# AgriVoltaic System's Digital Twin

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## 1. Introduction

Agrivoltaics (APV) has seen a surge in research publications over the past decade, notably peaking in the last five years. The projects span diverse geographical regions, with the United States and Germany leading in research output, closely followed by Japan, Italy, and France. These studies encompass various scales, from small trials to commercial projects, shedding light on critical aspects such as geographical distribution, economics, operational considerations, and policy implications [1]. Research teams worldwide have delved into agronomical studies, microclimatic impacts, and PV design analyses to investigate crop shading effects and the compatibility of crops with PV modules. Furthermore, technical reports from entities like the National Renewable Energy Laboratory (NREL) in the U.S. and Fraunhofer Institute for Solar Energy Systems ISE in Germany have added depth to the scientific understanding of agrivoltaic systems [2]. Commercial APV projects have emerged in Japan, Europe (Italy, France, Germany), the USA, and notably in China, where large-scale implementations with irrigation systems and dual-axis tracking have become the norm. These endeavors aim to combine solar energy production with crop cultivation, harnessing the synergy between electricity output and agricultural yield.

As stated in 2019, despite the global expansion of APV technology, comprehensive scientific studies assessing its impacts on agronomic parameters remain limited, emphasizing the need for further investigations to determine its full potential, particularly in arid regions and land-constrained areas. Initiatives like APV-RwESOLA in Germany represent concerted efforts to comprehensively examine the multifaceted impacts of agrivoltaics, encompassing renewable energy production, economic viability, crop production, societal acceptance, and technological design [3]. The ongoing research not only underscores the technical dimensions of agrivoltaics but also highlights its potential as a sustainable solution at the nexus of energy and agriculture, demanding a holistic evaluation including technical, economic, and social aspects.

## 2. From Internet of Things to Digital Twin

APV systems are built with IoT sensors and cameras. As a complex system, digital twin is a good way to handle large amounts of data and, thanks to methods like machine learning (predictive maintenance, forecasting, images analysis), it can create a realistic model of the whole system. The digital twin is built thanks to the DTOps methodology [4]. A digital twin is a virtual representation of a physical system, and in the case of APV systems, it can serve various purposes:

- Performance monitoring and optimization: It captures and analyzes data related to energy production, environmental conditions, and equipment status. This information is crucial for optimizing the system's efficiency and identifying potential issues promptly.
- Predictive Maintenance, Fault Detection and Diagnosis: This predictive capability helps in scheduling maintenance activities proactively, reducing downtime and ensuring the longevity of the system. Moreover, the early detection of fault or error enables quick response and troubleshooting, minimizing the impact of malfunctions and preventing potential damage to the equipment.
- Resource Management: It can simulate the impact of different environmental factors on the agriPV system. This includes sunlight exposure, weather conditions, and soil moisture levels. By understanding these variables, farmers and operators can make informed decisions about resource

allocation and crop planning.

– Scenario Analysis and Precision Agriculture: It allows researchers and operators to simulate different conditions and configurations. This is valuable for assessing the system's performance under various scenarios, helping in decision-making and future system design. This synergy enables a holistic approach to farming by combining data from agriPV systems with information on crop health, irrigation, and other relevant factors.

## 2. Conclusion

The digital twin's ability to monitor and simulate the agriPV system's performance in diverse environmental conditions enables precise control and optimization. Through predictive analytics, it not only anticipates potential issues but also enables proactive maintenance scheduling, minimizing downtime and optimizing resource utilization. Furthermore, the integration of a digital twin with precision agriculture practices creates a holistic approach to farming. The synergy between agriPV data and other agricultural metrics provides a comprehensive understanding of the entire ecosystem, fostering sustainable practices and informed decision-making for both energy production and crop management. As technology evolves and more data becomes available, continuous improvement and refinement of the digital twin models thanks to DTOps Methodology ensure adaptability to changing conditions. This iterative process contributes to the long-term effectiveness of the digital twin in supporting agriPV systems.

## References


[1] Mohammad Abdullah Al Mamun, Paul Dargusch, David Wadley, Noor Azwa Zulkarnain, and Ammar Abdul Aziz. 2022. A review of research on agrivoltaic systems. Renewable and Sustainable Energy Reviews 161 (2022), 112351. https://doi.org/10.1016/j.rser.2022.112351

[2] Max Trommsdorff, Ipsa Sweta Dhal, Özal Emre Özdemir, Daniel Ketzer, Nora Weinberger, and Christine Rösch. 2022. Chapter 5 - Agrivoltaics: solar power generation and food production. In Solar Energy Advancements in Agriculture and Food Production Systems, Shiva Gorjian and Pietro Elia Campana (Eds.). Academic Press, 159–210. https://doi.org/10.1016/B978-0-323-89866-9.00012-2

[3] Axel Weselek, Andrea Ehmann, Sabine Zikeli, Iris Lewandowski, Stephan Schindele, and Petra Högy. 2019. Agropho-tovoltaic systems: applications, challenges, and opportunities. A review. Agronomy for Sustainable Development 39 (2019), 1–20.

[5] Djebali, S., Guerard, G. and Taleb, I., 2023. Survey and insights on digital twins design and smart grid's applications. *Future Generation Computer Systems*.