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*Proceeding Paper*

# Study on the Feasibility of Agrivoltaics in the Kansai Region of Japan †

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**Abstract:** As the climate crisis intensifies, the urgency for sustainable, agroecological farming practices has never been greater. This study explores the potential of agrivoltaic systems (AVSs) to meet these needs efficiently. Utilizing geographic information systems for quantitative analysis, this research assesses the electricity generation, agricultural output, job creation, and economic impact of implementing AVS in Japan's Kansai region. The study identifies an ample generation potential, including up to 14,041 GWh/year of electricity generation, suggesting that AVSs could be instrumental in shaping effective policies for both decarbonization and food security.

**Keywords:** agrivoltaics; geographic information system; decarbonizing agriculture

## 1. Introduction

The escalating climate crisis means decarbonizing all sectors, including agriculture. Approximately 30% of global greenhouse gas emissions originate from agriculture, necessitating immediate measures for its decarbonization [1]. To tackle this, the agrivoltaic system (AVS), which allows for both farming and solar power generation on one land tract, has gained much interest. The agrivoltaic concept was originally introduced in 1982 by Goetzberger and Zastrow, affiliated with Germany's Fraunhofer Institute for Solar Energy Systems ISE [2]. In Japan, an AVS support program was initiated in 2013, and as of 2021, a cumulative total of 3474 AVSs had been approved for establishment [3].

AVSs offer multiple benefits rooted in agroecology [4,5]. As an example, AVSs protect the ground and plants from direct sunlight and increase water use efficiency. Furthermore, the revenue generated by AVSs has the effect of diversifying farmers' incomes. This diversification provides farmers with opportunities for economic independence and adding value to their products. In addition, AVSs encourages farmers to reclaim farmland by increasing the profitability of abandoned farmland with unfavorable agricultural conditions. This process preserves above- and below-ground biodiversity. AVS-based synergies can practically implement agroecology principles.

On the other hand, certain instances of AVSs diverge from the foundational principles of agroecology. For example, in Japan, there are more than 100 instances where agricultural yields, influenced by AVSs, fall below 20% of the region's average agricultural output [6]. Among various reasons contributing to these problematic cases is an inappropriate balance between power generation and agriculture. In particular, there are cases where solar power generation has been excessively prioritized—by installing too many solar panels, for instance—to the point that it has interfered with agriculture, and agriculture has been relegated to a perfunctory role, known as "pseudo-farming". Appropriate system design is essential to prevent such instances.

Against this backdrop, the objective of this research is to assess the viability of introducing AVSs in a manner that maintains a balanced relationship between agricultural and



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power-generation activities. Moreover, it aims to acquire an in-depth understanding of the prevailing conditions in the region under study. The results of this research will present policy makers with critical insights into the current status of agroecology in the region, thereby aiding in appropriate system design and the formulation of effective policies.

## 2. Methods

### *2.1. Study Area*

For the geographical focus of this research, the Kansai region of Japan serves as the study area. Situated in the southern central part of the country, this region encompasses seven prefectures and 227 municipalities. As of 2020, the total population amounted to 22,311,695, spread over an area of 33,125.70 km$^2$ [7]. The region is home to Japan's second-largest industrial zone, the Hanshin Industrial Region, where manufacturing predominates [8].

### *2.2. Scenario Development and Analysys*

This study undertakes a quantitative evaluation of the prospects for introducing AVS. The target areas for this deployment were circumscribed to reclaimable idle farmland, a choice that was influenced by considerations of food and energy security. Moreover, farmlands that are severely degraded—such as those converted into forest lands—were excluded from the project's scope. The estimated cost for rehabilitating idle, yet minimally devastated, farmland ranges between EUR 15,000 and EUR 18,000 per hectare [9]. Although the introduction of AVSs to severely devastated farmland would have a greater potential, the cost of rehabilitating farmland would be too high and difficult to commercialize, so it is not included in the scope of this study.

We limited the land area occupation ratio (LAOR) of the AVSs to be introduced to 35%. The LAOR is "the ratio between the area of the modules and the area of land that they occupy" [10]. The value of 35% is a level that does not interfere with agricultural production for many crop species grown in Japan [11]. For the system architecture, a rattan-shelf open-field-type AVS was selected.

This study employed soybean as the chosen crop, owing to its versatility in serving as food, livestock feed, and a meat substitute. Given that Japan's self-sufficiency rate for soybeans languishes at merely 6–7%, the production of this crop was considered to bolster national food security [12].

Finally, two distinct scenarios inform the estimation of idle farmland distribution. The Full Coverage Scenario (FC) contemplates the installation of AVSs across all reclaimable idle farmlands, whereas the Priority Coverage Scenario (PC) restricts AVS implementation to areas that are identified as being particularly conducive for AVS deployment based on the FC Scenario.

In this study, to accurately estimate the distribution of revitalizable idle agricultural land, we employed agricultural land polygon data and the High-Resolution Land Use and Land Cover Map of Japan (HRLULC). The former are published by Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF) and were developed through the interpretation of satellite imagery to capture the footprints of potential agricultural land [13]. These data allow for high-precision, parcel-by-parcel identification of farmland while excluding non-cropland and severely devastated farmland. To further refine the target area by excluding currently used farmland, HRLULC data from the Japan Aerospace Exploration Agency (JAXA) were utilized. These machine-classified data comprise 12 categories, such as paddy fields, croplands, and grasslands, based on average usage from 2018 to 2020. The data are resolved to a mesh size (1/12,000) degree $\times$ (1/12,000) degree, corresponding to an approximate 10 m $\times$ 10 m, with an overall accuracy reported at 88.85% [14].

To mitigate disaster risk, the selection of target areas was further constrained. Specifically, areas vulnerable to landslides and flooding, as delineated in Table 1, were excluded, as were lands requiring ecosystem conservation. In the PC scenario, AVS introduction was confined to farmlands with high suitability for AVSs, based on slope and aspect indicators. Farmlands intersecting with areas identified in the lower part of Table 1 were solely excluded from the PC scenario.

**Table 1.** High-risk areas excluded from this study's consideration.

| Scenarios | High-Risk Areas |
|---|---|
| Both scenarios | Sediment-disaster alert areas<br>Steep-slope-failure hazard areas<br>Flood disaster alert areas<br>Areas with steep slopes (20 or more degrees)<br>Natural parks<br>Landscape districts<br>Wildlife-protection areas |
| Only PC scenario | Areas with moderate slopes (10–20 degrees)<br>Areas with northern maximum slope directions |

Source: compiled from [15,16].

In addition, a non-installed area was established 5 m inward from the boundary of each agricultural field based on a survey by the Japanese Ministry of the Environment (MOE) [17]. This non-installed area was established to avoid shadowing of the AVS structures on adjacent land and to maintain operational efficiency. In addition, based on the MOE survey, parcels with an area of less than 16 $m^2$ after exclusion were excluded from the survey.

Following the mapping of idle farmland, the impact of AVS installation was quantified. Power generation was estimated utilizing solar radiation and temperature data from Japan's New Energy and Industrial Technology Development Organization (NEDO) [18]. Agricultural yields were assessed at 80% of the per-area soybean harvest in each prefecture, premised on the use of conventional farming methods [19]. This 80% threshold serves as the minimum yield required for the ongoing approval under Japan's AVS support program, constituting a conservative assumption [20]. Prior research indicates that even at 73–75% solar transmittance, 85–92% of control yields were achieved, justifying this as a prudent assumption [11].

Economic and employment impacts were also analyzed. Ripple effects within each prefecture were assessed using the economic ripple effect analysis tool published by the MOE [21]. The economic impact in the power generation sector is predicated on electricity sales through the feed-in tariff system. In agriculture, ripple effects were calculated using the average bid price of Japanese soybeans in 2022 (70.5EUR /60 kg) [22].

Employment creation effects were estimated for the power generation and agricultural sectors [23]. For the power generation sector, an employment coefficient per GWh of electricity generated per year was used. This employment factor took into account direct and indirect employment in both the construction and operation and maintenance phases [24]. In the agricultural sector, the detected idle farmland area was multiplied by the average number of agricultural workers per area in each province [25].

## 3. Results and Discussion

### *3.1. Full Coverage Scenario*

The results of the FC scenario analysis are summarized in Table 2. The highest estimated annual power generation in the first year reached 3953.59 GWh in Mie, compared to a low of 708.42 GWh in Osaka. In Wakayama, the data suggest that nearly 30% of annual electricity consumption could be sourced from photovoltaic power generation. Furthermore, the implementation of AVSs could potentially create employment opportunities ranging from 2653.88 person years in Nara to 12,803.41 person years in Mie. The majority of regional economic ripple effects are attributable to the power-generation sector, with impacts varying from 0.14% of the Gross Regional Product (GRP) in Osaka to 3.51% in Mie at the construction stage.

**Table 2.** Results of the full coverage scenario analysis.

| Indicators of Performance | Unit | Mie | Shiga | Kyoto | Osaka | Hyogo | Nara | Wakayama | Total |
|---|---|---|---|---|---|---|---|---|---|
| Idle cropland area | $km^2$ | 39.59 | 22.73 | 14.67 | 7.45 | 37.29 | 8.16 | 17.09 | 33,125.97 |
| The rate of idle cropland area to total area | % | 0.69 | 0.57 | 0.32 | 0.39 | 0.44 | 0.22 | 0.36 | 0.44 |
| System capacity | MWac | 3353.59 | 1872.26 | 1190.38 | 615.19 | 3096.18 | 669.76 | 1419.09 | 12,216.43 |
| Annual electricity generation (1st year) | GWh | 3954.12 | 2104.31 | 1271.87 | 708.42 | 3575.55 | 749.55 | 1677.67 | 14,041.49 |
| The rate of electricity generated compared to consumption [1] | % | 21.4 | 18.5 | 8.0 | 1.3 | 10.7 | 11.9 | 28.2 | 9.6 |
| Food production (soybeans) | t | 234.40 | 278.20 | 100.91 | 42.29 | 253.55 | 61.34 | 120.31 | 1091.00 |
| Job creation (Construction) | Person years | 6761.55 | 3598.38 | 2174.9 | 1211.39 | 6114.19 | 1281.73 | 2868.82 | 24,010.95 |
| Job creation (O and M) | Person years | 4468.16 | 2377.88 | 1437.21 | 800.51 | 4040.37 | 846.99 | 1895.77 | 15,866.88 |
| Job creation (Agriculture) | Person years | 1573.70 | 743.42 | 883.08 | 652.97 | 2146.89 | 525.16 | 1648.32 | 8173.54 |
| Economic ripple effects (Construction) | EUR 1M | 4811.75 | 2656.85 | 1766.44 | 943.09 | 4581.82 | 999.90 | 2027.28 | 17,787.14 |
| Economic ripple effects (O and M, 1st year) | EUR 1M | 507.79 | 279.49 | 188.86 | 101.02 | 487.04 | 108.38 | 215.5 | 1888.08 |
| Economic ripple effects (Agriculture) | EUR 1M years | 0.33 | 0.38 | 0.14 | 0.06 | 0.36 | 0.09 | 0.17 | 1.54 |
| Nominal gross regional product [2] | EUR 1M | 58,683 | 50,067 | 78,177 | 299,810 | 161,916 | 28,485 | 27,262 | 704,400 |

[1] FY2021 electricity consumptions [26], [2] FY2019 nominal gross regional product [27].

### 3.2. Priority Coverage Scenario

In the PC scenario, the potential assessment was limited to areas with high potential for AVS installation, so the scale of installation was smaller. Actually, as shown in Table 3, the area of idle farmland diminished substantially: 3.41 $km^2$ in Osaka compared to 16.97 $km^2$ in Mie under the FC scenario. The most marked reduction occurred in Shiga, where the area decreased from 22.73 $km^2$ in the FC scenario to just 7.11 $km^2$—a 68.7% reduction. Conversely, both Mie and Wakayama still demonstrated the potential to cover about 10% of their annual electricity consumption through solar power, even within the constraints of the PC scenario.

### 3.3. Discussion

Focusing on the Kansai region of Japan, this study suggests that the implementation of AVSs serves as an effective means for achieving agroecological principles. Under both the FC and PC scenarios, the reclamation of idle cropland encompassed an area ranging from 59 to 147 $km^2$. This reclamation provided multiple benefits, including enhanced food and energy security, ecosystem preservation, and increased resilience in agricultural operations. Policy makers should consider leveraging these benefits while mitigating inappropriate land use by operators pursuing short-term economic gains. Immediate tasks for achieving this may include disseminating best practices, providing financial incentives, or strictly regulating problematic practices.

Additionally, one key aspect that was underexplored in this study relates to the diversity of agriculture and AVS practices. This current research focuses primarily on soybean cultivation, using both rattan-shelf AVS and conventional farming methods. However, from an agroecological standpoint, the incorporation of more complex agricultural systems—such as variety mixtures and crop-livestock integration—is warranted. In the domain of power generation, a diverse range of systems exists, including vertical bifacial setups, PV greenhouse systems, and spectrally selective solar modules. Although these advanced systems are not explored in this study, their integration could offer synergistic advantages within an agroecological framework.

**Table 3.** Results of the priority coverage scenario analysis.

| Indicators of Performance | Unit | Mie | Shiga | Kyoto | Osaka | Hyogo | Nara | Wakayama | Total |
|---|---|---|---|---|---|---|---|---|---|
| Idle cropland area | $km^2$ | 16.97 | 7.11 | 5.48 | 3.41 | 16.41 | 3.82 | 6.20 | 59.39 |
| The percentage of idle cropland area to total area | % | 0.29 | 0.18 | 0.12 | 0.18 | 0.20 | 0.10 | 0.13 | 0.18 |
| System capacity | MWac | 1436.35 | 584.48 | 444.36 | 282.22 | 1361.58 | 313.12 | 515.42 | 4937.54 |
| Annual electricity generation (1st year) | GWh | 1689.39 | 651.26 | 474.04 | 325.07 | 1569.14 | 350.00 | 610.54 | 5669.44 |
| The rate of electricity generated compared to consumption | % | 9.1 | 5.7 | 3.0 | 0.6 | 4.7 | 5.6 | 10.3 | 3.9 |
| Food production (soybeans) | t | 100.48 | 87.03 | 37.69 | 19.38 | 111.56 | 28.70 | 43.62 | 428.46 |
| Job creation (Construction) | Person years | 2888.86 | 1113.65 | 810.62 | 555.88 | 2683.23 | 598.50 | 1044.02 | 9694.74 |
| Job creation (O and M) | Person years | 1909.01 | 735.92 | 535.67 | 367.33 | 1773.13 | 395.50 | 689.91 | 6406.47 |
| Job creation (Agriculture) | Person years | 674.59 | 232.56 | 329.86 | 299.32 | 944.59 | 245.67 | 597.59 | 3324.18 |
| Economic ripple effects (Construction) | EUR 1M | 2060.78 | 829.39 | 659.39 | 432.65 | 2014.87 | 467.45 | 736.27 | 7200.81 |
| Economic ripple effects (O and M, 1st year) | EUR 1M | 219.85 | 88.27 | 70.71 | 46.38 | 214.78 | 50.91 | 78.93 | 769.82 |
| Economic ripple effects (Agriculture) | EUR 1M years | 0.14 | 0.12 | 0.05 | 0.03 | 0.16 | 0.04 | 0.06 | 0.61 |
| Nominal gross regional product | EUR 1M | 58,683 | 50,067 | 78,177 | 299,810 | 161,916 | 28,485 | 27,262 | 704,400 |

## 4. Conclusions

AVS is an effective tool for achieving agroecological principles. Our study shows 59–147 $km^2$ of idle cropland in Japan's Kansai region. AVSs on these lands could produce 5669–14,041 GWh of power and 428–1091 tons of soybeans yearly. This effort could create jobs and economic revenue from construction to maintenance. These findings underscore the considerable contributions that AVSs can make to agroecology, which is critical information for policy makers. Utilizing these data could aid in developing policies for effective agroecology.

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