Journal of
Electronics Technology Exploration

Homepage: htttps://shmpublisher.com/index.php/joetex
p-ISSN 3025-3470 | e-ISSN 3026-1066

Agrivoltaics in Japan: A Review of Current Practices, Challenges, and Future Directions

Ahmad Zein Al Wafi[1], Kevin Muhammad Tegar Aditama[2]
[1]Department of Electrical, Universitas Negeri Semarang, Indonesia
[2]Department Computer Engineering, Universitas Negeri Semarang, Indonesia

Article Info

Article history:

Received Dec 30, 2025
Revised Jan 04, 2026
Accepted Jan 16, 2026

Keywords:

Agrivoltaics
Photovoltaic systems
Sustainable agriculture
Land-use efficiency
Food–energy nexus

ABSTRACT

This review examines agrivoltaics in Japan integrating solar photovoltaic (PV) systems with agricultural production as a dual-use land strategy to address constrained arable land, decarbonization goals, and energy security. Using a thematic synthesis of published studies and documented Japanese cases, the paper maps current deployment practices, reported agronomic and energy outcomes, and the main constraints shaping adoption. The literature indicates that well-designed agrivoltaic configurations can maintain crop production while adding renewable electricity generation, with outcomes strongly influenced by site conditions, crop type, shading design, and farm management. Evidence also points to potential co-benefits such as reduced heat stress and improved microclimate stability, but trade-offs may emerge for light-sensitive crops or under suboptimal PV spacing and height. Key barriers in Japan include high upfront investment, complex permitting and compliance requirements, and concerns over land-use integrity and long-term agricultural continuity. Future research should prioritize longitudinal field data on crop yield and quality, soil and water dynamics, and ecosystem effects, alongside standardized performance metrics and policy/financing mechanisms that align farmer incentives with grid and climate objectives.

Corresponding Author:

Wafi,
Department of Electrical,
Universitas Negeri Semarang,
Semarang, Jawa Tengah, Indonesia.
Email: ahmadzeinalwafi@outlook.com
https://doi.org/10.52465/joetex.v3i2.642

1. INTRODUCTION

The simultaneous global pressures on energy systems and food security require land-use strategies that can deliver both essential services without intensifying competition for space [1]. Agrivoltaics (agro-photovoltaics) addresses this dual challenge by co-locating solar photovoltaic (PV) systems with active agricultural production, enabling the same land area to generate electricity while sustaining farming activities. Evidence from the broader agrivoltaics literature suggests that outcomes depend strongly on system design and crop–site conditions; well-matched configurations can maintain agricultural productivity while adding low-carbon electricity and potential environmental co-benefits (e.g., microclimate moderation and improved water-use efficiency) [2], [3]. This approach is particularly relevant for Japan, where energy security remains a high policy priority and energy self-sufficiency has been persistently low since the 2011 Fukushima-related disruption [4].

Japan's geographical and economic conditions make it a compelling context for agrivoltaic deployment. Farmland constitutes only about 12% of the national territory, intensifying competition among agriculture, settlement, and infrastructure and making land-use efficiency a central policy concern [5]. At the same time, Japan is a highly populated country (around 342 people per km² in recent estimates), which further constrains available space for standalone energy developments [6]. In the energy domain, Japan's structural vulnerability is evident in its low energy self-sufficiency approximately 94% of primary energy supply depends on imports—which heightens exposure to external price and supply shocks [7] Fukushima Daiichi accident (2011) accelerated momentum to diversify the energy mix and scale renewable energy, including policy instruments such as the feed-in tariff introduced in 2012 [8]. Within this landscape of land scarcity and energy security pressures, agrivoltaics offers a dual-use pathway to expand solar generation while safeguarding agricultural function, provided that system design and governance carefully manage trade-offs.

Agrivoltaics typically places photovoltaic (PV) modules above or adjacent to cultivated plots, creating partial shading that alters the local radiation, temperature, and moisture regime experienced by crops. This modified microclimate can reduce thermal stress and evapotranspiration and may improve soil moisture retention and water-use efficiency under hot or drought-prone conditions. Evidence also suggests that performance is strongly context-dependent: while some configurations maintain or in certain cases improve crop outcomes through microclimate moderation, shade-intolerant crops or suboptimal PV geometry can introduce yield or quality trade-offs [9]. In addition to agricultural effects, the co-location of PV and vegetation can influence system-level energy performance through biophysical interactions such as panel temperature moderation [2], [10]–[12].

Several studies have examined agrivoltaics from both biophysical and land-use efficiency perspectives, with implications that are highly relevant to Japan. Foundational work on agrivoltaic schemes argues that co-locating photovoltaic (PV) generation with crops can increase overall land-use efficiency, often expressed through land-equivalent metrics (e.g., land equivalent ratio), compared to allocating separate land for farming and PV. [2] Subsequent crop-focused experiments further show that partial shading can reshape microclimate and plant water balance, producing benefits under certain conditions but also trade-offs depending on crop type and system design. [11] In the Japanese context, field and case-based studies indicate that performance hinges on matching PV configuration to local agronomic requirements (particularly for shade-intolerant crops) and maintaining agricultural continuity under governance constraints, suggesting agrivoltaics can be a viable pathway to optimize land use provided that design and management are carefully tailored [9], [12], [13].

Despite its promise, scaling agrivoltaics in Japan faces intertwined economic, operational, regulatory, and social challenges. Upfront capital requirements and limited access to suitable financing can be prohibitive especially for farmers and small rural actors while project economics remain sensitive to policy support and grid/market conditions [14]. Operationally, dual land use demands careful co-design of PV geometry and farm management to avoid compromising cultivation continuity; in Japan this is reinforced by governance expectations that agricultural activity must be maintained and, in many cases, crop yields should remain above a defined threshold (often framed as maintaining at least ~80% of local baseline yield), creating additional monitoring and compliance burdens [15]. Regulatory complexity is also non-trivial because agrivoltaics sits at the boundary of agricultural land protection and renewable energy policy, requiring coordination across land-use permissions, agricultural committees, and renewable energy incentive rules [16]. Finally, social acceptance can become a binding constraint: experiences from Japan's rapid PV expansion under the FIT regime show how perceived landscape change, trust deficits, and procedural concerns can trigger local resistance, increasing transaction costs and project timelines [17].

Furthermore, the long-term impacts of agrivoltaic systems on crop yield stability, soil ecological processes, and local biodiversity remain insufficiently characterized, as much of the available evidence is short- to medium-term and highly context-dependent. Recent reviews emphasize that agrivoltaic outcomes can vary across climates and management regimes, warranting longitudinal field monitoring of agronomic performance alongside soil–water dynamics and ecosystem indicators [18].This variability is largely driven by both environmental and design factors including crop type, local climate, and PV configuration parameters such as ground coverage ratio, clearance height, tilt/tracking, and resulting shading patterns which can produce non-linear trade-offs between crop productivity and electricity generation [19]. Accordingly, future work should prioritize context-specific optimization frameworks and standardized metrics to compare systems across sites and guide design choices that balance agricultural continuity with energy output [19].

Agriculture remains a vital sector in Japan, yet it faces structural pressures from constrained arable land and an ageing farming population. In this context, agrivoltaics is increasingly discussed as a dual-use strategy that can support farm viability while expanding domestic renewable electricity; however, Japan-specific evidence remains fragmented across agronomic performance, system design, socio-regulatory governance, and economic feasibility. This paper therefore aims to synthesize the existing body of research on agrivoltaics in Japan by consolidating reported practices and outcomes, identifying key barriers and enabling conditions, and outlining priority directions for future research and policy. To do so, we review the literature through an integrated lens spanning agricultural, environmental, and economic dimensions to clarify both the potential and the limitations of agrivoltaics under Japan's institutional and biophysical constraints.

2. BACKGROUND AND CONTEXT

Agrivoltaics emerged in response to growing competition for land between agricultural production and renewable energy development. Conventional land-use models often treat farming areas and solar farms as mutually exclusive, creating a trade-off between food production and electricity generation. Agrivoltaics reframes this trade-off by enabling the co-location of photovoltaic (PV) systems and active cultivation on the same parcel of land, with the goal of improving overall land-use efficiency. By combining energy generation with continued agricultural activity, agrivoltaic designs seek to capture synergies between PV infrastructure and crop management, while managing site- and crop-specific trade-offs [2], [3].

Japan's energy landscape has been substantially reshaped over the past two decades, driven by the dual imperative of diversifying supply and strengthening energy security. The Fukushima Daiichi accident in 2011 marked a critical inflection point, prompting a reassessment of nuclear generation and accelerating policy attention toward renewable energy deployment. Following this shift, solar photovoltaic (PV) rapidly expanded in Japan, supported by strong policy incentives and investment signals. In particular, the nationwide feed-in tariff (FIT) scheme introduced in July 2012 provided guaranteed purchase prices for renewable electricity, improving revenue certainty and stimulating large-scale PV diffusion. This post-Fukushima policy environment also strengthened the economic rationale for agrivoltaics by enabling PV deployment while maintaining agricultural activity on the same land parcel [8], [20]–[22].

Japan's agrivoltaics (often referred to as solar sharing) has developed in response to intertwined pressures on the rural sector, including concerns over food security, increasing farmland abandonment, and structural declines in agricultural capacity associated with demographic change [23], [24]. In contrast to conventional ground-mounted PV that can displace cultivation, Japan's policy approach has sought to keep farmland in active agricultural use while allowing PV co-location under defined conditions. Key institutional developments such as MAFF directives that formalized the use of farmland for agrivoltaics have supported a regulatory framework in which continued farming is required and performance is often evaluated against local yield baselines (commonly framed as maintaining at least ~80% of conventional yields), reinforcing the primacy of agricultural continuity [24], [25].Empirical and case-based studies in Japan further indicate that agrivoltaics can be feasible when system design and farm management are adapted to crop requirements and local conditions, including evidence from rice-based agrivoltaic deployments [23], [25].

In Japan, a growing number of pilot projects and research initiatives have been implemented to assess the feasibility and practical benefits of agrivoltaics (solar sharing) under local agronomic and regulatory conditions [24]. These initiatives commonly test alternative PV configurations (e.g., module density, height, and spacing) to identify designs that balance electricity generation with continued cultivation. For instance, field experiments conducted at the agrivoltaic experimental farm operated by the CHO Institute of Technology in Ichihara City, Chiba Prefecture evaluated system performance over sweetcorn, a shade-intolerant crop, indicating that appropriately designed stilt-mounted systems can mitigate the trade-off between crop production and power generation—suggesting applicability beyond only shade-tolerant crops [9]. Evidence from Japanese case studies on staple crops such as rice further supports the feasibility of agrivoltaic deployment when cultivation continuity and site-specific management are maintained. Collectively, these demonstrations highlight agrivoltaics' potential to contribute to rural revitalization and local energy development in Japan when integrated with local agricultural practices and value chains [24].

Moreover, agrivoltaics aligns with Japan's national policy priorities on decarbonization, renewable energy expansion, and energy security. Japan's Strategic Energy Plan frames the scaling of renewable electricity as a key pathway to reduce greenhouse gas emissions while maintaining a stable and resilient energy supply. Agrivoltaics can contribute to these goals by enabling additional solar PV deployment without converting agricultural land to single-use energy infrastructure, thereby improving land-use efficiency and potentially reducing environmental and social impacts associated with new land allocation [26].

3. CURRENT RESEARCH AND CASE STUDIES

Recent studies have assessed the technical and economic feasibility of agrivoltaics in Japan using location-specific, data-driven approaches. For example, a GIS-based analysis in the Kansai region quantified agrivoltaic potential by focusing on low-risk, reclaimable idle croplands, producing a conservative estimate of deployable

.

sites. The study estimated that Kansai could generate 4,564.08 GWh of electricity annually (approximately 0.8% of the region's annual energy consumption) while maintaining agricultural output, including up to 930.82 tons of soybeans (about 6.2% of annual soybean production). These results highlight the potential of agrivoltaics to contribute simultaneously to regional energy supply and agricultural production without requiring additional land conversion [27].

A complementary line of research has focused on the suitability of rice paddies as a major pathway for scaling agrivoltaics across Japan. Given that rice cultivation accounts for a substantial share of the country's cultivated land (reported at around 35%), rice-based agrivoltaics is often discussed as a high-impact option for nationwide deployment. The study suggests that integrating agrivoltaic systems into large-scale commercial rice operations could provide additional, cost-effective economic value (e.g., electricity revenue alongside continued production), deliver environmental co-benefits, and support decentralized power generation, particularly because rice is cultivated across all regions of Japan [25].

The economic implications of agrivoltaics are also substantial. By adding an electricity revenue stream alongside continued cultivation, agrivoltaics can improve farm income diversification and reduce exposure to agricultural price and yield volatility. This is particularly relevant in Japan, where structural pressures—including an ageing farming population, rural depopulation, and increasing land underuse—challenge the long-term viability of agricultural operations. When integrated with local value chains and designed to preserve cultivation continuity, agrivoltaics can support more resilient rural business models that combine food production with renewable electricity generation [23], [28], [29].

Studies examining agrivoltaic deployment on abandoned or underutilized farmland in Japan highlight a central design trade-off between electricity yield and agricultural flexibility. In one case, the system adopted a relatively low LAOR (Land Area Occupation Ratio) of approximately 35%, indicating a lower effective shading/land occupation intensity. A lower LAOR typically reduces electricity generation potential but can improve agronomic compatibility by allowing a wider range of crops to be cultivated and by lowering production risks associated with excessive shading. Conversely, fixed agrivoltaic systems with a higher LAOR tend to increase power output but can restrict crop choice, often favoring shade-tolerant varieties and narrowing farmers' options. Some projects have pursued high-value shade-tolerant crops such as mushrooms and ornamental plants; however, these markets may be limited and sensitive to demand fluctuations. Therefore, designs that maintain lower shading intensity can provide greater crop diversification and adaptability under changing market conditions, strengthening the resilience of agrivoltaic business models [23], [30].

4. CHALLENGES AND FUTURE DIRECTION

Despite encouraging results from early studies and pilot projects, several barriers still constrain the scale-up of agrivoltaics in Japan. A key challenge is the high upfront capital expenditure for PV modules and, in particular, the mounting/trestle structures and associated balance-of-system components, which can elevate project costs and weaken financing feasibility for farmers and small rural actors [23]. In addition, agrivoltaic layouts may increase agricultural operating costs when machinery movement and field operations must be adapted to navigate around structural pillars, headlands, and buffer zones factors that can reduce field efficiency and raise labor and operational burdens. [31] Accordingly, targeted financial incentives and supportive policy measures remain important to lower adoption barriers and improve investment attractiveness for agrivoltaic projects.

Managing dual-use land in agrivoltaics requires careful planning and multi-actor coordination across technical, agronomic, and local governance dimensions. Site selection is particularly complex because projects must satisfy not only resource suitability (irradiance, grid proximity, and land characteristics) but also local socio-environmental requirements and community expectations. [32] Beyond technical feasibility, evidence from agrivoltaics and renewable-energy deployment highlights that project risks and failure are often driven more by financial viability and social acceptance (e.g., trust, perceived fairness, and procedural legitimacy) than by engineering constraints alone. [17], [33] To reduce negative outcomes and implementation friction, it is therefore critical to provide farm operators and local stakeholders with clear, practical guidance on expected economic performance, agronomic best practices, and operational management options tailored to agrivoltaic system types and crop requirements [30], [34].

Agrivoltaic systems must be designed in a crop- and site-specific manner to balance agricultural performance with electricity generation. Key design and operational parameters include panel height/clearance, row spacing, tilt/tracking strategy, and the resulting shading rate and temporal shading pattern, which must be aligned with crop light requirements and field operations (e.g., planting/harvest windows and mechanization constraints). [4], [30], [34] A central technical challenge is managing the physiological effects of reduced photosynthetically active radiation (PAR) on crop yield and quality: while partial shading can be beneficial under heat or drought stress, it can also create yield penalties or quality changes for light-demanding crops, including impacts on fruit traits such as sugar accumulation, coloration, and harvest quality under certain shading regimes. [9], [11], [22], [35] Beyond crop physiology, site suitability is not uniform across Japan; mountainous topography, fragmented parcels, and access limitations can restrict feasible deployment in some prefectures. For example, assessments in Kyoto Prefecture highlight constraints on viable agrivoltaic siting in the northern mountainous areas, underscoring the need for spatially explicit planning and design optimization [32], [36].

Regulatory frameworks also need to evolve to better support the integration of agrivoltaics as a dual-use system. This includes aligning agricultural land-use rules, subsidy structures, and renewable energy policies so that agrivoltaics is recognized as continued farming rather than de facto land conversion. Clear guidelines and standardized procedures are critical to reduce uncertainty and transaction costs and to ensure that both agricultural continuity and electricity generation objectives are met. In Japan, agrivoltaic projects typically require a temporary farmland conversion permit and must use simple support structures that are easily removable, which can increase engineering complexity and contribute to higher upfront costs compared with conventional ground-mounted PV. [16] Finally, macro-level uncertainty also matters: empirical evidence suggests that geopolitical risk can exert a negative influence on renewable (including solar) energy development/consumption in Japan, highlighting the importance of stable policy and financing conditions to sustain investment [26].

Socio-economic incentives can also tilt agrivoltaic projects toward "power-first" outcomes. Evidence from rural Japan indicates that project developers often prioritize PV design parameters particularly shading intensity / LAOR—to increase revenue from electricity sales, and only subsequently adjust crop choices to match the resulting light environment. In Japan, many commercial AVSs have adopted high LAOR (≥60%) to raise power producers' returns; however, higher shading can narrow feasible crop options and encourage shifts toward shade-tolerant (and sometimes non-staple) crops such as ornamentals or mushrooms. In problematic cases, this imbalance has been described as "pseudo-farming/pseudo-agriculture," where agricultural activity becomes nominal and excessive panel density interferes with cultivation. [23], [27] These observations underscore the importance of governance and accountability mechanisms such as yield-based monitoring requirements and clear standards for agricultural activity to preserve agrivoltaics' intended dual benefits for both energy and food security.

5. CONCLUSION

grivoltaics offers a strategically relevant pathway for Japan to address two tightly coupled constraints: limited cultivable land and persistent energy import dependence under post-Fukushima decarbonization goals. By co-locating photovoltaic generation with continued farming activity, agrivoltaics can expand renewable electricity supply without displacing agriculture, potentially strengthening land-use efficiency, rural livelihoods, and energy security. However, evidence reviewed in this paper also shows that agrivoltaic outcomes are highly design- and context-dependent. High upfront costs, added operational complexity for mechanized farming, and regulatory requirements tied to farmland governance remain major barriers to broader deployment. Moreover, socio-economic incentives can skew projects toward "power-first" configurations, increasing the risk of pseudo-farming and undermining the dual-use intent.

This review contributes to the literature by synthesizing Japan-focused findings across agronomic performance, system design choices (e.g., shading intensity/LAOR and layout), economic feasibility, and socio-regulatory governance. The synthesis highlights that scaling agrivoltaics in Japan requires not only technological optimization but also institutional alignment to preserve agricultural continuity and local legitimacy. Future work should prioritize longitudinal field monitoring of crop yield and quality, soil–water dynamics, and biodiversity; develop standardized performance metrics to compare systems across sites; and strengthen policy and financing mechanisms that reward verified agricultural activity alongside electricity generation. With clearer standards, targeted incentives, and stakeholder-centered implementation, agrivoltaics can become a credible pillar of Japan's renewable energy transition while supporting sustainable agriculture and rural revitalization.

REFERENCES

[1] M. P. I. F. Putra, P. Pradhan, and J. P. Kropp, "A systematic analysis of Water-Energy-Food security nexus: A South Asian case study," *Sci. Total Environ.*, vol. 728, Aug. 2020.

[2] C. Dupraz, H. Marrou, G. Talbot, L. Dufour, A. Nogier, and Y. Ferard, "Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes," *Renew. Energy*, vol. 36, no. 10, pp. 2725–2732, Oct. 2011.

[3] M. A. Al Mamun, P. Dargusch, D. Wadley, N. A. Zulkarnain, and A. A. Aziz, "A review of research on agrivoltaic systems," *Renew. Sustain. Energy Rev.*, Jun. 2022.

.

[4] International Energy Agency, “Japan 2021 - Energy Policy Review.” 2021.

[5] M. B. Fuhrmann-Aoyagi, K. Miura, and K. Watanabe, “Sustainability in Japan’s Agriculture: An Analysis of Current Approaches,” *Sustainability*, vol. 16, no. 2, 2024.

[6] Trading Economics, “Japan | Population density (people per sq. km of land area).” 2026.

[7] X. Zhang, Y. Li, F. Xiao, and W. Gao, “Energy efficiency measures towards decarbonizing Japanese residential sector: Techniques, application evidence and future perspectives,” *Energy Build.*, Sep. 2024.

[8] J. Huenteler, T. S. Schmidt, and N. Kanie, “Japan’s post-Fukushima challenge - implications from the German experience on renewable energy policy,” *Energy Policy*, vol. 45, pp. 6–11, Jun. 2012.

[9] T. Sekiyama and A. Nagashima, “Solar sharing for both food and clean energy production: Performance of agrivoltaic systems for corn, a typical shade-intolerant crop,” *Environments*, vol. 6, no. 6, 2019.

[10] E. H. Adeh, J. S. Selker, and C. W. Higgins, “Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency,” *PLoS One*, vol. 13, no. 11, 2018.

[11] H. Marrou, J. Wery, L. Dufour, and C. Dupraz, “Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels,” *Eur. J. Agron.*, vol. 44, pp. 54–66, Jan. 2013.

[12] M. Taylor, J. Pettit, T. Sekiyama, and M. M. Sokołowski, “Justice-driven agrivoltaics: Facilitating agrivoltaics embedded in energy justice,” *Renew. Sustain. Energy Rev.*, vol. 188, Dec. 2023.

[13] R. A. Gonocruz, S. Uchiyama, Y. Yoshida, and others, “Analysis of the rice yield under an agrivoltaic system: A case study in Japan,” *Environments*, vol. 8, no. 7, 2021.

[14] Y. Okada, A. Kotagiri, T. Sakamoto, M. Itoh, and M. Misawa, “Case study of rice farming in Japan under agriphotovoltaic system,” *J. Photonics Energy*, vol. 15, no. 3, 2025.

[15] H. Nasukawa, Y. Kuwabara, K. Tatsumi, and R. Tajima, “Rice yield and energy balance in an agrivoltaic system established in Shonai plain, northern Japan,” *Sci. Total Environ.*, vol. 959, 2025.

[16] N. Kodama, “Considerations in the Temporary Farmland Conversion Permission Process for Solar Sharing,” *J. Japan Sol. Energy Soc.*

[17] N. Akita, Y. Ohe, S. Araki, M. Yokohari, T. Terada, and J. Bolthouse, “Managing conflicts with local communities over the introduction of renewable energy: The solar-rush experience in Japan,” *Land*, vol. 9, no. 9, 2020.

[18] Y. Tan and others, “Agrivoltaics development progresses: From the perspective of photovoltaic impact on crops, soil ecology and climate,” *Environ. Res.*, 2025.

[19] D. Mazzeo, A. Di Zio, C. Pesenti, and S. Leva, “Optimizing agrivoltaic systems: A comprehensive analysis of design, crop productivity and energy performance in open-field configurations,” *Appl. Energy*, vol. 390, 2025.

[20] F. Muhammad-Sukki and others, “Feed-in tariff for solar photovoltaic: The rise of Japan,” *Renew. Energy*, vol. 68, pp. 636–643, 2014.

[21] K. Kimura, L. Lundberg, and T. Kåberger, “How high feed-in tariffs impacted the capital cost of solar PV in Japan,” *Renew. Energy*, vol. 244, May 2025.

[22] T. Kuramochi, “Review of energy and climate policy developments in Japan before and after Fukushima,” *Renew. Sustain. Energy Rev.*, 2015.

[23] H. Nakata and S. Ogata, “Integrating Agrivoltaic Systems into Local Industries: A Case Study and Economic Analysis of Rural Japan,” *Agronomy*, vol. 13, no. 2, 2023.

[24] M. Tajima and T. Iida, “Evolution of agrivoltaic farms in Japan,” in *AIP Conference Proceedings*, 2021.

[25] R. A. Gonocruz, S. Uchiyama, and Y. Yoshida, “Modeling of large-scale integration of agrivoltaic systems: Impact on the Japanese power grid,” *J. Clean. Prod.*, vol. 363, 2022.

[26] F. Taghizadeh-Hesary, H. Phoumin, and E. Rasoulinezhad, “Assessment of role of green bond in renewable energy resource development in Japan,” *Resour. Policy*, vol. 80, 2023.

[27] H. Nakata and S. Ogata, “Geographic Information System-Based Analysis of Reclaimable Idle Cropland for Agrivoltaics in Kansai, Japan: Enhancing Energy and Food Security,” *Agronomy*, vol. 14, no. 2, 2024.

[28] T. Takayama, T. Nakatani, T. Senda, and T. Fujie, “Less-favoured-area payments, farmland abandonment and farm size: evidence from hilly and mountainous areas in Japan,” *Aust. J. Agric. Resour. Econ.*, vol. 65, no. 3, pp. 658–678, 2021.

[29] A. S. Pascaris, C. Schelly, L. Burnham, and J. M. Pearce, “Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of agrivoltaics,” *Energy Res. \& Soc. Sci.*, vol. 75, 2021.

[30] E. Warmann, G. D. Jenerette, and G. A. Barron-Gafford, “Agrivoltaic system design tools for managing trade-offs between energy production, crop productivity and water consumption,” *Environ. Res. Lett.*, vol. 19, no. 3, 2024.

[31] Y. Bellone and others, “Agricultural mechanization in agrivoltaic systems: Challenges, adaptation, and possible advancements,” *Renew. Sustain. Energy Rev.*, 2026.
[32] N. Irie, R. Iwamura, K. Sugiura, and N. Kawahara, “Siting Renewable Energy Facilities Using a Matching Algorithm: A Case Study in Japan,” *Land*, vol. 12, no. 1, 2023.
[33] N. Irie, N. Kawahara, and A. M. Esteves, “Sector-wide social impact scoping of agrivoltaic systems: A case study in Japan,” *Renew. Energy*, vol. 139, pp. 1463–1476, 2019.
[34] M. A. Z. Abidin, M. N. Mahyuddin, and M. A. A. M. Zainuri, “Solar photovoltaic architecture and agronomic management in agrivoltaic system: A review,” *Sustainability*, vol. 13, 2021.
[35] P. Juillion, G. Lopez, D. Fumey, V. Lesniak, M. Génard, and G. Vercambre, “Combining field experiments under an agrivoltaic system and a kinetic fruit model to understand the impact of shading on apple carbohydrate metabolism and quality,” *Agrofor. Syst.*, vol. 98, no. 8, pp. 2829–2846, 2024.
[36] A. Yamada and S. Ogata, “Potential evaluation of agrivoltaic case of Kyoto prefecture Japan,” in *AIP Conference Proceedings*, 2021.
.