

Model Region Agrivoltaics

Baden-Württemberg

Protecting Apple Orchards with a Day-Ahead Tracker Control Strategy



SCAN TO LEARN MORE

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1. Introduction

- **Agrivoltaic systems** provide an innovative solution to land-use conflicts that often arise between agriculture and energy production.
- **Horizontal single-axis tracking (HSAT) agrivoltaic system** enable effective management of light distribution between solar panels and the underlying crops through innovative control algorithms [1].
- This work presents the tracking strategy methodology implemented at the Nussbach facility, located in Western Germany, as part of the Model Region Agrivoltaics BW project [2]

2. Methodology

The methodology is structured in several parts:

- **Tracking Optimization:** Analyzes five statistically representative days per month using historical data to account for weather variability obtaining the optimized tracking profiles.
- **Day-Ahead Control:** Utilizes next-day weather forecasts to align operational strategies with irradiation profiles, ensuring optimal light exposure.
- **Day-Ahead Adaptive Strategy:** Incorporates sensor data to fine-tune the tracking strategy based on the health status of the crops.

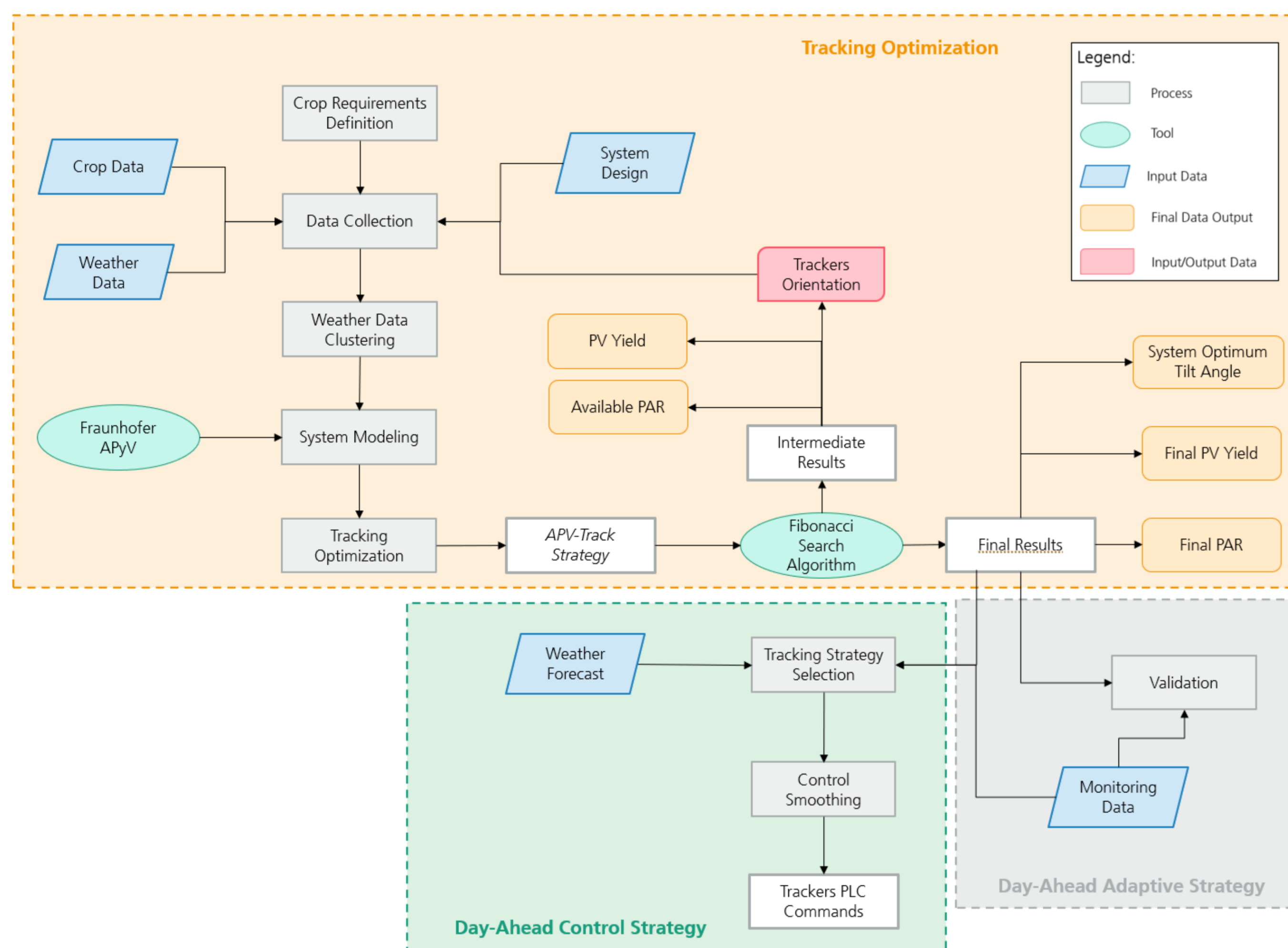


Figure 1: Methodology Flowchart

- **Forecast data:** In a first step, day-ahead control strategies are utilized. Corrective actions during the day are not possible based on updated forecasts, however, day-ahead sensor-based protective measures are enabled. The strategy therefore relies on the weather forecast from the previous night that inherently shows increasing uncertainty over the course of a day.
- **Validation:** Temporally dependent differences between simulated and measured data are crucial to be evaluated. Thus, sensors data are also used to validate the simulation results. The location and type of sensors used is illustrated in Figure 2.

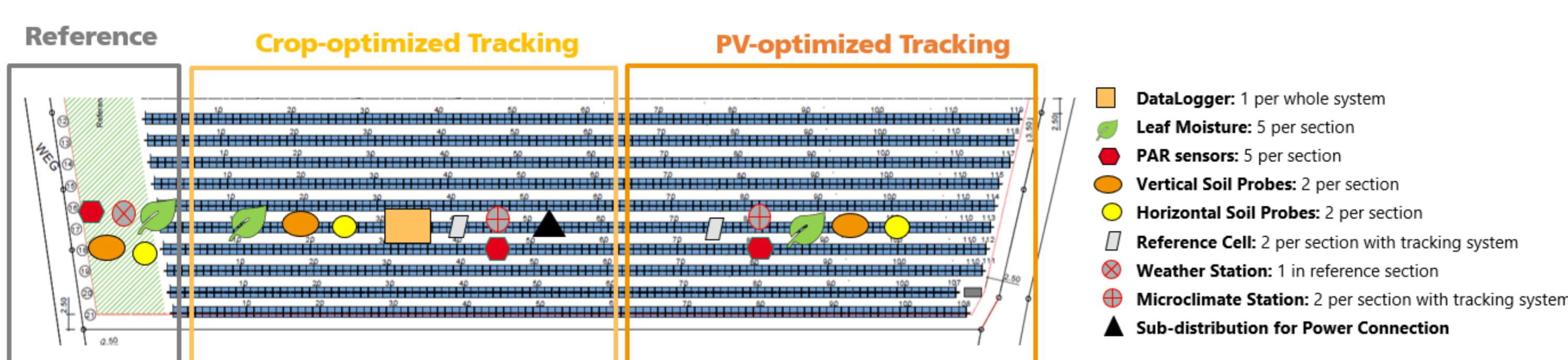


Figure 2: Overview of the Monitoring concept in Nussbach

3. Crop Requirements

- The definition of the crop requirements starts from **PAR reduction rates** reported in Table 1. These values are provided by LTZ [3], the agricultural partner of the Model Region project, and are empirically derived based on their long-term agronomical experience.
- Different thresholds are identified for the different phases of crop's development, based on the **phenological stage of the apple trees**. Particularly critical stages occur during the flowering and fruit colouring processes.

Month	Max PAR reduction [%]	Phase
March	40%	Budding/Sprouting
April	20-30%	Flowering sensitive to shading
May	20-30%	High importance of carbohydrate assimilation during flower formation
Juni	30-35%	Heat reduction for better fruit quality and sunburn protection
July until Mid-August	30-35%	Fruit ripening
Mid-August until September	20-30%	Fruit coloring

Table 1: Acceptable PAR reduction rates in the cropping season (© LTZ Augustenberg)

- Using a percentage threshold however is not ideal in optimization work. In fact, if the same threshold is applied to a sunny day or an overcast day, it leads to very different values of **DLI (Daily Light Integral)** for the plant.
- In this study, **absolute PAR targets in W/m²** are introduced. The targets are obtained by simulating the light received by the apple orchard using historical weather data from 1994 to 2014, and average weather conditions for each month.



Figure 3: 3D rendering (© Fraunhofer ISE) and picture (© Intech) of the pilot project in Nussbach

- This approach mitigates the impact of climate change and increasing GHI values, setting lower irradiation targets for the trees, thus ensuring that **power production is not excessively compromised**.

4. Results

- This study introduces an innovative approach by incorporating **crop shade sensitivity across various developmental stages** into the optimization process. As more data become available, the methodology can seamlessly adapt to consider variations in intraday shade sensitivity.
- Results indicate that **91% of the target irradiation for apples can be achieved** in the simulated year with tailored PV control, resulting in a moderate **20% reduction in electrical yield** [2].
- The field testing started in March and will continue until September. Expectations will be confirmed or refuted by field trial during the 2025 growing season currently ongoing.
- The results demonstrate **that efficient and sustainable dual land use** is achievable through the implementation of a well-managed agrivoltaic system.

[1] C. Toledo and A. Scognamiglio. "Agrivoltaic systems design and assessment: A critical review, and a descriptive model towards a sustainable landscape vision (three-dimensional agrivoltaic patterns)". In: Sustainability 13.12 (2021), p. 6871. DOI: <https://doi.org/10.3390/su13126871>

[2] Maddalena Bruno, Leonhard J. Gfüllner, and Matthew F. Berwind "Enhancing agrivoltaic synergies through optimized tracking strategies," *Journal of Photonics for Energy* 15(3), 032703 (27 January 2025) <https://doi.org/10.1117/1.JPE.15.032703>

[3] Landwirtschaftliches Technologiezentrum (LTZ) Augustenberg. <https://ltz.landwirtschaft-bw.de/Lde/Startseite>

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