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PERSPECTIVE ARTICLE

Ecological uplift through agrivoltaics: A new framework for sustainable energy and agriculture integration

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Abstract

Ecological uplift is a quantified improvement in ecosystem condition (structure, function, and associated services) relative to baseline (pre-existing) conditions over a defined time horizon following a land-use intervention. Agrivoltaics (AV) is a dual-use strategy that integrates photovoltaic energy generation with agricultural land uses and is increasingly promoted for environmental and working-land benefits. Recent literature indicates AV can improve outcomes such as soil moisture retention, infiltration, soil carbon, pollinator habitat, and water-use efficiency relative to conventional agriculture or conventional ground-mounted photovoltaic vegetation management, although performance varies by design and context. A persistent gap is the lack of standardized, transparent evaluation methods that distinguish between realized and assumed benefits. This article frames ecological uplift as a rigorous evaluative construct for AV and introduces the Agrivoltaic Ecological Uplift Index as a metrics-based reporting scaffold across five outcome domains to support consistent monitoring, comparison, and decision-making.

Keywords: Agrivoltaics; Ecological uplift; Photovoltaics; Sustainable land use; Soil health; Hydrologic function; Biodiversity; Land-use efficiency

1. Introduction

The rapid expansion of utility-scale solar photovoltaics (PV) is intensifying global competition for land, especially in agricultural regions where energy development and food production are increasingly intersecting. PV are solid-state semiconductor devices, typically made of crystalline silicon or thin-film modules, that convert sunlight directly into electricity via the PV effect.[1] As national and corporate commitments to renewable energy intensify, the demand for specific land types and locations for solar deployment has faced increasing scrutiny. This shift raises significant concerns and controversies, particularly when large-scale installations encroach on prime farmland and vital ecological resources.[2] In response, agrivoltaics (AV) have emerged as a dual-use land strategy in which agricultural production, such as crops, grazing, or pollinator habitat, co-occurs beneath and around PV systems. AV extends beyond mere co-location; it encompasses a deliberate approach to design, infrastructure configuration, and land management. This approach seeks to preserve or enhance agricultural productivity while simultaneously generating renewable energy.[3] Figure 1 provides a generalized visual overview of the major AV components and typical design configurations referenced throughout this perspective.

Despite its increasing acceptance, AV faces a significant challenge: its ecological and agricultural claims necessitate empirical evidence rather than mere assumptions. Many AV systems are still evaluated qualitatively or symbolically, with limited frameworks for measuring their actual environmental performance relative to conventional agriculture or conventional ground-mounted solar farms. Notably, PV companies may also use the term AV to market installations to landowners, often without accountability regarding the implications of this terminology. This raises questions about the integrity of their claims and highlights the necessity for rigorous scientific evaluation in this rapidly evolving field. The concept of ecological uplift may offer a comprehensive, scientifically grounded means to assess these outcomes. Ecological uplift refers to a quantifiable improvement in ecosystem condition (structure, function, and associated services) over a defined time horizon, relative to a stated comparator (baseline and, where applicable, a reference condition), following a land-use intervention.[4] AV systems may yield significant ecological benefits while establishing a robust framework for evaluating sustainability, conservation, and land-use productivity in PV-agricultural landscapes. It is, however, imperative that these systems be underpinned by endorsed scientific principles and sound agronomic practices. The following sections delineate the concept of ecological uplift, describe the mechanisms through which AV can achieve it, and introduce the Agrivoltaic Ecological Uplift Index (AEUI) as a standardized framework for evaluating this phenomenon across various systems.

As a perspective, this article adopts a framing-focused approach. Its purpose is to define ecological uplift as a measurable evaluative construct for AV and to propose the AEUI as a transparent organizing scaffold for comparable reporting across projects. Detailed parameterization, weighting, and validation are identified as priorities for future empirical research and standard-setting efforts. The literature cited is intentionally selective and illustrative, and the article is not presented as a systematic review.

2. Ecological uplift as an evaluative construct

Ecological uplift is widely used in restoration ecology, mitigation banking, and ecosystem services research to describe measurable improvements in ecological condition over time. It represents not the work performed, such as installing vegetation or modifying landforms, but the demonstrated functional improvement.[5] In this article, ecological uplift is treated as a comparative, evidence-based change in ecological condition. It is related to, but distinct from, ecosystem services (the benefits people derive from ecosystems) and broader framing such as "net ecological benefit" or "nature-positive" outcomes, which may include social, economic, or policy commitments that extend beyond measurable ecological condition alone. Here, uplift specifically denotes observed ecological improvement relative to a stated comparator. The uplift framing is used to keep the evaluation anchored to decision contexts that require valuation or human-benefit framing. In AV, ecological uplift provides a scientifically grounded approach to evaluating whether land used for both energy and agriculture is performing better ecologically than under its previous management regime or under single-use alternatives. Given that AV modifies microclimate, soil processes, hydrology, vegetation dynamics, and habitat structure, it provides an opportunity to measure gains in ecosystem function through direct comparisons with pre-installation baselines and appropriate reference conditions.[3,6]

Evaluating ecological uplift requires establishing clear baseline conditions, which vary according to the land's prior use. In many regions, AV is deployed on intensively tilled cropland, degraded pasturelands, or fallow fields, all of which are associated with reduced ecological function, lower biodiversity, and degraded soil structure.[7] Accordingly, uplift in AV should be reported relative to clearly stated comparators, which may include baseline conventional agriculture, conventional ground-mounted PV vegetation management, and, where feasible, pre-project reference ecosystems that reflect achievable ecological conditions in the region. When AV installations introduce perennial vegetation, minimize soil disturbance, and create microclimatic heterogeneity, these systems may outperform the baseline ecosystems they replace. Baseline comparisons must also consider "conventional solar" vegetation management, which typically involves intensive mowing and/or grazing, minimal vegetation diversity, and frequent soil disturbance, creating a second baseline against which AV ecological uplift may be measured.[2]

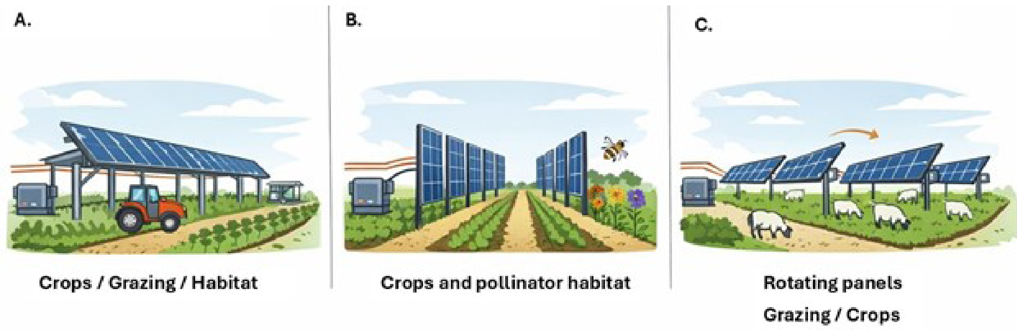

Figure 1. Representative agrivoltaic (AV) system components and common configurations. Illustrated elements include photovoltaic modules and racking, inverters and electrical infrastructure, access and maintenance lanes, and the co-located land-use layer (cropping, managed grazing, or habitat plantings). Configurations shown include (A) elevated fixed-tilt arrays, (B) vertical bifacial arrays, and (C) single-axis tracking systems designed to maintain agricultural access and light availability. Image created using Google Gemini (Google LLC, Mountain View, United States of America; accessed 02/08/2026) and finalized by the authors in Microsoft PowerPoint for Microsoft 365. The figure was reviewed and edited by the authors for scientific accuracy.

Establishing reference conditions is equally important. Reference conditions serve as ecological benchmarks, often drawn from regional grasslands, polyculture agricultural systems, or naturalized pastures that offer higher ecological function than monocultures. Time horizons for uplift measurement must distinguish short-term construction impacts, often negative, from long-term ecological trajectories that tend to improve as vegetation establishes and soil microbial and faunal communities recover and develop.[8] Together, baselines and reference conditions allow ecological uplift to be quantified, monitored, and validated over time.

3. Mechanisms of agrivoltaics-generated ecological uplift

3.1. Microclimate mediation

One of the central ecological mechanisms of AV is the modification of the microclimate. PV panels reduce direct solar radiation, resulting in lower air and soil temperatures, increased relative humidity, and moderated vapor pressure deficits beneath and between panel rows.[9] These changes buffer crops and vegetation from heat extremes, especially during periods of climate-induced drought or high evaporative demand. Numerous studies show that microclimate buffering increases water-use efficiency and reduces heat stress for both crops and soil microbial communities, thereby improving ecological and biophysical functioning.[3,10] Microclimate mediation influences plant phenology, soil moisture retention, and overall ecosystem resilience, establishing a foundation for measurable uplift relative to conventional agricultural fields or conventional solar installations.

3.2. Soil health uplift

Agrivoltaic installations often reduce soil disturbance and maintain continuous vegetation cover, leading to verifiable improvements in soil health. Under AV systems, soils typically show higher moisture retention, lower temperature extremes, and reduced evaporative losses.[9] Increased perennial groundcover reduces erosion and enhances soil organic matter accumulation, particularly relative to tilled agricultural systems or mowed conventional PV sites.[7] Studies of AV installations in Europe and East Asia show measurable increases in soil organic carbon and improved aggregate stability within three to five years after installation.[11] These outcomes reflect improved soil microbial activity and reduced mechanical disturbance. As soil health influences productivity, hydrologic regulation, carbon storage, and long-term land stewardship, gains in soil structure and function represent a significant component of ecological uplift.

3.3. Hydrologic function uplift

Agrivoltaics can improve hydrologic function by shading, enhancing vegetation, and reducing disturbance. Soils under AV systems often have higher infiltration rates and greater persistence of soil moisture than conventional croplands, where frequent tillage reduces aggregate stability and infiltration capacity.[6] Research from controlled field experiments demonstrates that AV systems reduce surface runoff and associated sediment transport during storm events, particularly when combined with perennial vegetation.[3] These hydrologic improvements support both ecological and agricultural functions by reducing erosion, improving root zone water availability, and moderating water stress during drought.[12] Enhanced hydrologic regulation also benefits watershed-scale processes, suggesting that AV may serve as a climate-resilient land management tool with broader hydrological implications.

3.4. Biodiversity and habitat uplift

Conventional solar installations often reduce habitat complexity through uniform mowing or gravel cover, but

AV, especially systems incorporating native plantings or managed grazing, can improve local biodiversity. Recent studies have documented increases in plant species richness, pollinator abundance, and functional biodiversity in AV systems compared with monoculture agriculture or conventional PV vegetation regimes.[11,13] Pollinator-focused AV installations enhance floral resources across growing seasons, supporting wild bees, butterflies, and other beneficial insects.[2] Increased habitat heterogeneity also supports higher trophic levels, including birds and small mammals, when vegetation matures. These biodiversity gains may represent a significant ecological uplift, particularly in regions where agricultural intensification has reduced wildlife habitat.

3.5. Agricultural productivity and land-use efficiency uplift

Agrivoltaics can enhance agricultural resilience and land-use efficiency, thereby providing a combined ecological and socioeconomic uplift. Many shade-tolerant crops, including leafy greens, berries, and forage grasses, show stable or increased yields under AV systems, particularly in hot or water-limited environments.[14,15] Studies increasingly report land equivalent ratios greater than 1.0, indicating that combined agricultural, agroforestry, and energy production surpasses the output achievable from single-use energy or agriculture alone.[6,16] For grazing-based AV systems, biomass quality and availability often improve due to moderated microclimate conditions, while sheep provide vegetation management services that reduce operational costs and chemical inputs.[7] These productivity outcomes illustrate that ecological uplift transcends mere environmental considerations; it also signifies improvements in land-use efficiency and economic resilience as captured in the AEUI domain structure (Figure 2). Together, these mechanisms motivate the AEUI domains and provide a practical basis for selecting measurable indicators to evaluate uplift consistently across projects.

4. The development of the Agrivoltaic Ecological Uplift Index

A standardized AEUI enables a transparent assessment across projects and facilitates communication with policymakers, developers, and communities. Microclimate mediation is treated here as a cross-domain driver that influences outcomes across the five AEUI domains and can be reported using domain-relevant indicators rather than as a separate scored domain. The AEUI is thus organized around soil health, hydrologic function, biodiversity and habitat, agricultural productivity and land-use efficiency, and carbon and climate regulation. Each domain can be evaluated using quantifiable indicators that reflect percent improvement relative to baseline conditions.[8,10,16] These domains capture the principal measurable biophysical and working-land outcome pathways emphasized in AV research; social equity, broader economic resilience, and landscape connectivity are important complementary considerations, but are not treated as scored AEUI domains in the context of the current article.

For soil health, indicators may include changes in soil organic carbon concentration, soil infiltration, bulk density, and infiltration capacity. Hydrologic indicators may also include reductions in runoff coefficients, increases in volumetric soil moisture content, and enhanced crop water-use efficiency.[3,12] Biodiversity indicators can include native species richness, pollinator abundance, and functional diversity metrics relevant to ecosystem stability.[13] Agricultural productivity indicators capture crop yield, forage biomass, animal performance, and land equivalent ratio.[14,15] Finally, carbon and climate indicators include soil carbon stocks, biomass accumulation, and climate regulation through reduced fossil-fuel-intensive management activities. Although developed here for AV, the same uplift-based structure could be adapted to ecovoltaic solar systems where the land management objective is ecological function, provided indicators and comparators are defined for that context.

The AEUI calculation is intended to be transparent and reproducible. For each domain, practitioners select a small set of indicators that are measurable with consistent methods and appropriate to the site and land use, then quantify change relative to a stated comparator over a defined time window. For early-stage planning, a preliminary AEUI can be scoped using a minimal indicator set and reasonable proxies (e.g., soil texture and baseline organic carbon, vegetation plan and management intensity, site hydrologic setting, and intended crop or grazing system), with final scoring based on post-installation monitoring data. Indicator values are normalized to a common scale (for example, percent change relative to baseline mapped to a 0 to 5 score using predefined bins), producing a domain score as the mean of its indicator scores. The 0–5 scale is used as a simple reporting convention to support communication and comparability; bin definitions, thresholds, and validation are intended to be refined through future empirical applications. By default, the overall AEUI can be reported as the unweighted mean of the five domain scores, with optional weighting used only when explicitly justified (for example, stakeholder, policy, or permitting priorities). As with any index, AEUI interpretation depends on data

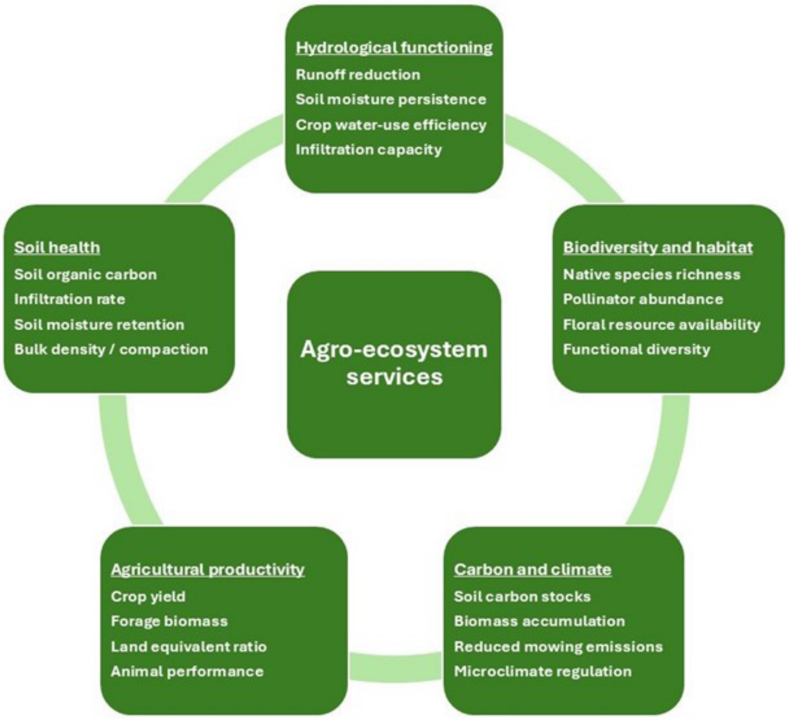

Figure 2. Conceptual structure of the Agrivoltaic Ecological Uplift Index (AEUI), organized around five outcome domains and representative indicators used to quantify uplift, or agro-ecosystem services in agrivoltaic systems. Image created by the authors in Microsoft PowerPoint for Microsoft 365.

completeness, indicator choice, and regional context (biome, crop system, and management). In the context of the current article, robustness is addressed by emphasizing transparent indicator selection, implementing consistent measurement methods, and reporting domain scores alongside the overall AEUI so that missing data or trade-offs are visible. Formal sensitivity testing, missing-data rules, and region-specific indicator standards are identified as priorities for future applied development of the AEUI.

Application of the AEUI can vary by context. For example, in water-limited climates, the hydrologic and productivity domains may be emphasized through indicators such as soil moisture persistence, infiltration, and water-use efficiency, whereas in humid regions, soil structure, runoff mitigation, and biodiversity habitat metrics may be more informative. Similarly, elevated fixed-tilt systems designed for equipment access may prioritize crop performance and minimize soil disturbance, while tracking systems may be evaluated for dynamic shading effects on microclimate-driven outcomes and for their efficiency in vegetation management. A fully parameterized worked example comparing designs and climates is identified as a priority for future applied studies using the AEUI scaffold.

Weighting factors could be customized to reflect local policy priorities, such as soil conservation in erosion-prone regions or biodiversity enhancement in conservation-sensitive landscapes. Monitoring could combine remote sensing for landscape-level vegetation and productivity patterns with ground-based measurements of soil, hydrology, and biodiversity. This multi-method approach ensures that AEUI scores reflect actual ecological performance rather than symbolic or assumed benefits. By translating measured performance into comparable indicators, the AEUI can also support practical cost–benefit discussions by clarifying where ecological gains coincide with operational savings or improved agricultural returns.

The AEUI is not intended to presume net-positive outcomes across all domains. For example, if carbon and climate indicators improve while biodiversity or crop yield indicators decline, the domain scores would reflect that divergence rather than masking it within a single headline value. Instead, the model should report domain-level changes transparently so that gains and trade-offs are transparent (for example, improved hydrologic function alongside limited biodiversity gains at early establishment stages). Where a "net-positive" determination is required for permitting, certification, or policy, the decision rules (domain thresholds, weighting, and acceptable trade-offs) should be explicitly stated and tailored to local objectives and are identified here as priorities for future development.

5. Policy and industry relevance

The concept of ecological uplift has significant implications for permitting, conservation, and renewable-energy development. Many stakeholders fear that large-scale solar installations displace agricultural production or reduce ecological value; uplift-based evaluation reframes AV as a strategy for net ecological gain rather than land-use loss.[17] Utilizing quantitative, evidence-based approaches is essential in addressing these stakeholder concerns, as it provides robust data to demonstrate the potential benefits of such projects. By leveraging quantitative analysis, decision-makers can effectively align project outcomes with stakeholder needs, facilitating greater buy-in and ensuring that ecological and agricultural interests are appropriately balanced.[18-20] This is important because regulators increasingly require evidence that solar developments deliver community benefits, and AV systems that demonstrate uplift may receive more favorable permitting outcomes and greater community acceptance. Rather than prescribing universal thresholds, this article aims to position AEUI outputs as a framework for measurable commitments and post-construction monitoring that can be incorporated into environmental impact assessment and permitting conditions, with thresholds defined by regulators based on local objectives and constraints. These considerations are offered as practical implications of an uplift-based framing, not as prescriptive requirements, and should be adapted to local regulatory, economic, and institutional constraints.

It follows that economic considerations are also central to adoption. AV can improve project economics through multiple pathways, including sustained or enhanced agricultural output on leased land, reduced vegetation management costs through managed grazing that replaces mowing or herbicides, improved drought resilience that stabilizes yields, and reduced risk of permitting delays when projects demonstrate verifiable community and environmental benefits. In addition, uplift-based monitoring provides a defensible basis for environmental, social, and governance reporting and may support participation in emerging ecosystem service and credit markets (for example, biodiversity, carbon, and water-related outcomes) that require transparent measurement and verification. In practice, land tenure, lease terms, farmer incentives, permitting requirements, and operational constraints can limit which ecological designs are feasible even when uplift metrics indicate potential improvement. A published example illustrates the potential magnitude of economic performance differences under certain contexts. In a northern latitude case study in Sweden, Campana *et al.*[6] reported that, from a net present value perspective, an AV system was approximately 30 times more profitable than a conventional crop rotation, while also enabling continued agricultural production under the array. This result is site- and assumption-dependent, but it provides a concrete illustration of why integrated energy and agricultural revenue streams can materially change the adoption calculus.

From a conservation perspective, AV can fill a critical gap between working-land conservation and renewable-energy expansion. AV systems can support ecosystem service recovery, such as pollination, carbon sequestration, and soil conservation, while maintaining agricultural viability, aligning with sustainability goals for multifunctional landscapes.[13] These outcomes are particularly important in regions facing climate-induced stress on agricultural productivity and biodiversity.[21,22]

For industries, ecological uplift provides a rigorous foundation for environmental, social, and governance claims. Corporate power purchasers increasingly demand verifiable environmental performance metrics, and uplift-based AV offers an evidence-based mechanism for demonstrating environmental co-benefits.[5] Furthermore, uplift data may enable credit stacking through biodiversity credits, carbon markets, and ecosystem service payments, improving project economics and expanding revenue streams. Future work can integrate AEUI domain scores with economic and social indicators in multi-criteria decision frameworks to support transparent trade-off analysis for AV expansion. Feasibility will depend on monitoring burden, cost, and institutional capacity, and the AEUI is intended to support scalable monitoring by encouraging small, transparent indicator sets that can be expanded where resources allow.

6. Research gaps and design priorities

Despite rapid advancement, substantial research gaps limit the widespread adoption of uplift-based AV evaluation. First, crop- and region-specific response curves are needed to optimize panel height, spacing, orientation, and canopy structure to improve both crop performance and ecological outcomes.[8] Studies remain short-term and small-scale, limiting the understanding of long-term ecological trajectories for soil carbon, hydrology, and biodiversity.[3] Evaluations must extend across five- to ten-year horizons to capture slow-developing ecological processes and provide credible evidence of uplift. The most urgent need is multi-year monitoring with clear comparators (ideally before-and-after control-impact style designs where feasible) and consistent indicator measurement to enable cross-site synthesis and refinement of AEUI scoring and thresholds. Importantly, AV outcomes can also be mixed or negative, depending on design and context (e.g., crop-specific yield reductions, temporary construction disturbance, or limited habitat value under simplified vegetation management), reinforcing the need for transparent, domain-level reporting rather than assumed benefits.

Limitations of the current evidence should be recognized, as many published field cases are concentrated in Europe and North America, with fewer studies in other regions and cropping systems. Many AV studies remain short-term, site-specific, and focused on particular regions and production contexts, which can bias inferences about broader ecological trajectories. Long-term field datasets remain scarce, and projecting soil, hydrologic, and biodiversity responses to interacting climate change pressures introduces additional uncertainty, especially as AV expands into new biomes, crops, and management regimes. These limitations reinforce the need for standardized, multi-year monitoring and cross-region comparison using transparent frameworks such as the AEUI. Additionally, methodological standardization remains limited. Different studies use variable measurement techniques, making cross-site comparisons difficult.[6] A unified AEUI framework would allow consistent measurement and comparison across regions, crops, and solar designs. Finally, certification or performance standards rooted in uplift rather than symbolic dual-use are needed to avoid greenwashing (i.e., overstating or fabricating the environmental value of AV) and ensure AV produces actual realized ecological value.[2] These standards must be transparent, scientifically grounded, and applicable across diverse land-use contexts.

7. Conclusion

Agrivoltaics offer a powerful model for integrating renewable energy production with sustainable land stewardship, agricultural resilience, and ecosystem restoration. The AEUI is intended to improve decision-making by making AV's performance measurable and comparable as uplift relative to baseline conditions, using repeated observations rather than assumed co-benefits. In practice, AEUI complements environmental impact assessment, life cycle assessment, and ecosystem services mapping frameworks by providing a structured set of site-level outcome metrics that can inform those assessments, support monitoring commitments, and distinguish realized ecological gains from symbolic claims. The AEUI is designed to operate at the plot and project footprint scale, with domain scores that can be aggregated across arrays or sites when regional planning requires it. When properly designed and managed, AV systems can deliver measurable ecological benefits, including improved soil health, hydrologic regulation, biodiversity, agricultural productivity, and carbon storage, relative to conventional agriculture or conventional solar installations. Measuring these benefits through a standardized AEUI ensures transparency, accountability, and comparability across projects. Given the escalating demand for renewable energy and the increasing pressures on agricultural and ecological systems, AV offers an emerging pathway toward multifunctional landscapes that can simultaneously meet food, energy, and environmental goals. As research expands and long-term monitoring improves, uplift-based AV may become a cornerstone of sustainable land-use planning, helping communities, policymakers, and developers achieve climate and conservation outcomes without sacrificing agricultural productivity or ecosystem integrity.

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

Conceptualization: Jason A. Hubbart
Visualization: Jason A. Hubbart
Writing–original draft: Jason A. Hubbart
Writing–review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Not applicable.

Further disclosure

Artificial intelligence tools were used in a limited and supporting capacity during the preparation of this manuscript. Specifically, ChatGPT was used to identify relevant literature and potential citations, and Grammarly was used to support grammar, clarity, and flow. All ideas, conceptual framing, theoretical development, analyses, interpretations, and conclusions are the sole work of the authors. The manuscript was written, reviewed, edited, and approved by the authors, who take full responsibility for the content, accuracy, and integrity of the work. No artificial intelligence tool generated original scholarly arguments, data interpretations, or conclusions presented herein.

References

1. Victoria M, Haegel N, Peters IM, *et al.* Solar photovoltaics is ready to power a sustainable future. *Joule*. 2021;5(5):1041–1056.

   doi: 10.1016/j.joule.2021.03.005

2. Gómez-Catasús J, Morales MB, Giralt D, *et al.* Solar photovoltaic energy development and biodiversity conservation: Current knowledge and research gaps. *Conserv Lett.* 2024;17(4).

   doi: 10.1111/conl.13025

3. Ali Abaker Omer A, Li M, Zhang F, *et al.* Impacts of agrivoltaic systems on microclimate, water use efficiency, and crop yield: A systematic review. *Renew Sustain Energy Rev.* 2025;221:115930.

   doi: 10.1016/j.rser.2025.115930

4. BenDor T, Lester TW, Livengood A, Davis A, Yonavjak L. Estimating the Size and Impact of the Ecological Restoration Economy. *PLoS ONE.* 2015;10(6):e0128339.

   doi: 10.1371/journal.pone.0128339

5. Stid JT, Shukla S, Kendall AD, *et al.* Impacts of agrisolar co-location on the food–energy–water nexus and economic security. *Nat Sustain.* 2025;8(6):702-713.

   doi: 10.1038/s41893-025-01546-4

6. Campana PE, Stridh B, Hörndahl T, *et al.* Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes. *J Clean Prod.* 2024;437:140235.

   doi: 10.1016/j.jclepro.2023.140235

7. Kumpanalaisatit M, Setthapun W, Sintuya H, Pattiya A, Jansri SN. Current status of agrivoltaic systems and their benefits to energy, food, environment, economy, and society. *Sustain Prod Consum.* 2022;33:952-963.

   doi: 10.1016/j.spc.2022.08.013

8. Pandey G, Lyden S, Franklin E, Millar B, Harrison MT. A systematic review of agrivoltaics: productivity, profitability, and environmental co-benefits. *Sustain Prod Consum.* 2025;56:13-36.

   doi: 10.1016/j.spc.2025.03.006

9. Weselek A, Bauerle A, Hartung J, Zikeli S, Lewandowski I, Högy P. Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate. *Agron Sustain Dev*. 2021;41(5).

   doi: 10.1007/s13593-021-00714-y

10. Hubbart JA. Environmental Biophysics. *Encyclopedia.* 2019;3.

    doi: 10.32545/encyclopedia201907.0001.v1

11. Ludzuweit A, Paterson J, Wydra K, Pump C, Müller K, Miller Y. Enhancing ecosystem services and biodiversity in agrivoltaics through habitat-enhancing strategies. *Renew Sustain Energy Rev.* 2025;212:115380.

    doi: 10.1016/j.rser.2025.115380

12. Hubbart JA, Kellner E, Zeiger SJ. A Case-Study Application of the Experimental Watershed Study Design to Advance Adaptive Management of Contemporary Watersheds. *Water*. 2019;11(11):2355.

    doi: 10.3390/w11112355

13. Time A, Gómez-Casanovas N, Mwebaze P, *et al.* Conservation agrivoltaics for sustainable food-energy production. *Plants People Planet.* 2024;6(3):558-569.

    doi: 10.1002/ppp3.10481

14. Reher T, Willockx B, Schenk A, *et al.* Agrivoltaic cultivation of pears under semi-transparent panels reduces yield consistently and maintains fruit quality in Belgium. *Agron Sustain Dev*. 2025;45(3).

    doi: 10.1007/s13593-025-01019-0

15. Magarelli A, Mazzeo A, Ferrara G. Exploring the Grape Agrivoltaic System: Climate Modulation and Vine Benefits in the Puglia Region, Southeastern Italy. *Horticulturae*. 2025;11(2):160.

    doi: 10.3390/horticulturae11020160

16. Hubbart JA, Comacho F, Gazal K, Martins L, Stephan K, Wood-Turner K. Growing Opportunities: Considering a Thriving Agroforestry Industry in Appalachia, USA. *Agric Rural Stud.* 2025;3(2).

    doi: 10.59978/ar03020007

17. Soto-Gómez D. Integration of Crops, Livestock, and Solar Panels: A Review of Agrivoltaic Systems. *Agronomy*. 2024;14(8):1824.

    doi: 10.3390/agronomy14081824

18. Hubbart JA. The Importance of Stakeholder Engagement Across Market Domains. *J Glob Entrep Manag.* 2024;2(1):1-7.

    doi: 10.59462/jgem.2.1.106

19. Hubbart, J.A. Considering Use-Inspired Design and Tangible Impacts in the Agricultural Sector. *OAJAR*. 2023;8(4):1-5.

doi: 10.23880/oajar-16000323

20. Hubbart JA. Harmonizing Science and Society: A Change Management Approach to Align Scientific Endeavors with Societal Needs. *Sustainability.* 2023;15(21):15233.

doi: 10.3390/su152115233

21. Abesh BF, Jin L, Hubbart JA. Predicting Climate Change Impacts on Water Balance Components of a Mountainous Watershed in the Northeastern USA. *Water*. 2022;14(20):3349.

doi: 10.3390/w14203349

22. Kutta E, Hubbart JA. Observed climatic changes in West Virginia and opportunities for agriculture. *Reg Environ Change.* 2019;19(4):1087-1099.

doi: 10.1007/s10113-018-1455-y