Geospatial Analysis of Agrivoltaic Suitability in the Philippines

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Abstract

Solar energy deployment increasingly competes with prime agricultural lands, creating conflicts between energy goals and food security. To resolve these competing demands, our study identified where agrivoltaic systems—combining solar energy and agricultural production on the same land—should be strategically deployed across the Philippines. Using geospatial analysis which integrates terrain suitability, solar photovoltaic (PV) potential, and crop compatibility with shade-tolerant crops, we identified 10.09 million has of cropland suitable for agrivoltaics, representing 81.8% of the nation's agricultural land. Regions in the Mindanao island emerged as premier agrivoltaic deployment zones, combining maximum crop compatibility (15 shade-tolerant crops), high solar PV potential (683-687 MW), and substantial suitable areas (587,000-715,000 has). These findings provide actionable recommendations for strategic agrivoltaic deployment that advances both food security and renewable energy goals in the Philippines simultaneously.

1. Introduction

Global surface temperatures have risen 1.1°C above pre-industrial levels between 2011 and 2020, with the Intergovernmental Panel on Climate Change (IPCC) attributing this warming to human activity (Arias et al., 2023). Climate change threatens both food security—through extreme weather events that disrupt agricultural systems (Dikitanan et al., 2017)—and energy security, as the world meets its growing energy demands while transitioning to renewables. The challenge intensifies when agriculture and energy production compete for the same land resources. This land use conflict has sparked community resistance to solar energy installations on agricultural land (Battersby, 2023), and innovation in agrivoltaic systems that offer a way to reconcile energy production with agricultural needs (Pascaris et al., 2023).

Agrivoltaics—the co-location of agricultural production and solar energy generation on the same land—enables harvesting sunlight twice (Goetzberger and Zastrow, 1982). The agrivoltaics system works by positioning solar panels between or above crops, creating microclimates that regulate temperatures, conserve water, and shield crops from extreme weather while maintaining access to agricultural equipment (Macknick et al., 2022; Max Trommsdorff et al., 2024). This approach offers social, economic, and environmental benefits while aligning with the Climate-Resilient Agriculture (CRA) principles which prioritize agricultural systems' ability to anticipate, adapt to, and recover from climate change impacts and extreme weather events (Agir et al., 2023; Alvar-Beltrán et al., 2021; Moore et al., 2022).

For climate-vulnerable countries like the Philippines, committed to ambitious renewable energy targets while facing climate risks, agrivoltaics presents a pathway toward sustainable development (Bündnis Entwicklung Hilft / IFHV, 2023; Department of Energy, 2023). However, no comprehensive assessment has yet mapped where agrivoltaic deployment would be, one that considers potential sites both as technically feasible and agriculturally strategic across the Philippines' diverse landscape and cropping systems. We addressed these questions through two key objectives: (1) identify and map geographical areas across the Philippines most suitable for agrivoltaic development using geospatial analysis (Spatial Suitability Analysis); and (2) evaluate the compatibility of Philippine crops under agrivoltaic shading conditions to provide recommendations for future researchers and developers (Crop Compatibility Assessment). By employing Geographic Information System (GIS), we aim to maximize both agricultural productivity and renewable energy generation while supporting the Philippines' transition toward climate-resilient agriculture. Our analysis reveals not just where agrivoltaics are technically feasible, but where they should be prioritized to maximize both energy and agricultural production.

2. Methodology

We identified whether an area in the Philippines is suitable for agrivoltaic systems based on the following criteria: (1) the area must be cropland because according to Adeh et al., "solar PV power potential is greatest over croplands" (Adeh et al., 2019), (2) and the cropland area must have a slope classification less than 10° because according to Jacobson and Jadhav (2018), the optimal tilt angle for the Philippines is 10°. We also quantified solar photovoltaic potential adjusted for local environmental conditions.

2.1 Data

We used the land use/cover map from the National Mapping and Resource Information Authority (NAMRIA, 2018) and digital elevation model raster data from the Shuttle Radar Topography Mission (NASA JPL, 2013). Although the 2020 land cover map is available, we used the 2015 version to include cropland areas that were converted from agricultural purposes to solar energy generation since 2013 (Department of Energy, 2024). For the solar PV output data, we used the effective output power potential PV (PPV) map from the works of Principe et al. (2023) and Sotto et al. (2024) which estimated the solar power production in the Philippines by accounting for cell temperature, dust accumulation, and precipitation. The land use/cover data and digital elevation model have a 30-meter spatial resolution.

Meanwhile, we resampled the PPV data from its five-kilometer spatial resolution into a 30-meter resolution.

For the crop data, we identified 22 Philippine crops: 21 were based on the Philippine Statistics Authority (PSA) while rice data was sourced from the Philippine Rice Research Institute (PhilRICE). The 22 crops are as follows: abaca, ampalaya fruit, banana, cabbage, cacao, calamansi, cassava, coconut, coffee, corn, eggplant, mango, mung bean, onion, pineapple, potato, rice, rubber, sugarcane, sweet potato, tobacco, and tomato (Philippine Rice Research Institute, 2023; Philippine Statistics Authority, 2025, 2024a, 2024b, 2024c). Due to data unavailability and complexity, we did not include seasonal crop rotations, intercropping, and land tenure. The Philippine regional boundary shapefile (17 regions in total) was obtained from the database of global administrative areas (GADM, 2022).

2.2 Methods

Technical suitability alone cannot be the sole basis for strategic deployment. Areas that can support agrivoltaic systems may not align with regions where existing crop production favors shade-compatible crops. Therefore, we developed a two-objective methodology framework (Fig. 1) to address the following complementary questions: where can agrivoltaics be installed (Objective 1: spatial suitability) and where should they be prioritized (Objective 2: crop compatibility with shade-tolerant crops that benefit from shading and conditionally shade-tolerant crops that respond positively under specific conditions).

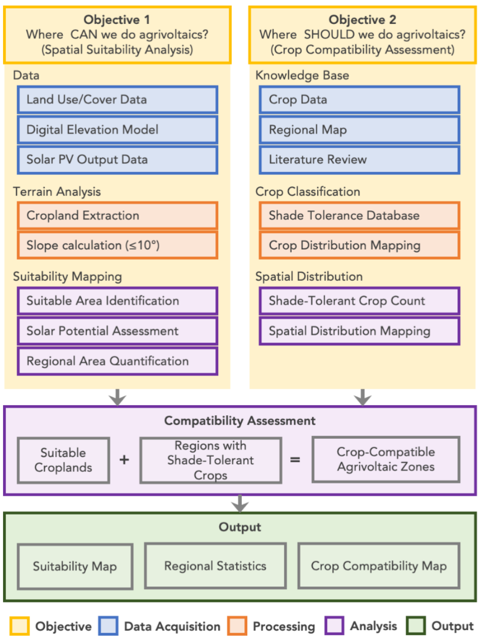


Figure 1. Agrivoltaic suitability assessment methodology.

Objective 1 establishes a technical foundation by mapping suitable croplands with adequate terrain and solar PV potential. Objective 2 builds upon this foundation by identifying regions where shade-tolerant and conditionally shade-tolerant crops are concentrated, enabling strategic deployment and leveraging existing agricultural practices. Objective 2 also assumes current land use classifications and does not account for temporal changes in cropping patterns. The integration of both objectives produces crop-compatible agrivoltaic zones where technical feasibility aligns with agricultural opportunity.

2.2.1 Spatial Suitability Analysis: Agrivoltaic deployment requires identifying technically feasible locations that combine suitable terrain, cropland availability, and solar PV potential. For this study, three spatial constraints must be simultaneously satisfied: slope limitations (≤10°), existing cropland classification, and sufficient solar PV potential. We used a three-step process in ArcGIS Pro Version 3.4 (Esri, 2024) to integrate the constraints systematically.

First, we identified areas with slopes of 10° or less by creating a binary mask where suitable slopes were assigned a value of one and unsuitable areas zero. Next, we isolated the cropland areas from our land use/cover dataset to preserve the hectare values for each pixel while setting the non-cropland areas to zero. It ensures that we only consider land classified as cropland (either annual or perennial). Finally, we combined the terrain and land use/cover filters with annual solar PV output data, where suitable areas reflected their corresponding annual solar PV output potential (measured in MW) and unsuitable areas were assigned a zero value.

We conducted a provincial-level analysis using Python to quantify agrivoltaic potential across the Philippines' 81 provinces. The national suitability raster was clipped using provincial boundary shapefiles through automated batch processing, generating individual suitability maps for each province. Then, we calculated the suitable area and solar PV output statistics for each province using pixel-level analysis with a fixed 30-meter by 30-meter resolution (900 square meters per pixel). Non-zero pixels represented suitable agrivoltaic areas which were then converted to hectares (has) by multiplying pixel counts by 0.09 has per pixel. For each provincial raster, we computed area statistics (total suitable has) and solar PV output potential (minimum, maximum, and mean values) for suitable areas only.

Provincial results were aggregated by administrative region to align with available agricultural statistics. We grouped the 81 provinces into 17 administrative regions and computed regional totals for suitable area and solar PV output statistics. The regional aggregation was necessary to match the spatial resolution of the PSA crop production data, which reports each region's percentage contribution to national crop production at the regional level only.

2.2.2 Crop Compatibility Assessment: Identifying where agrivoltaics should be deployed requires integrating suitable croplands with regions that produce shade-compatible crops. While Objective 1 addresses the concern of where agrivoltaics can be installed, Objective 2 addresses where they should be prioritized based on crop compatibility. We developed a systematic framework for crop compatibility which followed four sequential steps.

First, we conducted a systematic literature review to establish crop shade tolerance classifications for 22 major Philippine crops and create the knowledge base for compatibility assessment. Few studies have directly tested these crops under solar panels in Philippine conditions, so we also reviewed studies that tested these crops under artificial shading. Since crops respond to the reduction of solar radiation regardless of the shading source, these experiments provide evidence for estimating their performance under agrivoltaic systems.

Due to the unavailability of literature about its crop shading response, we removed calamansi from the list of crops. The remaining 21 crops received one of three classifications: (1)

Crops that showed enhanced yield, growth, or quality under shading conditions are considered shade tolerant; (2) Crops that experienced reduced yield, growth, or quality under shading, or crops explicitly identified in literature as intolerant to shade conditions are considered shade intolerant; and (3) Crops that demonstrated positive shading responses under specific conditions such as varying shade levels, cultivars, growth phases, irrigation, or climate conditions are considered conditionally shade tolerant.

Next, we compiled the regional crop production data and calculated each region's percentage contribution to the national production of all 21 crops. Then, we quantified and mapped the number of shade-tolerant and conditionally shade-tolerant crops produced in each region to visualize the geographic concentration of shade-compatible crops.

Finally, we evaluated regional crop compatibility data against regional suitability to assess how shade-tolerant and conditionally shade-tolerant crops align with the available suitable area and solar potential across the 17 administrative regions in the Philippines.

Integrating the results from Objectives 1 and 2 identified regions where agrivoltaic systems can leverage existing shade-compatible crops while utilizing areas with substantial suitable land and favorable solar conditions.

3. Results and Discussion

3.1. Suitability Considering Spatial Constraints

The spatial analysis identified approximately 10.09 million has suitable for agrivoltaics, representing 81.8% of the Philippines' total agricultural land area of 12,334,000 has (Dikitanan et al., 2017). Cropland distribution showed suitable agricultural lands growing annual and perennial crops clustered in distinct regions across the Philippines (Fig. 2), with white areas representing non-cropland cover types including forests, built-up areas, and water bodies. Terrain constraints eliminated areas with slopes >10° despite their agricultural value (Fig.3), demonstrating why the mountainous areas in the country were excluded from analysis regardless of agricultural potential.

Solar resource availability was consistent across the country (Fig. 4), with annual solar PV output showing minimal variation—15 of 17 regions achieved 93-100% of maximum potential (Ilocos Region at 701.01 MW). The variation range of only 17.4% indicated that solar resource availability is not a limiting factor for most regions. High solar potential regions spanned all three major island groups: Luzon (Ilocos, CAR), Visayas (Central Visayas), and Mindanao (Northern Mindanao, Davao).

The applied spatial constraints (i.e., land cover must be cropland, slopes ≤10°, and adequate solar potential) proved less limiting than anticipated, indicating substantial agrivoltaic potential across the country (Fig. 5 and Table 1). Luzon dominated suitable area availability with 4.41 million has (43.7% of national total), followed by Mindanao at 3.48 million has and Visayas at 2.20 million has. Since technical constraints have demonstrated minimal limitations, the strategic focus can shift toward optimizing agrivoltaic deployment based on crop compatibility and regional agricultural priorities.

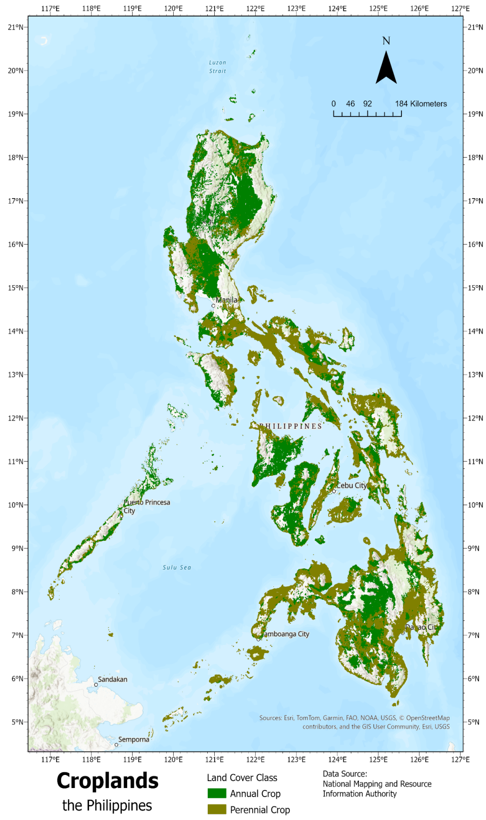


Figure 2. Cropland distribution across the Philippines showing annual and perennial crops.

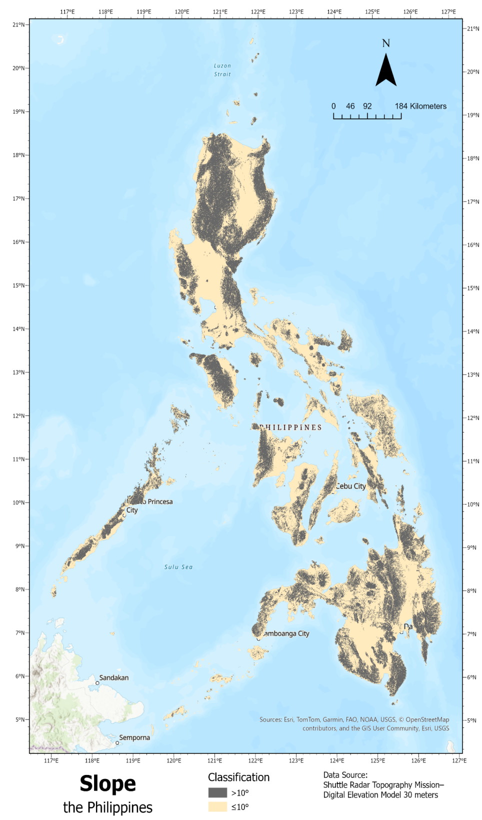


Figure 3. Terrain suitability for agrivoltaic development based on slope constraint.

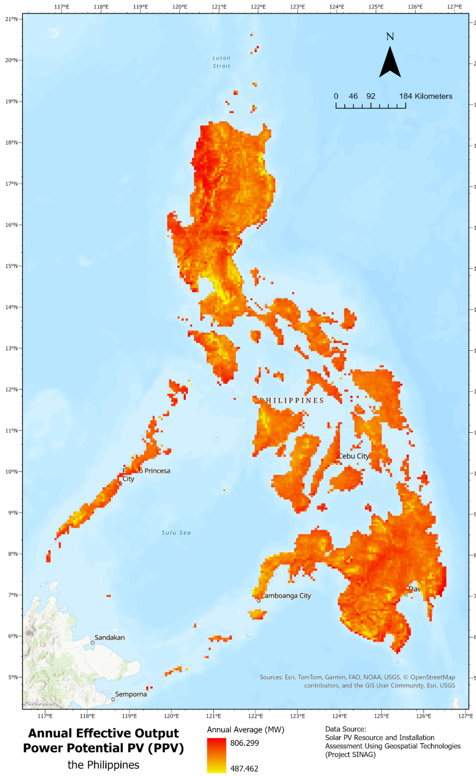


Figure 4. Annual solar photovoltaic output potential across the Philippines.

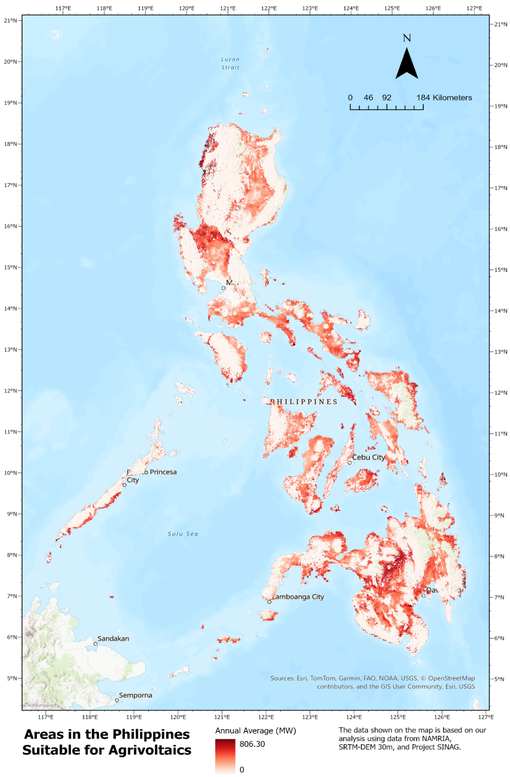


Figure 5. Agrivoltaic suitability map of the Philippines showing suitable areas for agrivoltaics and their mean annual solar PV power potential.

Region	PPV* (MW)	Total suitable area (has)
National Capital Region (NCR)	578.91	355.95
Cordillera Administrative Region (CAR)	681.20	165,058.02
Ilocos Region (I)	701.01	435,969.54
Cagayan Valley (Region II)	671.30	884,854.53
Central Luzon (Region III)	655.63	758,922.21
CALABARZON (Region IV-A)	653.78	756,775.89
MIMAROPA (Region IV-B)	678.19	542,395.08
Bicol Region (Region V)	680.05	866,932.56
Western Visayas (Region VI)	668.54	834,528.51
Central Visayas (Region VII)	692.87	558,223.56
Eastern Visayas (Region VIII)	673.92	808,858.98
Zamboanga Peninsula (Region IX)	664.58	547,238.61
Northern Mindanao (Region X)	687.24	678,791.88
Davao Region (Region XI)	683.44	587,299.95
SOCCSKSARGEN (Region XII)	674.36	714,612.96
Caraga (Region XIII)	678.99	454,108.77
Bangsamoro Autonomous Region in Muslim Mindanao (BARMM)	674.00	497,887.20

*Annual mean effective solar PV output power.

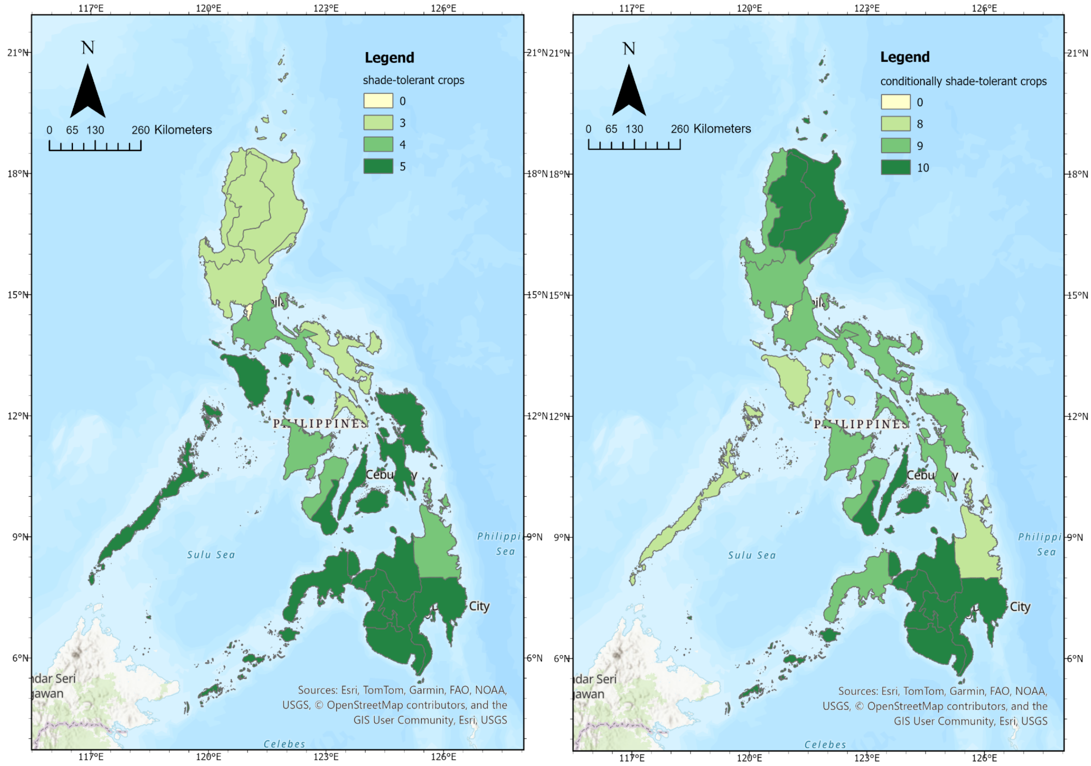
Table 1. Agrivoltaic-suitable area and solar potential by Philippine administrative region.

3.2. Suitability with Crop Compatibility

With solar resources abundant, suitable area and crop compatibility determine agrivoltaic deployment priorities. Regional distribution varies among shade-tolerant (abaca, banana, cabbage, rubber, tobacco), conditionally shade-tolerant (cacao, coffee, corn, mango, onion, pineapple, potato, rice, sugarcane, tomato), and shade-intolerant crops (ampalaya fruit, cassava, coconut, eggplant, mung bean, sweet potato) (Fig. 6; Appendix, Table 2).

Mindanao emerges as the premier region, combining maximum crop compatibility, high solar potential, and substantial areas. Northern Mindanao (678,792 ha) offers five shade-tolerant and 10 conditionally shade-tolerant crops with 687.24 MW solar potential (third nationally). Davao and SOCCSKSARGEN show similar strengths: both produce five shade-tolerant and 10 conditionally shade-tolerant crops with 683.44 MW and 674.36 MW respectively.

Luzon demonstrates how optimal solar conditions enhance shade-tolerant crop zones. Ilocos Region (435,970 ha) combines the Philippines' highest solar potential (701.01 MW) with crop compatibility: three shade-tolerant and nine conditionally shade-tolerant crops, including tobacco (93.2% national production). CAR features three shade-tolerant and 10 conditionally shade-tolerant crops, notably cabbage (65.60% national production), despite smaller area (165,058 ha). Central Luzon (758,922 ha) offers substantial area with moderate solar potential (655.63 MW) and crop compatibility.



Spatial Distribution of Shade-Tolerant Crops in the Philippines

(a)

Spatial Distribution of Conditionally Shade-Tolerant Crops in the Philippines

(b)

Figure 6. Regional spatial distribution of (a) shade-tolerant and (b) conditionally shade-tolerant crops in the Philippines.

The Visayas demonstrated how high crop compatibility can enhance agrivoltaic potential despite area constraints. Central Visayas (558,224 has) achieved both the second-highest solar potential nationally (692.87 MW) and maximum crop compatibility, with five (5) shade-tolerant and 10 conditionally shade-tolerant crops. Eastern Visayas (808,859 has) has five (5) shade-tolerant and nine (9) conditionally shade-tolerant crops and moderate solar potential (673.92 MW, 3.9% below highest). Western Visayas (834,529 has) combined substantial suitable area with solar potential of 668.54 MW (4.6% below highest), and good crop compatibility (four shade-tolerant and nine conditionally shade-tolerant crops).

The crop compatibility assessment revealed a clear regional hierarchy based on shade tolerance. Tier 1 regions achieved maximum crop compatibility with 15 crops: Northern Mindanao, Davao, SOCCSKSARGEN, BARMM, and Central Visayas all offer the full range of shade-tolerant (five crops) and conditionally shade-tolerant (10 crops) options identified in this study. Tier 2 regions with 13-14 shade-compatible crops include CAR, CALABARZON, MIMAROPA, Western Visayas, Eastern Visayas, and Zamboanga Peninsula. Tier 3 regions with 12 shade-compatible crops include Ilocos, Cagayan Valley, Central Luzon, Bicol, and Caraga.

4. Conclusion

Our comprehensive geospatial analysis revealed that the Philippines possesses substantial agrivoltaic potential, with 10.09 million has—81.8% of the nation's agricultural land—meeting technical suitability criteria. Solar resources prove abundant and consistent across the archipelago, with 15 of 17 regions achieving 93-100% of maximum solar potential. Mindanao emerges as the premier region for agrivoltaics deployment, with Northern Mindanao, Davao, and SOCCSKSARGEN combining maximum agricultural diversity (15 shade-compatible crops), high solar potential (683-687 MW), and substantial suitable areas (587,000-715,000 has each). Central Visayas demonstrated similar crop compatibility with the second-highest solar potential nationally (692.87 MW). The abundance of technically suitable land fundamentally shifts deployment strategy from addressing technical constraints to optimizing agricultural compatibility. Strategic deployment should prioritize regions where shade-tolerant crops align with high solar potential, rather than simply maximizing installed capacity. This integration potentially resolves the perceived conflict between renewable energy and food security, allowing agrivoltaic systems to simultaneously meet both objectives when deployed in areas where existing agricultural practices favor shade-compatible crops.

Priority deployment should target: (1) Mindanao's premier zones where agrivoltaic systems can immediately leverage existing shade-tolerant crop systems (coffee, rubber, cacao, banana); (2) Central Visayas demonstration projects to validate feasibility in smaller island contexts before broader Visayas adoption; and (3) Crop-specific agrivoltaic system designs should align with regional agricultural strengths—tobacco in Ilocos, coffee and rubber in SOCCSKSARGEN, and cacao and banana in Davao—maximizing both energy output and agricultural productivity. Field trials testing crop performance under actual solar panels represent the critical next step, since our analysis relied on literature-based shade tolerance classifications rather than agrivoltaic-specific studies in Philippine conditions. Economic feasibility analysis incorporating power grid proximity, local electricity prices, agricultural returns, and infrastructure costs, would strengthen deployment prioritization, while social acceptance studies would refine implementation strategies across different regions. Other nations facing similar land-use competition can replicate our proposed methodology to identify optimal locations for agrivoltaic deployment.

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Appendix

Crop	Regional % Contribution to National Production	Total % Contribution to National Production	Crop Classification
Abaca	Bicol Region (39.89), Eastern Visayas (12.32), Davao Region (11.3)	63.51	shade-tolerant; yield improved under 50% shading (Bande et al., 2013)
Banana	Davao Region (34.6), Northern Mindanao (27.9), SOCCSKSARGEN (12.1)	74.6	shade-tolerant; 50% shading enhanced plant physiology (Aprianto et al., 2023)
Cabbage	CAR (65.5), Central Visayas (11.81), Cagayan Valley (7.6)	84.91	shade-tolerant; net shading between 50-70% increased head weight (Daniel et al., 2022)
Cacao	Davao Region (73.6)	73.6	conditionally shade-tolerant; shading helped improve crop growth in dry seasons (Acheampong et al., 2019)
Coffee	SOCCSKSARGEN (50.12), Northern Mindanao (11.21), Davao Region (9.68)	71.01	conditionally shade-tolerant; coffee benefited from shading lower than 50% (Soto-Pinto et al., 2000).
Corn	Cagayan Valley (23), Northern Mindanao (17), SOCCSKSARGEN (14), BARMM (14)	68	conditionally shade-tolerant; shading reduced water evaporation and increased corn yield in the drought season but yield decreased when shading is at ≥50% (Amaducci et al., 2018; Sekiyama and Nagashima, 2019; Yang et al., 2019)
Mango	Ilocos Region (47.2), Central Luzon (25.8), Western Visayas (7.3)	80.3	conditionally shade-tolerant; shaded fruits are better but a shading level >20% negatively affects fruit quality and yield (Jutamanee and Onnom, 2016; Mthembu, 2006)
Onion	Central Luzon (67.44), Ilocos Region (18.67), MIMAROPA Region (9.55)	95.66	conditionally shade-tolerant; yield increased at 35-55% net shading but decreased by 15-20% under PV modules (Kim et al., 2023; Son et al., 2013)
Pineapple	Northern Mindanao (58.1), SOCCSKSARGEN (32.1), Bicol Region (6.4)	96.6	conditionally shade-tolerant; net shading prevented fruit sunburn but 80% shading reduced fruit yield and quality (Araújo et al., 2022; Weifeng et al., 2020)
Potato	CAR (81.54), Davao Region (11.83), Northern Mindanao (4.67)	98.04	conditionally shade-tolerant; no change in yield when grown under PV modules but increased when precipitation was scarce (Lee et al., 2022; Trommsdorff et al., 2022)
Rice	Central Luzon (18.14), Cagayan Valley (15.09), Western Visayas (11.28)	44.51	conditionally shade-tolerant; only sustains <39% shading under PV modules (Gonocruz et al., 2021)
Rubber	SOCCSKSARGEN (38.79), Zamboanga Peninsula (37.03), BARMM (13.35)	89.17	shade-tolerant; healthy rootstock growth under screen shading at 50% (Vieira et al., 2016)
Sugarcane	Western Visayas (50.5), Northern Mindanao (19), Central Visayas (12.9)	82.4	conditionally shade-tolerant; shade nets are helpful for seedling growth but required more sunlight and heat beyond their first 27 days (Cordeiro Júnior et al., 2020)
Tobacco	Ilocos Region (93.2)	93.2	shade-tolerant; adapts to shading (Yan et al., 2024)
Tomato	Ilocos Region (38.77), Central Luzon (28.06), Western Visayas (8.71)	75.54	conditionally shade-tolerant; ≥50% shading reduced yield and fruit quality (Cossu et al., 2014; López-Díaz et al., 2020).

Table 2. Regional percentage contribution (%) to national production of the Philippine crops identified as shade tolerant and conditionally shade tolerant based on the literature review.