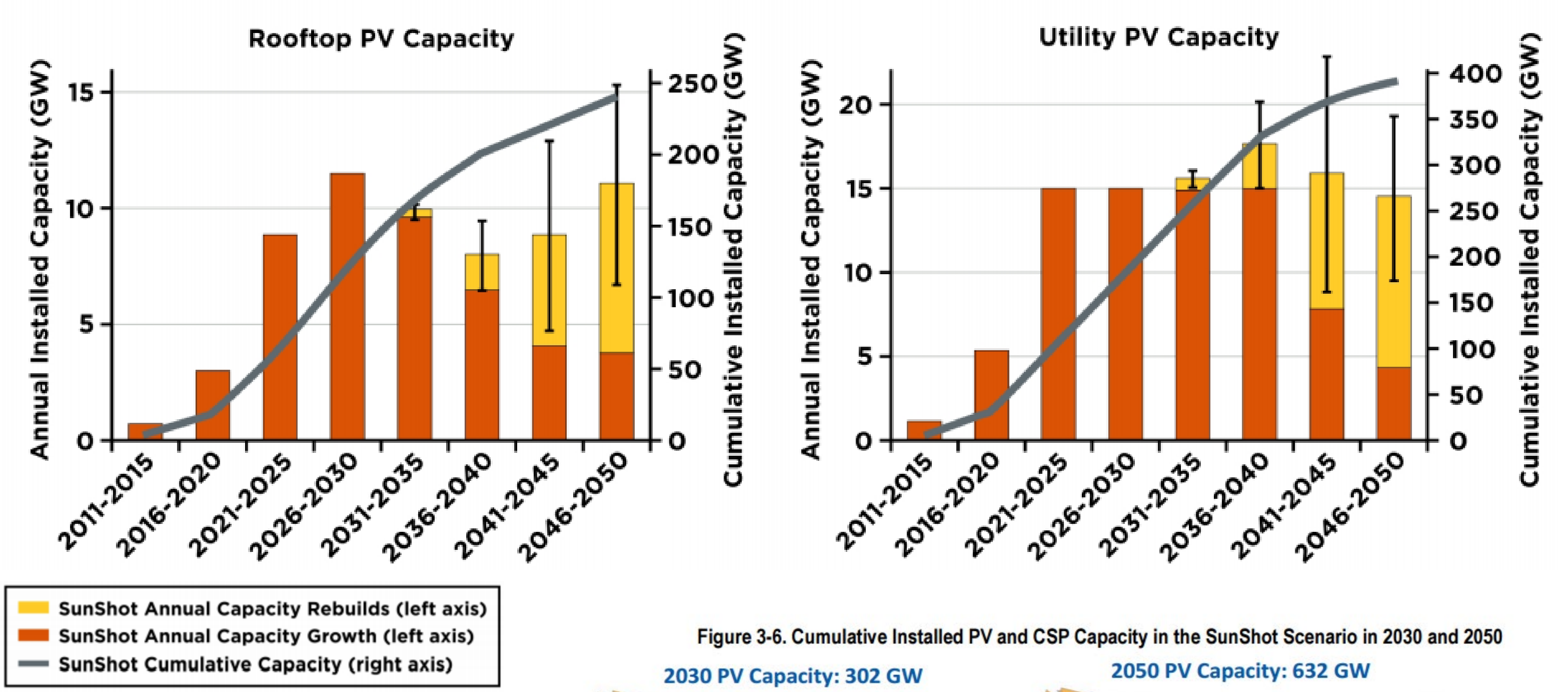
The InSPIRE Project: Agrivoltaic Research Across the United States

International Solar Energy Society

Jordan Macknick

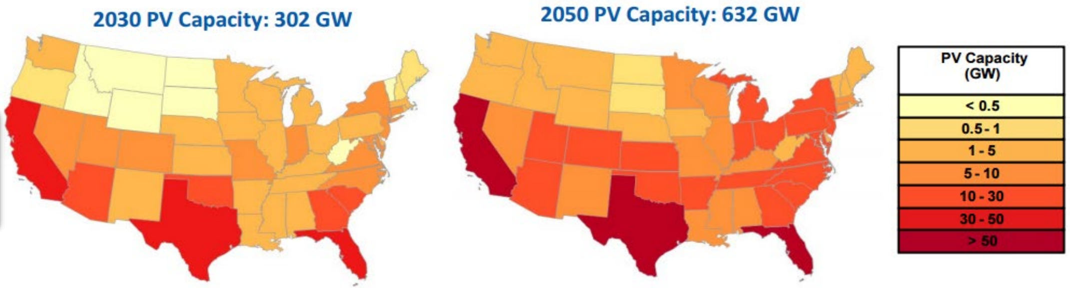
February 10, 2022

Land Use Requirements of Solar Deployment Projections

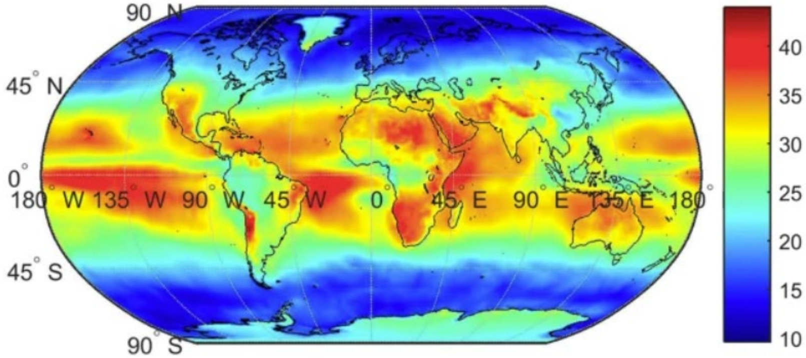


2030: 0.8-1.2 million hectares
2050: 1.6-2.4 million hectares

Figure 3-6. Cumulative Installed PV and CSP Capacity in the SunShot Scenario in 2030 and 2050



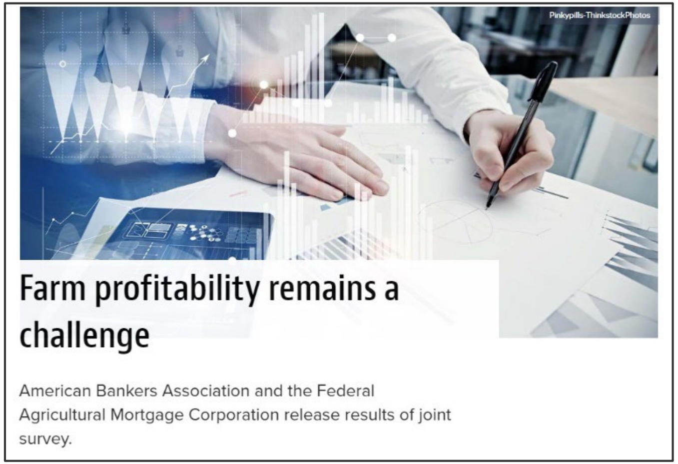
Matchmaking: Agricultural Lands and Solar Development



Solar PV Power Potential is Greatest Over Croplands

Elnaz H. Adeh, Stephen P. Good, M. Calaf & Chad W. Higgins

Scientific Reports **9**, Article number: 11442 (2019) | Cite this article



Farm profitability remains a challenge

American Bankers Association and the Federal Agricultural Mortgage Corporation release results of joint survey.

Business

The next money crop for farmers: Solar panels

Resistance: Rural communities can oppose solar development on farms

Sections ☰ The Washington Post *Democracy Dies in Darkness* Get 1 year for $29

Georgetown's 'green' plan to destroy a forest for a solar farm is met with resistance

METRO | SPORTS | BUSINESS | OPINION | RHODE ISLAND | POLITICS | EDUCATION | LIFESTYLE | MARIJUANA | ARTS | MAGAZINE | CARS

Solar projects increasingly meeting local resistance

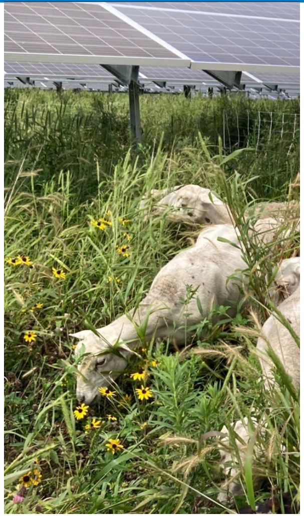
By **Katheleen Conti** Globe Staff, May 5, 2013, 12:00 a.m.

The New York Times

He Set Up a Big Solar Farm. His Neighbors Hated It.

A push toward renewable energy is facing resistance in rural areas where conspicuous panels are affecting vistas and squeezing small farmers.

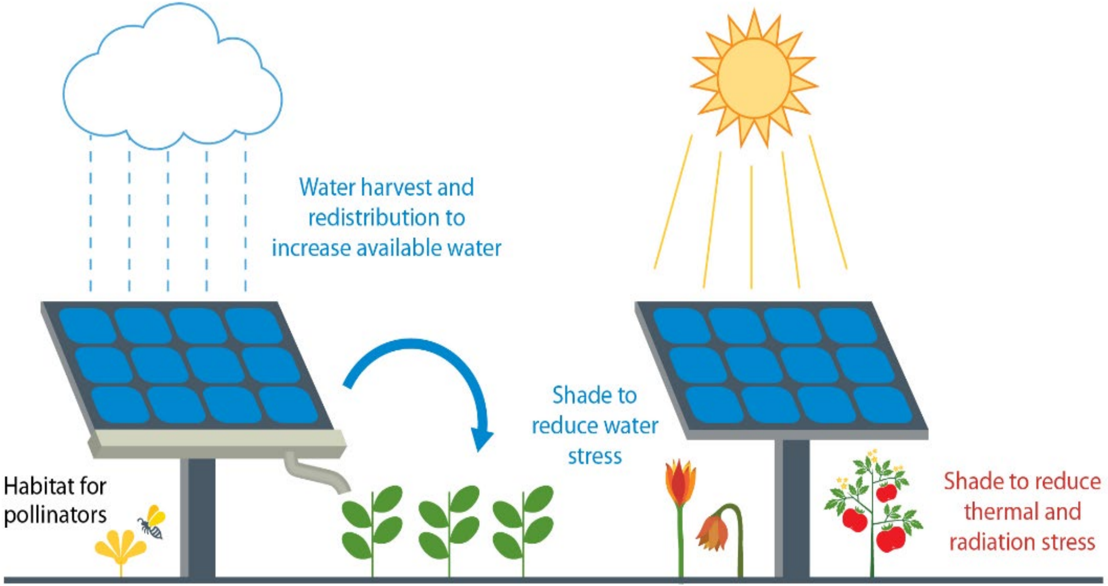
Vision: Mutual Benefits of Solar and Agriculture




Photos courtesy of Rob Davis, Fresh Energy; Werner Slocum, Dennis Schroeder, NREL

InSPIRE: Innovative Solar Practices Integrated with Rural Economies and Ecosystems



Select from the options below to display all sites using that technology.

- Beekeeping
- Co-location of Solar and Agriculture
- Native Vegetation
- Solar-Integrated Greenhouse
- Beneficial Predators
- Dryland Agriculture Co-location
- Pollinator Habitat

U.S. Department of Energy Funded (2015-2024)

Extensive Industry Partnerships

Field Research and Analytical Modeling

https://openei.org/wiki/InSPIRE

InSPIRE Project Sites

Overview of Field Research Activities at InSPIRE Agrivoltaic Sites

Vegetation Monitoring

Beneficial Insect Populations

Detailed Instrumentation

Temperature Probe

Soil Carbon

Relative Humidity Probe

Rain Gauge

Datalogger

Soil Heat Flux Plate

Wind Anemometer

Soil Thermocouple

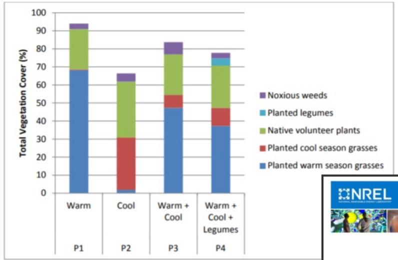
Pyranometer

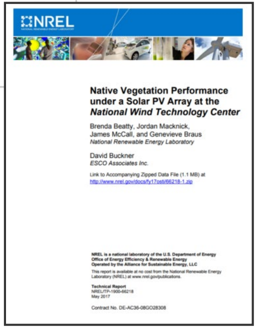
Armstrong et al., 2016

Soil Moisture Reflectometer

PV Panel Thermocouple

Standard Protocols for Vegetation Evaluation





NREL

Native Vegetation Performance under a Solar PV Array at the *National Wind Technology Center*

Brenda Beatty, Jordan Macknick, James McCall, and Genevieve Braus
National Renewable Energy Laboratory

David Buckner
ESCO Associates Inc.

Link to Accompanying Zipped Data File (1.1 MB) at
http://www.nrel.gov/docs/fy17osti/66218-1.zip

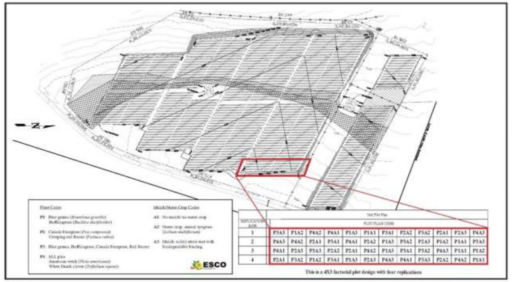
NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-1900-66218
May 2017

Contract No. DE-AC36-08GO28308

Figure 1. Plot Layout - Revegetation Test Plots. Sun Edison PV Array, National Renewable Energy Laboratory (NREL) Test Site, Jefferson Co., Colorado



Beatty, B., Macknick, J., McCall, J., Braus, G., and Buckner, D. 2017. *Vegetation Performance under a Solar PV Installation.* NREL/TP-1900-66218. National Renewable Energy Laboratory, Golden.
http://www.nrel.gov/docs/fy17osti/66218.pdf

ASTRO Advisory Group

Research and Outreach Advisory Group

Quarterly Zoom calls since Jan 2019

Feedback on research directions and study designs

Development of new InSPIRE research sites and activities

Coordinated outreach activities

Community leading to new collaborations

Partial list of ASTRO Members

Unique Features of InSPIRE Research

- ASTRO advisory group
- Coordinator and convener for US agrivoltaics research projects
- Multiple agricultural activities
  - Crops, grazing, pollinator/ecosystem services, controlled environment
- Diverse geographic coverage
- Multiple solar configurations
- Long-term research sites (since 2010)
- Mission to support research community

Agricultural Crop Publications and Focus

- Tradeoffs in crop yields
- Irrigation water requirements
- Microclimate conditions
- Shading modeling
- Crop production in off-grid areas

Ecosystem Services Publications and Focus

- Beneficial insect populations
- Potential impact of beneficial insects at solar sites on agricultural yields
- Approaches to revegetation of utility-scale solar projects
- Impacts of vegetation on soil and nutrient characteristics
- Impacts of vegetation on PV output

General Agrivoltaic Publications and Focus

- Capital cost impacts of Agrivoltaic configurations
- O&M cost impacts of different groundcovers
- Current groundcover of utility-scale PV projects
- Lessons learned from Agrivoltaic research projects
- Compatibility of agricultural activities with solar

InSPIRE Research Highlight: Ecosystem Services from Solar Sites in Minnesota

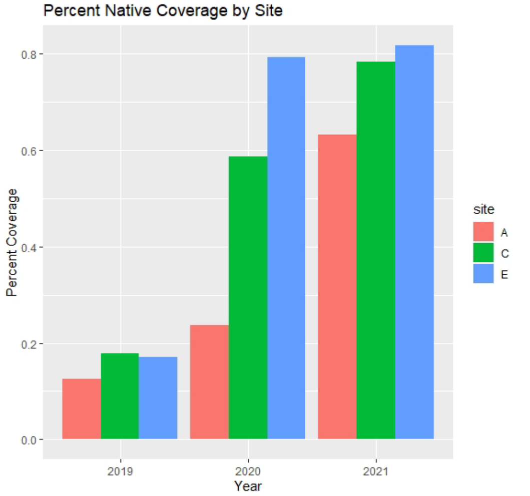
- InSPIRE Holistic Research Design in Minnesota
  - Vegetation and seed mix field study
  - Instrumentation for validation and connecting vegetation with PV performance
  - Pollinator population field study

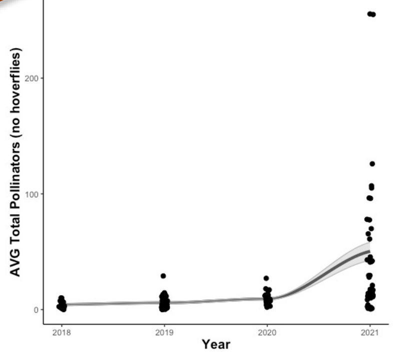
  - 3 sites with diverse soil/ecotypes and nine test seed mixes
  - 9 acres of field research
  - Partnerships with Enel Green Power, State of Minnesota, Minnesota Native Landscapes, University of Minnesota

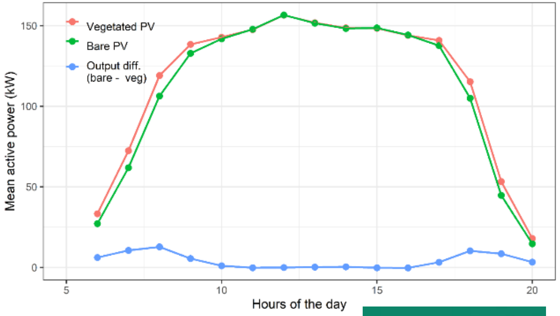
Benefits of Pollinator-Friendly Solar Installations in Minnesota

Research at three utility-scale solar sites in different ecoregions in MN

- **Pollinator Habitat:** 5x increase in beneficial habitat from 2019-2021
- **Beneficial Insects:** 20x increase in pollinators from 2018-2021
- **Energy Production:** PV panel temperature differences
- **O&M Costs:** Establishment of pollinator habitat leads to fewer mowing events each year





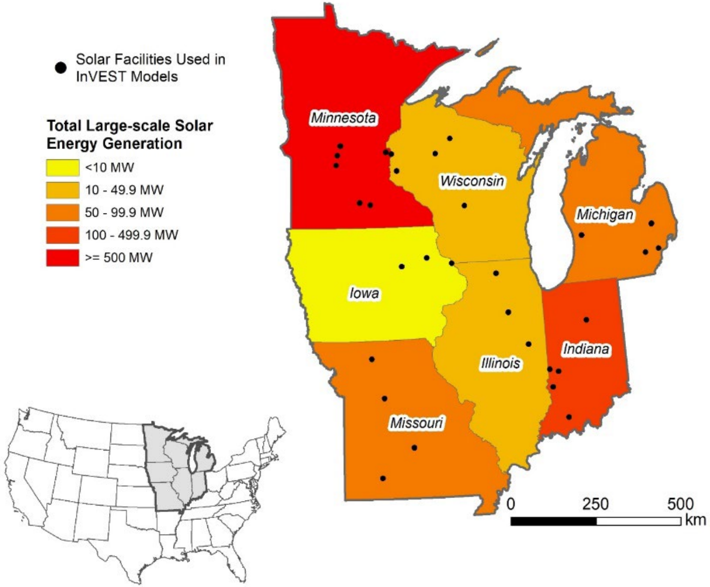


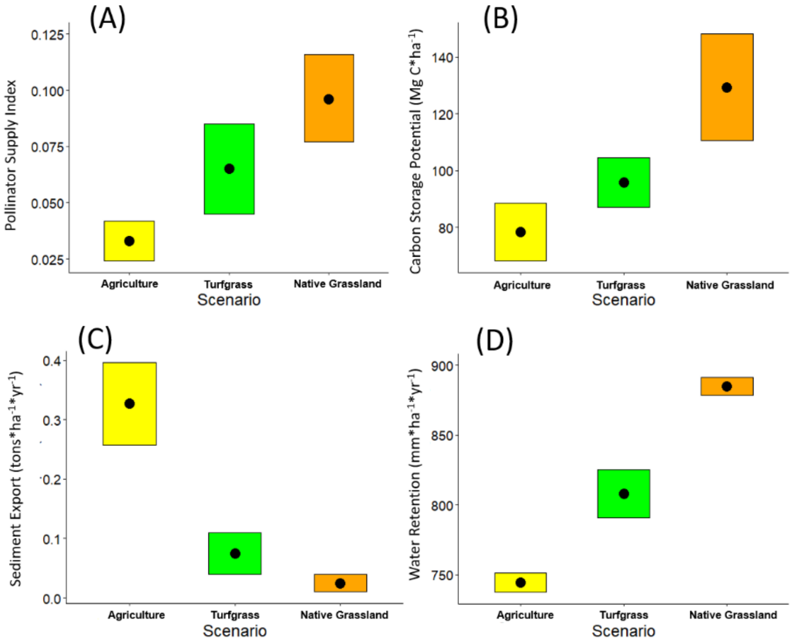
enel Green Power

Preliminary Results—Do Not Cite

InSPIRE Research Highlight: Ecosystem Services of Pollinator-Friendly Solar

Ecosystem Service tradeoffs associated with solar land use scenarios modeled from 30 sites





Ecosystem benefits

- Increased biodiversity
- Storm water & erosion control
- Better soil quality and quantity
- Carbon storage
- Agricultural benefits

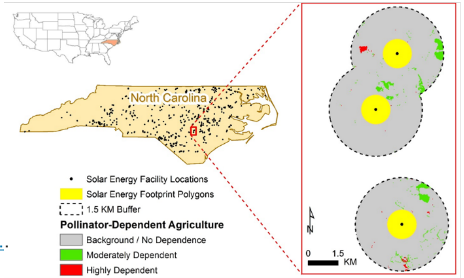
Modeling the Ecosystem Services of Native Vegetation Management Practices at Solar Energy Facilities in the Midwestern United States *(2020)*

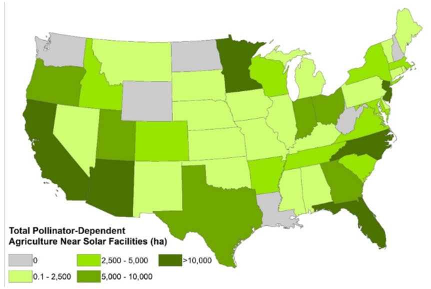
Leroy J. Walston, Yudi Li, Heidi M. Hartmann, Jordan Macknick, Aaron Hanson, Chris Nootenboom, Eric Lonsdorf, Jessica Hellmann

https://doi.org/10.1016/j.ecoser.2020.101227

Key Highlight: Pollinator-Friendly Solar

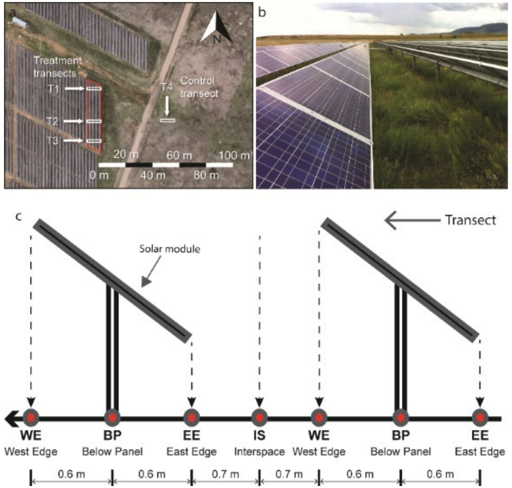
Over 800,000 acres of agricultural land would benefit if existing solar facilities had pollinator-friendly vegetation

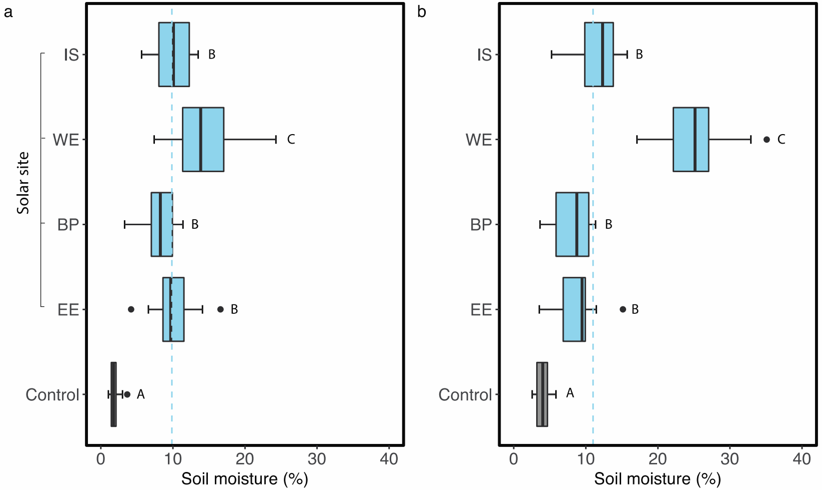




Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States..
Leroy J. Walston, Shruti K. Mishra, Heidi M. Hartmann, Ihor Hlohowskyj, James McCall,
Jordan Macknick 2018. Environmental Science & Technology Vol. 52 (13) 3 July 2018 pp. 7566-7576.

Publication Highlight: Soil Characteristics Under Solar Arrays 10 Years After Revegetation

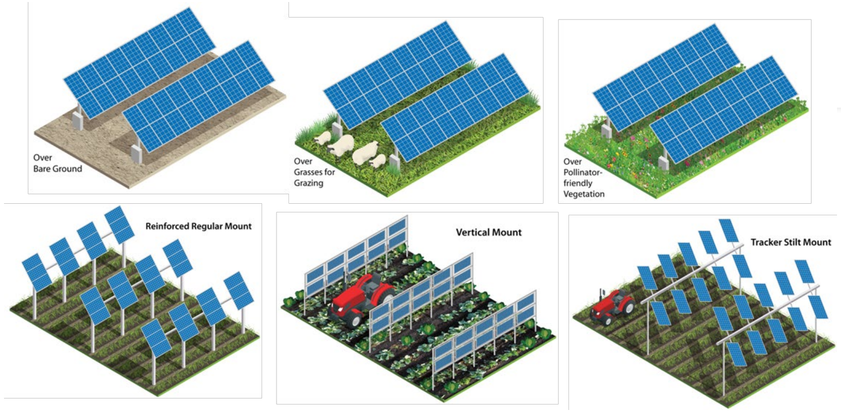




- Data collected from NREL NWTC site
- Evaluation of soil moisture patterns underneath solar arrays
- Frontiers in Environmental Science
- https://doi.org/10.3389/fenvs.2020.00140

Effects of Revegetation on Soil Physical and Chemical Properties in Solar Photovoltaic Infrastructure. Chong Seok Choi, Alexander E. Cagle, Jordan Macknick, Dellena E. Bloom, Joshua S. Caplan and Sujith Ravi. Frontiers in Environmental Science. 11. 2020.

Publication Highlight: Capital Cost Tradeoffs of Agrivoltaic Systems



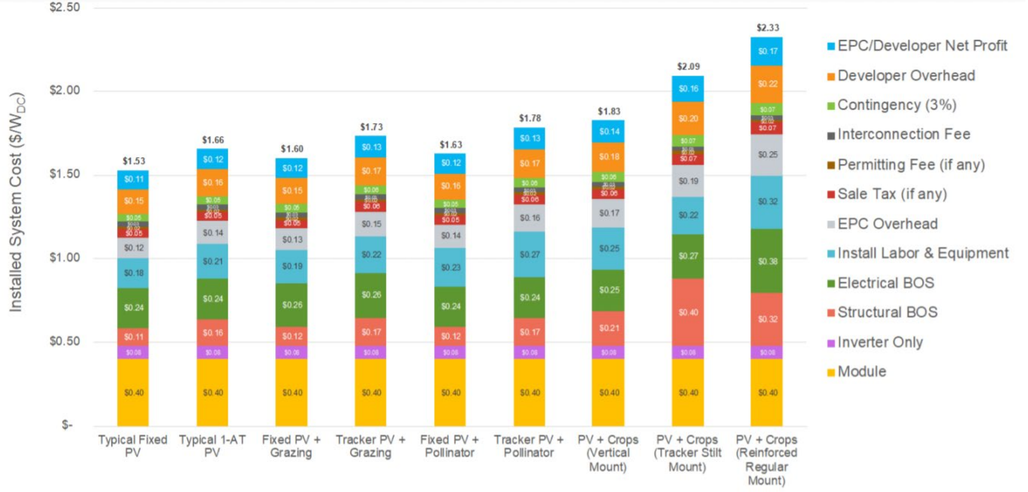


Figure 3. PV installed system costs for each dual-use scenario with benchmark assumptions for a PV system with 500 kW rated power

Costs are based on a simple average of modeled costs in Oregon, Arizona, Michigan, Massachusetts, New York, Connecticut, California, and Illinois—states that currently have one or more types of dual-use PV systems installed.

- Capital Cost Considerations
  - Module type and equipment
  - Panel height
  - Racking/Tracking system
  - Land acquisition costs
  - Installation labor costs
  - Site preparation costs
  - Risks

Kelsey Horowitz, Vignesh Ramasamy, Jordan Macknick and Robert Margolis. 2020. *Capital Costs for Multi-Land Use Photovoltaic Installations*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77811
https://www.nrel.gov/docs/fy21osti/77811.pdf

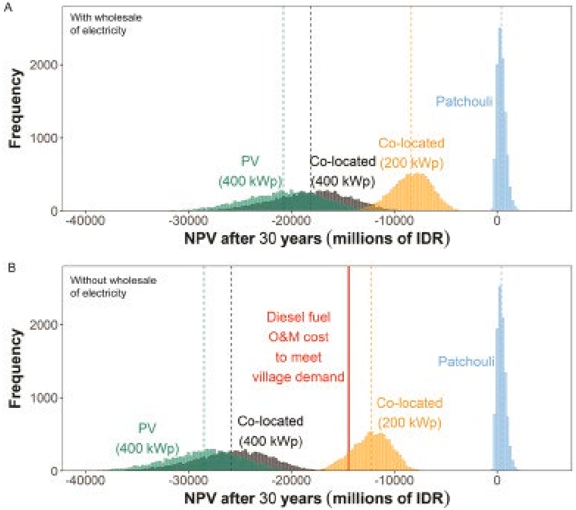
Publication Highlight: Off-Grid Agrivoltaics for Food and Energy Co-Benefits

ELSEVIER

Renewable and Sustainable Energy Reviews

Volume 151, November 2021, 111610

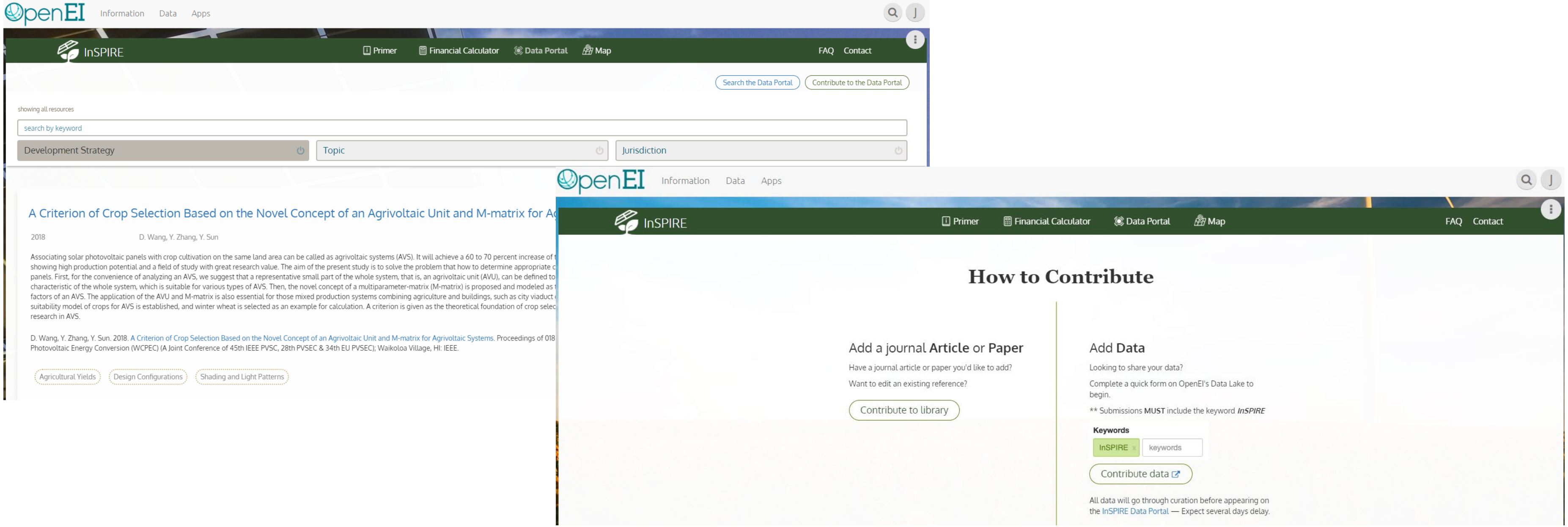
Combined land use of solar infrastructure and agriculture for socioeconomic and environmental co-benefits in the tropics



Chong Seok Choi, Sujith Ravi, Iskandar Z. Siregar, Fifi Gus Dwiyanti, Jordan Macknick, Michael Elchinger, Nicholas C. Davatzes. Combined land use of solar infrastructure and agriculture for socioeconomic and environmental co-benefits in the tropics. Renewable and Sustainable Energy Reviews. Volume 151. 2021. 111610. https://doi.org/10.1016/j.rser.2021.111610.

InSPIRE Data Portal

The InSPIRE data portal (https://openei.org/wiki/InSPIRE/Data_Portal) serves as the starting point for hosting and contributing relevant agrivoltaic research data



InSPIRE Agrivoltaics Financial Calculator

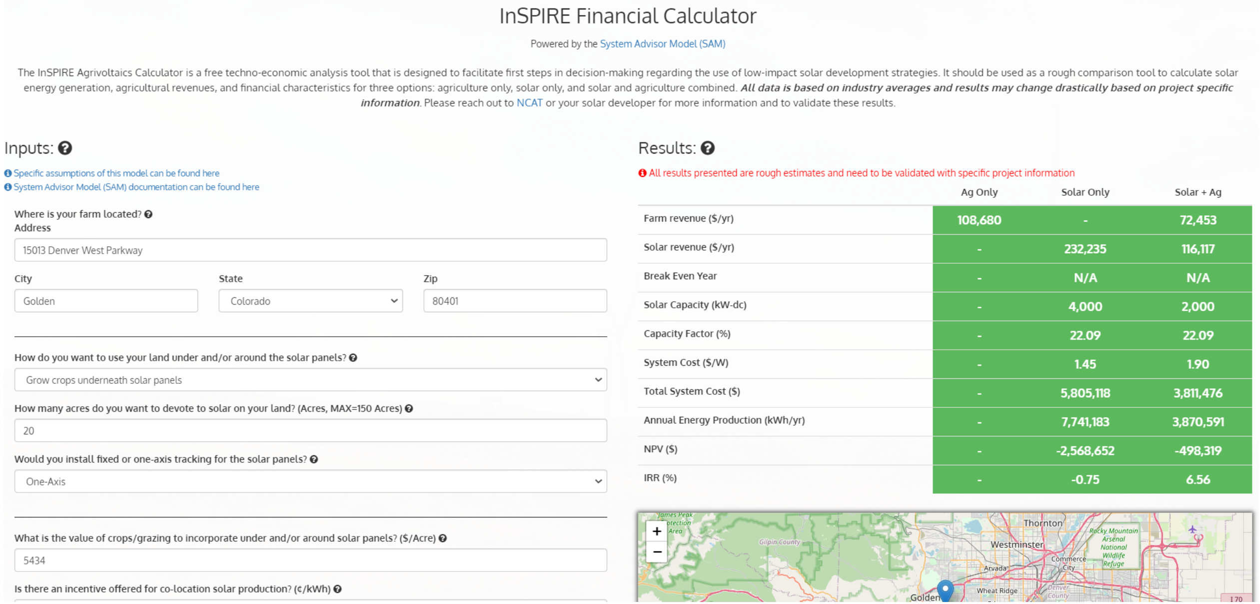
The InSPIRE financial calculator (https://openei.org/wiki/InSPIRE/Financial_Calculator) serves as the starting point for calculating economic viability of agrivoltaic projects

Adapts available tools (e.g., System Advisor Model [SAM]) plus latest data (e.g., capital cost and O&M studies) for easy-to-use, online co-location techno-economic assessment tool

Public-facing tool is customized for farmer use, but can also provide developers with validation and verification tools

User answers set questions that feed inputs into SAM API that calculate performance and economic metrics

Additional capabilities and customization available in non-public-facing version



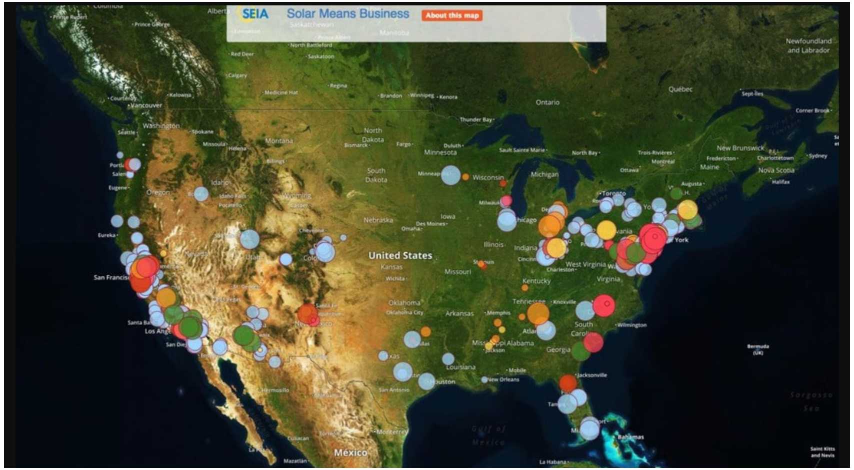
InSPIRE 2022-2024 Foundational Research Services

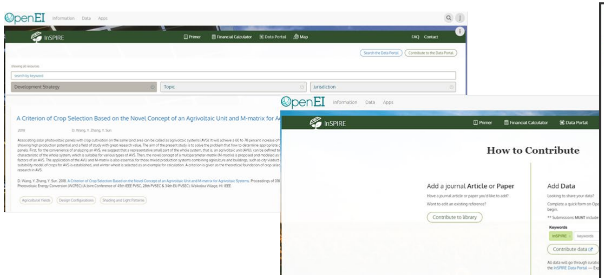
1. **Track US-Based Agrivoltaics Projects**

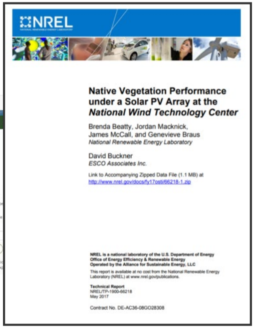
2. **Maintain and Update InSPIRE Data Portal and Website**

3. **Publish Standardized Research Protocols and Research Roadmap**

4. **Analyze Economics of Scaling Agrivoltaics**







InSPIRE 2022-2024 Field Research

1. Agrivoltaic Crop Production and Irrigation Tradeoffs

2. Ecosystem Services at Long-Term and New Research Sites

3. Bifacial PV Agrivoltaics Groundcover

4. Sheep Grazing Evaluation Standards and Guidelines

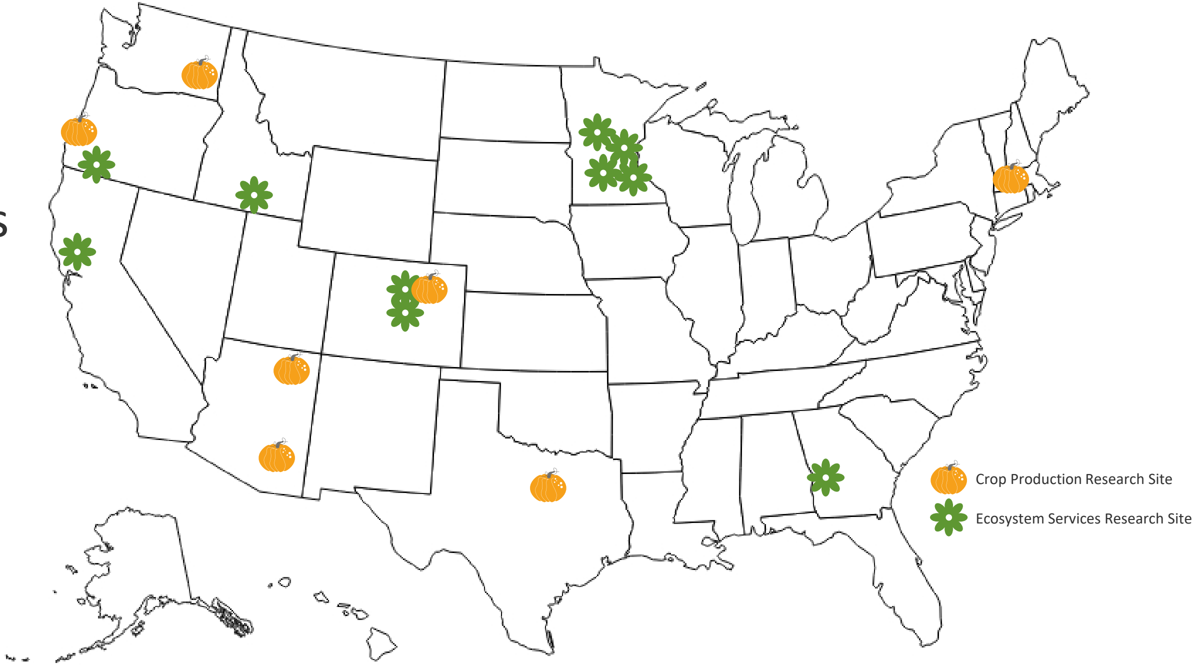
5. Soil Quality at Solar and Agrivoltaic Sites

InSPIRE Active Field Research Site Locations 2022-2024

10 ecosystem services and pollinator habitat research sites

7 crop production research sites

Other sites to be confirmed



Lego Solar Farm

http://www.legosolarfarm.me/

- "It is amazing" - Jon Powers, former Federal chief sustainability officer
- "So fun!!" - Kelsey Misbrener, Senior Editor, Solar Power World
- "My son loved it!" - Jigar Shah, solar industry pioneer
- "Let's do this" - Joel Makower, CEO, GreenBiz Group
- "Vote for this solar Lego kit!" -Julia Pyper, founder Political Climate Podcast
- "This is awesome!" - Elaine Hsieh, co-founder Third Derivative

LEGO IDEAS

Thank you

Jordan.Macknick@nrel.gov

https://openei.org/wiki/InSPIRE

NREL Transforming ENERGY

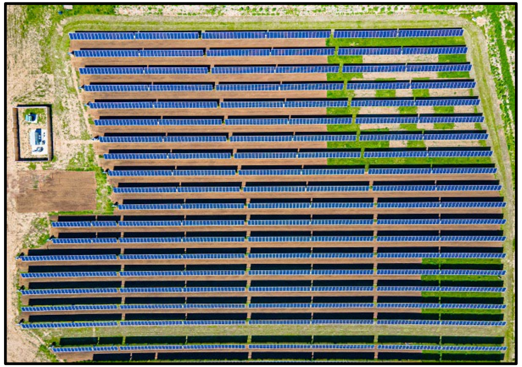
Jack's

SOLAR GARDEN

We Turned Our Hay Field into …

… a 1.2 MW Solar Array

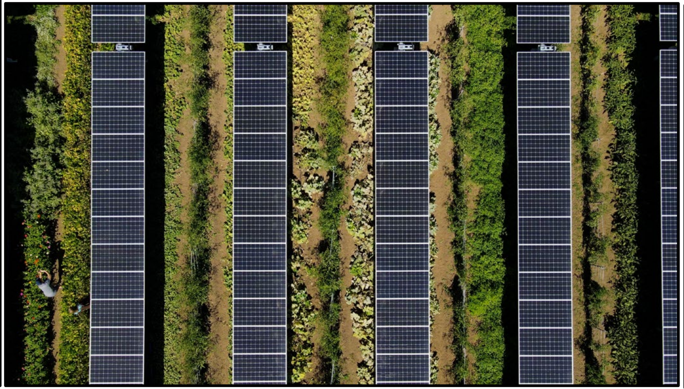
What We Created



Credit:
Namaste Solar

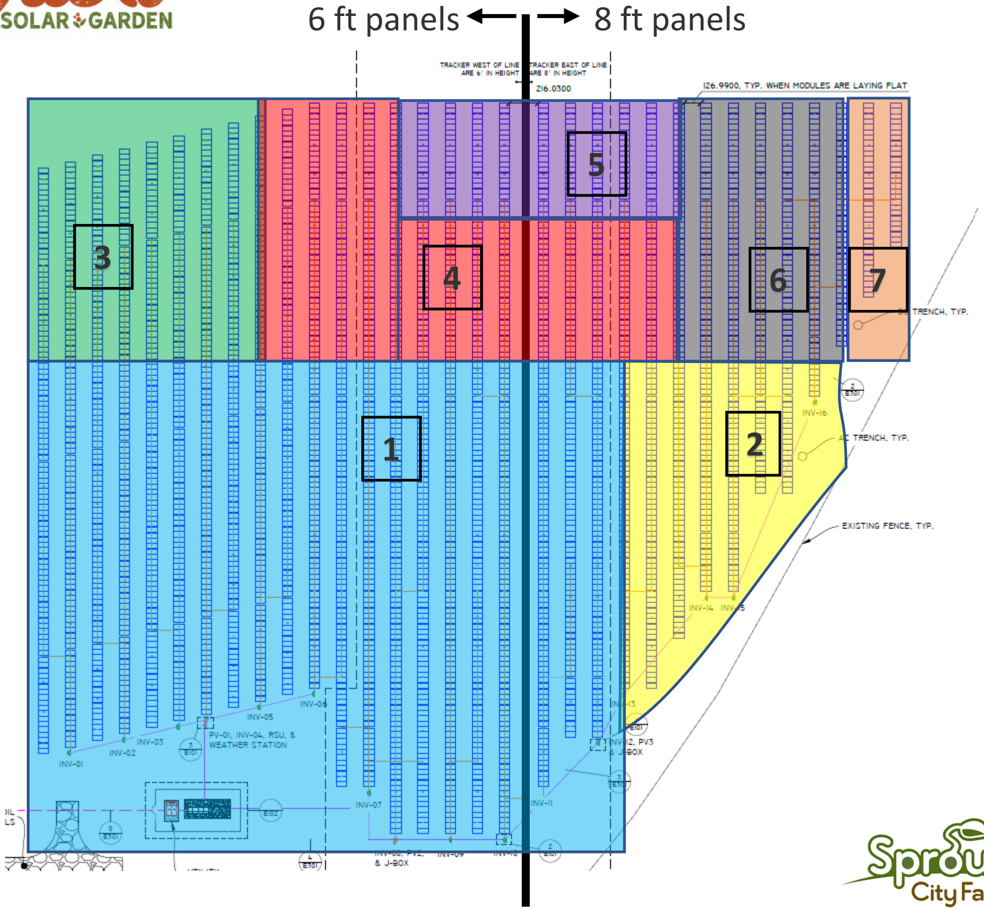
How We Use Our Space




Credit:
Werner Slocum/NREL

How We Use Our Space



Jack's Solar Garden Research Layout

1. SCF Farm Production site
2. Pollinator and native vegetation test plot
3. Pollinator habitat test plot
4. Agricultural test plot
5. Water management test plot
6. Pasture/grassland/nutrient cycling test plot
7. Educational Zone

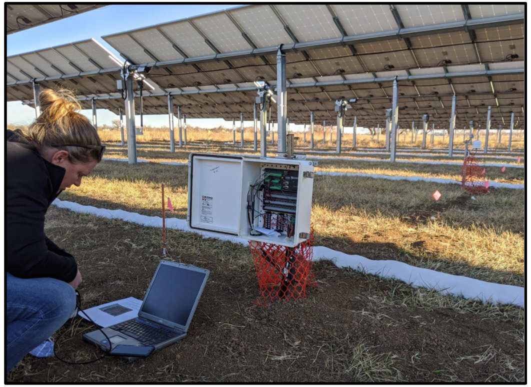
Jack's SOLAR GARDEN

Advancing Research

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Colorado State University

ARIZONA



Growing Vegetables

Credit:
Werner Slocum/NREL

Jack's SOLAR GARDEN

Growing Vegetables

Sprout City Farms

Supporting Pollinators



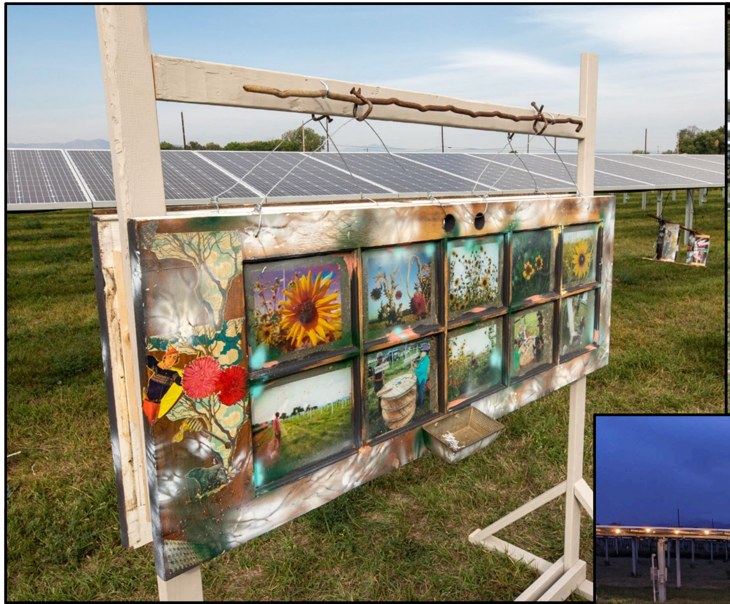

Credit:
Werner Slocum/NREL

Hosting Events

Credit:
Werner Slocum/NREL

Jack's SOLAR GARDEN

Promoting Artists



Jack's Solar Garden

Teaching Young People

Colorado Agrivoltaic Learning Center

Jack's SOLAR GARDEN

Creating Community

Credit:
Matt Maenpaa of
Longmont Leader

Colorado Agrivoltaic

LEARNING CENTER

We teach the next generation of sustainability leaders by connecting students, community members, and policymakers to clean energy, local food, and responsible land use management through agrivoltaic tours and events at **Jack's Solar Garden**.

www.coagrivoltaic.org

Our Three Educational Pillars

Youth — Tours and activities for students

Communities — Tours, events, and volunteering

Policymakers — Tours, events, and policy suggestions

Jack's Solar Garden

Byron Kominek

byron@jackssolargarden.com