

PASE: a Python Agrivoltaic Simulation Environment

Liège University (DEAL): Roxane Bruhwyler, Nicolas De Cock, Louis Lemaire,
Arnaud Bouvry and Frédéric Lebeau (f.lebeau@uliege.be)

Naldeo Technologies & Industries: Pascal Brunet

LuciSun: Jonathan Leloux

Evaluation of AV systems land productivity

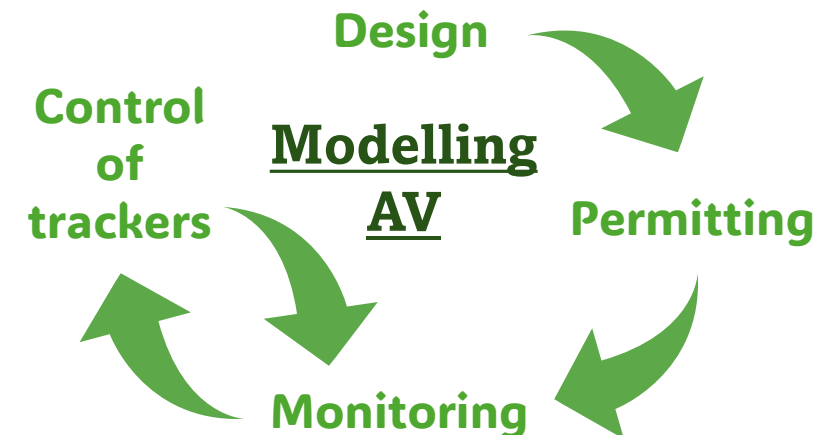
- AV evolving legal frameworks in leader countries



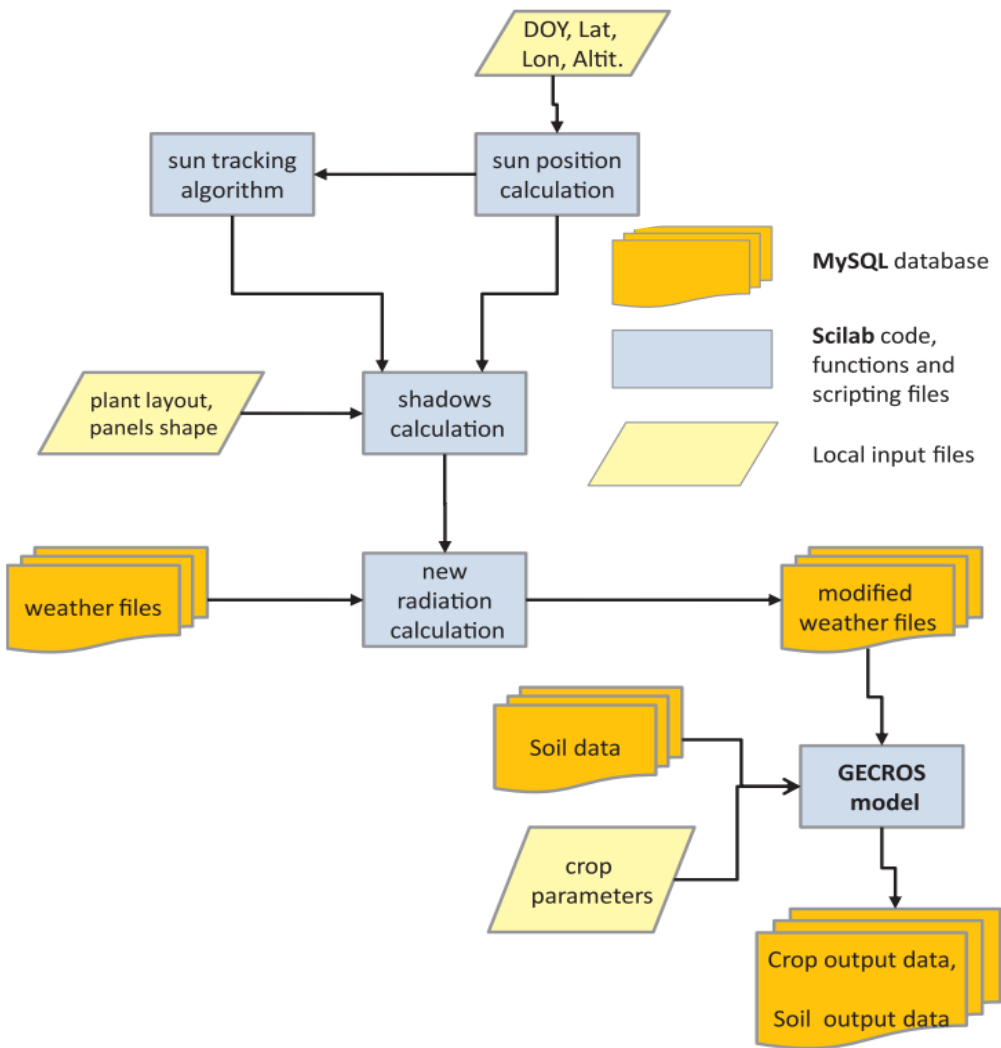
- Geometrical constraints : min. vertical clearance, max. lost area & max. GCR
- Thresholds on crop yield loss OR obligation to maintain crop yield

- Legal thresholds require to assess the impact of PV geometry and trackers control strategy on crops
- Bankable energy projects require to assess the PV energy production
- Models can also → ease field reporting interpretation

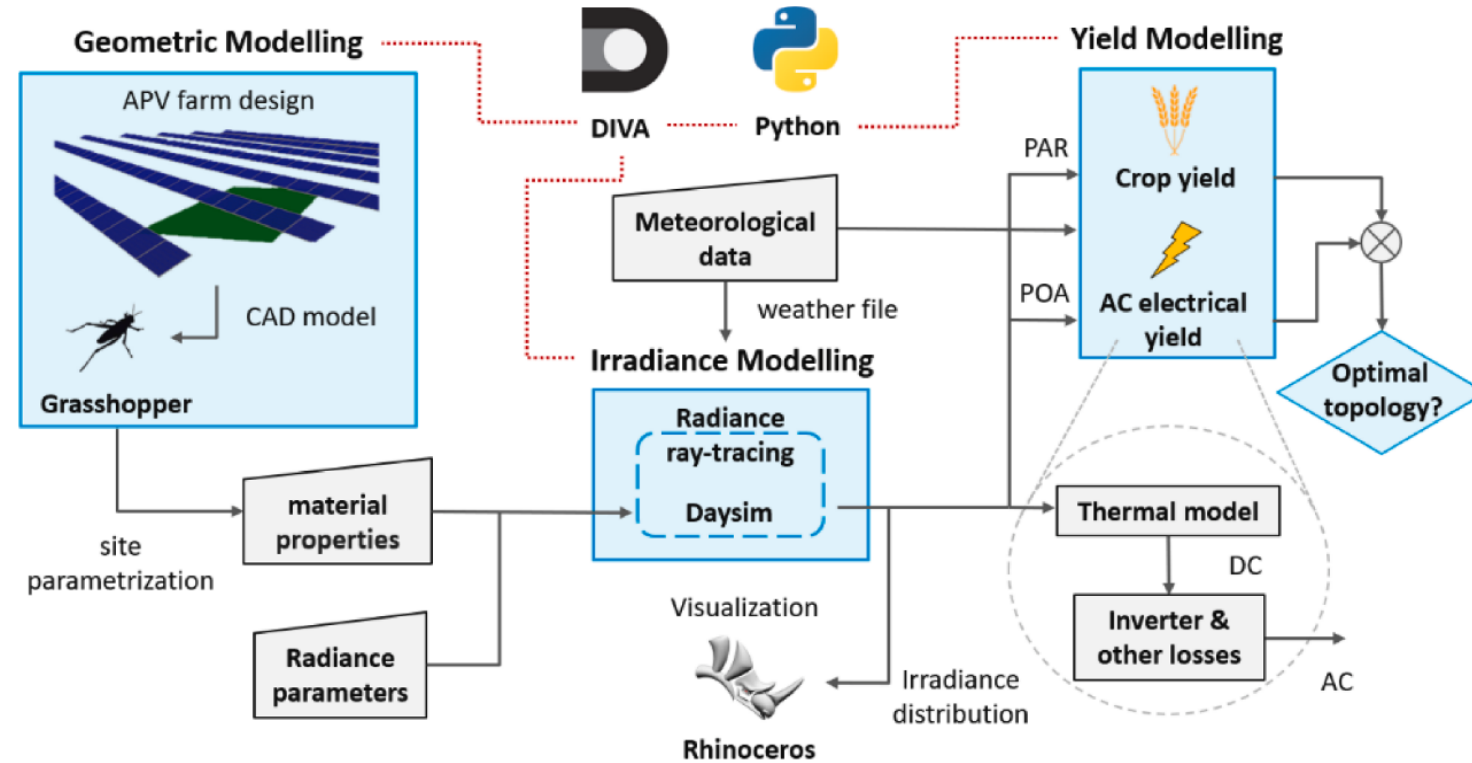
→ **Need of modelling tools to assess the efficiency of AV systems**



Several modelling tools developed



Source: Amaducci et al., 2018. Agrivoltaic systems to optimise land use for electric energy production



Source: Katsikogiannis et al., 2022. Integration of bifacial photovoltaics in agrivoltaic systems: A synergistic design approach

- Few models are well-balanced between:   
- Empirical models fail to reach genericity of process-based models
- Sub-models present various complexity levels
- Many open-source components are mobilised but no complete open-source framework is available

What is needed ?

1. A user friendly and open-source tool with a strong community engagement
2. A well-balanced tool between: 
3. A generic tool to reflect the diversity of AV systems



↗ complexity



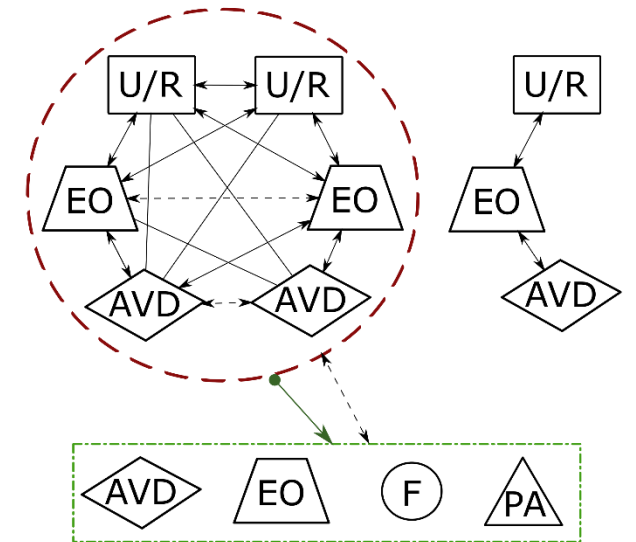
↗ complexity

- Modularity to facilitate the inclusion of different complexity levels models
- Efficient computation organisation to perform multi-years simulations and high temporal and spatial resolutions

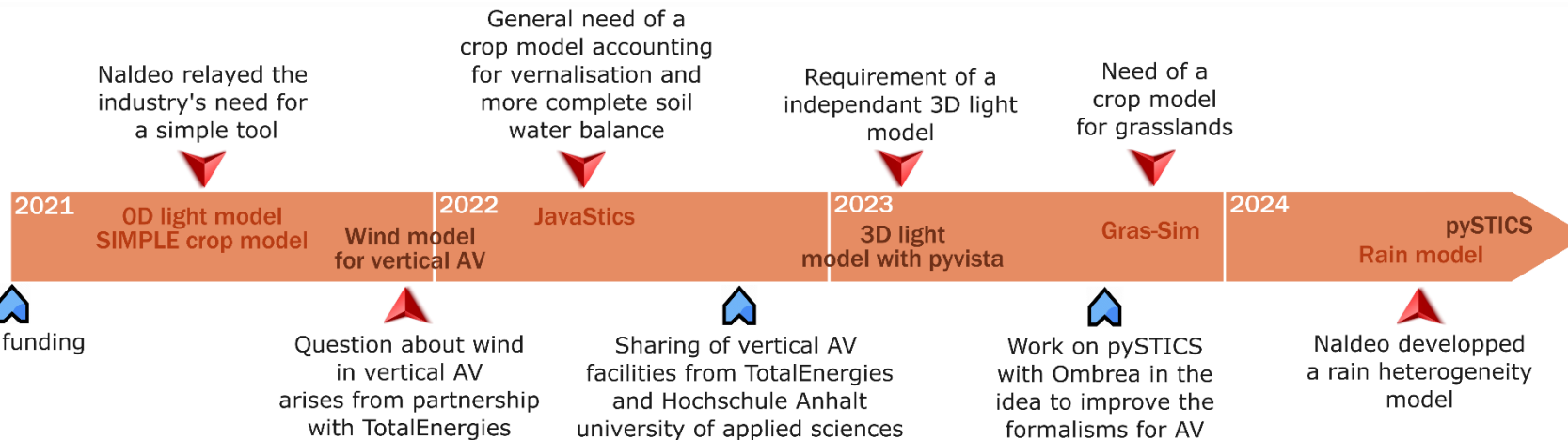
Development of PASE

- Adoption of an open-source business model with academic and private partners

→ Ideas, feedbacks, equipment and developments are shared

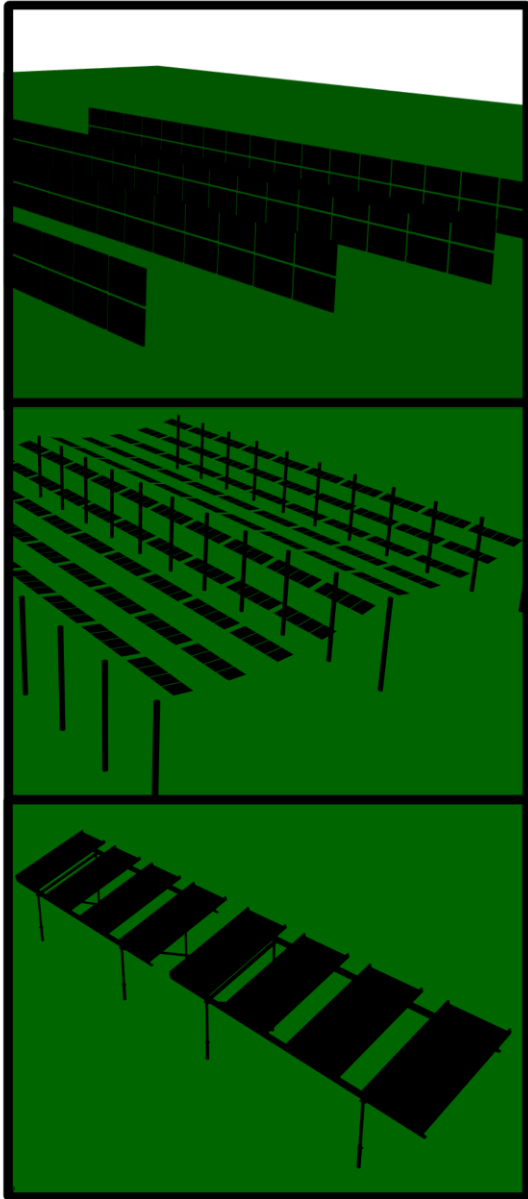


U/R	University or research centre
EO	Engineering office
AVD	Agrivoltaic plant developer
F	Farmer
PA	Public administration
↔	Ideas, equipment and developments are transferred and feedback and sharing occurs
↔--↔	Only feedback and sharing occurs
→	Developments are used
- - -	Partnership agreement
⋯	External users



PhD funded by the  → First stabilised version of PASE

PASE 1.0: 3D CAD modelling



AV system configuration

PV plant geometry

- i - Geometric parameters of PV modules, PV blocks and PV plant
- i - Location and type of structures

Other objects in the scene

- i - Location and geometry
- i - Topography

- The Visualization Toolkit (VTK) open-source software (using PyVista pythonic wrapper) allows 3D CAD modelling:

- programmatic inclusion of PV modules:
 - 15 parameters to create any regular PV plant
 - Sun-tracking with back-tracking NREL algorithm

- importation of CAD files: structures, building, 3D plant architecture, ...

PASE 1.0: micro-climate modelling

Microclimate models

i- Weather data (hourly or higher resolution)

> Light module

i - Sun positions (same resolution as weather data)
m- Erbs et al. correlation: DHI from GHI

> Wind module

Vertical AV

m- Hedge windbreak model of Campi et al (2011)

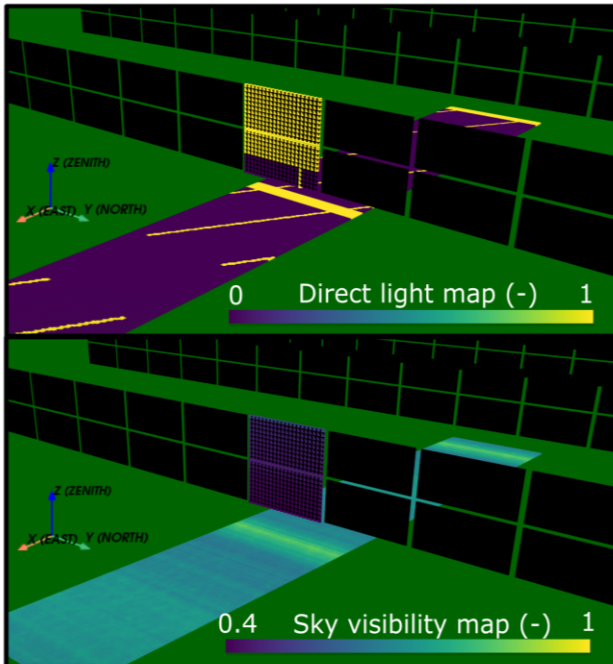
Irradiance on PV modules

m- HDKR model: GPOA calculation (non isotropic sky)
OR
m- Ray casting algorithm (isotropic sky OR anisotropic sky)

> Rain module

Irradiance on crop

i - Area of interest
m- Ray casting algorithm (isotropic sky OR anisotropic sky)



Light module:

- Customisable level of resolution on sun positions (by default: monthly, weekly or daily sampling)
- Customisable temporal resolution (by default: 10, 15 and 60 min)
- Customisable interest zone resolution, size and location
- HDKR transposition model for POA prediction by default but ray casting also available for PV modules

More advanced work on wind modification in AV: poster session
→ Joran Dartevelle

Wind module:

- Possibility to use the windbreak model proposed by Campi et al., (2011) when modelling vertical AV

PASE 1.0: crop and PV productivity modelling

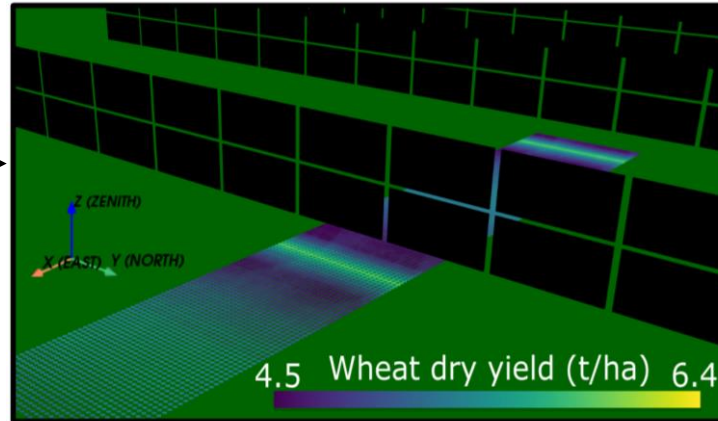
Crop models

Yield & agronomic indicators along cropping seasons

- i - Soil, crop, management and modelling parameters
- i - Daily weather data
OR higher resolution
- m- SIMPLE
OR
- m- STICS
OR
- m- Gras-Sim
OR
- m- *pySTICS (some process refined for AV)*
OR
- m- *CPlantBox*

Agricultural module:

- Different crop models available: SIMPLE, JavaStics & Gras-Sim
- Light response of crop models is spatialized



PV production module:

- PV energy production model performing at the same temporal resolution than light model
- Bifacial production computation
- Quite simple model considering only PV modules efficiency, thermal losses and mutual shading factor (geometric computation)

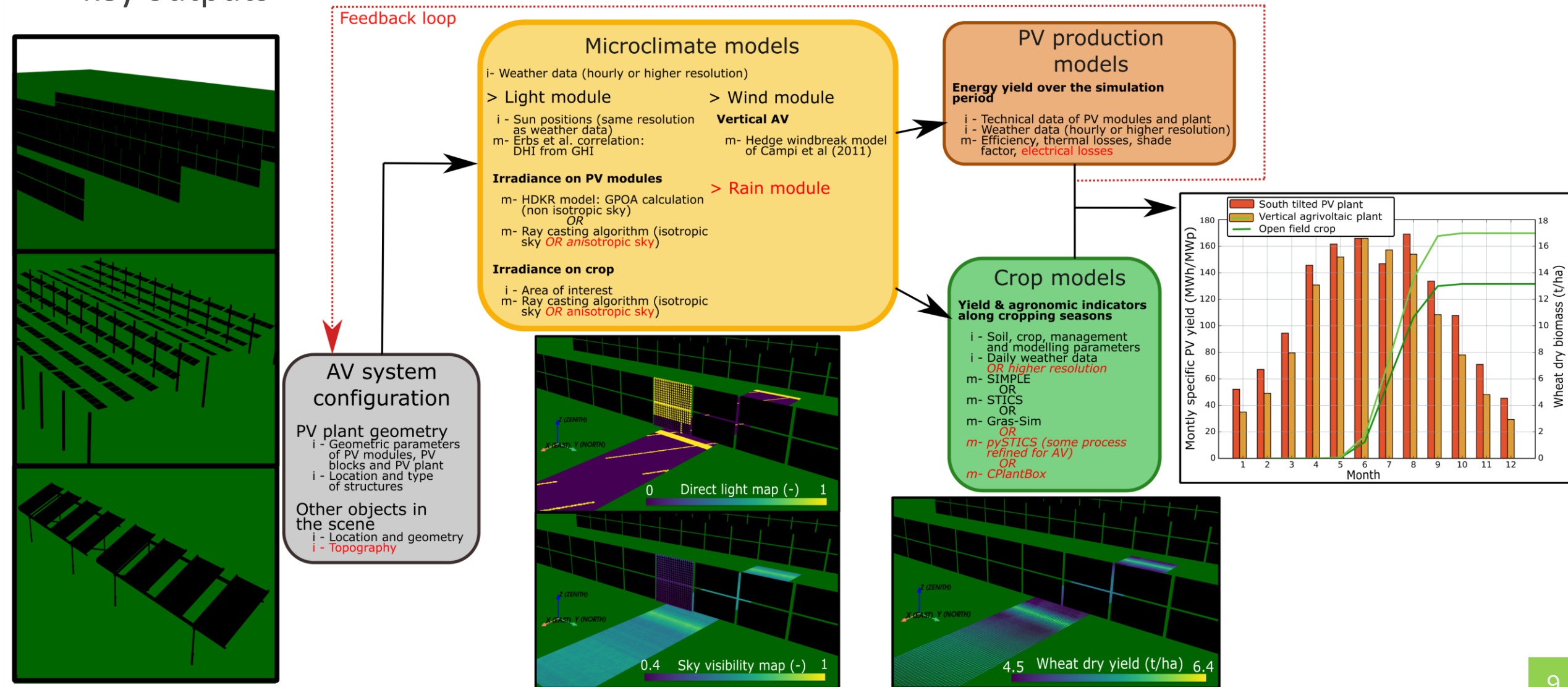
PV production models

Energy yield over the simulation period

- i - Technical data of PV modules and plant
- i - Weather data (hourly or higher resolution)
- m- Efficiency, thermal losses, shade factor, *electrical losses*

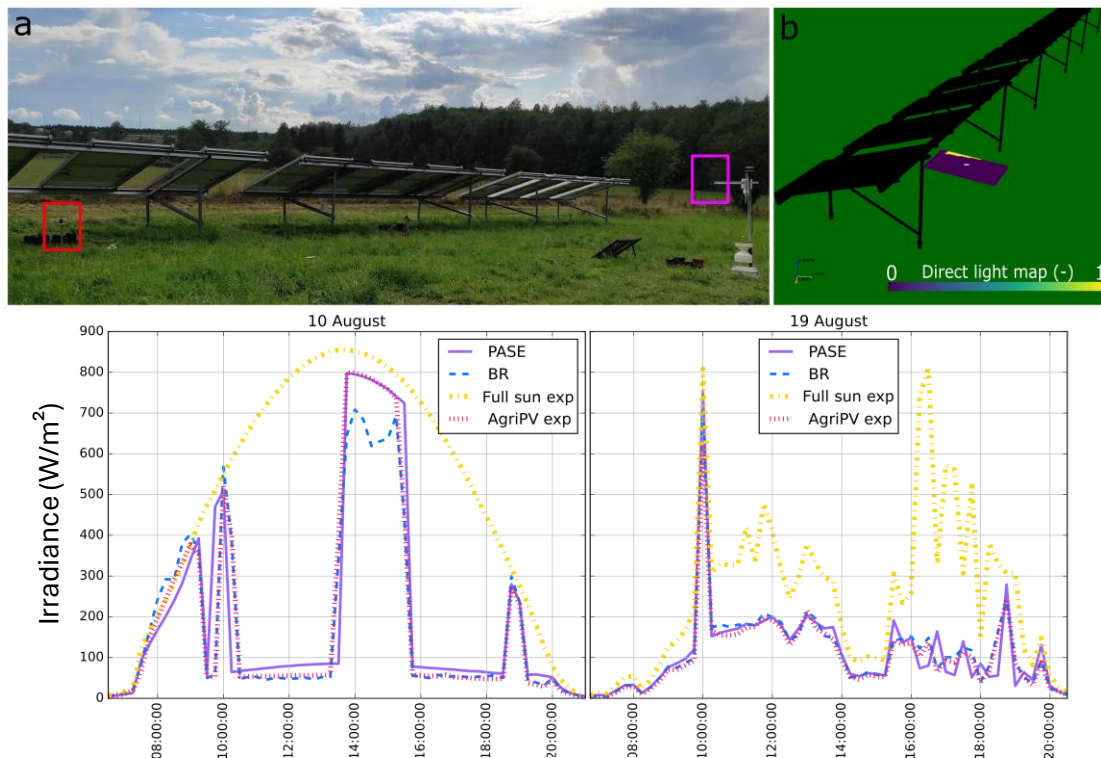
PASE 1.0

- Sub-models are integrated using YAML serialisation language into the framework to produce key outputs



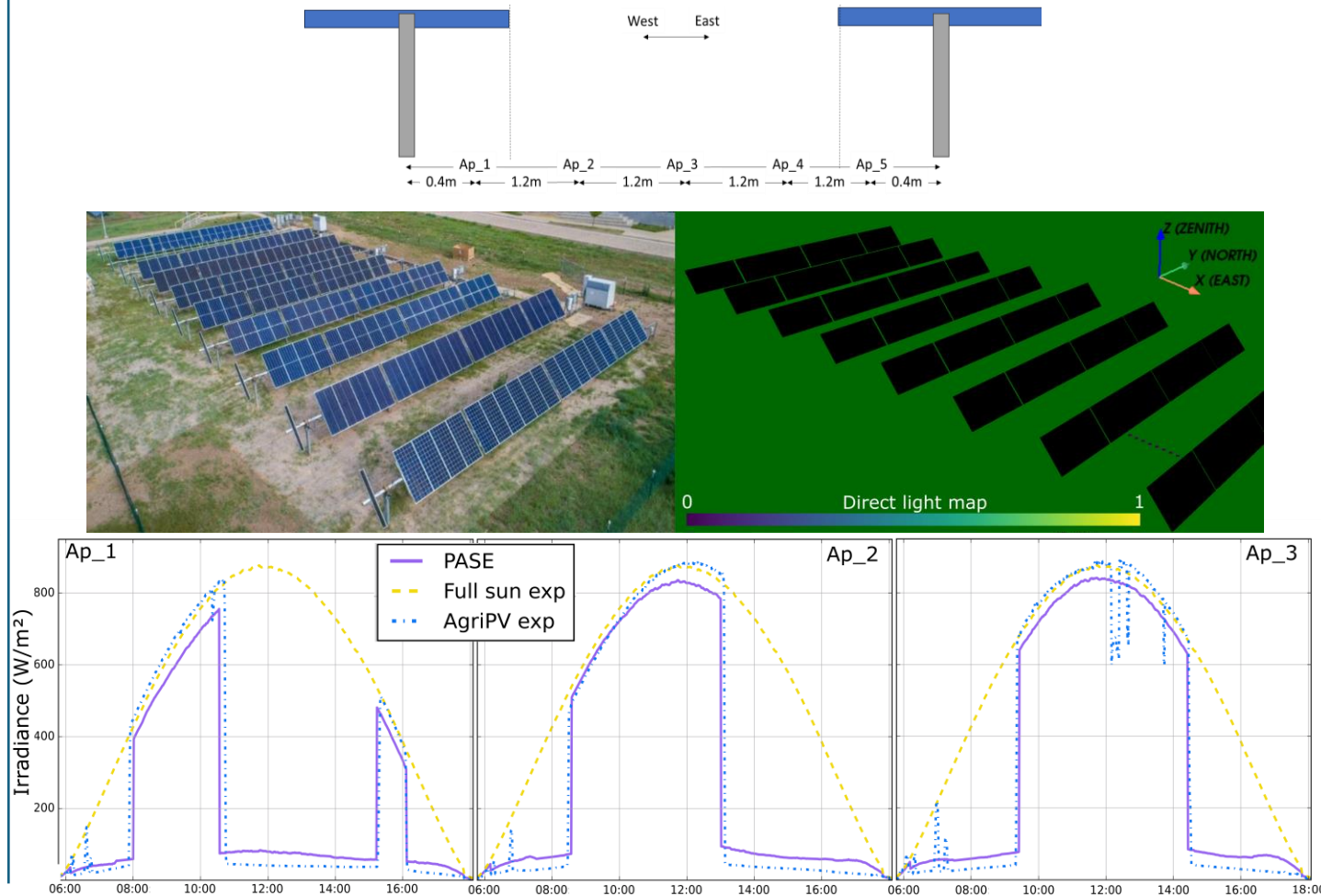
PASE 1.0 light model validation → poster session

- Validation with light data from DEAL experiment on the SigueSol AV pilot at Werbomont (Belgium)
- Comparison with simulations performed with bifacial_radiance by  **HOCHSCHULE ANHALT** University of Applied Sciences



- Validation with light data from NREL experiment on their BEST AV pilot at Golden (USA)

Data availability: <https://datahub.duramat.org/dataset/best-field-data>



Access to PASE 1.0

- PASE 1.0 is distributed under the MIT license
- Available in zip file on  : <https://hdl.handle.net/2268/310262>
- Also hosted on gitlab  : https://gitlab.uliege.be/pase/pase_1.0
where issues can be used to report bugs, suggestions, ...



Do not hesitate to contact us if you want to collaborate on future developments of PASE !!

Thank you for your attention !

 **Roxane BRUHWYLER**

PhD student at Gembloux Agro Bio Tech
Digital Energy and Agriculture Lab

 roxane.bruhwyler@hotmail.com

roxane.bruhwyler@uliege.be

 +32497/488.652



TSE AgriPV system, Source: TSE