# Harvesting Both Wealth and Sustainability: The Lucrative Promise of Agrivoltaics

*Growing crops and raising animals under solar panels helps cool down the Earth and gives us delectable food. But the question remains, are we truly prepared for such an innovation?*

April 1, 2024

Kyungdoe "Doe" Han

Postdoctoral Research Associate

Department of Civil and Environmental Engineering, University of Wisconsin-Madison, 1415 Engineering Dr., Madison, WI 53706

## Introduction

I am pleased to participate in the "Sharing UW-Madison Postdoctoral Scholarly Research with Non-Science Audiences" program, facilitated by the Wisconsin Initiative for Science Literacy (WISL). I recognize the dedication of the esteemed WISL team, including Cayce Osborne, Elizabeth Reynolds, and Professor Bassam Shakhashiri, significantly contributes to narrowing the divide between scientific research and the wider public.

As a postdoctoral researcher, my focus is on the water cycle, which tracks water's journey from rainfall to the earth, through rivers and lakes, into the ground, and eventually to the ocean or back into the atmosphere through evaporation. Human actions—like extracting groundwater, constructing roads and buildings, converting forests into agricultural land, and reshaping the landscape—significantly influence this cycle. Such activities can lead to drastic changes in local and regional water cycles, causing water scarcity in some places and flooding in others. The movement of water through the environment is governed by intricate processes. Nevertheless, by monitoring the variations in ground water absorption, we can gain insights into how human interventions affect the water cycle.

Agrivoltaics is an innovative approach that merges agriculture with solar power production, allowing for dual use of land to both grow crops and generate electricity, offering significant benefits to rural communities. However, since it's a relatively recent concept, the full scope of its environmental impacts is not yet completely understood. The effect of agrivoltaics on local water cycles can vary with the climate, potentially decreasing or increasing ground water absorption and surface runoff to bodies of water.

My ultimate goal is to achieve a balanced water cycle, ensuring the right amount of water is available for various needs. In arid regions, the focus is on preserving or increasing soil moisture for drinking and farming purposes, while in more humid areas, the objective is to mitigate excess water to enhance agricultural productivity. My research is dedicated to discovering this equilibrium, aiming to determine optimal practices that enhance the effectiveness of agrivoltaics.

The rise of sustainable energy and food sources has garnered significant support and enthusiasm, yet it also faces resistance from those skeptical about renewable energy due to concerns over aesthetics, vandalism, and the financial impact on families. My work as a researcher extends beyond the confines of the lab, embracing a collaborative effort to demystify scientific concepts for a broad audience. I believe that a thorough introduction to new technologies and their advantages can bridge the gap between researchers, policymakers, and the general public. Hence, in this article, I present the challenges to advancing sustainable energy initiatives, delve into agrivoltaics—a fusion of agriculture and solar power generation—and outline my research in this field. Additionally, I propose future directions that require collective support, emphasizing that achieving our goals in sustainable energy necessitates a united effort.


Concern is mounting over resistance to sustainable energy practices, particularly the establishment of solar farms in rural communities. Source photograph by Josh Arnold, UW-Madison Office of Sustainability.

## Sunlight Sabotage: The Rising Challenge of Solar Panel Vandalism

As the deployment of solar farms increases across the US, numerous concerns have emerged about the "sustainability of sustainable energy." Last year, vandals caused $160,000 in damage to solar panels in Arkansas, rendering them inoperable. Unfortunately, this trend is on the rise. Wisconsin has not significantly witnessed this trend, yet the number of rural community members opposed to the concept of renewable energy is growing.

A recent study by Dutch researchers, including Wouter Schram, uncovered that the main concerns about solar farms relate to their substantial land requirements, and the visual and auditory disruptions caused by panel installations. Additionally, University of Twente researchers Eugene Ikejemba and Peter Schuur have found that vandalism at solar sites in Saharan Africa is primarily motivated by theft, with destruction as a secondary outcome when theft attempts fail. However, in the US, another dynamic is at play: a backlash against technological advancement, often characterized as "rage against the machine."

Some people find the reflective panels, generally crafted from glass, metal, and crystalline silicon, to be an eyesore as they traverse rural landscapes, obscuring the picturesque views of farmlands and mountains. There's also a general aversion to the technology among some people. However, a significant concern highlighted by researchers from the Pacific Northwest National Laboratory, including Sharlissa Moore, centers on midwestern landowners and farmers' hesitation to repurpose their land for solar-only fields. The researchers point out that landowners are apprehensive about whether leasing their lands to solar farm operators will provide a sustainable livelihood for their children. Essentially, it boils down to a conflict between sustainable energy needs and also sustainable family livelihoods.

“Agrivoltaics” makes it possible to farm, raise animals, and keep bees in a way that's good for the planet. At the same time, farmers can still grow their crops and make a lot of electricity. Source photograph by Alliant Energy.

## What if you could farm and rent out your land at the same time?

So, the concept of "agrivoltaics" now becomes relevant. This term merges "agriculture" and "photovoltaics," with the latter referring to the technology of converting light into electricity, a nod to the Greek word "photo" for "light" and "voltaic" for electric currents. This is in homage to the renowned Italian physicist Alessandro Volta, the inventor of the electric battery.

That said, agrivoltaics involves both farming and generating electricity. But how does this work when your land is overshadowed by large solar panels? Here's how: First, plants don't need sunlight all the time; they only need it for part of the day. Second, many plants thrive in shaded areas, benefiting from reflected and diffused light. Third, solar farms don't cover the entire area with panels, so sunlight can still reach the ground underneath through reflection and diffusion. Fourth, modern panels and their foundation are designed to move; they tilt and even rotate to follow the sun, meaning the shaded areas shift throughout the day, allowing more sunlight to reach the ground. Therefore, agrivoltaics can transform solar farms into "real farms" by integrating agriculture into these areas.

Many authorities and companies don't actually own the land for solar power generation; instead, they frequently lease it from private or corporate owners. Typically, these leased lands are managed by the operating companies, meaning that the original landowners don't have unrestricted access to them. Landowners and farmers often express concerns about losing control over their lands through such leasing arrangements, especially when these areas are covered with panels and enclosed by fences and gates installed by solar operation companies. This situation might leave them feeling like Rapunzel, gazing out at lands they can no longer access. Adopting agrivoltaic practices allows landowners to maintain their traditional land use, ensuring they retain free access to their own land. This means farmers can continue to cultivate their crops and graziers can continue to graze livestock on the same land. So, they can generate a steady income from their crops, livestock, and honey production.

Researchers have shown that through the adoption of agrivoltaics, farmers can protect against 48-53% of losses in their worst yield years, while also generating consistent income from land leasing. Additionally, by selecting appropriate crop types and lighting strategies, farmers may achieve a 20 to 60% increase in their annual yields.

The discrepancy between the anticipated benefits and the real-world implementation of agrivoltaics stems from several factors. Primarily, agrivoltaics is a relatively new technology, and more research is necessary to discover the most effective methods for its application. Secondly, there is a lack of public awareness about agrivoltaics, underscoring the need for improved educational efforts to broaden understanding of the technology. Lastly, support and encouragement from state and local governments are crucial for promoting the adoption of agrivoltaics.

## Agrivoltaics for more money for you and cooler climate

In a recent report by the International Energy Agency (IEA), it was revealed that solar energy accounted for a mere 6% of global power needs in 2023. This figure is projected to surge to 30% by the year 2030, highlighting the growing significance of solar power in the global energy landscape. Despite these advancements, the adoption of agrivoltaic practices—combining agriculture and photovoltaics—remains largely experimental, with widespread implementation yet to be seen. Agrivoltaics hold promise for enhancing the benefits of solar farms by allowing for the simultaneous cultivation of crops, yet their full potential remains untapped.

The transition to agrivoltaics faces several hurdles that need addressing. Identifying crops that can thrive under reduced sunlight conditions near solar panels is a primary challenge. Researchers are in search of species that can tolerate shade while still yielding substantial growth, a quest that remains in progress. So far, kale, spinach, broccoli, sweet potatoes, and other crops have been identified as potential candidates for successful growth.

Moreover, the impact of altered microclimates created by solar panels on crop growth, soil health, and water dynamics is under investigation. These environmental variables present unique challenges that differ from traditional agricultural settings.

Another concern is the environmental footprint of expanding solar infrastructure. The effects of increased solar panel coverage on local ecosystems and water and air flow patterns are yet unknown, raising questions about the potential for either beneficial or detrimental outcomes. Additionally, the aesthetic and ecological impact of securing large-scale solar installations—with measures such as high fences and razor wire—poses a dilemma. Finding ways to integrate these energy producers into landscapes without harming ecosystems or disrupting the visual harmony of the surroundings is a critical issue that needs resolution.

As the world leans more towards renewable energy sources, the integration of agrivoltaics into the solar energy sector represents a promising frontier. However, overcoming these challenges is essential for realizing the full benefits of this innovative approach to sustainable energy and agriculture.

## Badgers Leading the Research on Agrivoltaics

Researchers at the University of Wisconsin-Madison are at the forefront of a groundbreaking initiative aimed at harnessing the dual potential of agrivoltaics. Our mission is to identify the perfect balance—or "Goldilocks areas"—where both solar power generation and agricultural yield are optimized on solar farms. This multi-faceted research effort spans several key areas, including the identification of crops that thrive under the shade of solar panels in Wisconsin's unique climate, the analysis of soil moisture and water flow alterations beneath these panels, and the evaluation of potential impacts on local climates. Furthermore, our team is dedicated to developing sustainable practices for agriculture and ranching that can coexist with solar energy production.

The detailed and thorough approach employed by the Badger research team, which includes my contribution, significantly enhances the long-term effectiveness and sustainability of agrivoltaic systems. My research focuses on understanding how agrivoltaic systems affect the water cycle. Water from rainfall naturally enters the earth's surface, with some of it flowing into rivers and lakes, while some seeps into the ground to become groundwater. This groundwater can either be stored in the soil or travel deeper to form larger bodies of groundwater, from which we can extract water. Plants play a crucial role in this cycle by absorbing water and releasing it back into the atmosphere as vapor.

The balance of groundwater depends on how efficiently plants use water; too much usage and we risk depleting groundwater levels, too little and we end up with an excess. Similarly, the ground itself re-emits water into the air through evaporation, a process that varies with the amount of sunlight exposure; shaded areas evaporate water more slowly than those fully exposed to the sun.

My study aims to dissect the intricate interactions among these elements within the context of agrivoltaics. This involves not just the factors mentioned, but also considering the impact of other elements, like wind speed and grazing activities, which can affect soil composition and, consequently, water cycles. By delving into these complex relationships, I hope to enhance our understanding of agrivoltaic systems, evaluating how they influence the water cycle and identifying optimal practices for their implementation. I plan to share the new findings and detailed results in my upcoming publications.

My initial research indicates that agrivoltaic system efficiency is heavily influenced by several factors, including panel placement design, soil type, vegetation and crop selection, and local climate conditions. These elements collectively determine the hydrologic changes resulting from agrivoltaics. Specifically, the regional climate plays a crucial role in dictating suitable crops for cultivation beneath solar panels, which in turn affects groundwater levels. This highlights the importance of tailoring agrivoltaic practices to local environmental conditions to optimize water usage and crop growth.

The scope of the Badger research encompasses much more than just the water cycle. It begins with the early phases of constructing solar arrays, with a keen focus on controlling erosion, and extends to preserving biodiversity by supporting pollinators and bees. Additionally, we meticulously monitor the annual water budget, which assesses the balance of water entering and exiting a specific area. This ensures that the incorporation of solar farms into the landscape has a beneficial impact on both the regional and global environment.

Under the leadership of figures like Steven Loheide, a Distinguished Professor of Water Resources Engineering at UW-Madison, the project is a beacon of interdisciplinary collaboration. In a recent interview with the Milwaukee Journal Sentinel, Loheide highlighted the diverse range of expertise involved in the project, from social sciences to physical sciences, biological sciences, law, and policy. This inclusive approach underscores the belief that effective solutions to the challenges of agrivoltaics will emerge from a broad spectrum of knowledge and perspectives.

My work with the University of Wisconsin-Madison sets a benchmark for sustainable development, aiming to make a substantial contribution to the global welfare of humanity. Through rigorous field studies, sampling, and laboratory experiments, our team, including myself, is establishing best practices in agrivoltaics. Our work transcends traditional boundaries of science and engineering, setting a precedent for future initiatives in sustainable energy and agriculture.

Changes in soil properties beneath the panels significantly influence the overall productivity and safety of an agrivoltaic farm. Professor Steven Loheide from the University of Wisconsin is sampling soil at the UW Kegonsa Research Campus in Stoughton, WI, to study these changes.
Source photograph by Mike De Sisti – Milwaukee Journal Sentinel.

## Future of Agrivoltaics

On May 31, 2023, a significant legislative step was taken toward a sustainable future with the passage of a bill introduced by Senators Heinrich (D-NM) and Braun (R-IN), showcasing a strategic plan for the integration and promotion of agrivoltaics, along with outlining research guidelines. This legislative move underscores the growing recognition of agrivoltaics as a pivotal solution for harmonizing the demands of energy production, agricultural activity, and environmental stewardship. Agrivoltaics represents a promising technological frontier that allows landowners to continue farming, energy companies to generate clean power, and municipal governments to benefit from the surplus electricity produced.

The bill emphasizes the importance of engaging farmers and landowners as key stakeholders in the agrivoltaic initiative, recognizing their critical role in the successful implementation of these systems. Public awareness and support are identified as essential elements, and the bill encourages policymakers to adopt more sustainable practices while fostering broader backing for ongoing research into agrivoltaics.

Furthermore, this legislative progress has opened new avenues for researchers, including myself, to delve into the details of agrivoltaics, exploring its benefits and challenges in depth. This initiative not only sets a high bar for sustainable development, but also promotes a collaborative effort towards achieving global environmental well-being through innovative technological solutions. My colleagues and I are eager to see the academic research funding opportunities that this bill will provide. This support is a significant boost, enabling us to continue our research by broadening our understanding of the environment. Given the high costs and competitive nature of research, the guidelines and funding provided by the bill are crucial for integrating more detailed and precise data into my studies.

To establish a sustainable, mutually beneficial framework, the bill suggests a collaborative approach among various parties: governments, energy companies, researchers, the general public, and landowners/farmers. It proposes that governments should facilitate the transformation of both unused and agricultural lands into solar farms. In turn, energy companies are encouraged to ensure the safety and reliability of data generation for research purposes. Researchers are tasked with leveraging this data to refine agrivoltaic practices, minimizing environmental impacts, and educating the public about the benefits of such systems. The bill's public announcement has facilitated my discussions with various stakeholders, including renewable energy companies, local farmers, governments, and journalists, to explore how to enhance the sustainability of agrivoltaics within the bill's framework. These conversations have allowed me to define precise research objectives and incorporate agrivoltaic stakeholders into my study. Importantly, this includes viewing landowners and farmers as active contributors to the upkeep and optimization of solar power generation, with responsibilities such as cleaning and dusting solar panels to boost efficiency and profitability.

For the long-term success and sustainability of agrivoltaic systems, the legislation suggests the development of a standardized contract model by the government. This contract would delineate the responsibilities and incentives for each stakeholder, promoting active participation and long-term commitment to the operational and environmental management of agrivoltaic sites. Furthermore, it recommends that federal and state governments support the expansion of agrivoltaics through tax credits and additional funding for farmers and solar developers. This approach aims not only to accelerate the adoption of agrivoltaic systems but also to ensure their contribution to a more sustainable and resilient future for energy, food production, and the environment.

I am grateful for the dedicated efforts of my colleagues in the field of agrivoltaics and the supportive legislative frameworks that propel the advancement of this pivotal technology. These contributions are instrumental in broadening the scope of my commitment to sustainable development. As we explore the intricacies of agrivoltaic systems more thoroughly, we are setting the stage for a future that promises greater sustainability and reduces humanity's dependence on natural resources. Being a part of this transformative project fills me with pride, as I recognize its potential to effectuate substantial improvements in our quality of life. With unwavering commitment, I am devoted to advancing this technology, ensuring that it serves as a legacy for future generations, fostering a more sustainable and resource-efficient world.

Groundbreaking utility-scale agrivoltaics farm set for construction at UW-Madison's Kegonsa Research Campus Solar Facility, Stoughton, WI. Source rendering by Ayres Associates draft Environmental Impact Assessment.

About the author

Kyungdoe "Doe" Han (He/His/Him) serves as a Postdoctoral Research Associate at the Hydroecology Lab within the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison. Having earned his PhD in hydrology from the New Mexico Institute of Mining and Technology under Professor John Wilson's mentorship, he is now dedicated to investigating the hydrological changes triggered by agrivoltaics, with a special emphasis on groundwater dynamics. Doe's background includes work on carbon sequestration and paleohydrologic reconstruction, employing numerical simulation methods across the board. He boasts over twelve national and international patents and has been honored with the Silver Medal at the Salon International des Inventions de Genève for his development of an autonomous vegetation growth monitoring system. His current projects are conducted under the guidance of Professor Steven P. Loheide II and benefit from the support of the UW-Madison Research Forward initiative and grants from the Wisconsin Department of Natural Resources.