

AGRIVOLTAICS IN PRACTICE: A POLICY APPROACH TO CLIMATE RESILIENCE
AND RURAL ECONOMIC DEVELOPMENT

Sofia Iuteri
Professor Guse
ECON 295
4/18/25

I. Introduction

This policy brief seeks to explore whether agrivoltaics (AV) can serve as both a climate resilience strategy and an economic development tool, as well as determine what policy actions can support its widespread adoption. The findings suggest a clear need for policy mechanisms — such as feed-in tariffs, subsidies, or tax credits—to make agrivoltaics financially viable for farmers. Farmers, energy producers, and governments recognize the trade-offs and tensions that go alongside the necessity to choose between fuel and farming, climate of conservation, and energy of rural economies. Despite growing interest, the absence of cohesive federal policy and financial support hinders AV adoption.

According to the International Energy Agency (IEA), solar photovoltaic (PV) technology is the fastest-growing source of renewable energy globally, due to its ability to supply electricity in locations where electricity distribution systems do not exist, to produce zero air pollutants, the quick installation time, and the variety of sizes of panels. While positively contributing to renewable energy capacity and enhanced energy security, ground-mounted PV installations require substantial amounts of land, creating competition with agricultural use: 20,000m² or approximately five acres of land is required to build a 1.0 MW solar PV power plant (Patel et al., as cited in NREL 2013). On top of this, according to the USDA Economic Research Service’s “Major Uses of Land in the United States, 2017,” over 57% of US land is used for agriculture. Evidently, both farming and solar panels occupy large quantities of land, creating a competitive landscape for both solar energy production and agriculture.

In the absence of policy intervention, the American Farmland Trust’s (AFT) Farms Under Threat 2040 solar modeling projects 83% of new solar development is expected to occur on farmland. Almost half of America’s most productive farmland is included in this expansion (American Farmland Trust [AFT], 2025). As a result, many small farmers face pressures to sell land to solar developers, especially in areas with weak land-use protections. For example, the 2021 elected government in Germany plans to increase PV capacity to 200 GW by 2030, reducing the availability of farmland by an estimated 6731 ha (Feuerbacher et al., 2022). Furthermore, in Japan, farmers are required to report their annual crop cultivation. If their crop yields fall below 80% compared to the original level, they will be required to dismantle the PV system entirely (Takashi, 2019). Therefore, AV plays a vital role in mitigating this increase in “land take” through combined agricultural and electricity production. This data begins to express

the essence of land-use competition between food production and clean energy production, a problem that agrivoltaics aims to resolve.

Agrivoltaics innovatively solves the dual challenge of achieving energy sustainability and agricultural efficiency by allowing the two goals to coexist and thrive, eliminating the conflict over land use demanded by the two projects. By resolving land-use conflicts, global food production and energy security improve for all of society. Agrivoltaic systems relieve economic pressure placed on rural communities by diversifying economic risk and providing a dual income stream, decreasing biodiversity loss, and supporting the energy transition away from fossil fuels and towards renewables. Specifically, agrivoltaics combine agriculture with photovoltaic energy creation into a combined space, creating an “efficient and sustainable land use system that benefits farmers, solar developers, rural communities, and the earth itself” (Pederson & Lamb, 2021). Further, capturing solar energy can be viewed by farmers as a form of insurance, especially in the face of climate change and an increase in severe weather events such as droughts. Shading from solar panels can also mitigate the impact of extreme weather events on crops, preventing crop yield losses and further costs, and therefore, implementing resilience to agricultural operations. This emerging technology blends the two practices and eliminates the myth of the “food or energy” dichotomy that traditionally dominated land use discussions.

II. Background and Motivation

In the absence of supportive policy, agrivoltaics are unlikely to scale due to the difficulty of ensuring viable returns for both solar and agricultural operations (NREL, 2022). In fact, building and landowners need financial incentives to install PV systems, as the cost of electricity from such systems exceeds that of electricity from fossil fuel-based utilities (Takashi, 2019). This underproduction of a socially beneficial technology represents a classic positive externality—a market failure where individual incentives do not produce the quantity for maximized societal welfare.

To experience the multifaceted benefits of food and clean energy production, the U.S. should adopt a comprehensive agrivoltaics support system combining feed-in tariffs (FITs), upfront subsidies, and targeted tax credits. Feed-in tariffs (FIT) require utility companies, by law, to purchase electricity from renewable energy producers, such as agrivoltaic farms, at a guaranteed price, usually above the market wholesale rate. This provides farmers with reliable

income, making agrivoltaic systems more attractive to invest in (Takashi, 2019). Subsidies help to offset the upfront cost of agrivoltaics installation, and production tax credits specifically reward ongoing clean energy generation, increasing the profitability of agrivoltaic systems.

The legislative history of agrivoltaics includes state and federal-level legislation, as well as an overall shift from general support to specific policy incentives. New Jersey, Colorado, and New York have passed the Dual-use Solar Act (2021), SB092 (2023), and the NY State Senate Bill S5628 (2025), respectively. These acts establish pilot programs, support agrivoltaics through grants for demonstration or research projects surrounding the integration of solar energy generation, and production tax credits for farmers. As states increasingly incorporate agrivoltaics into their renewable energy strategies, the practice is gaining momentum due to its multifaceted benefits, including job creation, rural development, and enhanced energy and food security. In regard to federal legislation, the Agrivoltaics Research and Demonstration Act (2023) establishes a framework for the US Department of Agriculture (USDA), defining and evaluating agrivoltaics in order to incorporate it into USDA programs.

In 2024, agrivoltaics projects made up less than 5% of solar projects in the US (American Farmland Trust [AFT], 2025). That said, the US agrivoltaic market is expected to grow at a compound annual rate (CAGR) of 11.6%, from \$323.6 million in 2024 to \$721.4 million by 2031 (Coherent Market Insights, 2024). Promising field experiments, such as those performed by Dupraz and colleagues, even found that agrivoltaic systems increased land productivity for durum wheat by 35-72% (Dupraz et al., 2011, as cited in Takashi, 2019). Other experiments provide evidence of increased economic value by over 30% compared to conventional agriculture in the context of shade-tolerant lettuce production (Dinesh & Pearce, 2016, as mentioned in Takashi, 2019).

Overall, legislative approaches in AV have evolved from general support for renewable energy production to increasingly specific policies that incentivize agrivoltaic systems, and guide farmers on optimal designs, crops, and business models.

III. Article 1: Takashi (2019) – Japan Field Trial on Shade-Intolerant Crops

Main Question:

The main question explored in “Performance of Agrivoltaic Systems for Shade-Intolerant Crops: Land for Both Food and Clean Energy Production” is whether stilt-mounted agrivoltaic systems can successfully grow shade-intolerant crops, such as corn, and remain financially feasible for farmers. This study hopes to demonstrate that AV systems can reduce land-use tensions between food and renewable energy demands. Studies prior to Takashi’s only indicate that agrivoltaics are effective for shade-resistant crops, such as kale, mustard greens, and broccoli. Other crops, such as corn, watermelon, and cucumbers, are shade intolerant and are understood to require large amounts of sunlight to thrive. Takashi challenges these notions by experimenting on corn growth in low-light environments, as well as analyzing the financial feasibility of agrivoltaic systems through cost-benefit analysis across varying regions.

Data:

The data for this field experiment were collected from a 100m² AV experimental farm operated by the CHO Technical Research Institute in Ichihara City, Chiba Prefecture, Japan. The corn was planted in early April 2018 and harvested in late July 2018. Power output (kWh) of stilt-mounted agrivoltaic PV modules was observed from September 2017 to August 2018.

Methods:

Three test configurations were used to measure the sensitivity of the corn yield per square meter when the level of shading varied: control (no PV), low-density, and high-density PV arrays. Figure 1 demonstrates the three distinct types of agrivoltaic systems, labeling them as control, low-density, and high-density. The 72 PV modules, standing at 2.7m high and tilted at an angle of 30 degrees, were monitored for growth, corn yield, biomass, and the annual profits per m² of the plots. The PV system output was 4.5 kW, and farmers received a feed-in-tariff (FIT) rate of 48 yen/kWh. The high-density configuration consisted of eight 0.76-m-wide PV module arrays, spaced at 0.71 m intervals. The low-density configuration consisted of four PV module arrays spaced at 1.67 m intervals. In the control configuration, there were no PV modules above the ground. There are six modules in each array, and the same soil, fertilizer, and water were used to grow all corn crops. In each configuration, 25 corn stalks were planted 0.5 m apart (9 stalks/m²).

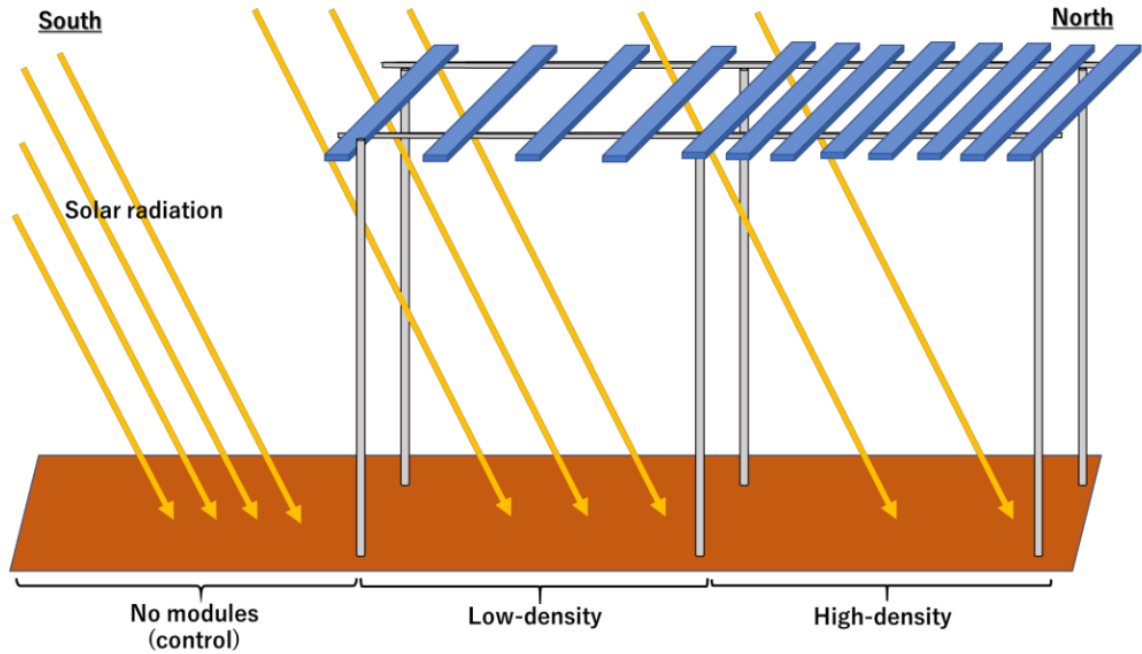


Figure 1 PV Module configurations at the agrivoltaic experimental farm

Results:

Surprisingly, the study showed that crop yields were 5.6% higher for the low-density coverage configuration, as opposed to both the high-density and control configurations. Figure 2 further demonstrates these results through the average fresh weight of corn crops being the highest for low-density configurations, at 393 g and 5.6% higher than the average fresh weight of the control. A similar result emerges for the average biomass of corn stover grown in low-density conditions, as the low-density configuration yields 4.9% higher biomass than the control. These results are further demonstrated in Figure 3. Therefore, $BC(\text{low}) / BC(\text{trad}) = 1.049 \therefore$

$BC(\text{trad}) < BC(\text{low})$.

As expected, the monthly kWh output of the PV modules in the high-density configurations showed the highest production rates, revenue per m^2 and total revenue. Figure 4 demonstrates this relation, revealing that high-density configurations produced double the electricity per square meter than the low-density configuration. That said, there is a trade-off

between the low-density configuration, which exploits more sunlight for crops underneath the PV modules, and its reduced PV output compared with the high-density configuration.

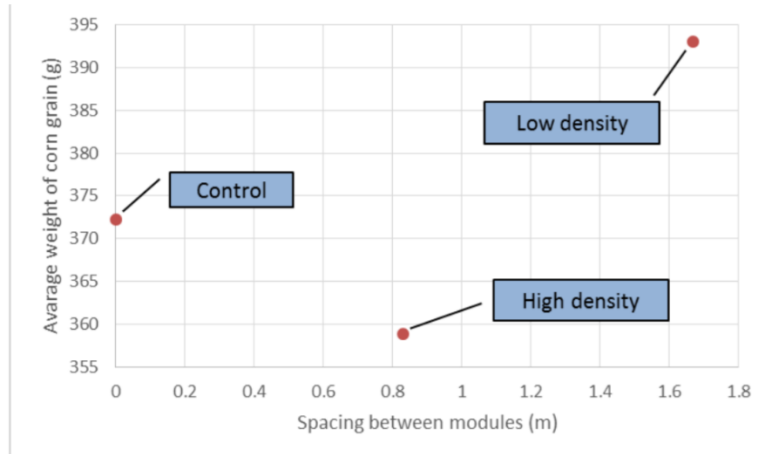


Figure 2: Sensitivity of fresh weight of reproductive corn parts with respect to the spacing between modules.

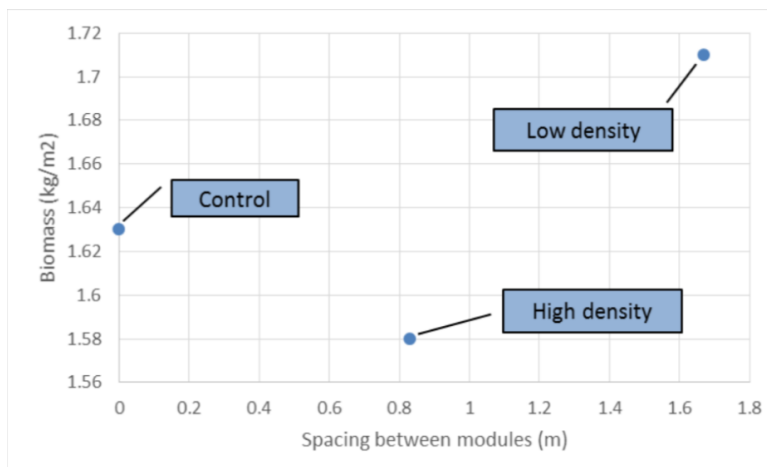


Figure 3: Sensitivity of crop biomass of corn stover with respect to the spacing between modules.

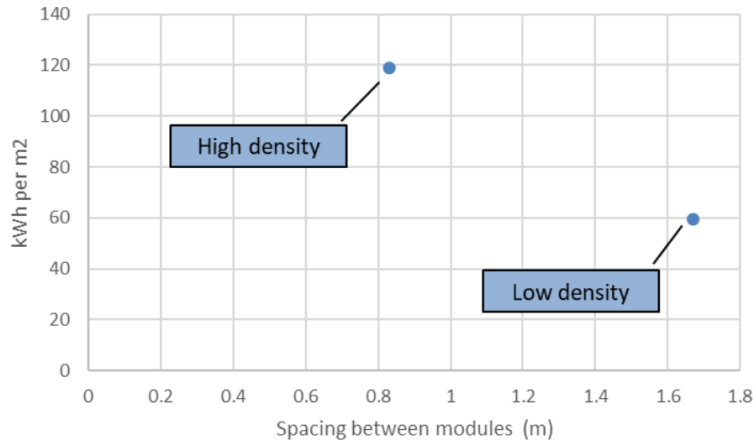


Figure 4: Sensitivity of annual PV power output with respect to the spacing between modules

Annual crop revenues per square meter from corn crops (see Figure 5 below) are the highest for low-density configurations, at 828.36 yen/m²; however, annual total revenue per square meter (see Figure 6 below) is highest in the high-density configurations, revealing that when PV energy generation is prioritized over crop production, farmers can bring in the highest revenue.

	Configurations		
	Control	Low-density	High-density
Crop revenue (yen/m ²)	783.90	828.36	755.82

Figure 5: Annual revenue per square meter from corn crops grown in different configurations.

	Configurations		
	Control	Low-density	High-density
Total revenue (yen/m ²)	783.90	3683.36	6465.82

Figure 6: Annual total revenue per square meter from corn crops and PV in different configurations

It is important to note that as the feed-in-tariff rate increases, so does the sensitivity of annual total revenue per square meter.

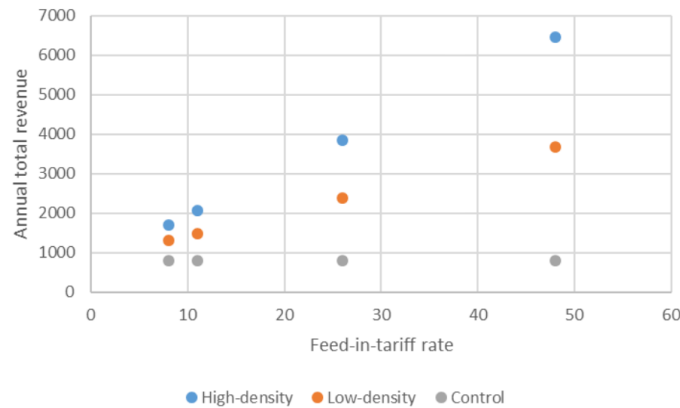


Figure 7 Sensitivity of annual total revenue per square meter to changes in the feed-in-tariff rate.

Overall, the study found that agrivoltaic systems improved both crop yield and economic outcomes. Corn grown under low-density solar panels (1.67m intervals) produced 4.9% more biomass and 5.6% higher yield per square meter than the control (Takashi, 2019). The total revenue of the high-density configuration was 8.3 times larger than that of the control, and the low-density configuration was 4.7 times larger.

These results can be explained by the fact that increasing light no longer drives photosynthesis beyond a light saturation point, too much sunlight hinders crop growth, and shading reduces water evaporation.

Financial feasibility:

The cost-benefit analysis conducted in the second half of the paper also uses the agrivoltaic system at the experimental farm of the CHI Institute of Technology in Japan. This is a crucial continuation of the study, as it explores whether or not the agrivoltaic system revenue can exceed the investment.

The cost-benefit analysis of the financial feasibility of the agrivoltaic system assumed a discount rate of 0.1% based on the interest rate of a 10-year Japanese government bond in October 2018 and a 1% interest loan of 100% debt. All benefits and costs in the study are expressed in discounted current values.

The study revealed that it would take approximately ten years or more before the investment in agrivoltaic systems equals the revenue in this case (Takashi, 2019).

The cost-benefit ratios of the high-density and low-density configurations for the 20-year period were 1.90 and 1.78, respectively, indicating that the discounted revenue from PV power generation and corn production would be nearly twice the discounted rate of the system for both configurations (Takashi, 2019). Additionally, the discounted annual profit per square meter from PV power generation was 12,372 JPY, which is 15 times the annual revenue per square meter from corn crops (Takashi, 2019).

So, it would take 10 years or more to break even, and about 20 years to make a significant profit. That said, it is important to note that this data was calculated given the 48 JPY per kWh feed-in-tariff rate. As tariff rates for PV power generation continue to decline, it will become increasingly difficult to make a profit when installation costs are considered.

Therefore, the solution is to decrease installation costs. Unfortunately, the pathway forward regarding this policy plan is not straightforward, as installation costs depend on a number of soft costs such as supply chains, labor and permit costs, and various financing mechanisms.

Size:

Stilt-mounted agrivoltaic systems could provide 100% of Japan's electricity demand using low-density configurations on just 30% of farmland. Among 1,296 AV voltaic farms in Japan, their solar setups vary from an electricity generation capacity of 10 kW to 393 kW, with an average capacity of approximately 50 kW (Solar Sharing Network, 2018b, as mentioned in Takashi, 2019). Total annual revenue was 4.7 times higher in the low-density configuration and 8.3 times higher in the high-density configuration compared to the control. Cost-benefit ratios over a 20-year period for high and low-density were 1.90 and 1.78, respectively. This result indicates strong financial feasibility for farmers regarding the implementation of stilt agrivoltaics (Takashi, 2019).

Precision/Confidence:

Moderate. Results are based on field trials, but no confidence intervals are reported.

Biases/Caveats:

This was a single-site study focused on a shade-tolerant corn crop, which may not generalize to other systems or crops such as pumpkin, turnip, and rice. Takashi (2019) notes that this agrivoltaic system is particularly suited for “densely populated regions, mountainous areas, small inhabited islands, and barren desert areas, where land resources are relatively scarce.” However, the study does not address the logistical challenges of harvesting corn beneath solar panels—an omission that may raise skepticism among readers and farmers. The analysis would have been strengthened by acknowledging the availability of technologies such as elevated or rotating panel structures and specialized, compact harvesting machinery designed to operate within agrivoltaic layouts.

Economic feasibility is highly sensitive to the FIT rate and soft costs, such as permitting and labor, as shown in Figure 8.

Lastly, PV panels do not produce a constant stream of energy and can cause pollution upon disposal without effective recycling methods.

(unit: USD/W)

	Australia	China	France	Germany	Italy	Japan	UK	US
Residential	1.8	1.5	4.1	2.4	2.8	4.2	2.8	4.9
Commercial	1.7	1.4	2.7	1.8	1.9	3.6	2.4	4.5
Utility-scale	2.0	1.4	2.2	1.4	1.5	2.9	1.9	3.3

Figure 8: Typical prices of PV systems in selected countries in 2013 (IEA, 2014)

IV. Article 2: Patel et al. (2023) – India: Techno-Economic AV with Tomatoes

Main Question:

This study principally explores whether an agrivoltaic (AV) system can simultaneously enhance agricultural productivity, improve microclimate conditions, and remain financially viable. The goal of the study is to evaluate the techno-economic performance of AV systems alongside crop cultivation and examine whether they support the UN Sustainable Development Goals.

Data:

The experiment was conducted between September 11, 2017, and February 28, 2018, at the College of Agricultural Engineering and Technology, Junagadh Agricultural University in Gujarat, India.

Methods:

The researchers conducted a split-plot field experiment comparing tomato growth under different AV configurations and land treatments, repeating each treatment four times to ensure reliability. A two-factor randomized design tested the independent and combined effects of AV environment and land treatment on crop parameters, solar energy output, and panel efficiency. The techno-economic evaluation included benefit-cost ratio (BCR), payback period, and land equivalent ratio (LER). They also conducted a sensitivity analysis using five years of tomato price data (from the National Horticulture Board), which reinforced the system's resilience to market fluctuations.

The research was conducted on the cultivation of the tomato, a shade-tolerant crop, unlike corn. The study operated a solar photovoltaic power plant which occupied 153.8 m² area for 7.2 kW capacity (0.047 kW/m²). Each row of the SPV plant had 12 panels, each with a 150W output capacity. positioned in the south-facing direction (Patel et al, 2023). A total of 48 panels were installed in four rows with a 1.36 m space between each row. The researchers chose four different land treatments: silver-black mulch in a raised bed (25 mm), a raised bed without mulch, a flat bed with drip irrigation and control, and a flat bed without a drip irrigation system installed.

The researchers tested eight different combinations of environment and land treatment using a standard experimental design. Each setup was repeated four times, and all plots received an identical fertilizer dosage to keep the conditions consistent. The exact crop plantation layout in each environment is represented in Figure 9.

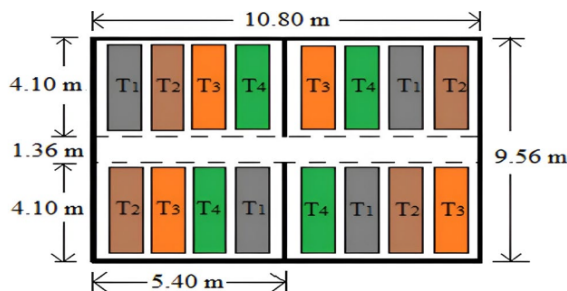


Figure 9 Crop plantation layout

To store electricity, batteries have been employed in an AV system with a “7.5 kVA hybrid inverter” (Patel et al, 2023). To visualize this flow of electricity from the solar photovoltaic (SPV) power plant output, see Figure 10.

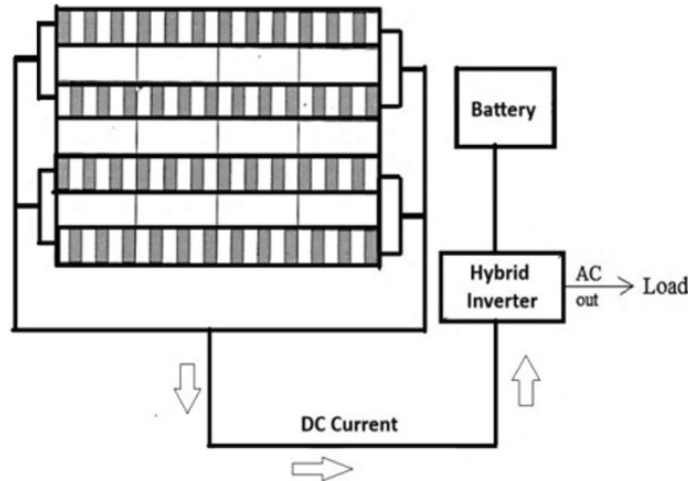


Figure 10: Flow of electricity from the SPV power plant output

This supports the power system in the event of a power outage, the absence of sunlight, or a collapse in the wiring or solar panels. The 7.5 kVA hybrid inverter is able to charge the battery using AC power. Otherwise, DC power is utilized to charge the batteries.

Energy output was measured in 30-minute intervals by recording the AC electricity produced after the DC/AC inverter. Final yield was calculated as the total AC energy generated over a defined period, divided by the rated capacity of the installed PV system.

Results:

Treatment	Number of fruits per plant	Fruits weight (g)	Fruits diameter (mm)	Yield (t/ha)
S_0T_1	71.50	37.94	45.28	51.86
S_0T_2	64.76	31.26	43.41	46.18
S_0T_3	62.72	30.74	42.08	44.24
S_0T_4	58.42	24.27	40.31	33.68
S_1T_1	82.44	39.45	47.79	59.69
S_1T_2	72.28	33.09	44.78	51.70
S_1T_3	74.88	32.43	43.28	48.46
S_1T_4	66.63	26.28	41.76	36.03
Environment (S)				
S.Em. $\pm$	0.50	0.19	0.31	0.57
C.D. at (5%)	2.26	0.85	1.42	2.55
C.V. (%)	2.90	2.36	2.89	4.87
Treatment (T)				
S.Em. $\pm$	2.40	0.18	0.19	1.19
C.D. at (5%)	7.13	0.53	0.57	3.53
C.V. (%)	9.81	1.57	1.25	7.24
Interaction (S $\times$ T)				
S.Em. $\pm$	3.39	0.25	0.27	1.68
C.D. at (5%)	NS	NS	NS	NS

* C.D. = Critical Difference, C.V. = Coefficient of Variance, S.Em. = Standard Error of Difference

Figure 11: Statistical performance of the tomato crop

The tomato yields under AV outperformed open-field farming in all treatments:

- T1: +15.09%
- T2: +11.95%
- T3: +9.54%
- T4: +6.98%

Land equivalent ratios ranged from 1.56 to 1.65, indicating more efficient use of land under AV. For example, the highest LER of 1.65 under the S1T1 treatment suggests that 1 hectare of dual-use land produced the same combined output as 1.65 hectares of land used separately for farming and solar. These LERs demonstrate the potential of agrivoltaic systems to improve total land productivity while maintaining economic viability.

The S1T1 treatment (raised bed with silver-black mulch under AV) had the best performance with a net profit of 167.85 INR/m², a Benefit-Cost Ratio of 2.59, and a payback

period of 7.9 years (without subsidies). The S0T4 (control treatment) produced the lowest yield and revenues across all treatments. Capital investment for the agrivoltaic system was calculated at 2,650.46 INR/m², assuming a 25-year lifespan for the structure (without subsidies).

The AV system generated 12,667.15 kWh of electricity from the 7.2 kW solar power plant, with 11.22% panel efficiency. Additionally, AV systems moderated climate with daytime temperatures up to 2°C lower and humidity 8–10% higher than open fields. The reduction of the monthly average highest solar radiation within the shadow of the AV structure for September was observed at 55.12%. In October, November, December, January, and February, the reductions increased to 77.20%, 77.11%, 75.66%, 76.52%, and 77.38%, respectively. A visual of the shadow cast by PV panels in the AV system is depicted in Figure 12, demonstrating the position of the shadow at 9:00, 12:00, 15:00, and 18:00. As seen in the figure and thanks to the “chessboard” panel design, the shadows are continuously moving throughout the day, allowing the crop to receive consistent sunlight throughout the day.



Figure 12: Movement of shadow over the day during crop growth

Figure 13 breaks down energy generation by month, showing that it is highest in the summer compared to other seasons.

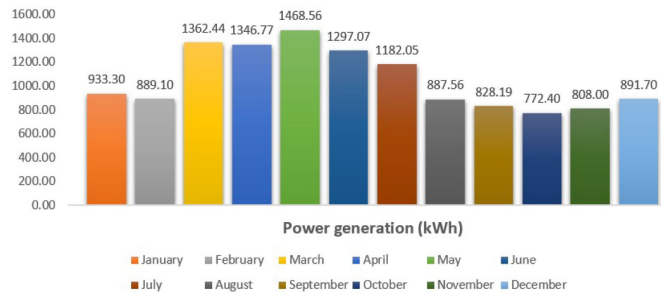


Figure 13 Monthly energy generation for September 2017 to August 2018 from the AV structure

As demonstrated in Figure 11, both the environment—agrivoltaic vs. open-field—and the land treatment type had significant effects on fruit weight, diameter, and overall crop productivity. For instance, different treatments produced noticeable variations in fruit weight per plant. However, there was no statistically significant interaction between environment and treatment, indicating that their effects on yield and fruit characteristics were independent and did not amplify or diminish one another when combined. Overall, the “use of chessboard pattern-type solar photovoltaic power plants as AV structures on farms increased the yield of tomatoes” (Patel et al, 2023).

Figure 14 compares the findings of this study with results from related agrivoltaic research, demonstrating consistency in productivity gains and supporting the external validity of the experimental results.

Year	AV configuration	Crop	Outcome	Country	Reference
2017	Chessboard-type half-density AV system	Tomato	LER of system is up to 1.65. BCR and PBP have been 2.59 and 7.90 respectively. Crop production is higher as compared to open field condition	Junagadh, India	Proposed work
2022	Fixed/three different design	Turmeric	The system's LER and payback period are 1.42 and up to 7.6 years, respectively. Additionally, under the same land use, the socioeconomic metrics of revenue, benefit–cost ratio, and price–performance ratio of turmeric are found to be 187.3 USD, 1.86, and 0.75, respectively	Odisha, India	Giri et al. (2022b)
2022	Fixed/bifacial AV plant	Blueberry	Comparing the E-W wing AV topology to conventional and separate food and energy production, the yield potential has been enhanced by 50% but electrical output has been decreased by 33%	Boston, USA	Katsikogiannis et al. (2022)
2022	Between solar photovoltaic array	Olive tree	The crop would not cover the solar panels because there is space between the collectors. According to this study, the LER for an AV system can rise from 28.9% to 47.2%	Córdoba, Spain	de la Torre et al. (2022)
2021	Fixed/EAS(even lighting AV system)	Lettuce	The EAS showed high LER (average 1.64) and crop quality levels comparable to those attained in a natural state	Hefei, China	Zheng et al. (2021)

Figure 14 Comparative experiment study of the AV system with related research

Size:

Crop productivity under agrivoltaic systems increased by 15.09%, 11.95%, 9.54%, and 6.98% across treatments compared to open-field farming, and the payback period for the best-performing treatment was under 8 years. Net profit reached 167.85 INR/m²

The highest Land Equivalent Ratio (LER) was 1.65, meaning the dual-use system produced the equivalent of 1.65 hectares' worth of output on a single hectare of land.

Precision/confidence:

Although the study presented clear percentage differences in crop yield, land equivalent ratios, and net revenue across treatments, it did not provide standard errors, confidence intervals, or p-values to assess statistical precision. The use of four replications per treatment in a split-plot experimental design strengthens the study's reliability.

Biases and Caveats:

Since the study was conducted at a single experimental site in Gujarat, India, and focused solely on tomatoes, its findings may not be generalizable to other climates, regions, or crop types. There's a potential for selection bias, as only specific crops, such as tomatoes, were evaluated, and the results may not hold for other crops.

The study also fails to discuss long-term maintenance costs or risks such as panel degradation, which could affect the payback period.

V. Article 3: Feuerbacher et al. (2022) – Farm-Level National Economic Simulation

Main Question:

This study explores the economic viability and adoption potential of AV systems across Germany under varying policy and land conditions. Specifically, the authors investigate which farm types and regions are most likely to become early adopters (defined as the 10% most cost-efficient farms), and how solar radiation (ASR), a binary economies of scale (EOS) treatment, and agronomic effects such as depressed yields, loss in area, and higher production influence adoption patterns and financial feasibility.

Data:

The researchers use nationally representative data from the German Farm Accountancy Data Network (FADN) between 2015 and 2018. The study models 137,925 eligible farms, representing 93% of Germany's arable land.

Methods:

Using the Framework to Estimate the Economic Benefits and Adoption Potential of Dual Land-Use Systems (FEADPLUS), a simulation-based economic model developed by Feuerbacher et al. (2022), the study estimates whether farms will adopt AV based on whether AV systems can generate higher profits than traditional farming alone. It incorporates farm-specific variables, such as crop type, land size, and yield losses from shading with an assumed 35% reduction in solar radiation, along with regional solar input using NUTS-3 codes. Break-even electricity tariffs are calculated, and economies of scale (EOS) are modeled using a nonlinear cost function. Although EOS are gradual in practice, Feuerbacher et al. (2022) model

EOS as a binary condition—comparing scenarios with and without scaling benefits—to isolate how system size impacts agrivoltaic feasibility and adoption potential. Only farms with at least 2.5 hectares, positive contribution margins, and three years of complete data were included.

Results:

The study identifies that solar radiation and investment costs are key determinants, and EOS significantly improves adoption potential. With EOS, the top 10% of adopters could meet 8.8% of Germany's electricity demand using just 0.7% of its arable land (85,175 ha). Without EOS, only 2.3% could be met using 0.2% of the land. EOS also increases the average system size from 1.6 ha to 6.3 ha and reduces the break-even tariff to 8.3 EUR/kWh. Regional variation is evident: Southern Germany is more cost-competitive without EOS, while Eastern Germany gains competitiveness with EOS due to larger farm sizes. Yield losses from shading average ~40%, with specialist granivores facing the steepest decline (45.7%) and milk farms the lowest. Farms with low baseline agricultural margins, such as mixed crop-livestock farms, are more likely to adopt AV because they face lower opportunity costs from potential yield losses. Without EOS, only 62% of early adopters maintain positive margins; with EOS, this drops to 38%, except specialist field crop farms, which maintain higher resilience. Simulations show that if AV costs fall by 3–5% annually, AV could become cost-competitive with conventional PV by 2031 or earlier.

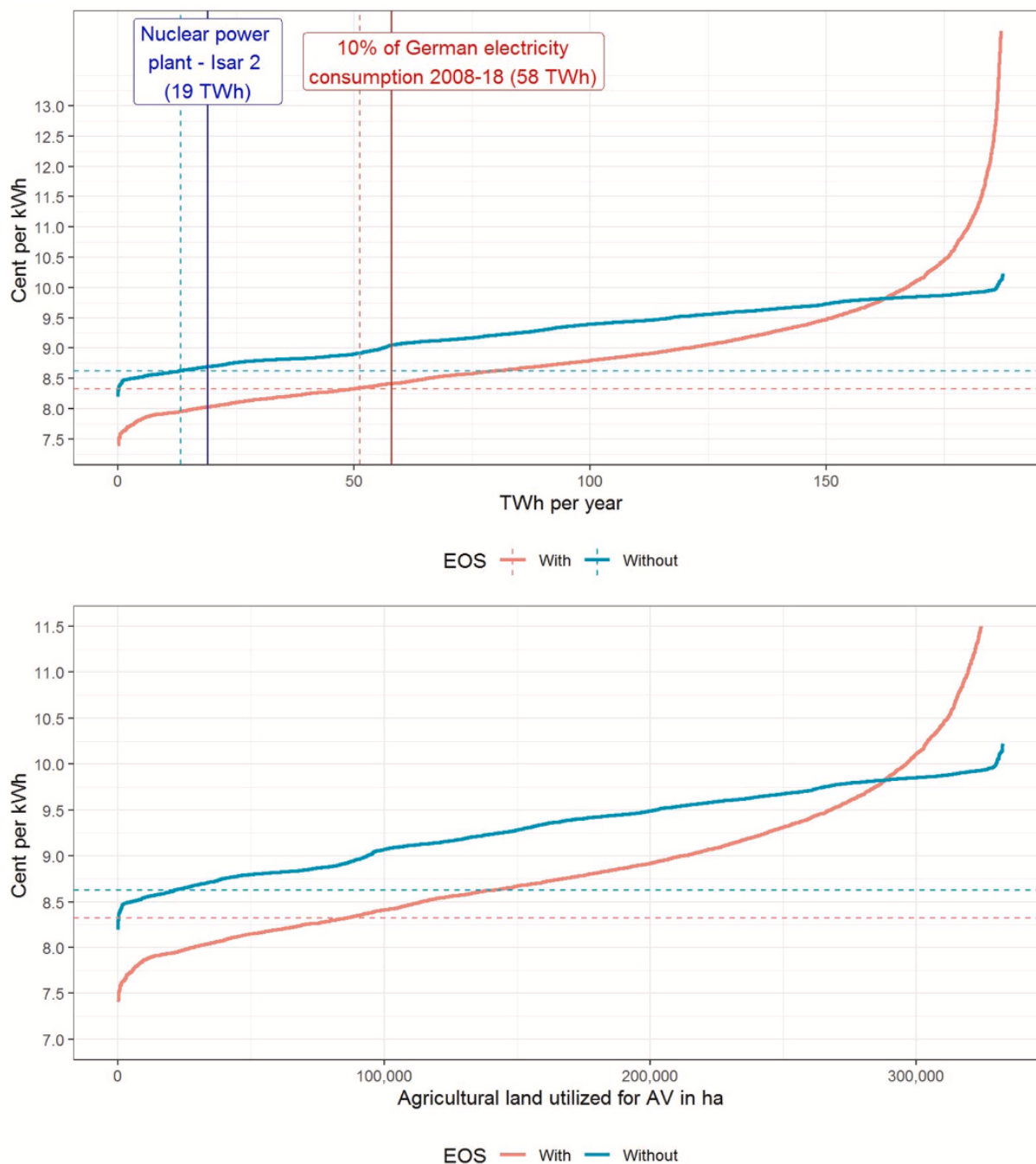


Figure 15: The top panel shows cumulative AV electricity potential (TWh/year) by electricity tariff and EOS presence. The blue line marks Isar nuclear plant output; the red line marks 10% of national electricity demand. Dotted lines represent break-even prices for the most cost-efficient 10% of adopters. Bottom panel shows corresponding cumulative AV land use (ha) across tariffs.

Size:

The dataset covers 137,925 farms across Germany. The top 10% most cost-efficient adopters could supply 51.3 TWh of electricity with EOS—covering 8.8% of national electricity demand—using about 1% of Germany’s arable land. Without EOS, this drops to 13.2 TWh (2.3%) using 0.2% of land. Nationally, excluding the highest-cost 10%, AV adoption could supply up to 33% of Germany’s electricity using 2.6–3.0% of cropland.

Precision/Confidence

The study models only one EOS function (economies of scale), limiting the ability to gauge how robust or sensitive the results are to different assumptions.

No confidence intervals or statistical measures of precision are reported, particularly around break-even electricity prices or yield changes.

The EOS equation was nonlinearly fitted with high explanatory power ($R^2 = 0.99$), but its external validity remains untested.

Biases and Caveats:

The simulation only assesses elevated, multi-row AV systems, excluding other potentially more viable designs. The assumption that farmers maintain fixed crop rotations and behave as rational profit-maximizers may oversimplify decision-making. Important variables such as financing risk, credit access, topographic suitability, grid connectivity, and policy acceptance were not modeled. Farms below 2.5 ha were excluded, biasing the model toward larger-scale operations. Lastly, no dynamic modeling of technology cost improvements beyond assumed rates was conducted.

VI. Conclusion:

Agrivolatics Case Study Comparison:

Country	Primary Crop(s)	Yield Impact	Benefit-Cost Ratio (BCR)	Payback Period	Key Insight
Japan	Corn (shade-intolerant)	5.6% increase (corn, low-density)	1.90 (high-density), 1.78 (low-density)	~10 years (high FIT rate)	Corn yield can improve with low-density AV; PV revenue far exceeds crop revenue.
India	Tomatoes (shade-tolerant)	15.09% increase (tomatoes, S1T1)	2.59 (S1T1)	7.9 years (no subsidies)	AV boosts yield and profit; climate moderation helps tomato growth.
Germany	Various (simulated)	Up to -40% (due to shading)	Modeled indirectly via margins	Not specified (simulated model)	EOS critical for adoption; AV on 1% land can meet 8.8% of electricity demand.

Figure 16 Comparative Summary of Agrivoltaics Case Studies in Japan, India, and Germany

This table contrasts key findings across three agrivoltaics studies, highlighting differences in crop types, yield impacts, financial feasibility (benefit-cost ratios and payback periods), and overarching policy insights.

Agrivoltaics presents a unique opportunity for the implementation of policies that can aid farmers and solar developers simultaneously, as well as improve the biodiversity and vitality of local ecosystems. This dual-use model not only increases land-use efficiency but also offers rural communities diversified income streams and resilience in the face of climate change.

Simulation results from Feuerbacher et al. (2022) show that with appropriate support and economies of scale, AV adoption on just 1% of Germany's arable land could meet 8.8% of the nation's electricity demand. In the absence of such economies of scale, the same level of adoption would only generate 2.3%. These findings highlight the critical importance of targeted policy incentives to uncover AV's full potential.

Similarly, Takashi (2019) demonstrates that AV systems can yield 5.6% more corn than traditional farming under certain conditions, and total revenues can be up to 8.3 times higher under high-density PV configurations. This supports the case for guaranteed feed-in tariffs (FITs), which were shown to provide farmers with a return up to 15x greater from PV than from agriculture alone in some regions of Japan.

However, these systems require significant upfront investment and often deliver lower energy output per acre compared to conventional ground-mounted PV farms. As a result, a comprehensive support framework is essential. Based on the evidence, the U.S. should adopt a multi-pronged approach including:

- The implementation of national feed-in tariffs (FITs) is to ensure a reliable energy income.

Drawback: May raise electricity prices or require taxpayer subsidies to fund above-market rates.

- Provide installation subsidies to ease capital burdens.

Drawback: High upfront government costs; risk of inefficient allocation.

- Provide production tax credits to reward ongoing clean energy generation

Drawback: Benefits may disproportionately favor larger or already-profitable farms.

- Fund pilot programs in agriculturally productive but climate-vulnerable regions.

Drawback: Limited scalability if site-specific results are unable to generalize; may exclude less visible regions.

Without these measures, AV will remain underproduced, exemplifying a classic positive externality resulting in market failure. Japan's policy requiring PV system removal if yields fall below 80% (Takashi, 2019) underscores the need for careful design to ensure AV systems protect rather than displace food production. Moreover, Patel et al. (2023) show that AV systems can increase crop productivity by up to 15.09% and deliver a benefit-cost ratio of 2.59 under optimal conditions, reinforcing their economic viability when well-designed.

Finally, AV systems are especially useful under extreme weather, as shown during the 2018 European heatwave, when shading mitigated crop loss and water evaporation (Feuerbacher et al., 2022). In an evolving climate, AV can be the key to building resilient, integrated land use that supports food and renewable energy production.

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