Dual Land Use for Agriculture and Solar Power Production: Overview and Performance of Agrivoltaic Systems

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Main Authors:
Max Trommsdorff, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany;
Pietro Elia Campana, Mälardalen University, Västerås, Sweden;
Jordan Macknick, National Renewable Energy Laboratory, Golden/Colorado, USA;
Álvaro Fernández Solas, German Aerospace Center (DLR), Institute of Solar Research, Cologne, Germany and Universidad de Jaén, Jaén, Spain;
Shiva Gorjian, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany;
Ioannis Tsanakas, Alternative Energies and Atomic Energy Commission (CEA), Institut National de l'Energie Solaire (INES), Le Bourget-du-Lac, France.

Editors:
M.Trommsdorff, Fraunhofer ISE, Germany;
Pietro Elia Campana, Mälardalen University, Västerås, Sweden;
U. Jahn, Fraunhofer CSP, Germany.

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Executive Summary

Our food and water systems are highly vulnerable to the impacts of projected climate change. At the same time, there is an urgent need to decarbonize the energy sector by rapidly and sustainably expanding photovoltaic (PV) systems. Coupled with the alarming rate of species extinction due to human activities and the resulting loss of biodiversity, these challenges highlight the need for new land use concepts to address these multiple crises.

Ground-mounted PV (GMPV) systems are one of the most cost-competitive solutions among renewable energy conversion technologies, but with the disadvantage of requiring more land per produced kWh compared to other technologies like wind power, hydropower, or geothermal power. Moreover, the typically high land lease prices for GMPV systems can be beneficial to single farmers while reducing the available area for agricultural production, leading to societal challenges threatening the acceptance towards the deployment of GMPV and potentially leading to restrictive legislations to prevent losses of fertile farmland.

Agrivoltaics (also known as agriphotovoltaics, APV) offers the possibility to simultaneously use land for agriculture production and solar power generation and provides opportunities to think beyond the way we have installed GMPV over the last two decades. The shading produced by the PV modules can increase the resilience of agriculture by protecting crops or animals against the rising number of severe weather events or, in more extensive applications, can provide habitats for flora and fauna to mitigate global biodiversity losses. Additionally, agrivoltaics can reduce water consumption and provide attractive business models enabling a more sustainable expansion of PV in accordance with local stakeholders and the farming sector. Driven by the great diversity of agricultural practices and applications, the ongoing market launch has led to a great variety of different technological approaches ranging from open systems on permanent and horticulture crops, arable farming, or permanent grassland, to closed systems like PV greenhouses.

This report provides a comprehensive overview of the definition of agrivoltaics, its current state of global research and development activities with a focus on open questions regarding technical performance. The presented research activities aim to optimize design through integrated modelling and simulation approaches.

Creating a common understanding of agrivoltaics seems key at this early stage of the market uptake. Though, the diversity of agricultural applications represents a challenge for the definition of agrivoltaics which varies globally, influenced by legislative, historical, and societal factors. More narrow definitions typically focus on productive agriculture (e.g., food, fibre, dairy), while wider definitions also include non-productive agriculture (e.g., ecosystem services). Countries with a narrower definition like Japan, Germany, and France have also set minimum agricultural production requirements to ensure the agricultural relevance of agrivoltaic systems. In the United States of America, in contrast, there is no clear definition of federal level resulting in a rather wide definition that also includes non-productive agriculture activities. While broader definitions encompass a wider variety of technological approaches by also considering systems that are technically and economically like GMPV, this may diminish the agricultural relevance, potentially undermining the concept of dual land use. In contrast, narrower definitions often demand more technical adjustments, resulting in higher costs compared to GMPV. For example, overhead systems used in horticulture, which generally offer higher agricultural value, tend to have greater investment costs than interspace systems designed for arable or grassland farming.

To meet some countries' legal definitions of agrivoltaics, predicting the agricultural performance based on different agrivoltaics designs represents a crucial task before the installation of a system. While several modelling and simulation approaches have been discussed, only very few software or a combination of software is available to clearly address the market's needs. One main challenge is to enable comprehensive models for of agrivoltaics that analyse crop relevant factors like light and water availability and the energy performance of the systems.

Unlike traditional agriculture or PV systems, monitoring of agrivoltaic systems requires the assessment of a much broader range of parameters. This task is especially complex due to the interactions between agricultural and PV-related factors. While a standardized monitoring can help to reduce this complexity, varying research questions and individual local conditions often demand for adjusted monitoring concepts. This report includes a guide to monitoring parameters commonly used to evaluate the overall performance of agrivoltaics systems and their respective relevance. Additionally, it provides an overview of existing regional databases of agrivoltaic facilities and proposes a framework for the global expansion of these databases to include installations worldwide.

Regarding operation and maintenance, this report provides an overview of common practices and challenges focusing on the PV components of agrivoltaic systems. Main identified aspects are soiling and increased damages or corrosivity of PV components due to farming activities and plant protection agents. Due to the few performed R&D works on existing projects and the resulting thin data basis, many questions remain still open. Future research could explore custom-designed farm equipment that can successfully operate within agrivoltaic facility configurations, anti-soiling technologies, integrated irrigation and PV module cleaning technologies, and novel tracking algorithms to reduce O&M costs.

The report also addresses legal and socio-economic aspects by summarizing the legal framework of six pioneer countries in Asia, Europe, and North America, highlighting main findings of factors influencing societal acceptance among different stakeholder groups, and providing an overview of the economic performance of agrivoltaic systems. Key drivers identified for successful project implementation are stakeholder involvement in an early stage, a supportive policy environment and incentive programs, and transparent performance standards. Also, the increasing importance of societal acceptance underpins the need to address existing limitations, gaps, and future opportunities of socio-economic and legal frameworks in the field of agrivoltaics. Earlier works on agrivoltaics of the IEA PVPS addressed performance indicators and presented a showcase from Germany.

To reach our climate goals, there are strong arguments in favour of using both GMPV systems and agrivoltaics. A primary challenge for policymakers is choosing the appropriate technologies by aligning local land use goals with national and global PV development goals. In areas where agrivoltaics provides agricultural benefits high enough to justify higher cost, agrivoltaics should generally be preferred. However, regional factors may shift the balance, influencing the value of each approach. Given the wide variety of agrivoltaic technologies and the current limitations in accurately assessing key factors, an interdisciplinary collaboration through existing and future IEA PVPS Tasks would be valuable to address the diverse aspects of agrivoltaic technology.

Key Takeaways

1. The complex interactions between the agricultural and PV sectors and the different perceptions of agrivoltaic systems demand high communication efforts to harmonize definitions and clarify targets.

2. Modelling and simulation of agrivoltaic systems represent a pivotal task in reliably predicting agricultural and electrical performances and optimizing systems design.

3. Key drivers for successful agrivoltaic project implementation are early stakeholder involvement, a supportive policy environment and incentive programs, and transparent performance standards.

Task 13 Managers: Ulrike Jahn (ulrike.jahn@imws.fraunhofer.de) and Giosuè Maugeri (giosue.maugeri@rse-web.it)