Yield Optimization Through Control Strategies in Tracked Agrivoltaic Systems

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1. Introduction and Problem Formulation

The rediscovered concept of agrivoltaics attempts to find a compromise for land-use scenarios where agriculture and power generation compete for the same areas. In the approach both domains are combined in the same plot, resulting in significant increase in land-use efficiency as measured by the so-called land equivalent ratio [1]. In realizing such dual-use systems, the fundamental question arises how the available light should be distributed to photosynthetic and photovoltaic purposes to maximize the output of both yields. Solar tracking systems provide unique solutions to this question in that they are capable of dynamically varying how much light passes the modules. In the present work, different tracking strategies were proposed, simulated, and their performances were compared to each other as well as to a static experimental system designed for light homogeneity. Three strategies were investigated that placed a focus on 1. photovoltaic production, 2. photosynthetic production, and 3. dual-use production.

2. Methodology

In strategy 1, standard horizontal single-axis, east-west tracking was implemented around the photovoltaic optimum. In strategy 2, the photosynthetic requirements of a plant crop were considered and deviations from the PV optimum were implemented to maximize plant growth. In strategy 3, a framework including economically weighted "PV or plant" decisions was implemented to investigate potential system optima. To date, no crop model is available which predicts crop yields under partially shaded conditions, therefore PV and plant yield quantifications were performed with the Radiance [2] ray-tracing engine and the WOFOST [3] crop simulation tool in an integrated environment, considering the effects of altered microclimate/light distribution on plant yield. Two sample years (2017 and 2018) were examined for the Lake Constance region in Germany with potatoes as a crop and the above tracking strategies. In figure 1 an exemplary day is depicted, showing how the light conditions on ground can be influenced throughout the day with a tracking system.

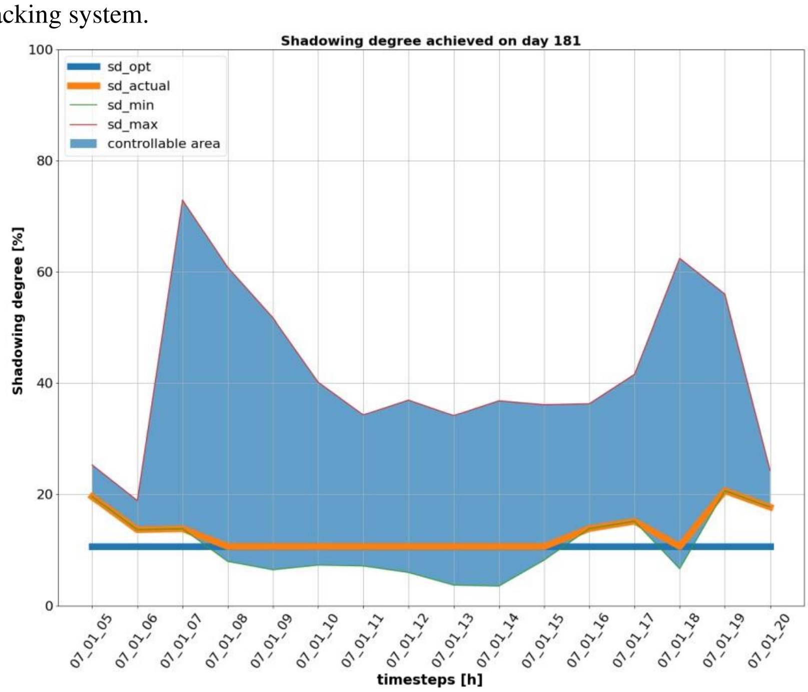

Figure 1: Depicted is one day during the cropping period. The y-axis represents the shading degree at each timestep on the x-axis caused by the panels. sd_opt represents the optimal shading degree determined by the tracking strategy. sd min (lower boundary of colored area) corresponds to the minimal shading degree, whereas sd_max (upper boundary of colored area) represents the maximal shading degree which can be provided by the tracking system. The area between those lines marks the controllable area, where the shading degree can be adjusted as wanted by the tracking-strategy. sd_actual is then the shading degree which the control of the tracking system can provide, and the crops finally experience on average.

3. Results

Comprehensive modeling tools are required to model conditions of partial shade in agrivoltaic systems. Comparing the numbers in Table 1 with the reference case show that agricultural yields are higher in the agrivoltaic system.

Parameter	Fixed-tilt system	Electricity maximizing tracking system	Crop growth maximizing tracking system	System optimal tracking system	Unit
Crop yield 2017	112.4	104.7	113.8	104.2	%
Crop yield 2018	114.1	118.5	121.8	118.3	%
Incident irradiation on panels 2017	1208.2	1748.6	1558.6	1735.4	kWh/m²
Incident irradiation on panels 2018	1266.6	1876.7	1784.9	1865.7	kWh/m²
LER value 2017	1.65	1.84	1.84	1.83	[]
LER value 2018	1.65	1.98	1.97	1.98	[]

Table 1: Summarized results of all scenarios for the years 2017 and 2018

This can be explained by an increased soil moisture level in later stages of the cropping period. Depending on the worth of different yields, optimized tracking schemes can shift these yields in a limited range because the light resource can be allocated.

4. Conclusion

The combination of the tools *bifacial_radiance* [4] (using the *Radiance* engine) and *PCSE* [3] (using the *WOFOST* model) was successful whereas it is beneficial for the combination that both are written in the same programming language. In general, LER values are increased in tracked systems due to strategic light management. Light reduction solely represented the influence of the PV system on crop yields – but other parameters such as soil temperature might also be relevant. To reflect plant needs at any point in time and to generate more meaningful results, a crop model with hourly timesteps is needed together with calibrated input parameters. Also, improved weather files should be used in the future to facilitate the prediction of long-term effects on crop yields. Additionally, investigations considering the water resource can be rewarding since it is suspected to be the major source of increased crop yields through optimized tracking. With these reasons in mind, an agrivoltaic test facility was constructed in the Rhine river valley to examine the effects of these different tracking paradigms. Experimentation with several chosen crops will take place for at least the next five years leveraging high throughput in-situ phenotyping.

References

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