

On the use of evapotranspiration resistive models in agrivoltaics modeling

2D CFD analysis of a classical evapotranspiration model

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1. Introduction

Agrivoltaics aims to enhance agricultural production, notably by reducing evapotranspiration. While studies have observed reductions under agrivoltaic systems, significant variability exists across seasons [1]. The role of wind and turbulence in evapotranspiration is often overlooked due to measurement challenges, with most analyses focusing on radiation balance and temperature. Bruhwyler et al. [2] examined windbreak effects in vertical systems using a resistive evapotranspiration model. Many researchers rely on the FAO's resistive model, often without assessing its fit for agrivoltaics, using either direct measurements or interpolated meteorological data [4,5]. This study addresses the validity of resistive models in agrivoltaics modeling, focusing on a six-row vertical agrivoltaic system. We approach this question through computational fluid dynamics (CFD) modeling to theoretically assess the aerodynamic effects of the power plant on evapotranspiration.

2. Material and Methods

This study is based on an ideal six rows vertical agrivoltaic power plant above an uniform grassland. The numerical study was carried out using OpenFoam v2312 software to model the flow around the demonstrator and the transport of water vapor between the meadow and the atmosphere using the RANS equations. An additional transport equation was added for water vapor, treating it as a passive scalar. Turbulence was treated using the model $k-\omega$ SST. The mesh was chosen by carrying out a convergence study using the flow parameters under the panels as indicators. The effect of the meadow on the flow was modelled by assuming it to be a porous blockage. The evapotranspiration was considered as a source for the water vapor transport equation described by a resistance for the plants.

3. Results and conclusions

3.1. Results

Figure 1 presents the comparison between the control simulations that correspond to a grassland and the simulations with the agrivoltaics demonstrator. The x-axis indicates the domain inlet velocity at 2m height and the y-axis represents the evapotranspiration. The curves correspond to the fitting of the resistive model presented by equation 1 with the so-called aerodynamic resistance. The green curve, fitted on the green points, shows that the resistive model is in very good agreement with the CFD simulations. On an other hand, the blue curve is made by assuming that only the aerodynamic resistance changes when the power plant is added. It presents a different behaviour than the simulations. In contrast to the red curve when it allowed to modify the system resistance (the sum of the plant and the rough sub-layer resistances), the resistive model is in good agreement with the simulations. We can see that the system resistance is increased by 50 s/m in comparison with the green curve.

$$ET = \frac{s^* - s_{ref}}{r_{sys} + \frac{\ln\left(\frac{z+z_0}{z_0}\right)}{\kappa^2 \times u}} \quad (1)$$

Where ET is the evapotranspiration rate, s_{ref} is the atmospheric concentration of water vapor. z is the velocity measurement height, u is the velocity and r_{sys} and z_0 are two parameters, the system resistance and the roughness height.

3.2. Conclusions

In conclusion, the panels influence evapotranspiration through aerodynamic effects beyond shading. While resistive models can estimate evapotranspiration from meteorological data, precautions are essential. Anemometric measurements must be taken several meters above the panels, as data taken inside the power plant is unsuitable for aerodynamic resistance calculations. Additionally, the demonstrator significantly increases system resistance, which must be accounted for. Proper modeling requires adapting resistance and roughness height to the plant geometry. It can however, with these adjustments, be an interesting method to improve explainability of measurements, and improve agri-PV microclimate studies.

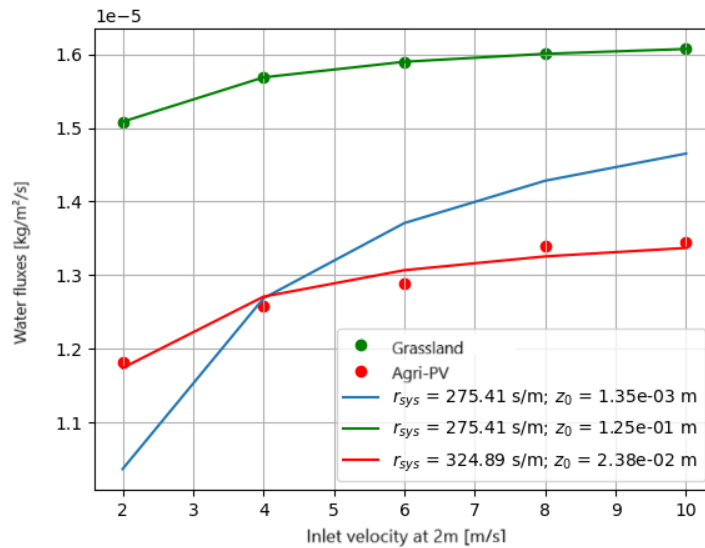


Figure 1. Comparison of water fluxes evolution between the control simulation (grassland) and the simulation with the agrivoltaics power plant (Agri-PV) with the inlet velocity. The points correspond to the simulations (Red : Agri-PV and Green : Grassland). The green curve corresponds to the resistive model fitting on the green point. The red and the blue curves correspond to the resistive model fitted on the red points.

4. References

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