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ADVANCED PV TECHNOLOGIES FOR INTEGRATED APPLICATIONS – THE PARADIGM OF AGRIVOLTAICS

Summary

Integration of Photovoltaics applications in sectors like energy efficient buildings, farming, etc. are of high priority for researchers and engineers. These applications are used to tackle spatial scarcity, and to optimize the design of a structure by combining the benefits of electricity production with other local parameters such as micro-climate conditions. In this context, the specific study addresses the use of PVs in agricultural applications also known as agrivoltaics. Emphasis through the specific study is given on the parametric analysis of the design requirements and the selection of novel products that lead to an optimal use of the PVs in order to improve specific conditions on the crop. The analysis includes assessment of technoeconomic, regulatory, and other aspects that engineers should consider towards optimal selection of the AgriPV design, while the proposed setup makes use of new types of PV modules and supporting structures. Even though the analysis is about AgriPVs, the approach is potentially replicable in other sectors such as Building Integrated PVs.

Keywords: Photovoltaics, Agrivoltaics, PV modules, supporting structures.

Field of application for the findings: Farming, Energy Production, Rural Areas, Suburban Areas.

Addressed audience: Engineers, Researchers.

1. Introduction

Environmental concerns including CO2 emissions and scarcity of energy reserves have led to the ever-expanding usage of Renewable Energy Sources (RES). Policies at national, EU, and international level foresee specific targets regarding the CO2 emissions reduction by 2030 and 2050 [1]. With the rapid growth of RES applications, such as Photovoltaics, specific needs and constraints emerge. A case in point is the local generation of electricity for use on the spot by the owner of the PV installation in a self-consumption approach.

Even though the use of private PV installations for covering own energy needs is a very efficient method, there are still some issues stemming from it that call for specific conceptual designs, namely integration of the PV installation into the area of use. Two particularly interesting areas of PV integration include Building Integrated PVs (BIPVs) and Agrivoltaics (AgriPVs), whereas other similar approaches include floating PVs, Vehicle Integrated PVs (VIPVs), etc. The main issues connected to these sectors and the reasons that have led the research and engineering community into exploring integrated PV applications are the following:

- Spatial scarcity, namely lack of available surfaces that could be used for the installation of the PVs [2], and,
- Impact of the PV installation on the occupied space underneath [3].

One very interesting application area is that of AgriPVs, which addresses the dual use of land for both electricity generation and farming. As can be seen in [2], AgriPVs is an area with huge research and deployment interest in terms of design optimization. Due to this potential, alongside the rising concerns regarding use of land, several studies have been conducted to propose alternative solutions. The most important takeaway from these studies, especially the pilot projects implemented, is the two different approaches regarding the impact of the AgriPVs. On the one hand, there are studies focusing on the minimal intrusion of the PV installation on the crops, whereas, other more state-of-the-art approaches propose the use of new products, technologies, and designs in order to further optimize the farming process. In this context, the specific study focuses on the analysis of an AgriPV for tree crops (orchards and vineyards), used to produce electrical energy, improve the microclimate conditions, and protect the crop against extreme weather events.

2. The proposed approach

The core idea of the proposed study is the use of a novel design for the AgriPV based on the two key constituent parts that follow:

- PV modules of significant transparency (e.g., 50%) that allow sufficient sunlight to reach the crop. The modules consist of single-crystalline Silicon PV cells arranged in such a way that allow the right amount of sunlight to pass through the modules and not hinder photosynthesis. The modules can also be bi-facial to exploit diffuse irradiance, while they use a special type of nano-coating on the glass panes in order to maximize the benefits of the light spectrum for the crop needs.
- Specially designed supporting structures that allow the growth of the orchard/vineyard. The structures are sufficiently elevated above the ground to allow the growth of the trees, while they are specially designed in terms of distancing in order to allow easy and unimpeded movement of machinery and personnel.

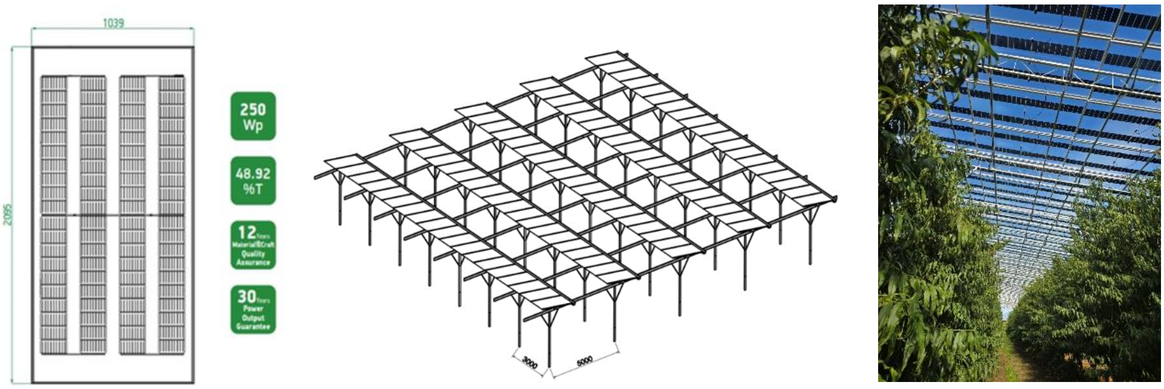

Fig. 1: Overview of the proposed AgriPV setup (distances are in mm)

An overview of the proposed PV modules and supporting structures is shown in Figure 1. This includes an example of the PV modules (left), the supporting structure (middle), and a picture of an actual installation (right). The whole setup allows for collection of rainwater for later use, hence contributing in the water needs for the crop. One additional benefit is the protection that the structure offers to the crop in extreme weather events such as snowfall, hail, heavy rain, etc. Also, with the placement of the modules and their special nano-coating, the microclimate conditions can be substantially improved, provided that the design, dimensioning, and parameters are properly selected.

Regarding the parameters, and dimensioning of the AgriPV, these are obtained through a selected design methodology that takes into account several aspects of the process [4]. The starting steps of the methodology as shown in Figure 2 address the following areas:

- Market conditions and regulatory framework: A crucial step that explains the feasibility in terms of market participation options, licensing limitations, and other regulatory constraints that the designer has to consider prior to launching a project like this.
- Crop requirements: Based on the selected type of crop different requirements should be met by the AgriPV. Such requirements include amount of Photosynthetically Active Radiation (PAR), soil and air humidity levels, temperature, etc. The specific requirements are used as constraints to the optimal design of the AgriPV.
- Microclimate impact: Strongly linked to the crop requirements, the impact on the microclimate parameters gives the estimation on how the AgriPV affects the local conditions.

The above three steps are used to identify the key design parameters and optimization constraints which can be quantified in the form of Key Performance Indicators (KPIs) and target metrics. Such KPIs may include the crop and energy yield and amount of water savings as well as costs, reflecting CAPEX and OPEX in order to give a holistic estimation and optimization of the project. In order to proceed with the design of the AgriPV two additional steps are needed that include the calculation of PAR levels underneath as well as the financial evaluation of the project. The dimensioning of the AgriPV can be done in several iterations in order to obtain the ultimate desired results in terms of performance, constraints, and return of investment.

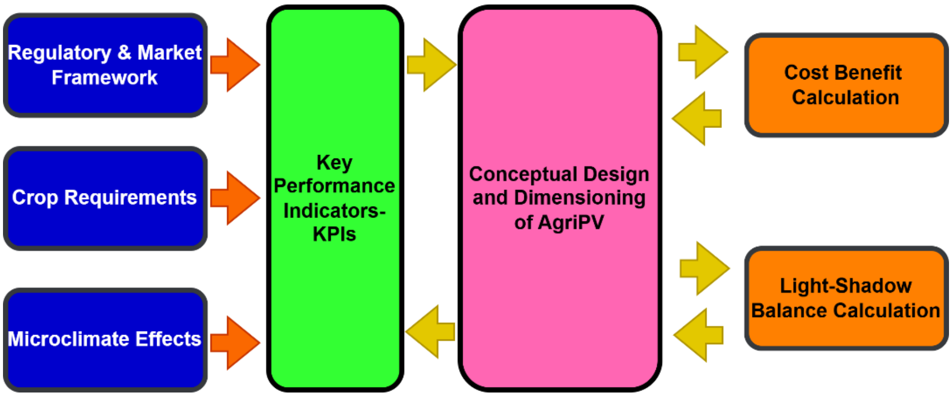

Fig. 2: Proposed design methodology

In the specific study, the methodology steps were implemented for two types of crops, peach trees and grapevines, in the area of the eastern Mediterranean (Greece and Türkiye). Some interesting findings regard the following: There are limited sources of international standards and regulations specifically dedicated to AgriPVs, let alone in the two countries of interest. For these applications more generic regulations and standards that govern PV systems in general usually apply. Remuneration schemes, on the other hand, for the electricity production are well covered by the existing models such as Net-Billing and Net-Metering. In terms of crop requirements and microclimate impact it turns out that such projects can significantly improve the microclimate conditions, e.g., by moderating extreme temperature variations, reducing the evapotranspiration of plants, and, therefore, reduce water needs, etc. It is also possible to improve the quality of the crop especially with the use of smart monitoring and control. Regarding the calculation tools, the light-shadow balance calculation can be done using off-the-shelf software solutions, however, in this study a suite of open-source tools has been proposed and developed for rapid assessment of the AgriPV performance. Lastly, the holistic financial assessment of such a project would require additional parameters in the calculation apart from the energy yield, such as estimation of water savings and crop yield. Due to the complex nature of these parameters, a methodology based on real-life data monitoring is also proposed.

3. References

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4. Acknowledgement

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