An Open-access Photosynthetically Active Radiation Modelling Approach for Designing Agri-PV Systems

Enhancing Yield of the Common Crops in the Developing World

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1. Introduction

Agrivoltaics (Agri-PV) combine photovoltaic (PV) electricity with agricultural production, enabling dual land use to enhance land efficiency, food security, and renewable energy generation. The success of Agri-PV relies on balancing light distribution between crops and PV panels, making a Photosynthetic Active Radiation (PAR) analysis essential. PAR, the spectrum of sunlight (400–700 nm) used for photosynthesis, is critical for crop growth and yield. Insufficient PAR reduces productivity, while excessive PAR can stress plants. Proper PAR management boosts yield, supports sustainable farming, and improves Agri-PV performance. Limited installations and knowledge gaps have hindered research on crop-specific PAR needs in Agri-PV designs. Light quality affects growth, and photosynthesis plateaus at the light saturation point. Existing software for PAR analysis resp. modelling often focuses on PV surface irradiation, not ground-level light, and many tools are underdeveloped or require (expensive) licenses. A lack of dedicated Agri-PV design tools further complicates research. This article presents a novel, open-access PAR modelling approach for common crops in developing countries, with Uzbekistan as a case study. The modelling analyses shading and light intensity, offering a unique solution explained in detail. The presented research develops a new PAR modelling method, applying it to local crops.

2. Research Methodology

The methodology presented is composed of three stages (c.f. Figure 1).
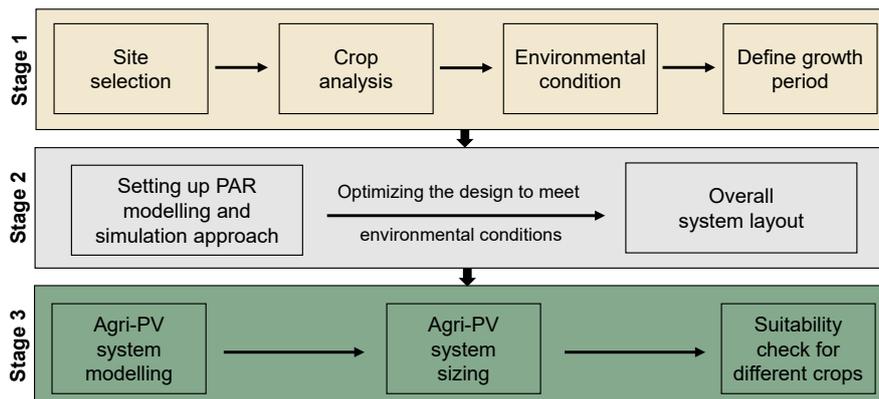
Figure 1. Research methodology including Photosynthetic Active Radiation analysis

Stage 1 begins with the selection of appropriate sites and crops for conducting Agri-PV system performance tests. The PAR values of the chosen crops are calculated using the PVSyst 7.4 software. It is used for designing and simulating Agri-PV models to determine the PAR values. The simulation period is defined to establish the initial framework for the system. Stage 2 evaluates the feasibility of the Agri-PV system with selected crops. It begins with selecting PV modules and inverters based on technical and economic factors. A modeling approach is then developed, considering parameters like row spacing, module distance, and tilt angle. After

simulating the model, PAR values are compared with the threshold required for plant growth from the literature. If deviations occur, the model is optimized until desired PAR values are achieved. Stage 3 commences once the Agri-PV model meets the required PAR range for the selected crops. This final stage involves sizing and dimensioning the land area, selecting appropriate PV modules and inverters for the area, and concluding with an analysis and discussion of the electricity generated by the system.

3. Results / Key Outcomes

The presented study assesses the performance of Agri-PV systems in Uzbekistan's key crop-producing regions, focusing on their effectiveness under varying weather conditions based on the proposed PAR modelling approach. Crops including cotton, wheat, rice, potato, and barley are examined. Over 100 simulations (c.f. Figure 2) were conducted with varying row distances, module spacing, and tilt angles to calculate the PAR beneath the panels and evaluate crop suitability for Agri-PV systems.

Module distance = Row distance	Module distance = 1 m	Module distance = 2 m
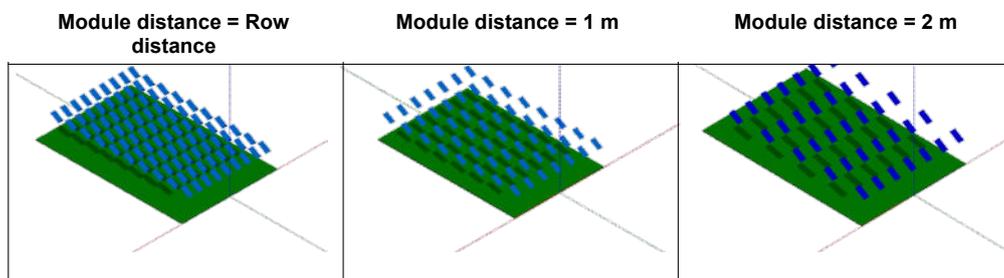
Figure 2. Some of the selected simulation configurations

Based on the novel PAR calculation modelling and Agri-PV simulation, Table 1 presents the key results for various crops across different regions during the crop growing season. If obtained PAR values are within the threshold required for plants to grow, the Agri-PV system is suitable/preferable with the crop.

Table 1. Suitability of Agri-PV systems for selected crops across agricultural regions in Uzbekistan based on the proposed model and simulation (green = low PAR values; red = high PAR values)

Name of the Region	Average PAR (W/m²)			Crops				
	June	July	August	Cotton	Wheat	Barley	Rice	Potatoes
Bukhara	⬆ 220.50	⬆ 215.80	⬆ 200.80	✓	✓	✓	✓	✓
Kashkadarya	⬆ 217.60	⬆ 218.80	⬆ 201.80	✓	✓	✓	✓	✓
Khorezm	⬆ 213.50	⬆ 215.80	⬆ 193.30	✓	✓	✓	✓	✓
Ferghana Valley	➡ 196.10	⬆ 213.80	➡ 191.90				✓	✓
Surkhandarya	⬇ 173.00	⬆ 218.40	⬆ 200.40				✓	✓
Jizzakh	⬆ 220.10	⬆ 213.10	⬆ 193.40	✓	✓	✓	✓	✓
Samarkand	➡ 203.50	➡ 210.60	⬆ 197.10				✓	✓
Tashkent	⬆ 213.20	➡ 210.60	⬆ 197.10	✓	✓	✓	✓	✓
Karakalpakstan	➡ 198.90	⬇ 200.00	⬇ 171.90				✓	✓

4. Conclusion

The presented study introduces a novel and straightforward approach for PAR modelling in Agri-PV design, tested in a case study in Uzbekistan for several key crops. Simulations show favourable conditions for integrating cotton, wheat, and barley in regions like Kashkadarya, Bukhara, and Tashkent, where PAR values match crop sunlight needs. In contrast, regions with lower irradiation, such as Ferghana Valley and Karakalpakstan, are less suitable for these crops but viable for rice and potatoes, which require less sunlight.