InSPIRE Research: Crunching the Numbers

Jordan Macknick, James McCall, Haley Paterson, Austin Kinzer, Silvana Ovaitt, Sami Ghantous, Hanna Fields, Brian Mirletz, Tom Hickey, Brittany Staie, Robin Burton, Dala Al-Mukhaini

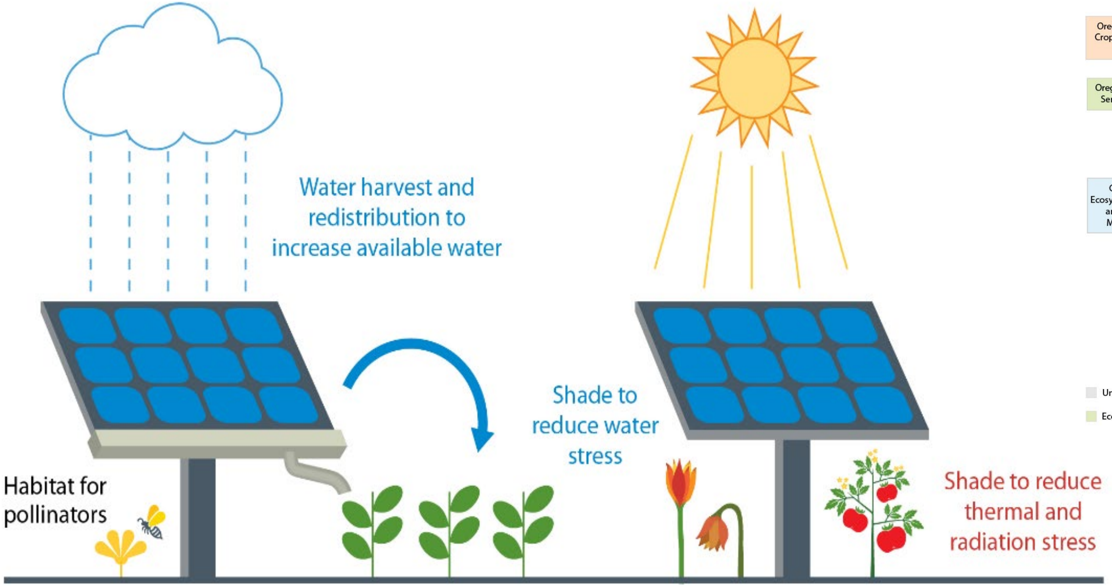
Agrisolar Clearinghouse Webinar Series

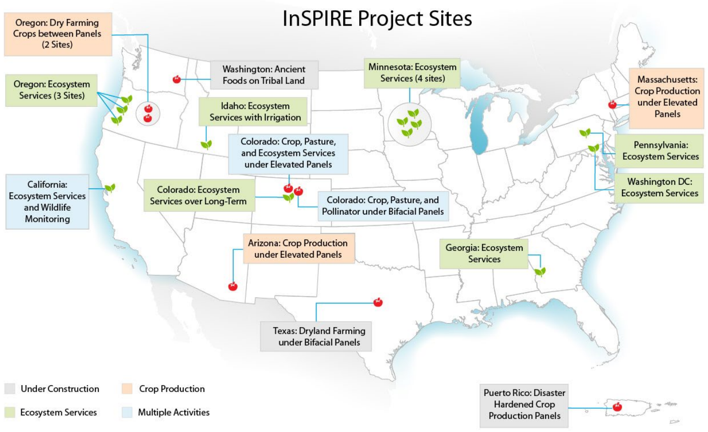
January 18, 2022

Crunching Numbers in Agrivoltaics

1. InSPIRE background
2. Agrivoltaics Map: Status of agrivoltaics in the United States
3. Agrivoltaic O&M Costs: Comparisons across groundcover types
4. Financial Calculator: Economic and energy tradeoffs on your farm
5. Data portal: State of agrivoltaics research
6. Next steps and discussion

DOE InSPIRE Research





Field-based research:

(1) Economic viability of solar-agriculture co-location configurations
(2) Increasing agricultural yields in arid environments
(3) Energy, water, and food security in remote, off-grid areas
(4) Pollinator habitat and ecological services

Analytical research:

(1) Tracking agrivoltaic projects
(2) Cost-benefit analysis of O&M groundcover types
(3) Economic impacts of alternative agrivoltaic configurations
(4) Quantification of ecological services of different groundcover types

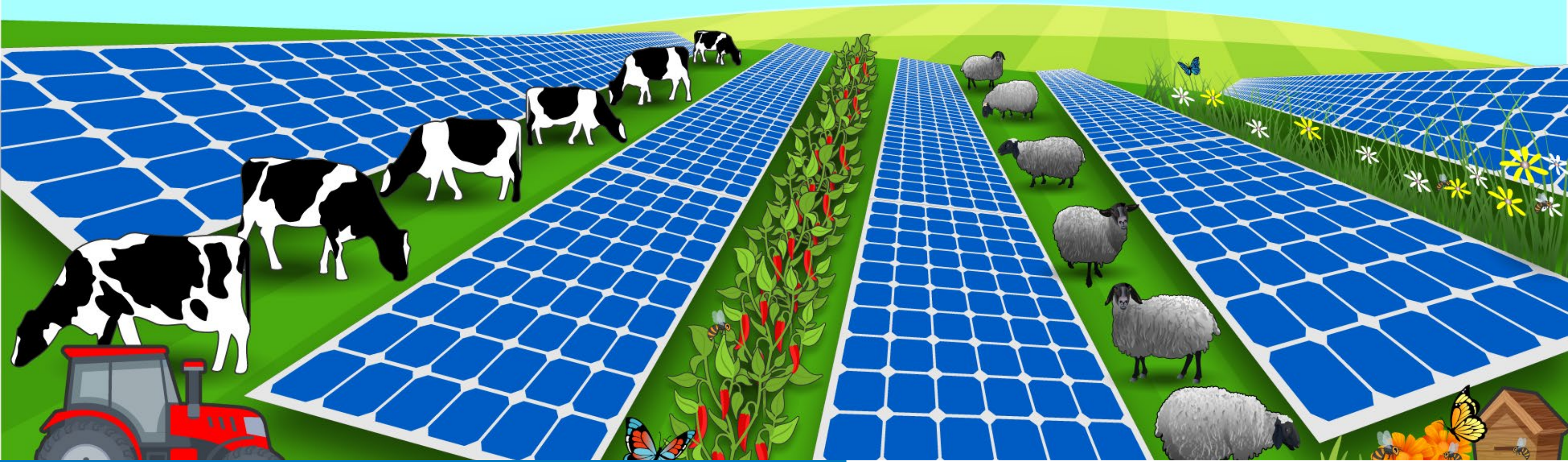
https://openei.org/wiki/InSPIRE

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Oregon State University
THE UNIVERSITY OF ARIZONA
University of Massachusetts Amherst 1863
Argonne NATIONAL LABORATORY
TEMPLE UNIVERSITY
HYPERION SYSTEMS Harvest the Sun!
Cornell University Founded A.D. 1865
Colorado State University
PINEGATE RENEWABLES
REGENERATE Integrated Systems for People and Place
Fresh Energy
MNL
enel Green Power

Vision: Mutual Benefits of Solar and Agriculture

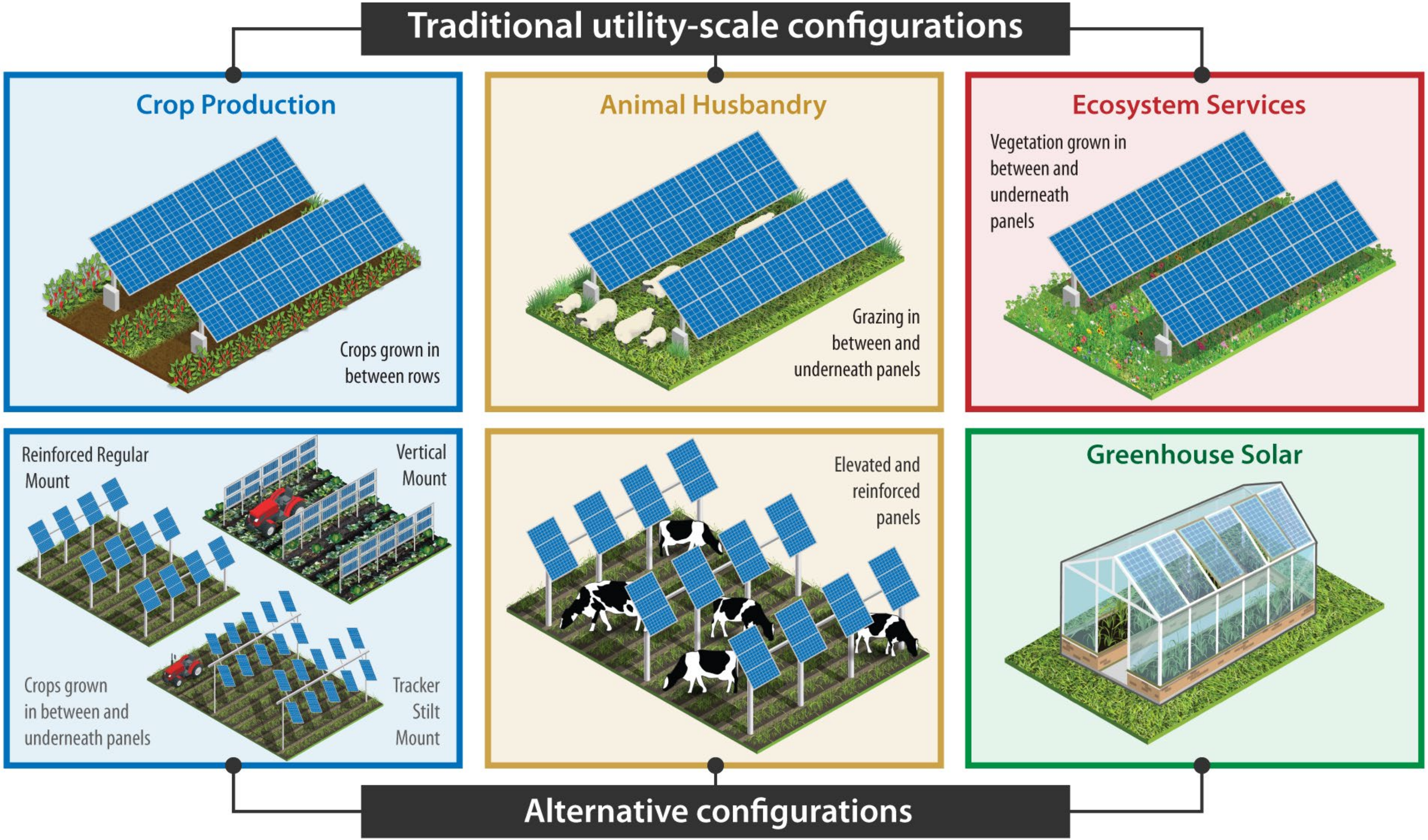
Photos courtesy of Rob Davis, Fresh Energy; Werner Slocum, Dennis Schroeder, NREL



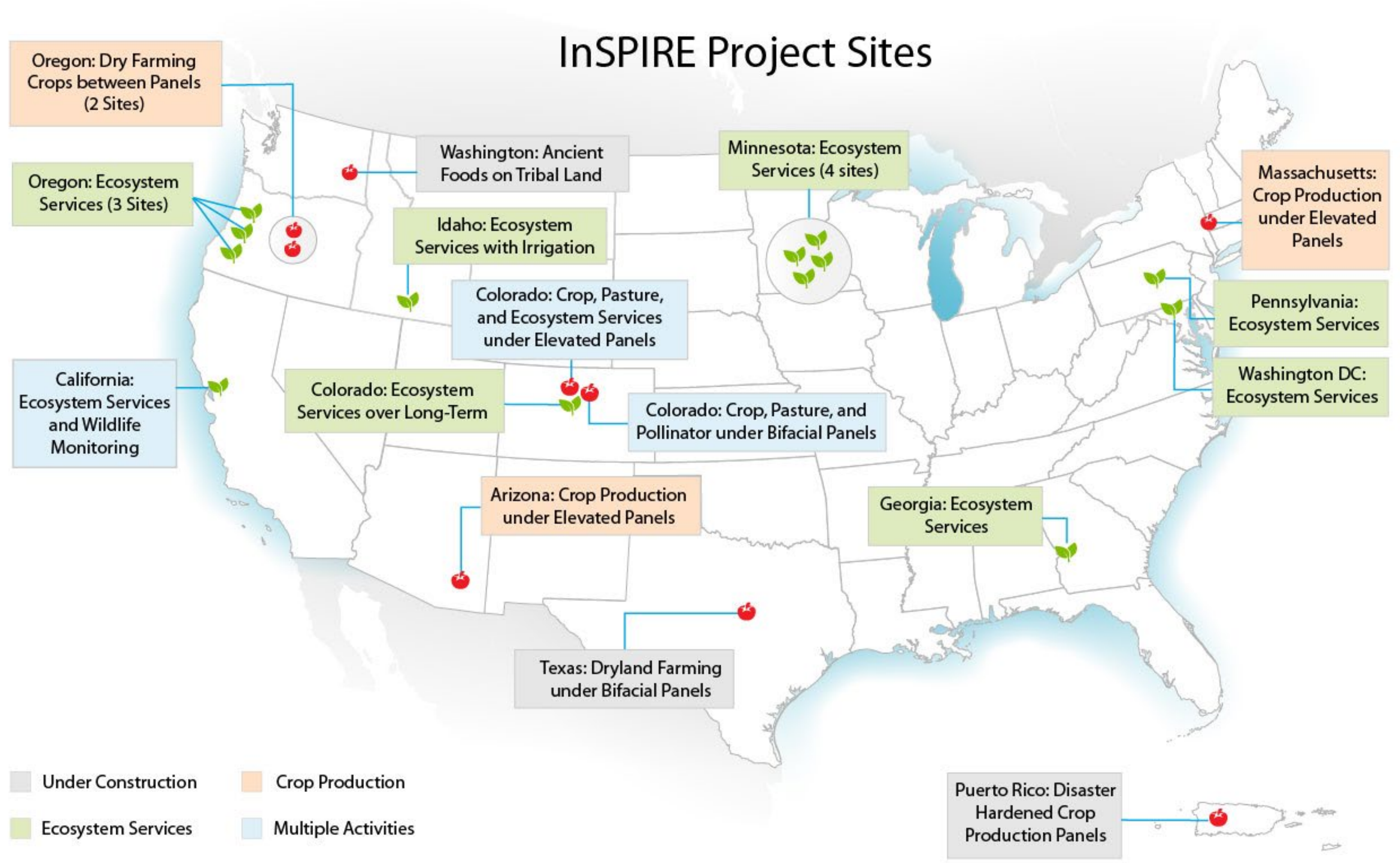
What is Agrivoltaics?

Agricultural activities performed underneath and around solar arrays:

- ❖ Crop production
- ❖ Grazing
- ❖ Ecosystem services (including pollinator habitat)
- ❖ Solar Greenhouses


Traditional utility-scale configurations
Crop Production
Crops grown in between rows
Animal Husbandry
Grazing in between and underneath panels
Ecosystem Services
Vegetation grown in between and underneath panels
Reinforced Regular Mount
Vertical Mount
Crops grown in between and underneath panels
Tracker Stilt Mount
Elevated and reinforced panels
Greenhouse Solar
Alternative configurations

InSPIRE Project Sites (2022-2024)



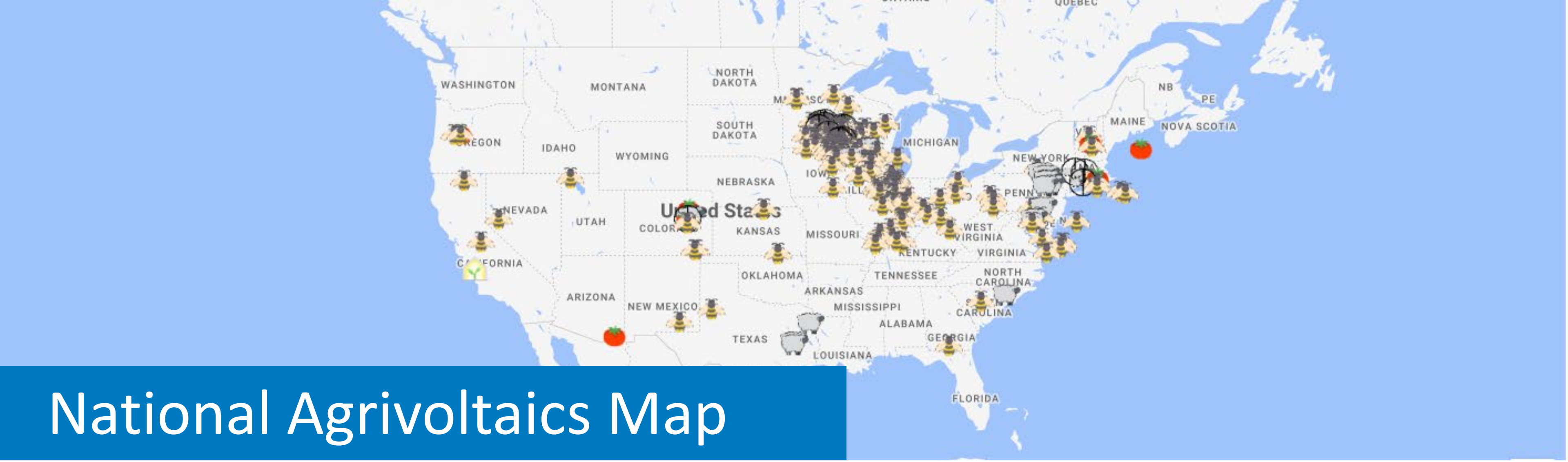
InSPIRE Foundational Analysis and Research

- Tracking and mapping agrivoltaic projects
- Standardized agrivoltaic research protocols
- Research Roadmap
- Economic tradeoffs of agrivoltaic systems
- Data Portal of agrivoltaic resources
- ASTRO Advisory Group
- Research workshops and conferences

Photo by Dennis Schroeder, NREL 55200

The Agrivoltaics Map

Haley Paterson



National Agrivoltaics Map

- https://openei.org/wiki/InSPIRE/Agrivoltaics_Map
- National database of agrivoltaic projects in the United States
- Interactive map with filter and sorting capabilities
- Regularly updated with new data and sites
- Crop production, Ecosystem services (pollinator), grazing, and greenhouse sites

The Agrivoltaics Map, NREL InSPIRE

Background & Motivation

- Why do we need an Agrivoltaics Map?

- Solar is rapidly expanding
- Higher occurrence of local resistance
- Agrivoltaics is emerging as a solution

- There is not a clear understanding of:
  - How many agrivoltaic sites are there?
  - Where are they?
  - How big are they?
  - What configuration do they use?
  - What type of agrivoltaics?

- Best way to address these questions was to develop a detailed map of agrivoltaic projects in the US

Methods

- **Template**
  - A template was created for ease of data collection and entry into the map.
  - There are opportunities to enter more information, but five key data for the map are:
    - Site Name
    - Site Location
    - Site Size
    - System Size
    - Agrivoltaic Activity
- **Partners**
  - We reached out to different partners requesting information on their agrivoltaic sites and provided them with the template.
- **Cleaning Data**
  - All data had to be cleaned, organized, and in some cases filled in for missing data.
    - Some sites only provided county level information, and latitude and longitude coordinates were needed. Other sites provided street addresses that were converted to geolocations.
    - Some sites were missing MWdc information and site size. The EIA website filled in some of these gaps where possible. In others, local newspapers could provide some information. Site size could be estimated if system size was available/found as 5 acres per MWdc.
- **Map Entry**
  - For large batches of information, sites were formatted and then uploaded using a script.
  - Some sites only provided county level information, and latitude and longitude coordinates were needed. Small batches of sites were entered by hand in the form available on the InSPIRE website.

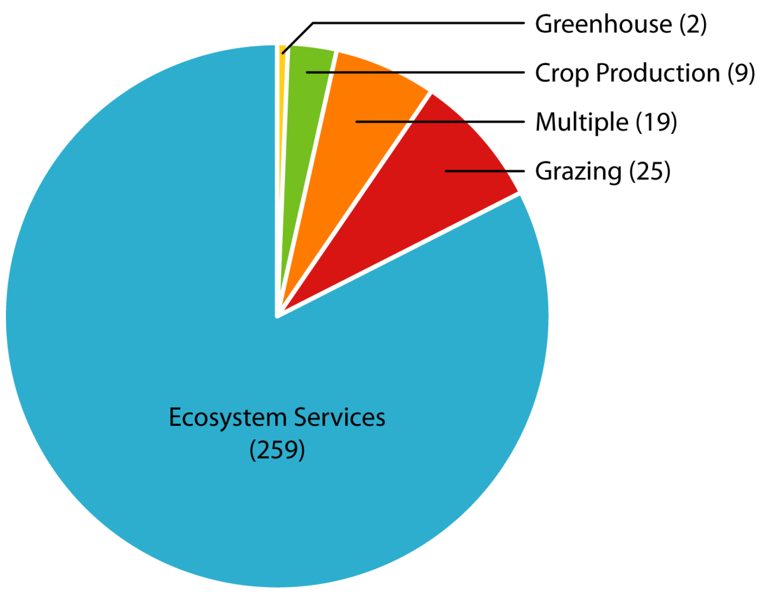
The contribute page options for the agrivoltaics map, NREL InSPIRE.

Summary of Agrivoltaics Map Data

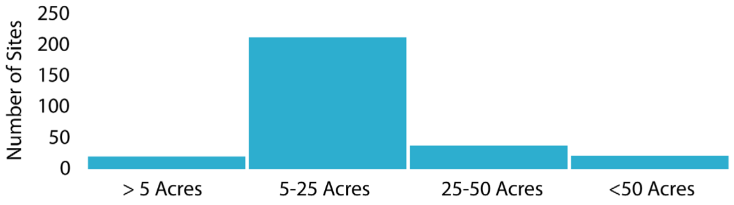
How Many Agrivoltaic Sites?

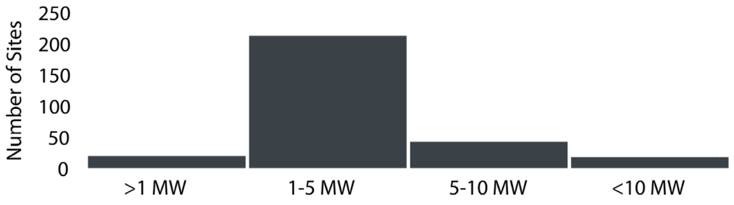
Totals tracked on the map (so far):
314 Sites
2,830 MWdc
17,342 Acres

Number of Agrivoltaic Sites



Agrivoltaic Site Size





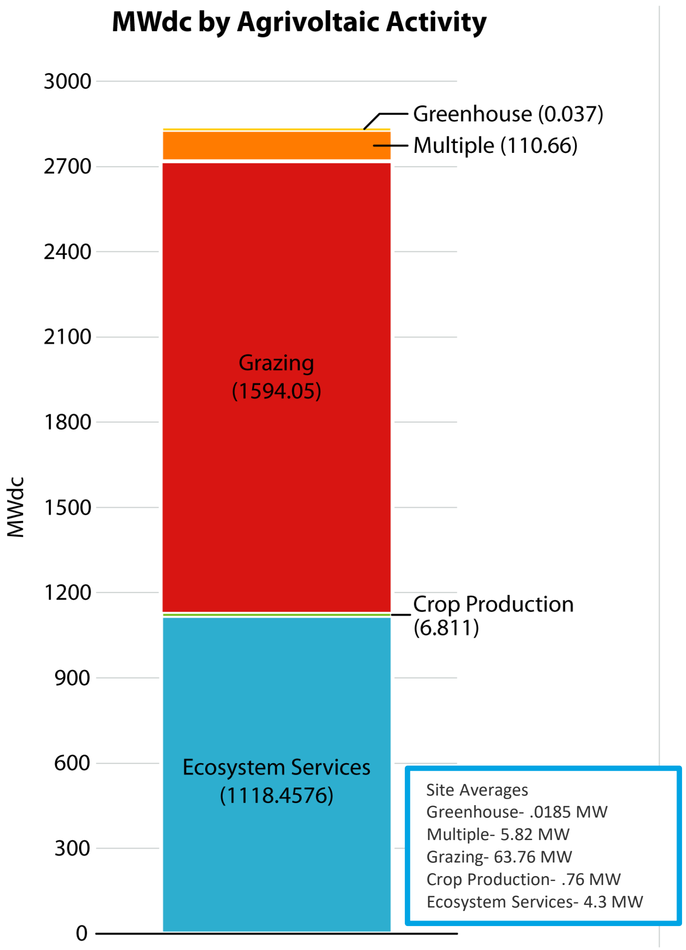
Key Takeaways:

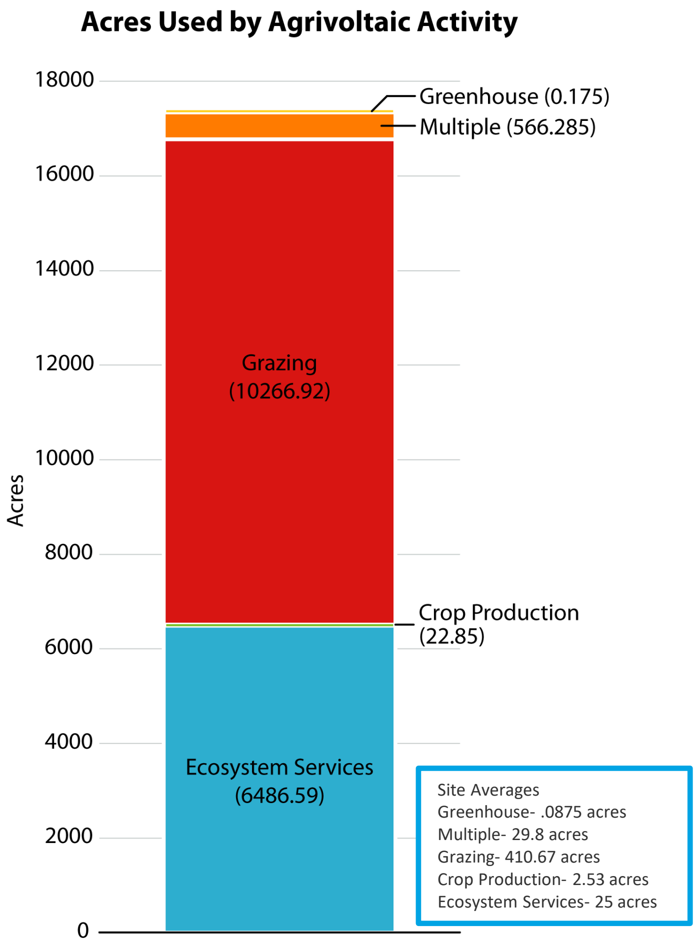
- 314 sites on the map
- Most sites on the map are ecosystem services.
- Most sites are in the mid range for both MWdc (1-5 MW) and acres (5-25 acres).

How Big Are Agrivoltaic Sites?

Key Takeaways

- Ecosystem service sites are smaller on average per site (~1/16th the average MWdc and acreage for grazing sites) but make up a large portion of total MWdc and acreage due to the number of sites.
- Grazing makes up most of the MWdc and acreage on the map and has the highest averages.

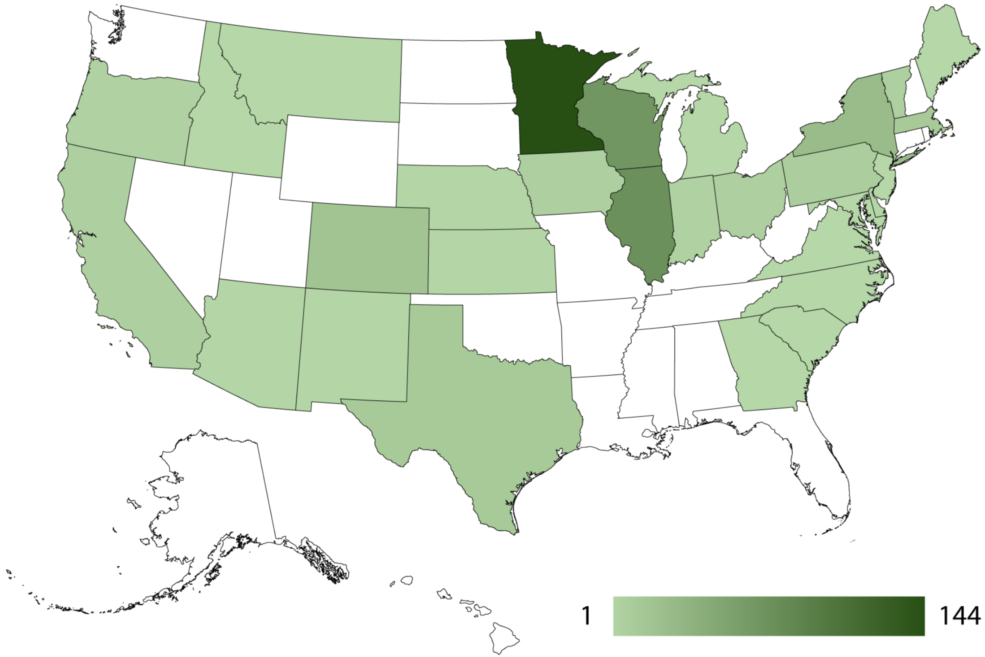




Where Are the Sites Located?

Minnesota has the most agrivoltaic sites in the US based on the current sites in the map.

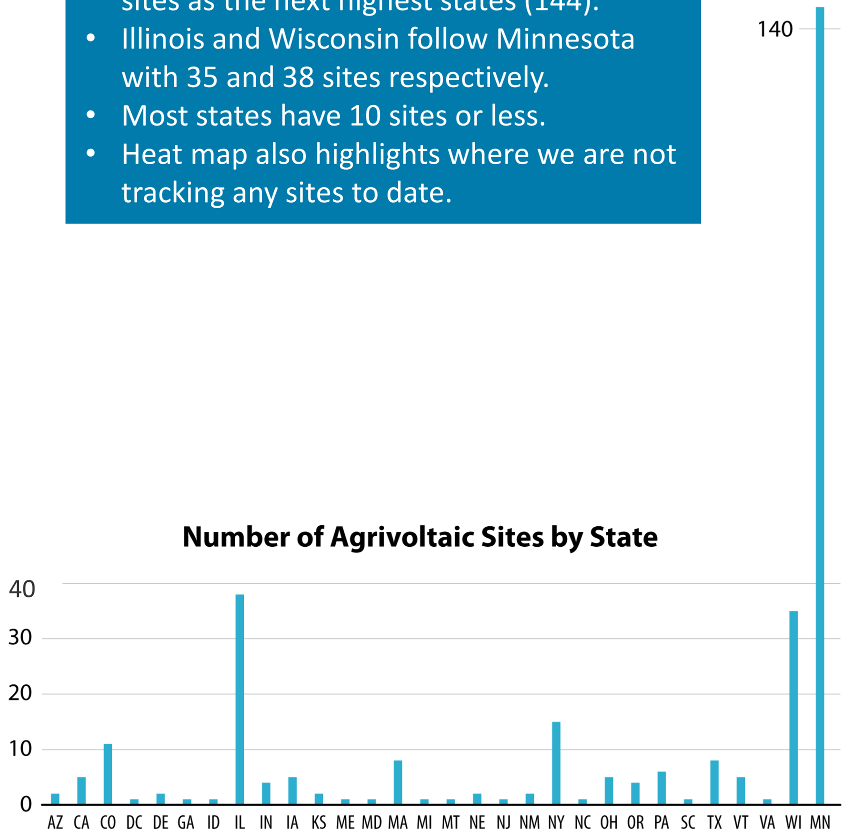
Illinois and Wisconsin have the most sites after Minnesota.



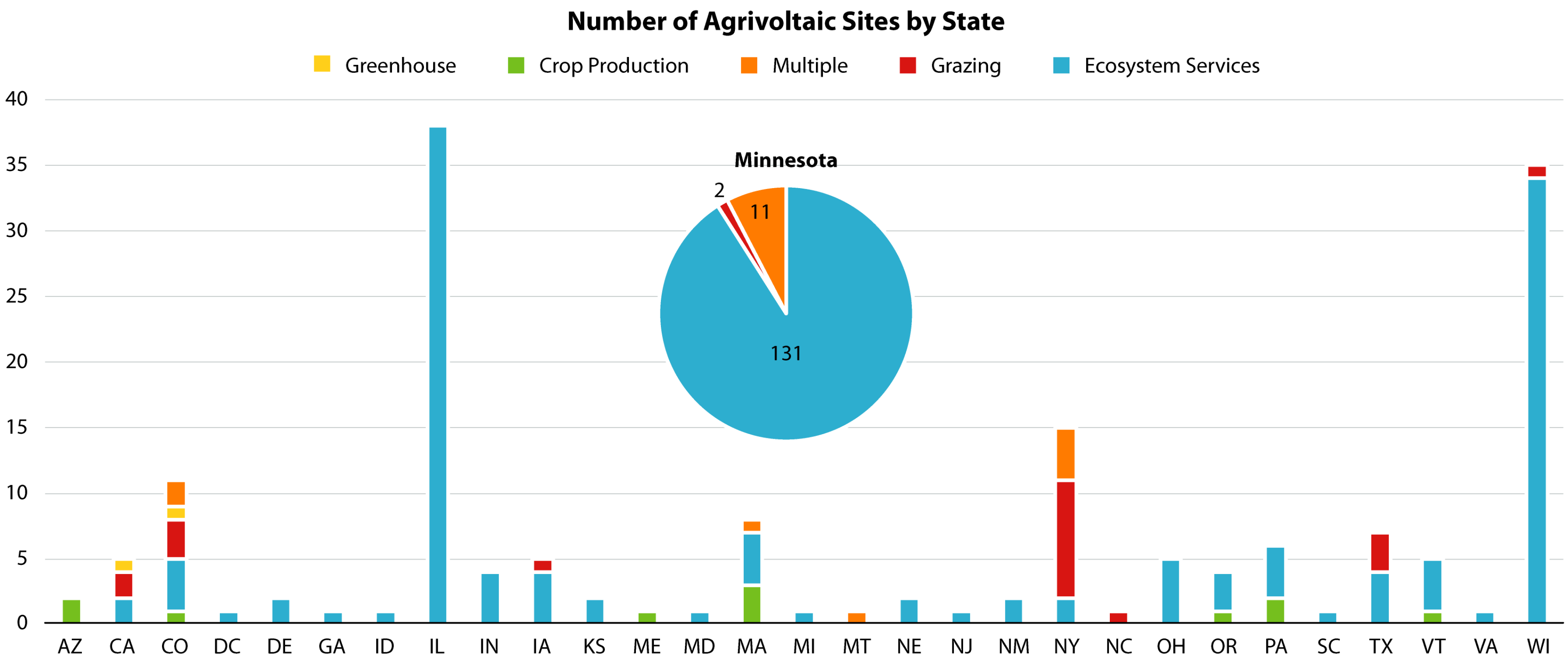
Key Takeaways

- Minnesota has more than 3 times as many sites as the next highest states (144).
- Illinois and Wisconsin follow Minnesota with 35 and 38 sites respectively.
- Most states have 10 sites or less.
- Heat map also highlights where we are not tracking any sites to date.

Number of Agrivoltaic Sites by State



Summary Statistics by State

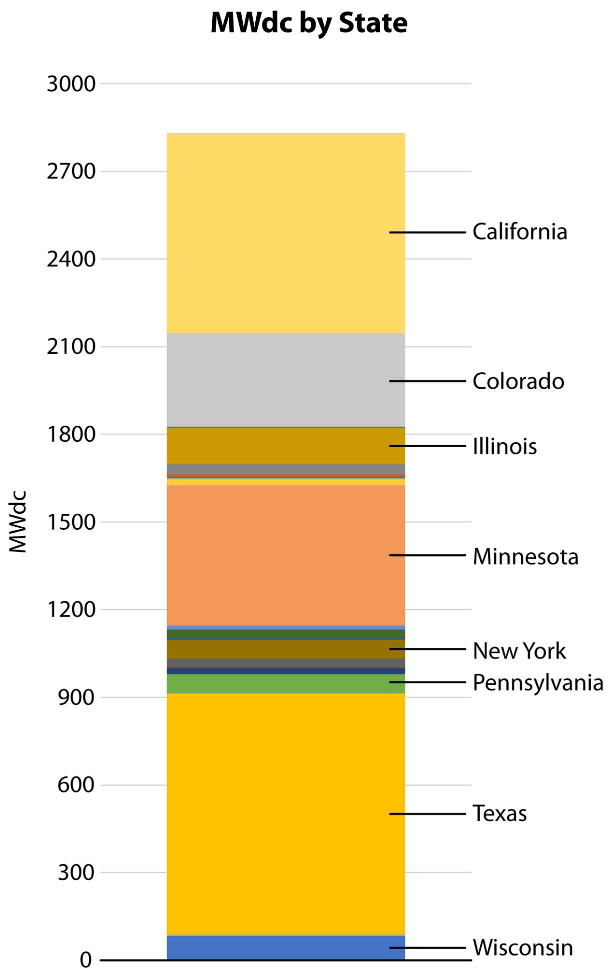


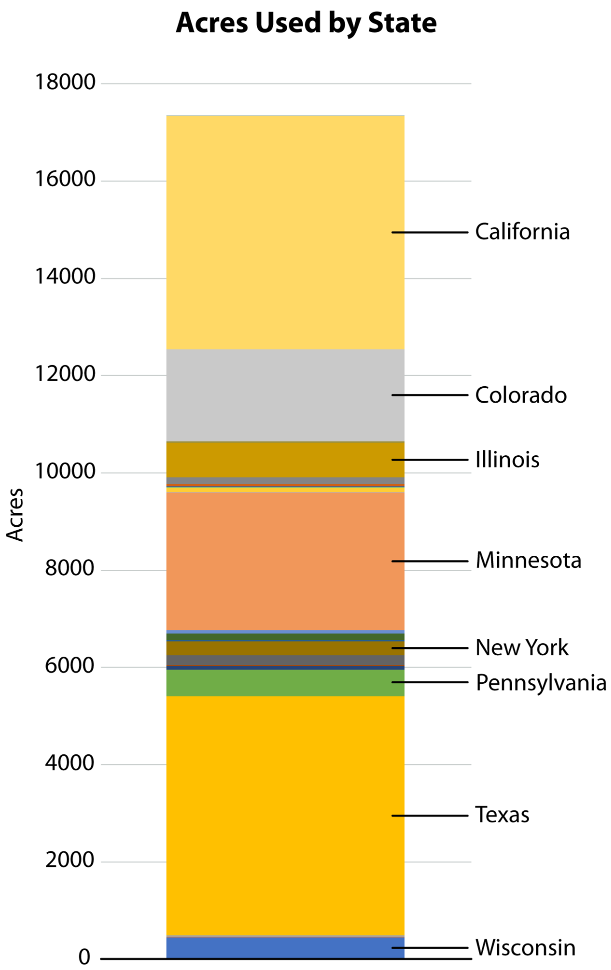
California and **Colorado** have the only agrivoltaic greenhouses on the map.

Capacity and Land Area of Agrivoltaics by State

Key Takeaways

- Texas and California have the most MWdc and acreage per state, despite having fewer sites than several other states.
- Texas and California both have large grazing sites that boost their totals over other states with more sites (Texas- two sites >950 acres with >150 MWdc, and California- 4700-acre site with 660 MWdc).





The Map in Action

A demonstration

InSPIRE Primer Financial Calculator Data Portal Map The 5 Cs Research FAQ Contact

Agrivoltaics Map

This dynamic map represents a census of agrivoltaic installations located across the United States. The map is constantly expanding as new sites are developed. If you are aware of agrivoltaic sites that should be added to the map or have a correction, please click on the "Contribute to the Agrivoltaics Map" button below.

Contribute to the Agrivoltaics Map

Displayed Results: **314**

Test Filters

Agrivoltaic Activities

- [x] Crop Production
- [x] Ecosystem Services
- [x] Grazing
- [x] Greenhouse

Photovoltaic Technology

- [x] Monocrystalline PV
- [x] Bifacial PV
- [x] Translucent PV

System Size MWdc

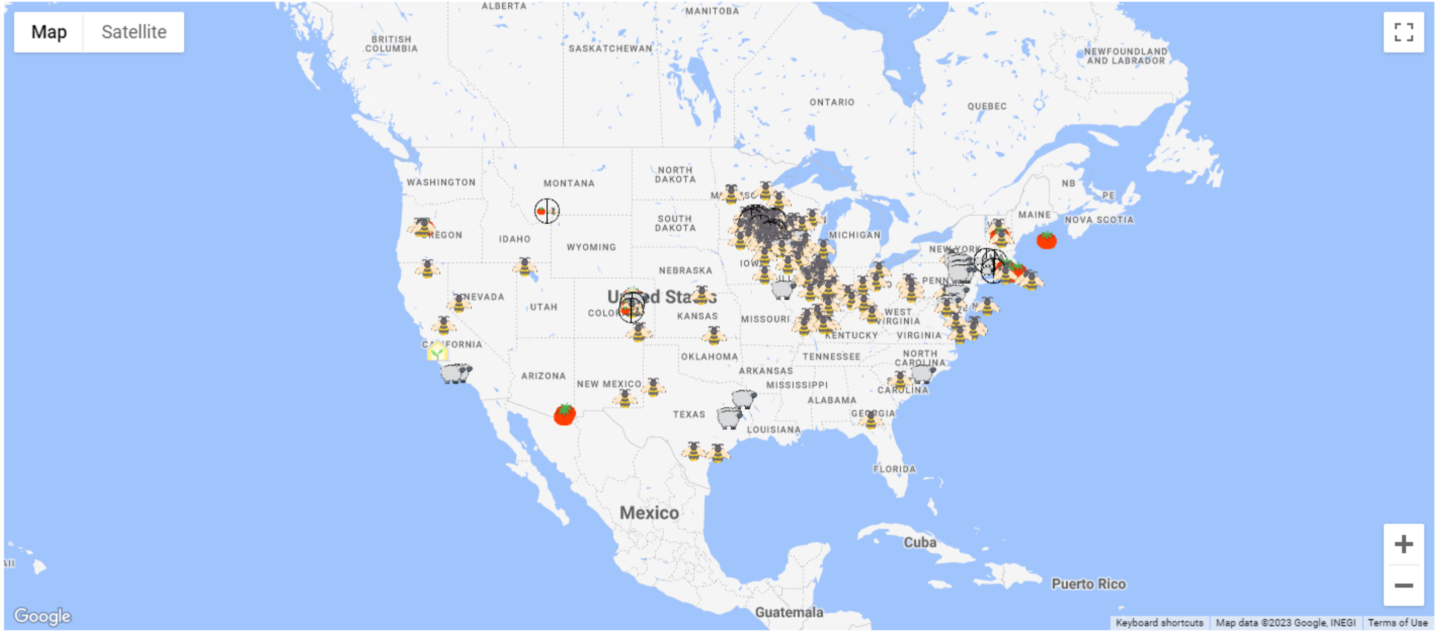
- [x] < 1 MW
- [x] 1-5 MW
- [x] 5-10 MW
- [x] >10 MW

Type of Array

- [x] Fixed
- [x] Single-axis Tracking
- [x] Dual-axis Tracking

Active Research

InSPIRE Research Site



Name	Agrivoltaic Activities	System Size (MWdc)	Site Size (Acres)	PV Technology	Type of Array	Ecosystem Services	Crop Type	Animal Type	Research Ongoing	InSPIRE Site	State
A (2019)	Ecosystem Services	1.3	9.25	Monocrystalline PV	Fixed	Pollinator					MN
Abel	Ecosystem Services	2.4	17			Pollinator Friendly			No	No	IL

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Contribute to the Agrivoltaics Map

Displayed Results: 54

Test Filters

Agrivoltaic Activities
- [x] Crop Production
- [ ] Ecosystem Services
- [x] Grazing
- [ ] Greenhouse

Photovoltaic Technology
- [x] Monocrystalline PV
- [x] Bifacial PV
- [x] Translucent PV

System Size MWdc
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- [x] 5-10 MW
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Type of Array
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- [x] Dual-axis Tracking

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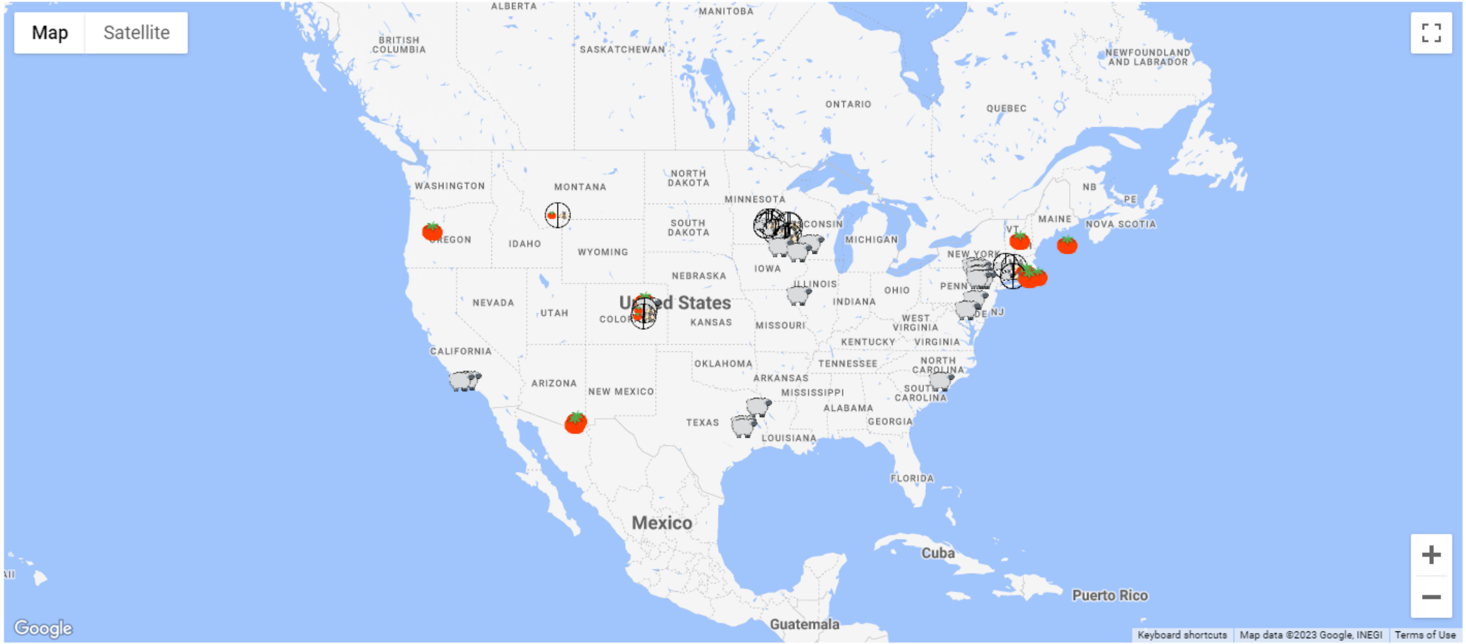

Name	Agrivoltaic Activities	System Size (MWdc)	Site Size (Acres)	PV Technology	Type of Array	Ecosystem Services	Crop Type	Animal Type	Research Ongoing	InSPIRE Site	State
Agard-enfield	Grazing	2.31	4.5	Monocrystalline PV	Fixed			Sheep			NY

InSPIRE

Primer | Financial Calculator | Data Portal | Map | The 5 Cs | Research | FAQ | Contact

Displayed Results: 314

Contribute to the Agrivoltaics Map

Test Filters

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- [x] Ecosystem Services
- [x] Grazing
- [x] Greenhouse

Photovoltaic Technology
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System Size MWdc
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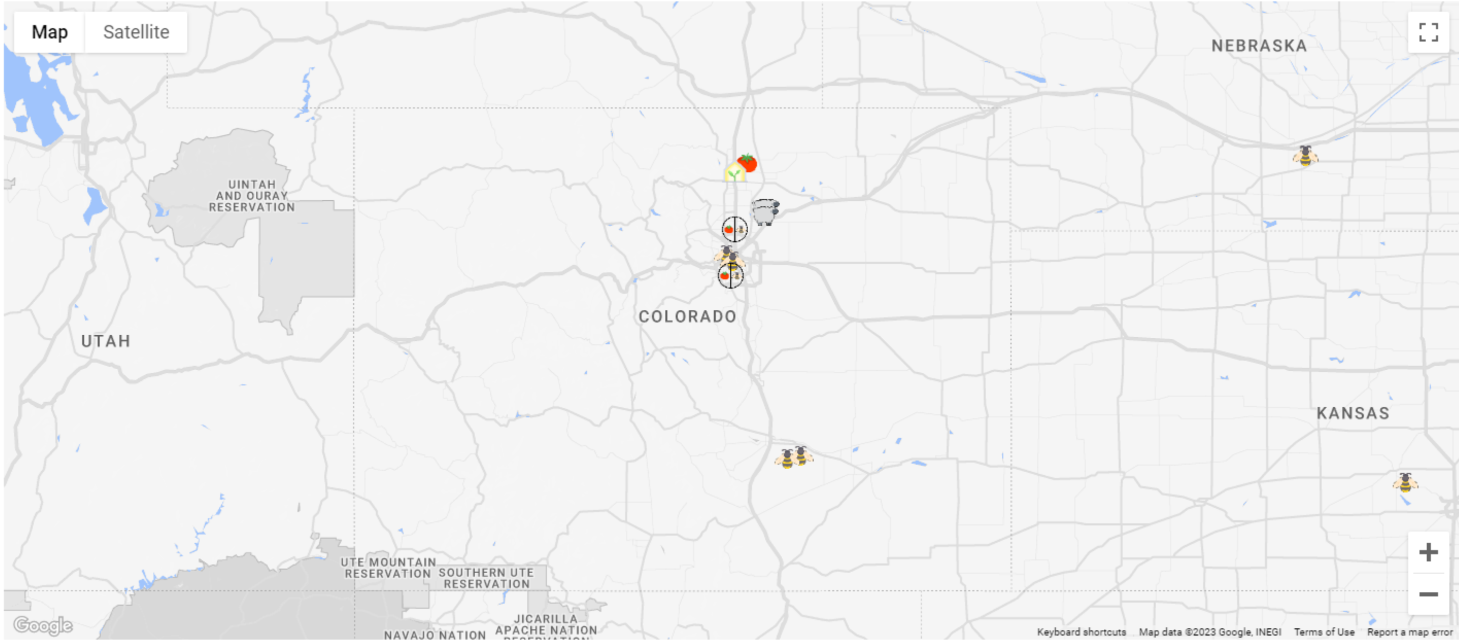

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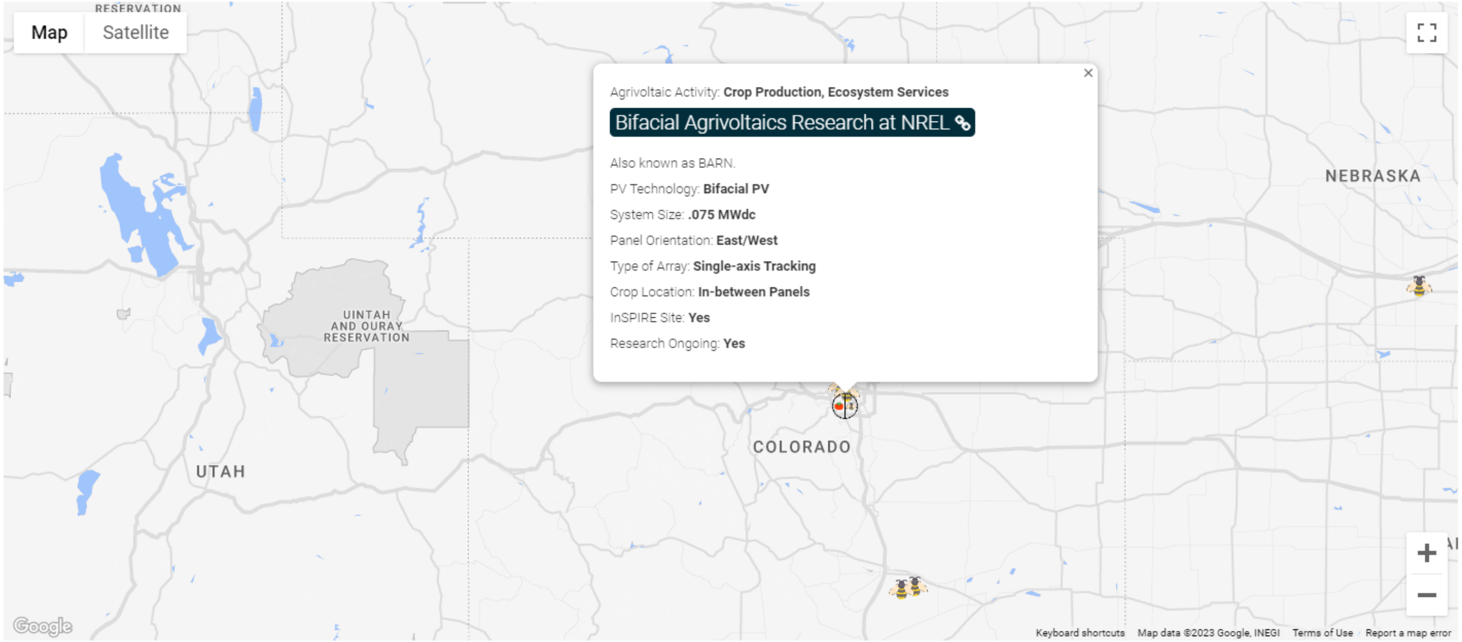

Name	Agrivoltaic Activities	System Size (MWdc)	Site Size (Acres)	PV Technology	Type of Array	Ecosystem Services	Crop Type	Animal Type	Research Ongoing	InSPIRE Site	State

Bifacial Agrivoltaics Research at NREL [edit]

Project Details

Also known as BARN.

Project Owner	NREL
Site Size	.3 Acres
System Size	.075 MWdc

Technology and Configuration Details

PV Technology	Bifacial PV
Type of Array	Single-axis Tracking
Panels Orientation	East/West

Agrivoltiac Details

Agrivoltaic Activities	Crop Production, Ecosystem Services
Crop Types	tomato, pepper, kale, basil, carrot, chard
Crop Location	In-between Panels
Irrigation	Yes

Research Details

Research Ongoing	Yes
Research Site	Yes

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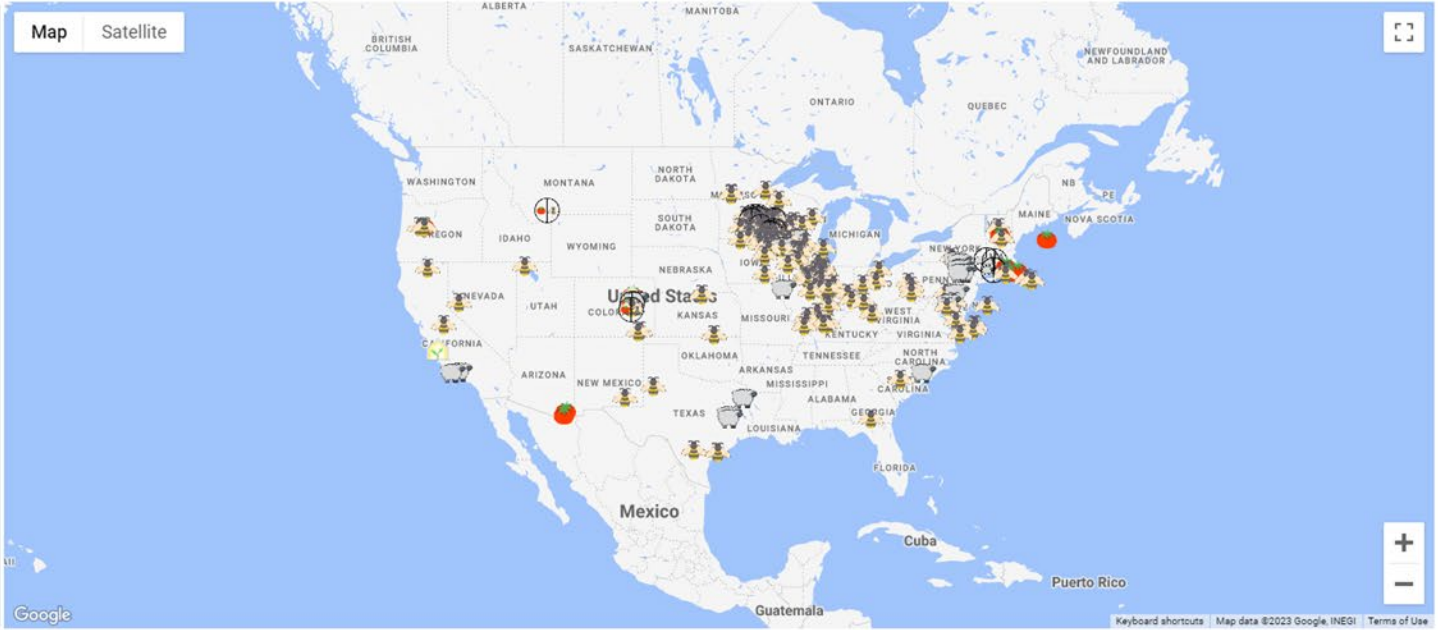

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Abel	Ecosystem Services	2.4	17			Pollinator Friendly			No	No	IL
Agard-enfield	Grazing	2.31	4.5	Monocrystalline PV	Fixed			Sheep			NY
Agawam	Ecosystem Services	1.8	9			Pollinator Friendly			No	No	MA
Albany	Grazing, Ecosystem Services	15.23	100.8	Monocrystalline PV	Single-axis Tracking	Pollinator		Sheep			MN
Alburgh	Ecosystem Services	1.2	6			Pollinator Friendly			No	No	VT
Alden Road Harvard Solar 1	Ecosystem Services	2.5	15.1			Pollinator Friendly			No	No	IL
All In Solar	Ecosystem Services	1.2	8.5		Single-axis Tracking	Pollinator Friendly			No	No	MN
American Bottoms	Ecosystem Services	2.2	6			Pollinator Friendly			No	No	IL
Ames Electric Services Power Plant	Ecosystem Services	2.2	10			Pollinator Habitat					IA
Annandale	Ecosystem Services	9.14	66.22	Monocrystalline PV	Single-axis Tracking	Pollinator					MN
Anoka County Solar Project	Ecosystem Services	4.6	23	Monocrystalline PV	Fixed	Pollinator Habitat, Native Vegetation			Yes	Yes	MN
Anoka Solar	Ecosystem Services	4.08	18		Fixed	Pollinator Friendly			No	No	MN
Arcadia DPC	Ecosystem Services	6	7			Pollinator Friendly			No	No	WI
Arcadia Solar	Ecosystem Services	6	30			Pollinator Habitat					WI
Ash Ridge	Ecosystem Services	0.72	5.4			Pollinator Friendly			No	No	WI
Athens Solar	Ecosystem Services	7.92	40.3		Fixed	Pollinator Friendly			No	No	MN
Atwater - O	Ecosystem Services	5.89	26.1	Monocrystalline PV	Single-axis Tracking	Pollinator			Yes	Yes	MN
Auburn Renewables Solar Array	Ecosystem Services	14.7	55		Fixed	Pollinator Habitat			Yes		IN
B&B Solar	Ecosystem Services	1.2	6.9		Single-axis Tracking	Pollinator Friendly			No	No	MN

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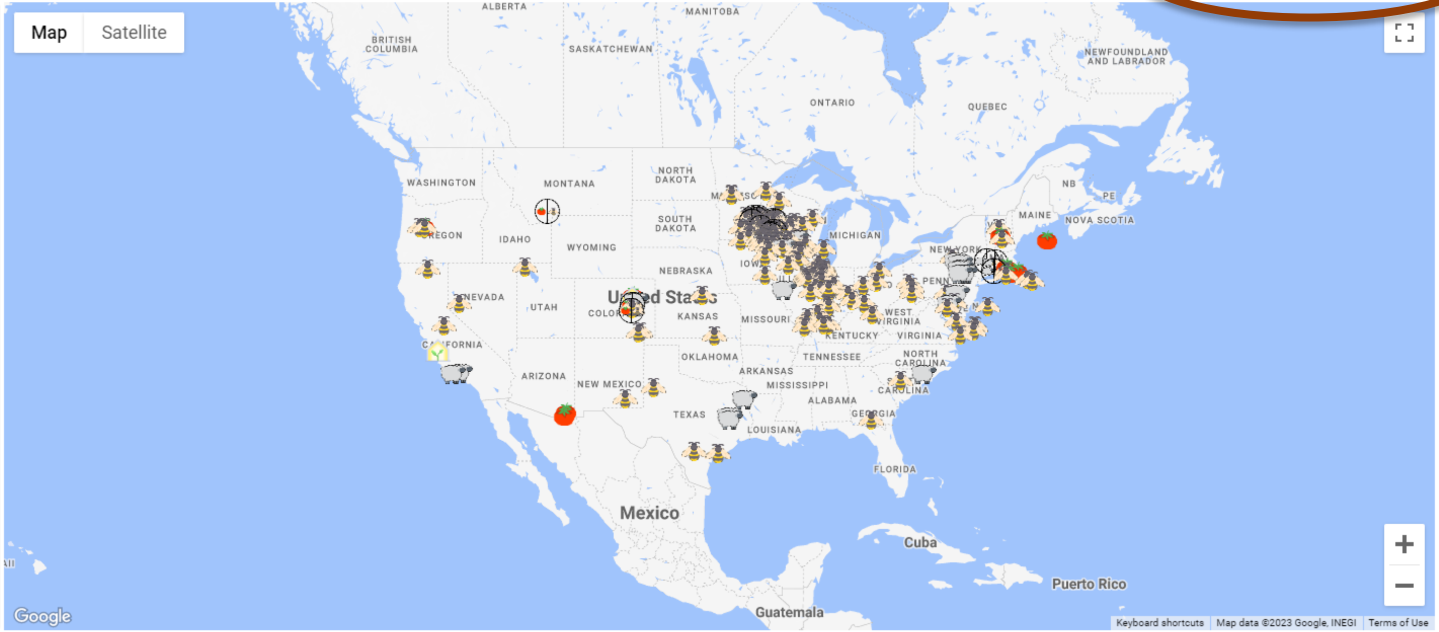

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How to Contribute to the Agrivoltaics Map

Add an **Agrivoltaic Site**

Have an agrivoltaic site you would like to add to the map now?

Want to edit an existing site?

Contribute to our map now

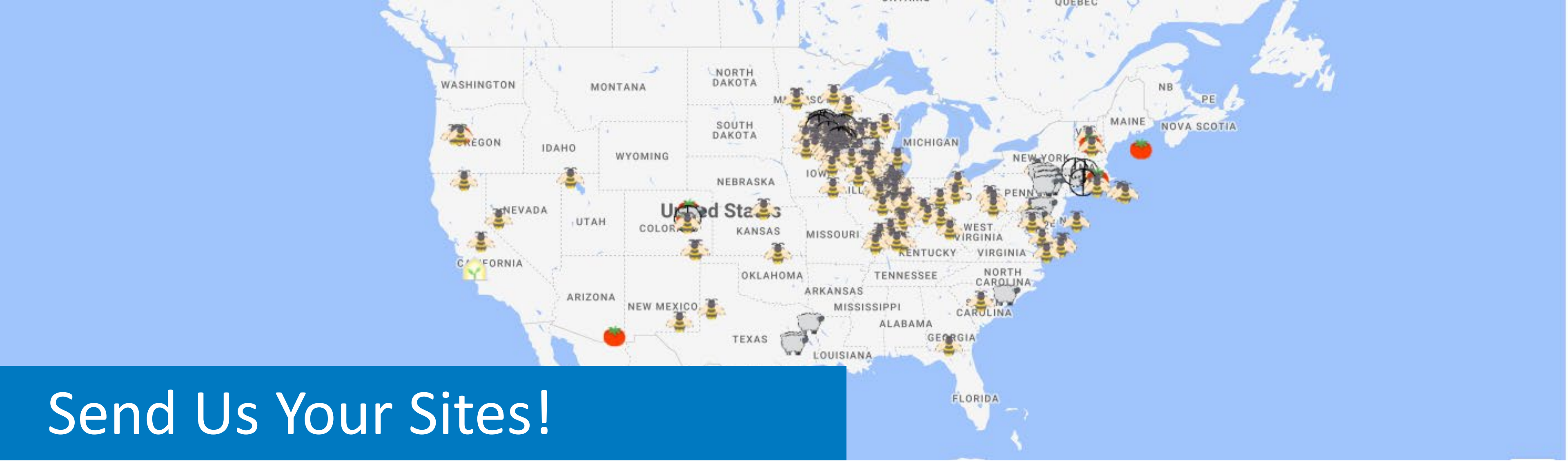
Have an agrivoltaic site you would like to send us that will be reviewed and then added to our map?

Submit map data for review

Have a large amount of agrivoltaic sites that you would like to submit for review?

Email Jordan Macknick

Can also email haley.paterson@nrel.gov



Send Us Your Sites!

- While 314 sites across 30 states is an excellent start (and the largest repository we know of), we know there are more sites out there!
- Notice a missing site? See any errors? Please let us know!

Haley.Paterson@nrel.gov
Map Link: https://openei.org/wiki/InSPIRE/Agrivoltaics_Map
Contribute Link: https://openei.org/wiki/InSPIRE/Agrivoltaics_Map/Contribute

NREL
Transforming ENERGY

Agrivoltaics O&M Cost Modeling and Comparisons

James McCall

Photo by Dennis Schroeder, NREL 55200

Purpose

- Quantify O&M cost impacts for different ground cover types
  - Gravel
  - Turfgrass
  - Native/pollinator habitat
  - Grazing
- Establish ranges for different O&M practices to assist in cost modeling
- Determine cost drivers for overall vegetation management
- Qualitatively examine industry perception of different covers and O&M implications

Overview of O&M Modeling Efforts

- Data collected from June 2019 to April 2020
  - Surveys, company outreach, and invoice review from project partners
- Companies surveyed
  - PV owner/operators
  - O&M service providers
  - Vegetation management contractors
- Costs collected by activity ($/kWdc-yr or $/acre-yr)
  - Mowing
  - Herbicide application
  - Weeding
  - Tree trimming
  - Grazing
  - Fencing
  - Site monitoring and vegetation management

Site Characteristics

a.

Region	count	percent
Pacific West	3	6
Plains	0	0
Midwest	36	67
Northeast	11	20
Southeast	4	7
	54	*100*

b.

Site size	count	percent
<=5 acres	4	7
6-10 acres	9	17
11-20 acres	6	11
21-50 acres	19	35
>50 acres	16	30
	54	*100*

c.

Hydrology	count	percent
Dry	12	22
Mesic	24	44
Wet	10	19
Not reported	8	15
	54	*100*

d.

Panel type	count	percent
Fixed	29	54
Tracking	24	44
Not reported	1	2
	54	*100*

e.

Panel height	count	percent
<=18"	14	26
19-24"	12	22
25-30"	16	30
31-36"	10	19
Not reported	2	4
	54	*100*

f.

Row distance	count	percent
<=20'	15	28
21-24'	3	6
25-28'	22	41
29-32'	5	9
>32'	1	2
Not reported	8	15
	54	*100*

g.

Practice	count	percent
Native vegetation/ pollinators	28	52
Sheep grazing	15	28
Turf grass	9	17
Gravel	2	4
	54	*100*

h.

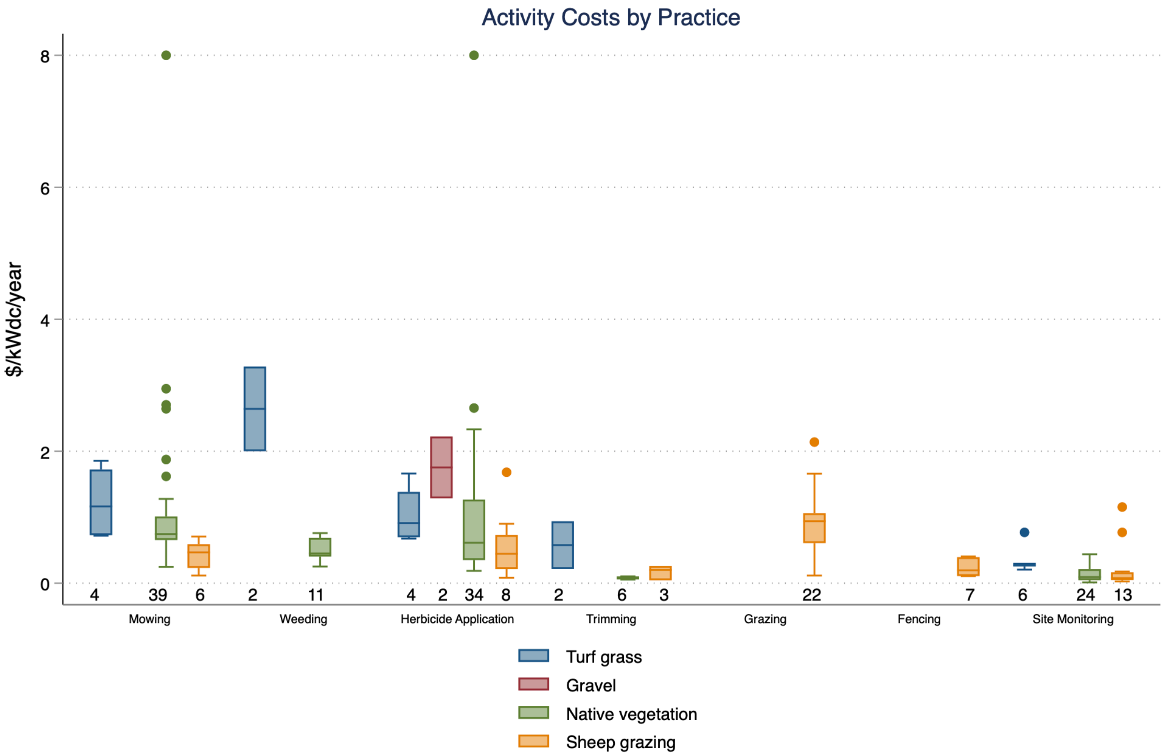
Year started	count	percent
2012	1	2
2013	1	2
2015	1	2
2016	8	15
2017	23	43
2018	12	22
2019	7	13
Not reported	1	2
	54	*100*

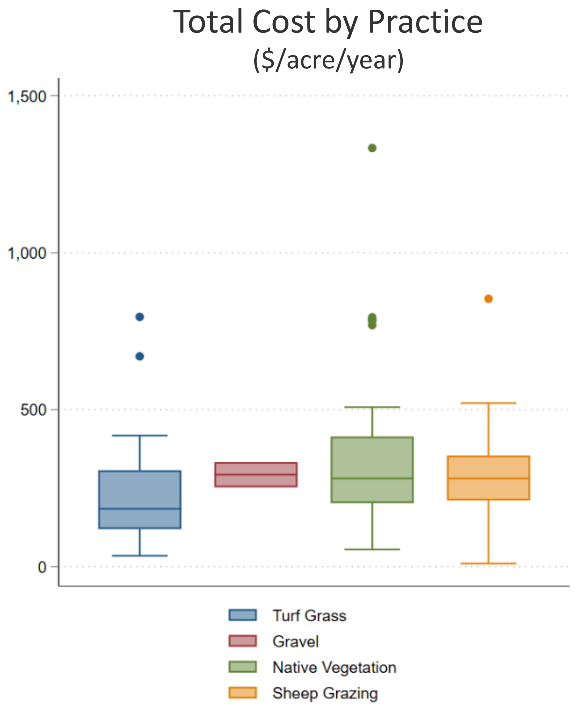
i.

Previous land use	count	percent
Agriculture	25	46
Ag, partially wooded, and/or wetland	17	31
Misc (abandoned ag, hay, open/wooded)	4	7
Landfill	1	2
Not reported	7	13
	54	*100*

Illustrative results—do not cite

Results – cost by activity and ground cover





Preliminary results—do not cite

Key Takeaways

- Overall, average total O&M cost across groundcover types is comparable
- Even though cost is comparable, different groundcover involve different types and frequency of activities
  - Demonstrated in wide variation in mowing costs – respondents noted $30-200/acre for mowing costs across regions
- Panel height doesn’t have a big impact on O&M costs, but fixed panels lead to more expensive trimming/mowing costs than tracking panels
- Vegetation establishment had impact on timing of costs and O&M events
  - More O&M costs up front to establish vegetation, but reduces after 3-5 years
- Weed control and mowing are main early O&M costs
  - Numerous respondents mentioned continual seeding before, during, and after reduced seeding and herbicide costs
- For grazing, water hauling, fencing management, and herd management were cost drivers
  - Grazing plan (intensive and recharge vs rotational grazing) impacts costs

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InSPIRE Agrivoltaics Financial Calculator

James McCall

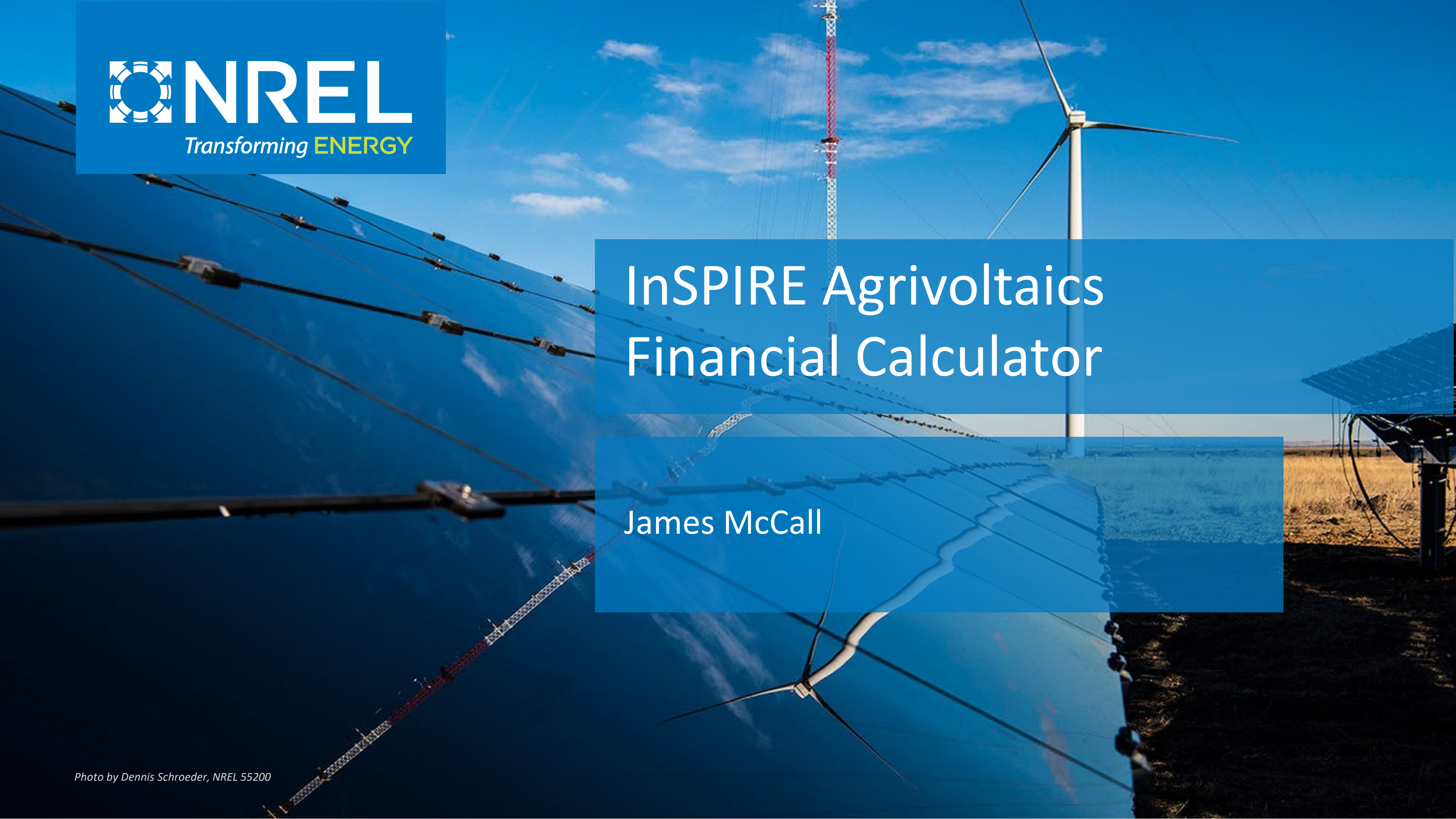
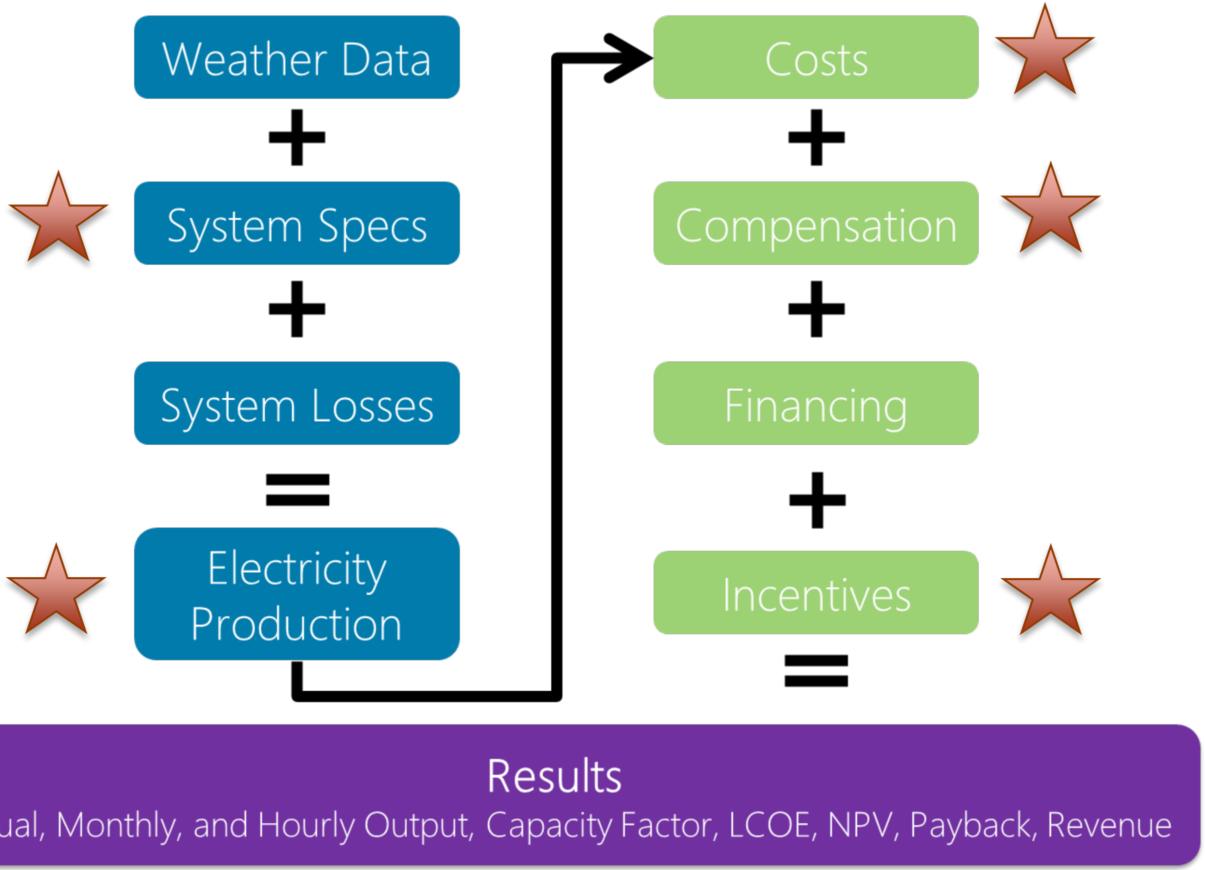


Photo by Dennis Schroeder, NREL 55200

Background and Motivation

- Growing interest in agrivoltaics from landowners, farmers, solar industry and others
- Agrivoltaic configurations can vary drastically, as can their installed cost, energy generation, and compatibility with farming
- There is no consistent, publicly available tool that can robustly provide solar cost and generation estimates for agrivoltaics
- Agrivoltaic crop modeling is still maturing and has ample room for improvement, but solar costs are better understood
- Build on prior success of NREL’s SAM tool

Steps to Modeling Renewable Energy



Capital Cost Factors for Agrivoltaics

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

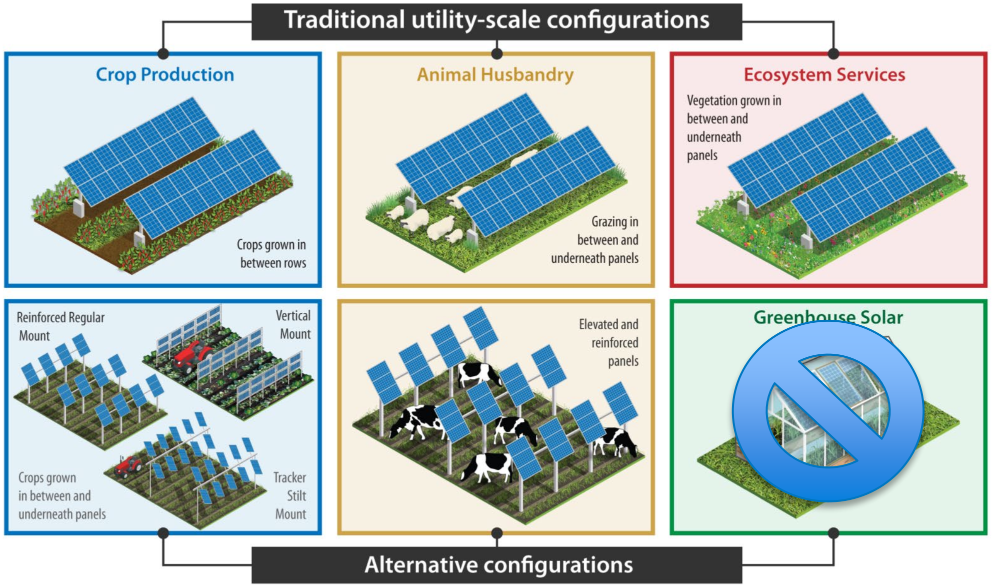
Figure 3. PV installed system costs for each dual-use scenario with benchmark assumptions for a PV system with 500 kW rated power

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.

Results are for 500-kW systems. Results can vary at lower and higher installed capacities

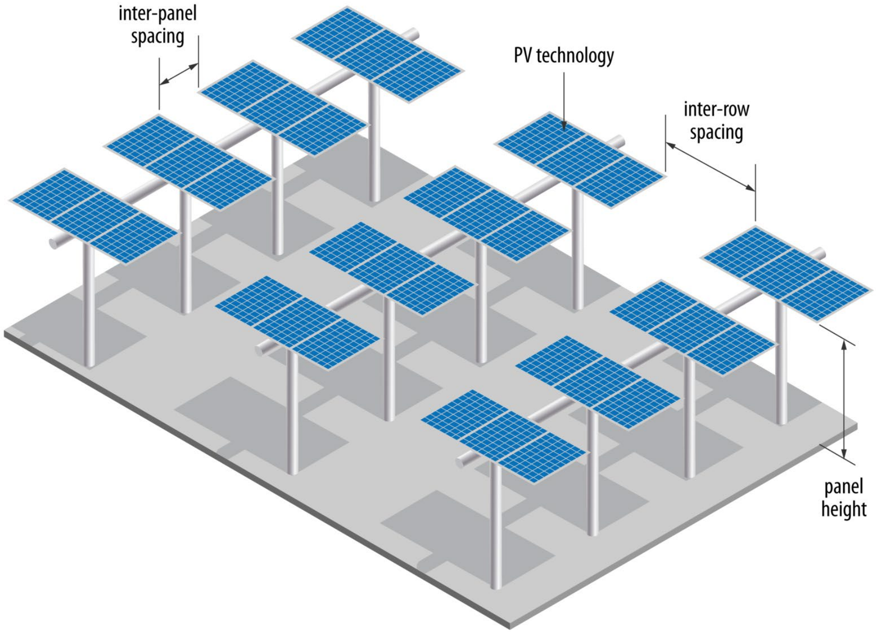
Kelsey Horowitz, Vignesh Ramasamy, Jordan Macknick and Robert Margolis. 2020. *Capital Costs for Multi-Land Use Photovoltaic Installations*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77811

Scenario Options



Agrivoltaic activities modeled

Solar configuration options



InSPIRE Agrivoltaics Financial Calculator

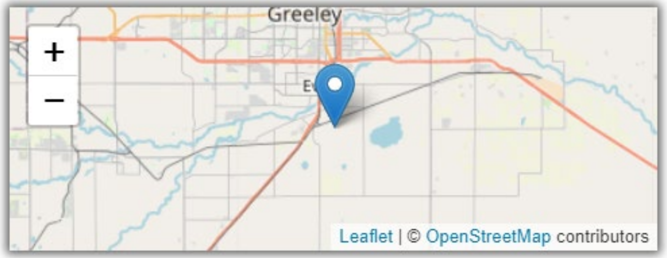
The InSPIRE financial calculator (https://openei.org/wiki/InSPIRE/Financial_Calculator) serves as the starting point for calculating economic viability of agrivoltaic projects

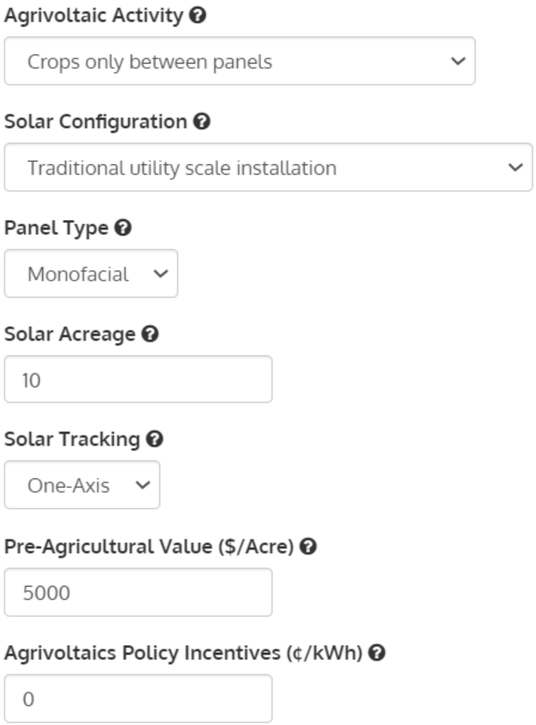
Adapts available tools (e.g., System Advisor Model [SAM]) plus latest data (e.g., capital cost and O&M studies) for easy-to-use, online co-location techno-economic assessment tool

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



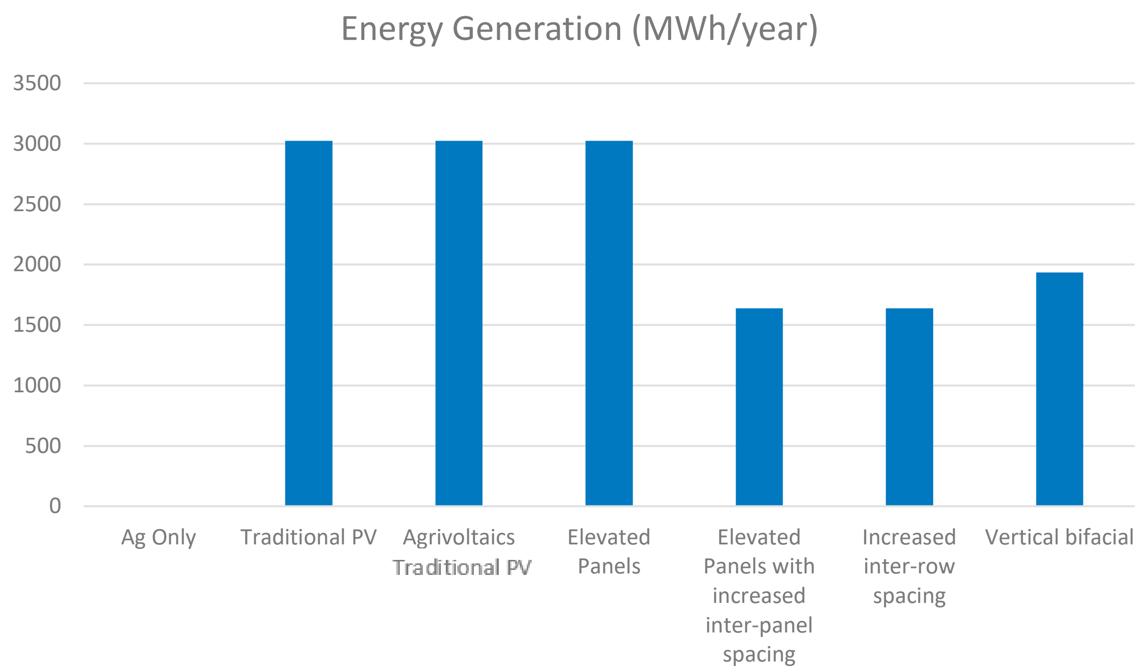


Example Results – Traditional PV and Crops

Results

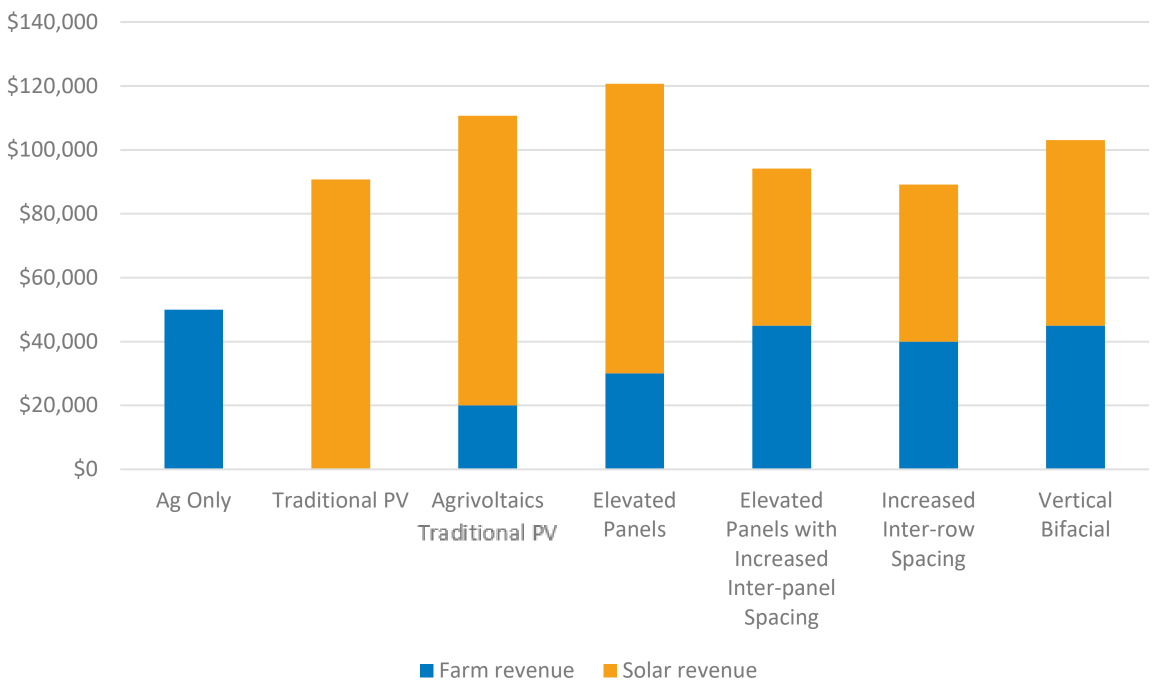
	Agriculture Only	Traditional Utility Scale PV Only	Agrivoltaics
Farm Revenue ($/yr)	50,000	-	20,000
Solar Revenue ($/yr)	-	90,723	90,723
Total Revenue ($/yr)	50,000	90,723	110,723
System Cost ($/W)	-	2.08	2.08
Total System Cost ($)	-	3,536,250	3,536,250
Break Even Year	-	N/A	N/A
NPV ($)	-	-1,791,364	-1,554,766
IRR (%)	-	-4.22	-0.94
Solar Capacity (kW-dc)	-	1,694	1,694
Capacity Factor (%)	-	20.36	20.36
Annual Energy Production (kWh/yr)	-	3,024,117	3,024,117

Comparison – Energy Generation



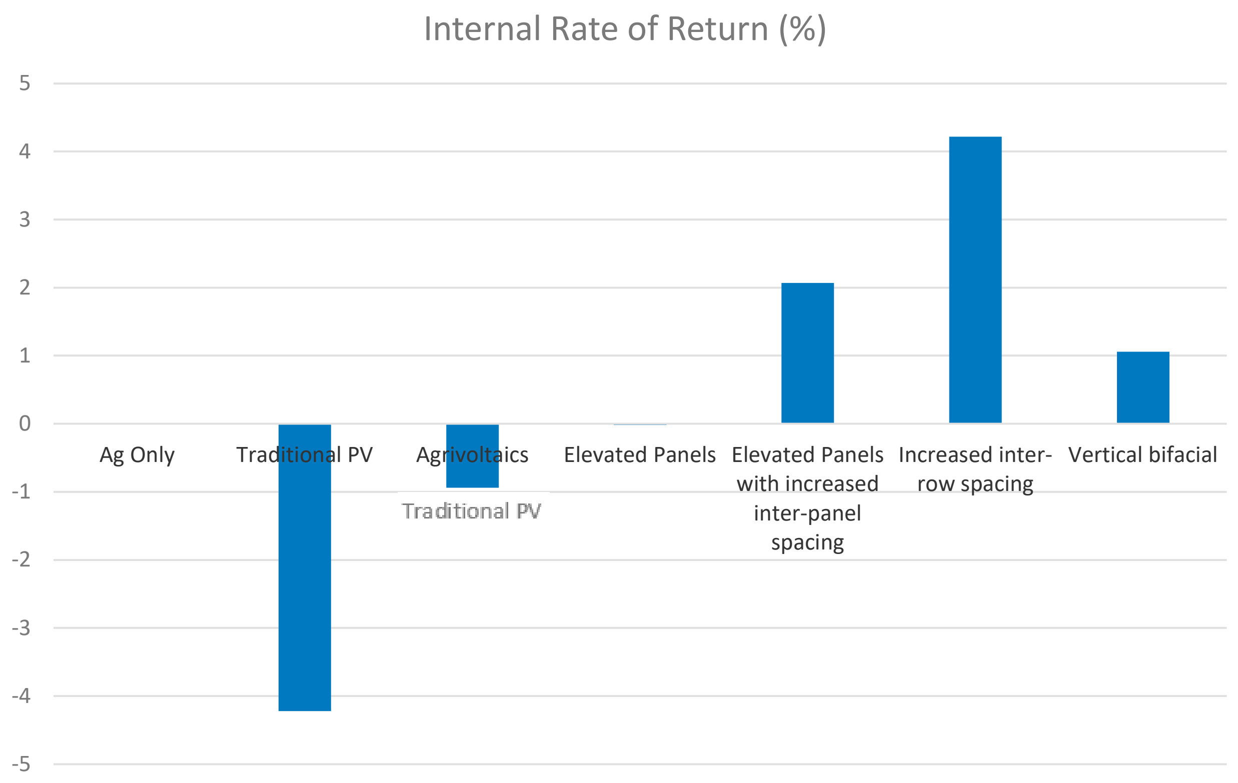
Illustrative results—do not cite

Comparison – Revenue per year



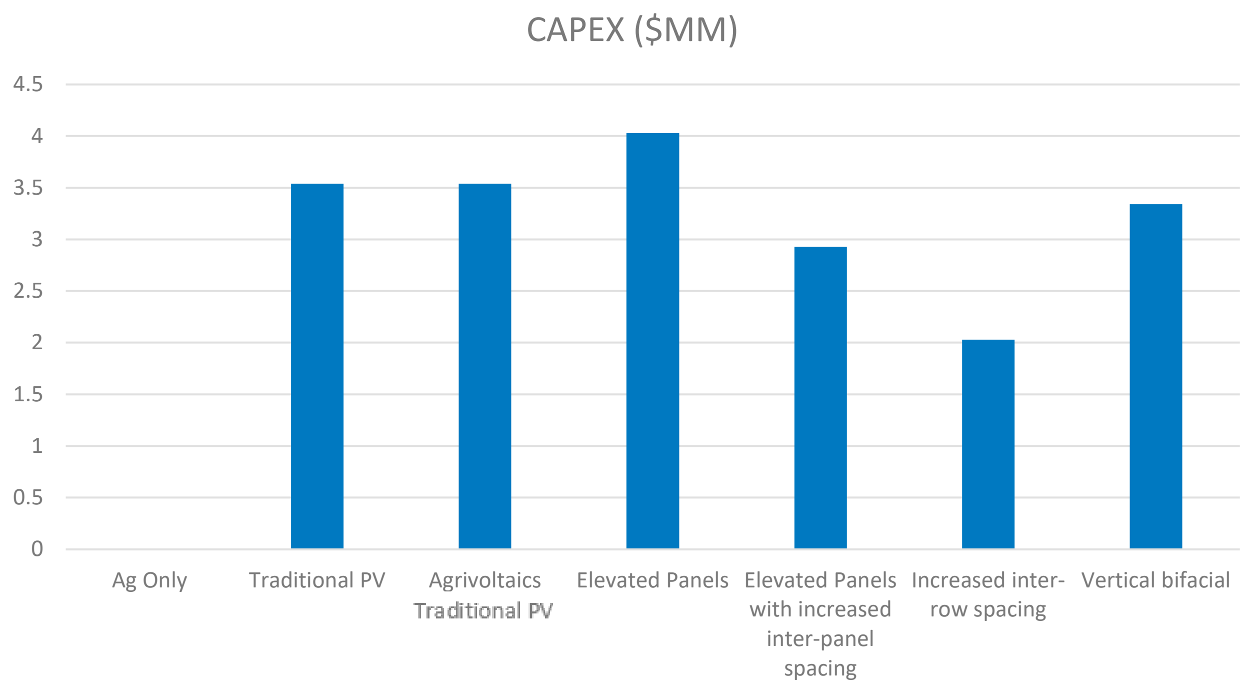
Illustrative results—do not cite

Comparison – Internal rate of return



Illustrative results—do not cite

Comparison – Solar Install Cost



Illustrative results—do not cite

Next Steps

- Update user interface to enable different scenarios
- Create visualization and comparisons graphics for results
- Update financial calculator with real-world cost, crop, performance, and electricity cost data
- Continue to refine model to represent different systems

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InSPIRE Data Portal

Photo by Dennis Schroeder, NREL 55200

Background & Motivation

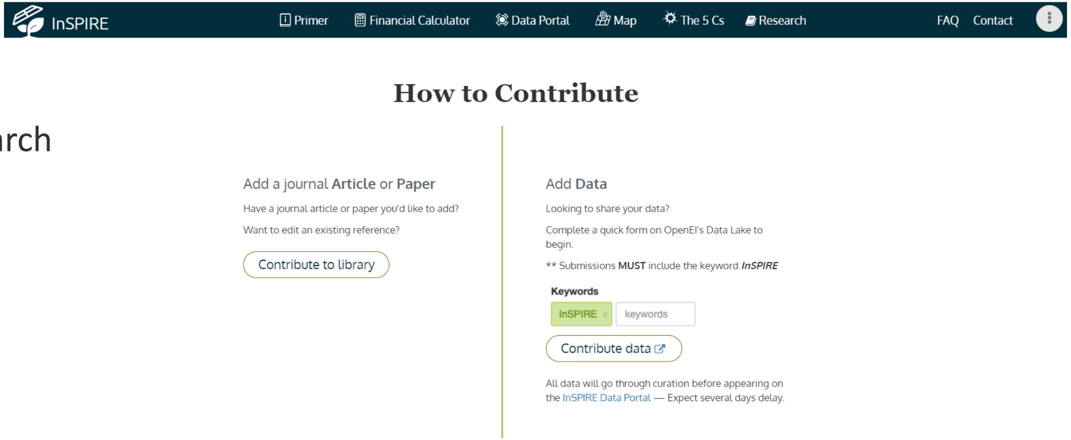
- Why do we need an Agrivoltaics Data Portal?

- The field of agrivoltaics research is rapidly developing across the globe
- There is no central repository for tracking and understanding recent agrivoltaics research
- Clearly organized research papers as well as datasets could improve the quality and impact of agrivoltaics research

https://openei.org/wiki/InSPIRE/Data_Portal

Methods

- **Research Paper Identification**
  - Exhaustive searches through online research, Google Scholar, paper bibliographies to identify and track relevant research papers

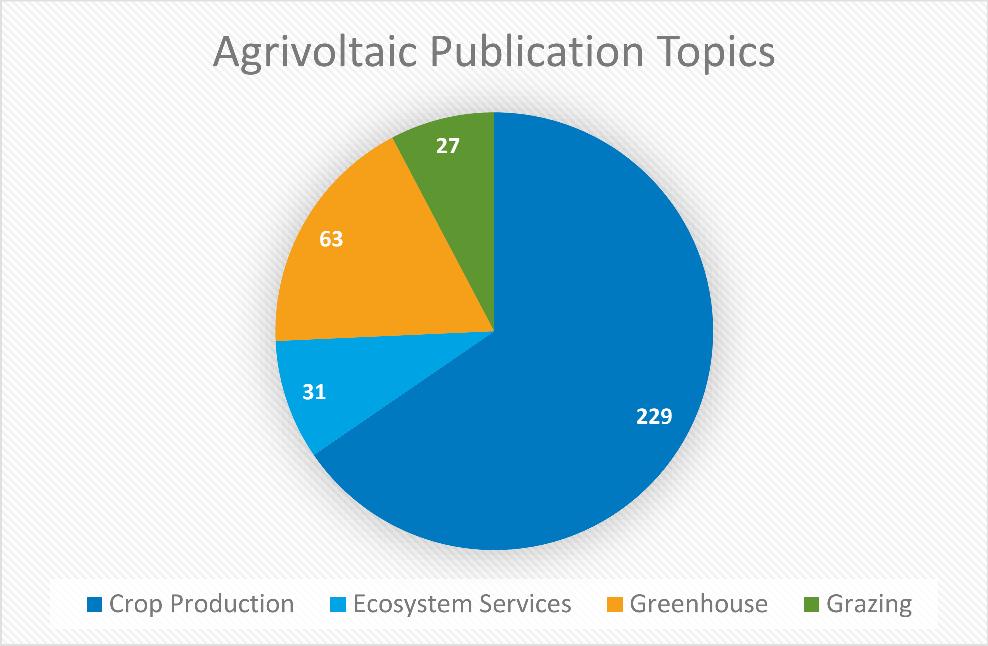


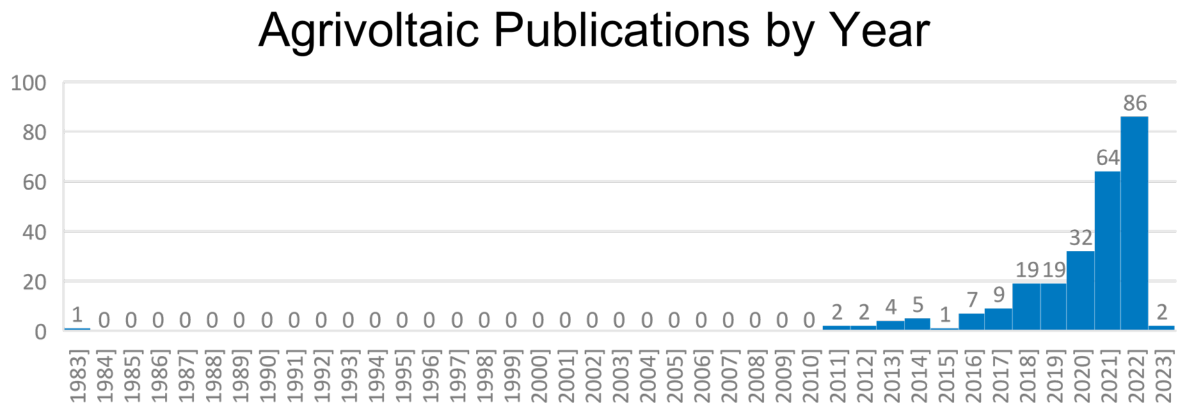
- **Evaluation and Categorization**
  - Systematic approach to characterizing research paper by multiple qualities, including:
    - Agrivoltaic activity
    - Research approach
    - Geography
    - Publication type

- **Data Portal Upload**
  - Standardized approach
  - Online entry forms

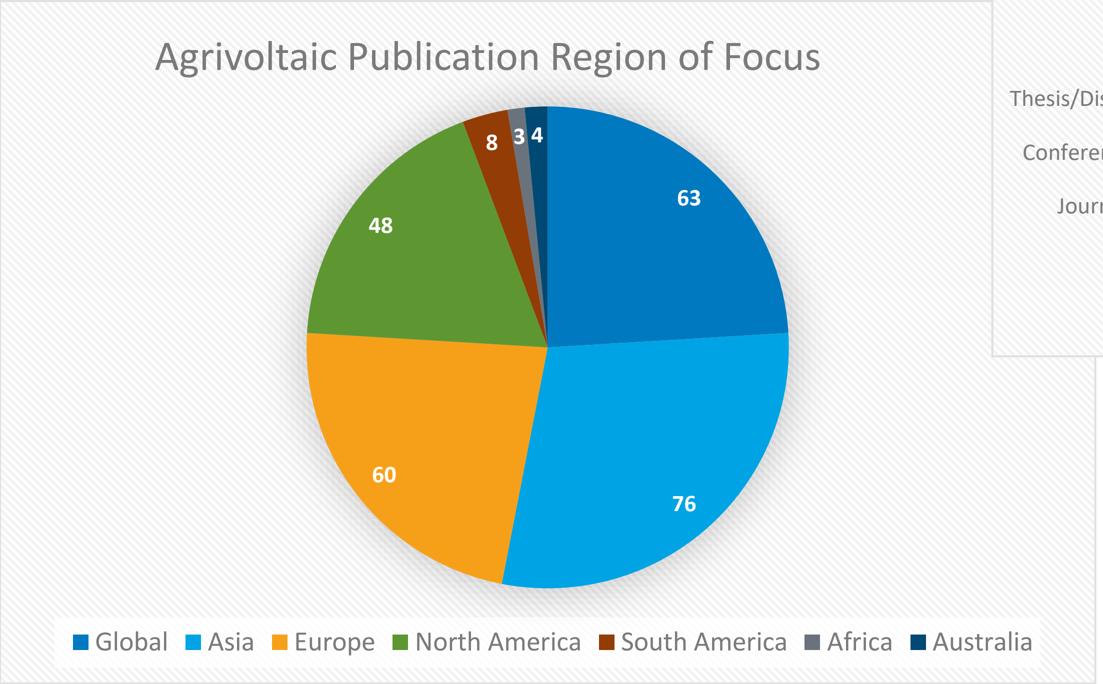
How many agrivoltaic research papers are on the InSPIRE Data Portal?

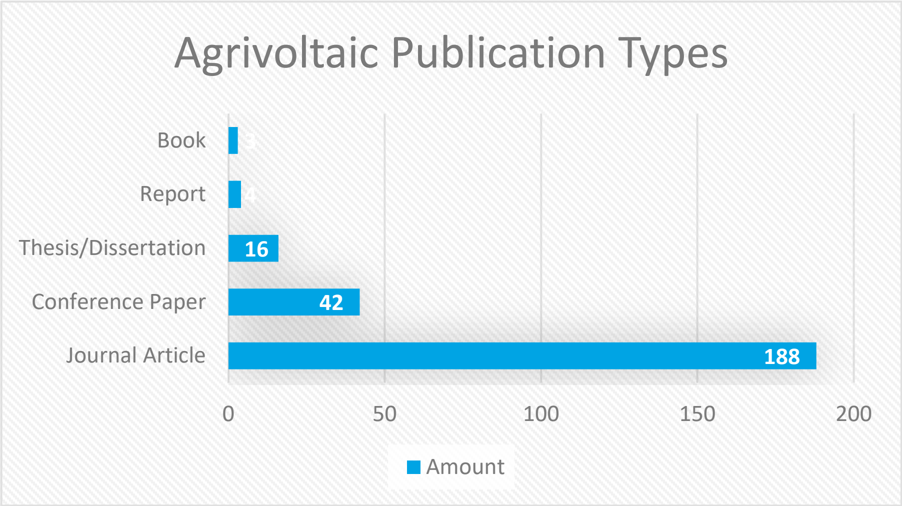
Totals of the Data Portal (so far): 250+ papers





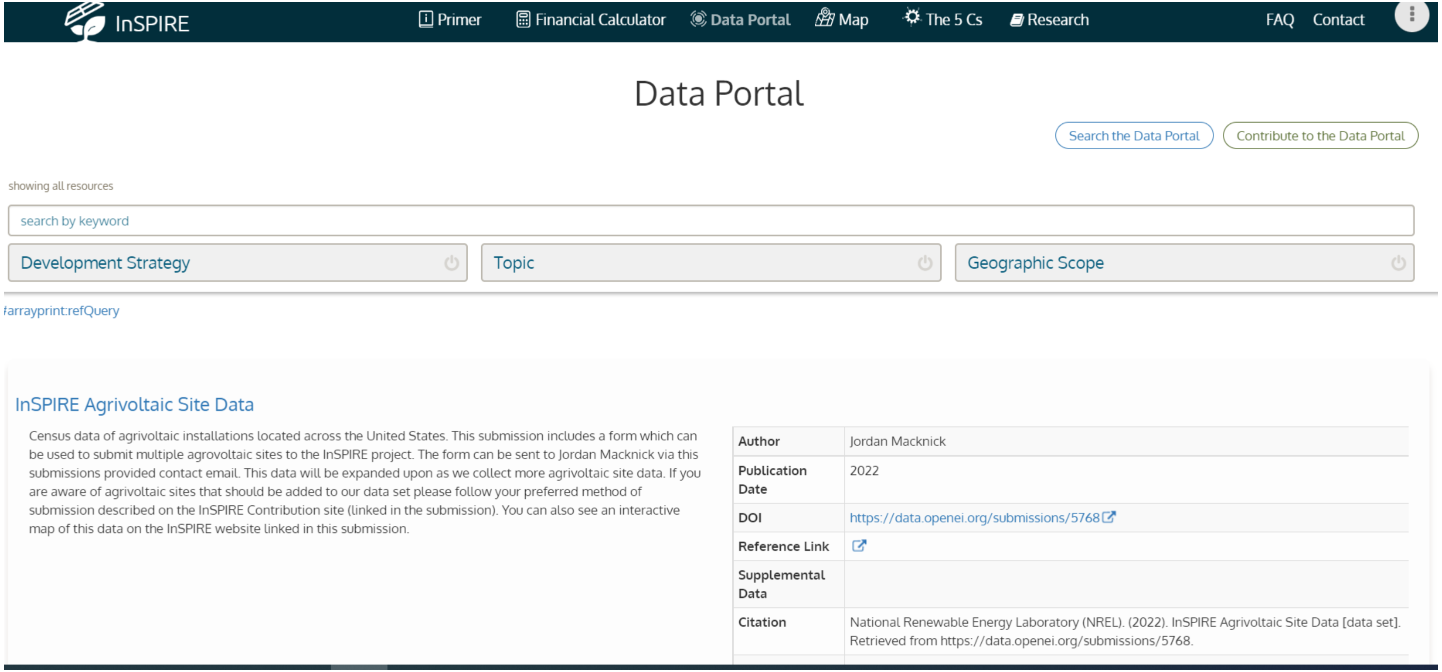
Agrivoltaic publication types and regions





Data Portal Updates

- Data portal is constantly being updated with new resources
- Next steps include adding datasets from agrivoltaic research sites



https://openei.org/wiki/InSPIRE/Data_Portal

ASTRO Advisory Group

Research and Outreach Advisory Group

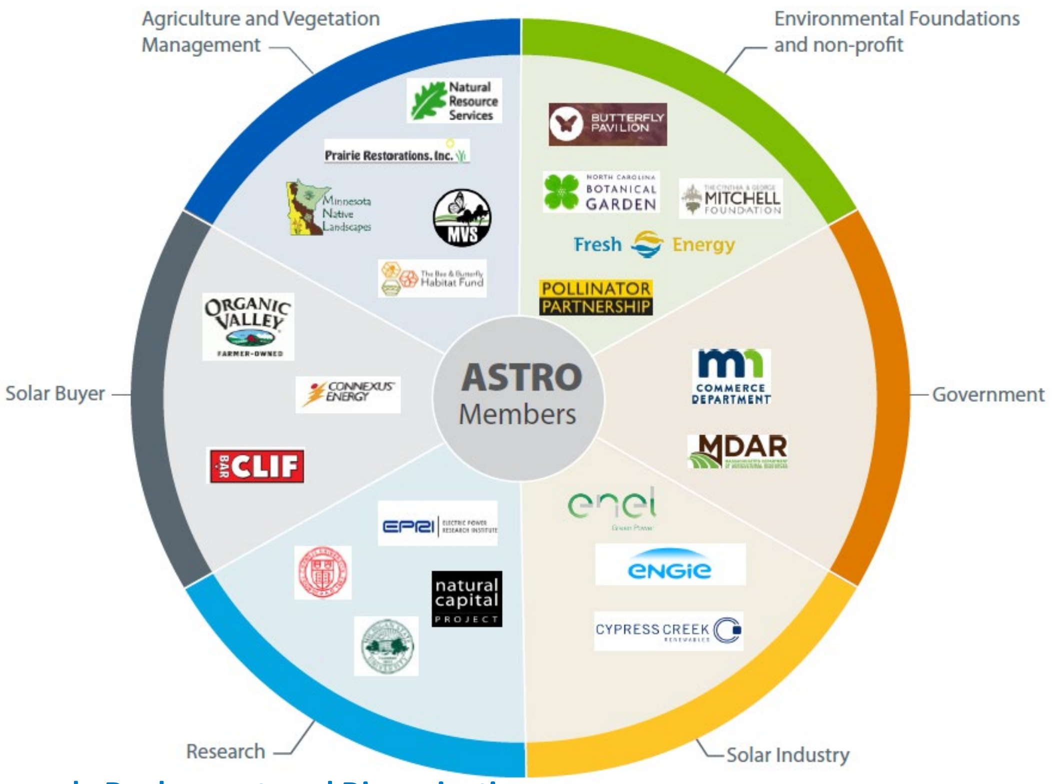
Quarterly Zoom calls since Jan 2019

Feedback on research directions and study designs

Development of new InSPIRE research sites and activities

Coordinated outreach activities

Seed grant dissemination

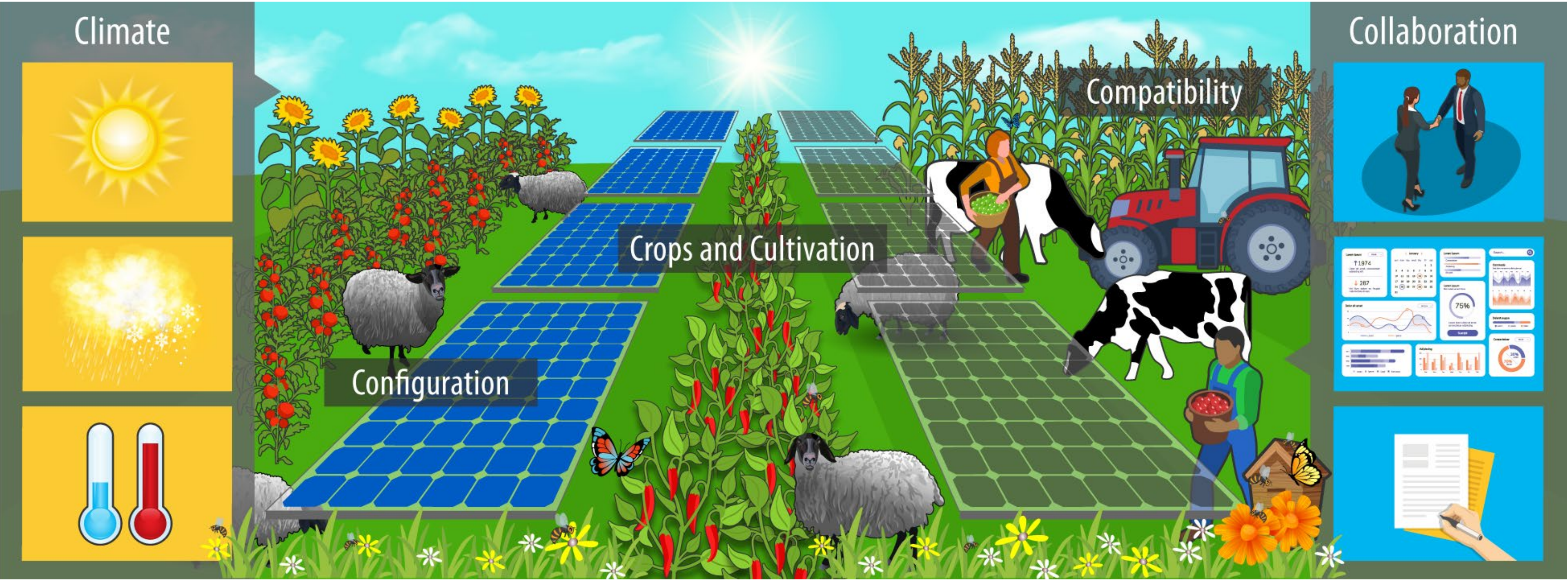


New publication:

[ASTRO: Facilitating Advancements in Low-Impact Solar Research, Deployment, and Dissemination](https://doi.org/10.2172/1882388)

https://doi.org/10.2172/1882388

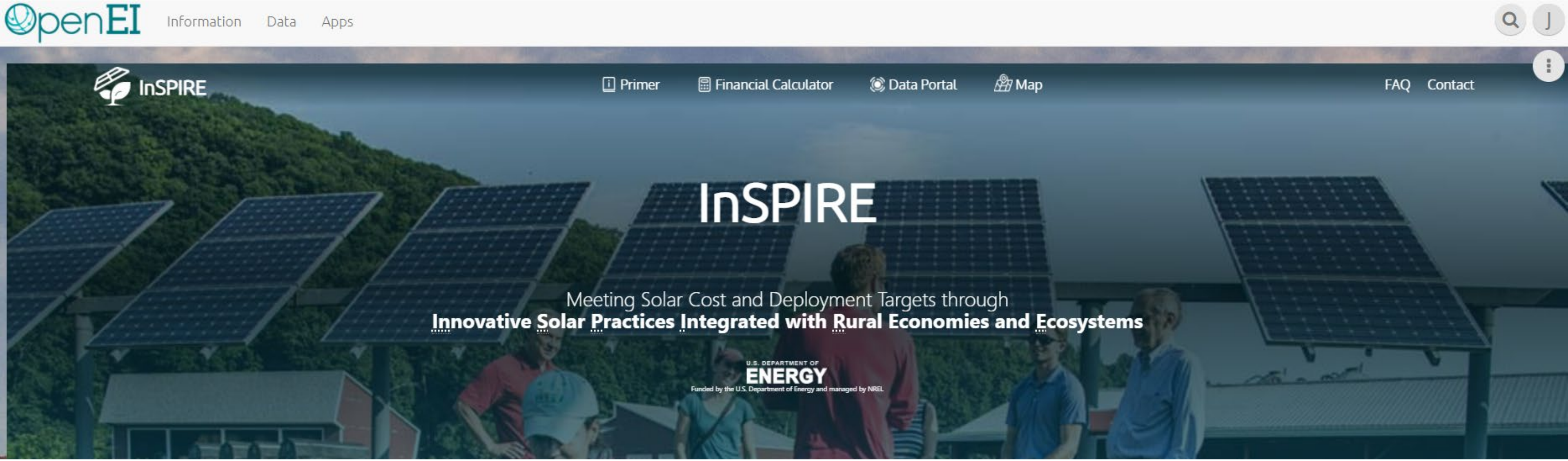
The 5 C's of Agrivoltaic Success



New Publication:

Macknick, Jordan, Hartmann, Heidi, Barron-Gafford, Greg, Beatty, Brenda, Burton, Robin, Seok-Choi, Chong, Davis, Matthew, Davis, Rob, Figueroa, Jorge, Garrett, Amy, Hain, Lexie, Herbert, Stephen, Janski, Jake, Kinzer, Austin, Knapp, Alan, Lehan, Michael, Losey, John, Marley, Jake, MacDonald, James, McCall, James, Nebert, Lucas, Ravi, Sujith, Schmidt, Jason, Staie, Brittany, & Walston, Leroy. The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study. NREL/TP-6A20-83566. https://doi.org/10.2172/1882930

Thank you!



InSPIRE website: https://openei.org/wiki/InSPIRE

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