Modeling of bifacial agrivoltaic greenhouses in southern Spain

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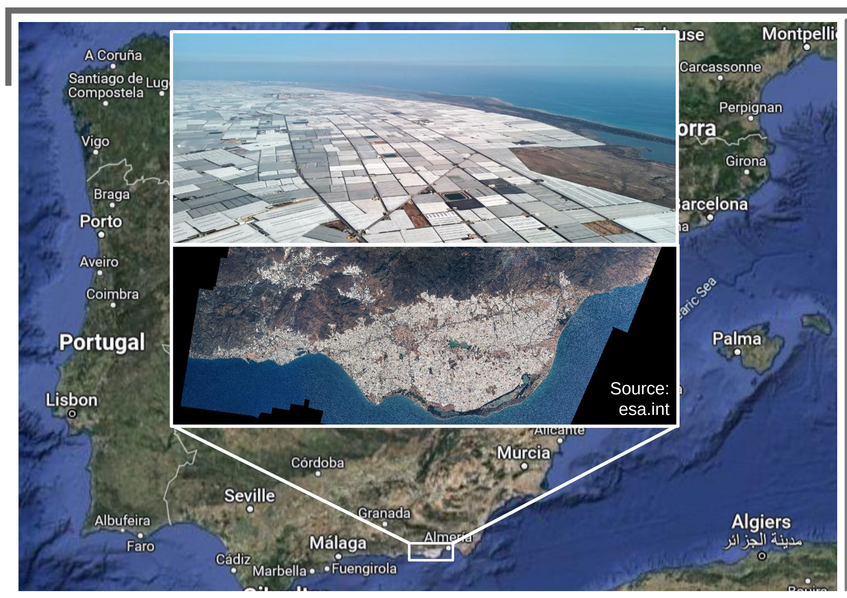
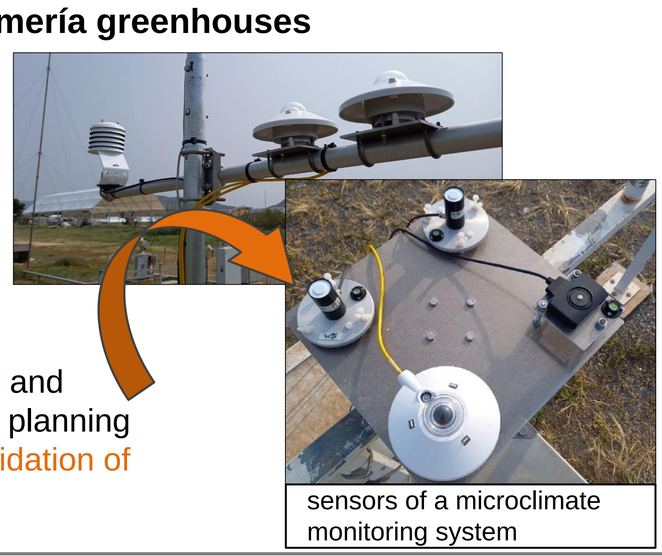


The potential of agrivoltaic concepts for Almería greenhouses

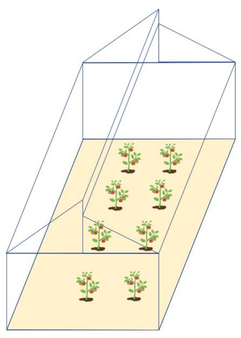
- province of Almería in southern Spain is known for intensive horticulture sector
- ~33.000 ha covered by so-called “raspa y amagado” plastic greenhouses in 2021 [1]
- local high irradiation levels combined with existing infrastructure provide great potential for agrivoltaic solutions [2]

- agrivoltaic yield models have to be developed and validated to allow for optimization and system planning
- demonstration, incl detailed monitoring for validation of concept needed

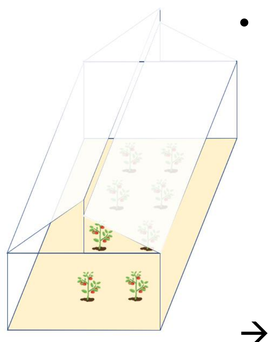


sensors of a microclimate monitoring system

The importance of light management for crop yield

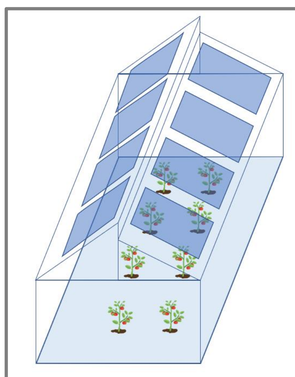


- plant development in greenhouses highly depends on irradiance distribution (among other factors) [3]
- too little or too much light can both harm plants
- active light management is needed



- due to high irradiation levels in Almería, 99% of growers increase albedo of plastic cover by applying white chalk paint onto the roofs several times throughout the year [1]

→ less light is transmitted



- agrivoltaic concepts can support light management
- influence of decreased irradiance not yet fully understood [4]
- critical threshold for healthy plant development unknown [4]

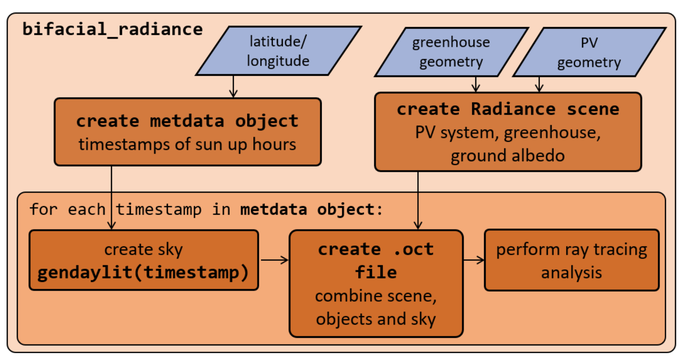
→ irradiance model for plastic greenhouses needed

Development and validation of a ray tracing model for agrivoltaic greenhouses

location: province Almería, Spain (36.77° N, -2.81° E)

climatic conditions modeled based on hourly PVGIS data

PV geometry: 1x1.7 m per module, 25% ground coverage ratio, modules facing South

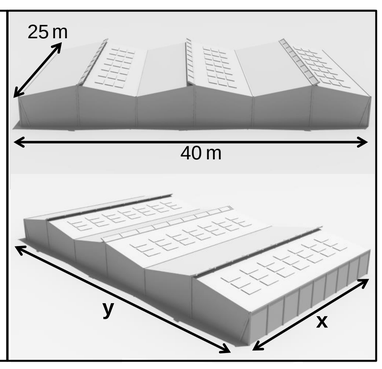


workflow of the model implemented in `bifacial_radiance` based on `Radiance` [5,6]
validation with data from literature

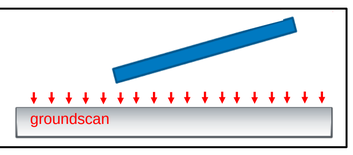
greenhouse modeled based on typical values for raspa y amagado greenhouses [1]

ground albedo: 0.2
plastic transmission: 0.7

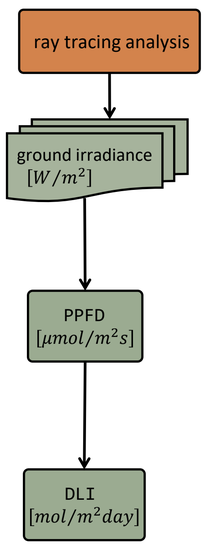
`bifacial_radiance` minimal example: 40 m width, 25 m length
→ can be scaled up



`Radiance` performs backward ray tracing → simulation of global horizontal irradiance GHI [W/m²]



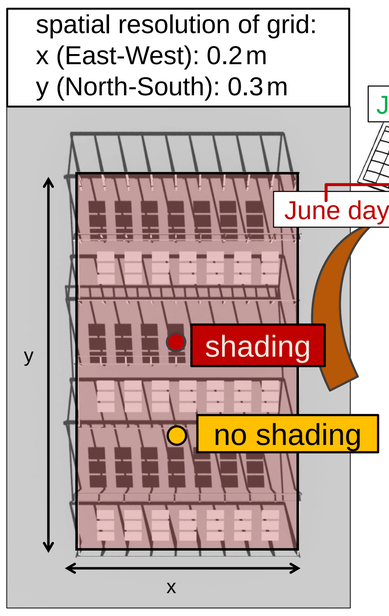
Irradiance analysis



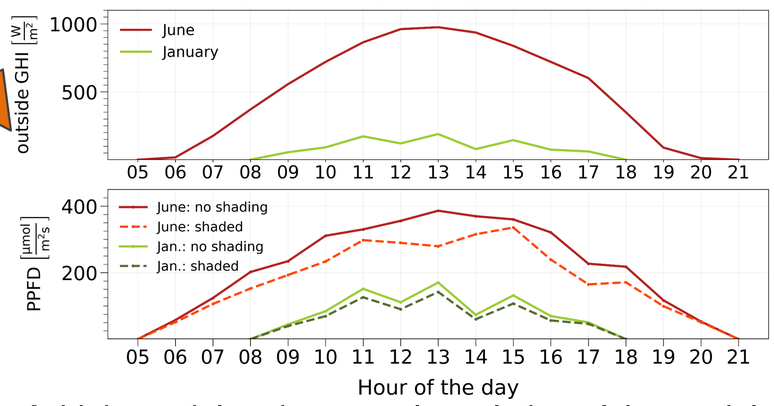
GHI at 0.1 m above greenhouse ground is evaluated along a user-defined grid

photosynthetic photon flux density (PPFD) in the photosynthetically active radiation (PAR) spectral range (400 - 700 nm) is derived via linear regression [7,8]

integrating the PPFD over time for each day results in the daily light integral (DLI, mol/m²d) [9]



PPFD of two distinct grid points for two different days
- clear sky: June day (red curve)
- overcast day: January day (green curve)



→ high spatial and temporal resolution of the model

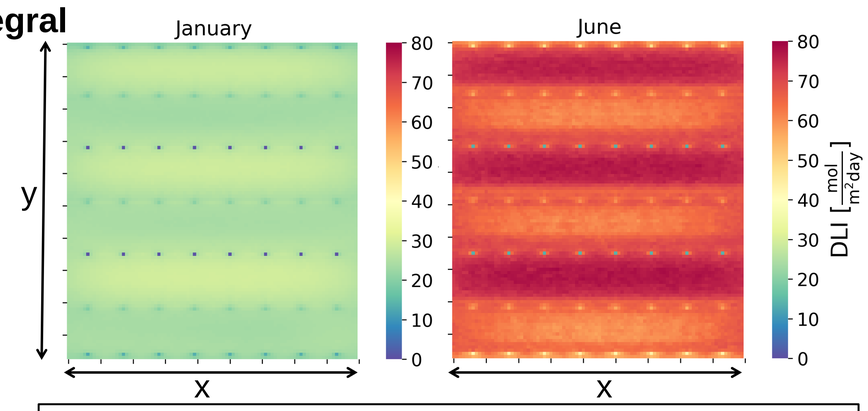
Evaluation of crop yield: daily light integral

- each crop demands different DLI levels for optimal crop growth [10]
- differentiate between low and high light demanding crops:

	sufficient DLI [mol/m²d]	optimal DLI [mol/m²d]
low	8	20
high	12	30

[2]

- most commonly crops in Almería are high light demanding crops: eg. tomato, cucumber, or sweet pepper [11]



overcast day (Jan.): DLI exceed threshold for sufficient crop growth
→ healthy crop growth maintained
clear sky day (June): DLI exceed 30 mol/m²d
→ typically irradiance would be decreased by applying white painting

Conclusion and Outlook

- model for agrivoltaic greenhouses has been developed
- validated with data from literature
- further experimental validation with detailed monitoring station ongoing
- exemplary days evaluated for the province of Almería, Spain
- sufficient DLI levels are maintained at the exemplary days with the modeled ground coverage ratio of 25%
- model can be used to optimize geometry and resulting light distribution of agrivoltaic greenhouses

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