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Optimised Tracker Algorithm Enables an Agri-PV Plant with Organic Strip Farming and Solar Electricity Generation

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Abstract. When constructing solar farms, it is important to consider the impact on our living environment and on the use of farmland, ideally contributing to biodiversity and maintaining soil quality. In the Symbizon project, we are developing algorithms for the solar trackers that will balance both crop demands and solar electricity yield. We have simulated the soil irradiance in the farmed strips and determined the annual electricity yield. We varied the algorithm that determines the tracker angle as function of the conditions, including position of the sun, amount of irradiance on panels or on the soil etc. We compare the electricity yield with that of a HSAT PV system with twice the number of trackers and the soil irradiance with that of a field without PV. We show that, for all investigated algorithms, the soil irradiance is at least 60% of the single-use strip farming irradiance. In addition, the electricity production of the agri-PV system varies between 20% and 66% of an optimised HSAT PV system without farming. The next step will be to also optimise the tracker strategy to adapt to local conditions, e.g., allowing more light on the crops during low temperature humid conditions, but shading crops during hot and dry conditions, taking into account actual crop models instead of soil irradiance. Combined, the sum of the relative crop and electricity yield is always larger than 100%, showing that these agri-PV systems make better use of the available land for food and energy harvesting.

Keywords: Strip Farming, Horizontal Single Axis Tracking, Algorithm Optimisation, Agrivoltaics

1. Introduction

In the Symbizon project we are building a 0.7 MWp agrivoltaic demonstrator to investigate the combination of solar panels and organic strip farming. The system is expected to be operational in summer 2022. Figure 1 shows a schematic cross-section of the demonstrator. The organically farmed strips of 6 m or 12 m wide are interdigitated with herb mixture strips. The herb stripes are co-located with the PV tables.

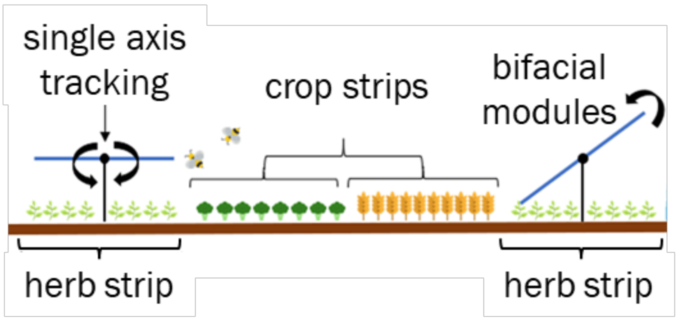

Figure 1. Schematic cross-section of horizontal single-axis trackers with bifacial modules placed above 3-m wide strips, sown with shadow-tolerant seed mixture in combination with 6 or 12 m wide strips of arable land.

We apply horizontal single-axis trackers (HSAT) as they offer several advantages, all originating in the ability to rotate the PV tables: control over the division of light between soil and PV panels; reduction of wind load in stowing position, visibility in the landscape and easy access to the farmland compared to "tandem" agri-PV where the PV panels are 5 to 8 m above the ground [1]. We simulated this agri-PV system with transitional zones of 0.5 m on either side of the ~4 m herb strip. Thus, the total pitch from tracker to tracker is either 11 m or 17 m, giving ground coverage ratios of 36% and 24%, much lower than the values for typical single-function solar parks in the Netherlands. Both the energy yield per ha and the cohabitation of PV with herb and crop strips benefit from the use of bifacial solar panels and solar trackers.

2. Methodology

BIGEYE, introduced in 2015, is a validated PV simulation tool that simulates the output of solar parks [2]. Further details of the BIGEYE software package have been published in the following years [3]–[5]. BIGEYE was developed when bifacial and semi-transparent PV panels could not be simulated with existing software packages. For many situations, the major part of the panels' rear irradiance is due to ground- or crop-reflected light, so-called albedo. Therefore, BIGEYE calculates the irradiance distribution on the ground in great detail, taking into account direct and diffuse contributions to the global irradiance, the distribution of shadow and beam light, the semi-transparency of the PV panels, the partial blocking of the sky by surrounding PV tables, causing the soft shadow.

Nussbaumer et al. validated the irradiance on the front and rear of PV panels by BIGEYE [6]. Validation of the daily ground irradiance with Si pyranometers shows an average deviation of 1% relative to the daily global horizontal irradiance.

The Symbizon agri-PV system is located near Almere, the Netherlands. Irradiance and ambient temperature data, 1 hour time step is taken from the nearby weather station at Amsterdam Airport for the year 2011. Next to this agri-PV system, we also define two single-use fields. The first consists of only the arable strips interdigitated with the herb mixture strips. This field will be called "no PV" in this contribution. The second is a PV farm with double the number of trackers, which corresponds, for this location, for a nearly optimal design for a HSAT solar farm. This will be referred to as the "only PV" field, for which ground irradiance will be ignored as the tracker-tracker distance is too small for farming purposes.

3. Results & Discussion

We simulated the annual energy yield and the annual soil irradiance of these HSAT systems. In the first section, we fix the tilt angle at various angles. In the second part, we apply various algorithms to explore the choice between ground irradiance and electricity generation. In both, the tracker-tracker distance is the same.

Figure 2 shows the hourly energy yield, summed over a full year, for various fixed PV table angles over the full year; not all simulated angles are shown for simplicity. Due to the slight predominance of irradiance in the afternoon, the fixed tilt angle of 10° W yields the highest energy gain. The vertically placed, west-facing (purple) and east-facing (dark red) PV panels show a large difference in the morning, around 8 am, and in the late afternoon, around 6pm. This is due to the 75% bifaciality factor of the PV panels: the morning sun irradiates the front of the east-facing panels and the, less efficient, rear side of the west-facing panels and vice versa after the solar noon.

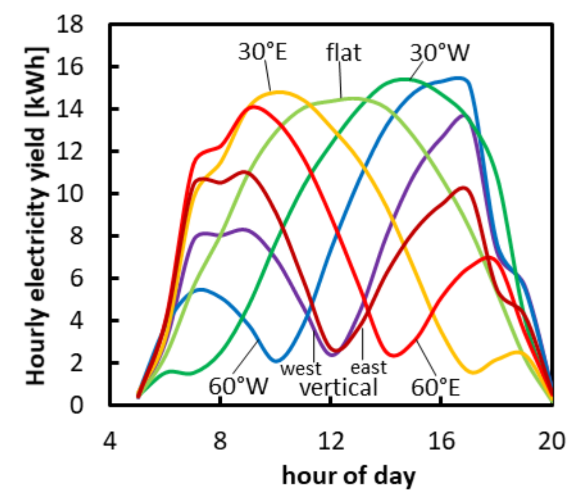

Figure 2. Hourly kWh yield per table as function of the fixed angle indicated in the graph.

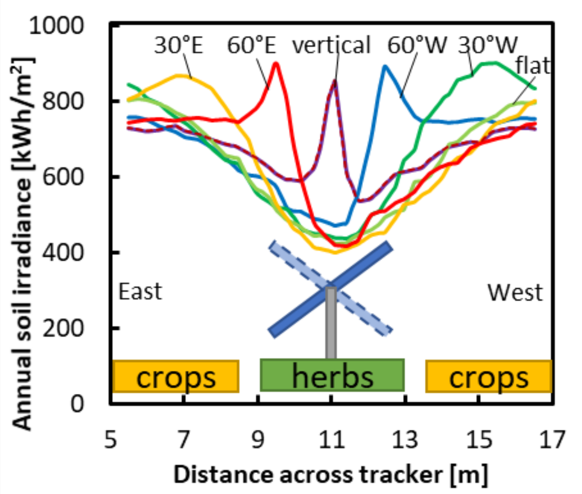

Figure 3. Spatial distribution of annual soil irradiance for some selected, fixed tilt angles.

Figure 3 shows for the same simulations the distribution of light on the soil, for the tracker at position 11 m. The green (yellow) boxes below the curves indicate the position of the herb (crop) strips. Clearly, the central 4-m strip generally coincides with the area of lower irradiance and the 6-m wide farm strips are in the zone with the higher irradiance levels. Note that the annual irradiance on the herb strip is still above 400 kWh/m^2, independent of the fixed angle of the PV tables.

Total soil irradiance is an important parameter for crop growth, but also precipitation and the distribution of the irradiance over the soil and the season and local temperatures between and below the PV panels are important. Also, crop growth is not linear with irradiance. Depending on the crop, at constant water, nutrient and temperature, the growth will saturate at high irradiance. Very high irradiance could even lead to a reduction in photosynthesis or premature senescence.

The previous sections show the irradiance distribution between the PV panels and the soil for various constant tilt angles. We now focus on the relation between tracker angle or algorithm and the resulting annual energy yield and resulting cumulative soil irradiance. The following fixed angles or algorithms are used:

- flat – all panels horizontal
- vertical West/East – All panels vertical, with the front size facing West, or east
- sun tracking – the panels track the sun's position across the sky
- back-tracking – to prevent direct shadow on the neighbouring tracker, when the sun's elevation is low, the panels are rotated towards horizontal
- optimal PV – for each hour the angle that yields the highest kWh
- lowest PV – for each hour the angle that yields the lowest kWh
- highest soil irr – for each hour the angle that yields the highest soil irradiance

Finally, we calculate the energy yield with HSAT PV with twice the number of PV trackers per ha, labelled "only PV", and the soil irradiance with "no PV". These two situations are used to normalise the energy and the soil irradiance performance of the other algorithms. Note that for "only PV", we ignore the soil irradiance. Obviously, the soil irradiance will never be 0% as around solar noon direct light will reach the soil, despite dense packing of trackers. Also, a fraction of diffuse light will always reach the ground. But because of the dense packing there will be no space for farming activities, hence we put the relative soil irradiance for the "only PV" case at 0%.

Figure 4 shows for each of the applied algorithms the simulated energy yield and soil irradiance in the farm strip for a full year, based on hourly time steps. It is clear that for all algorithms, the sum of the relative energy performance and the relative irradiance performance is larger than 100%, even though the dual use system has only 50% of the number of PV panels.

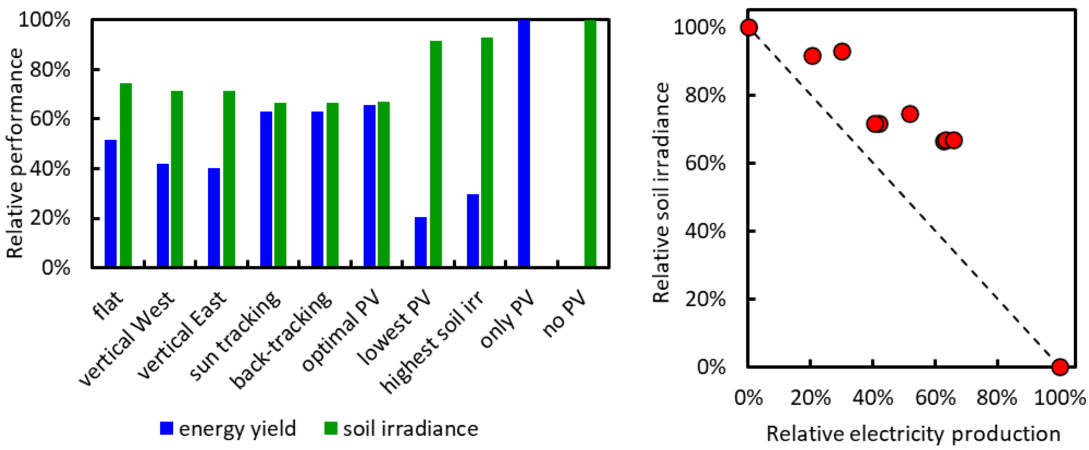

Figure 4. (left) Relative electricity production (blue) and relative soil irradiance in the farmed strip (green) for various tracker algorithms, relative to "only PV" and "no PV". (right) Relative soil irradiance as function of the relative electricity production for the algorithms introduced in the lefthand panel. The dashed line indicates the line where the sum of the relative electricity production and relative soil irradiance 100% is.

4. Conclusions

We have simulated the energy yield and the soil irradiance for a combination of HSAT trackers above herb strips that are in-between organically farmed crop strips. We have shown that, for all investigated algorithms, the annual soil irradiance is at least 60% of the irradiance of single-use strip farming. In addition, the electricity production of the agri-PV system varies between 20% and 66% of an optimised HSAT PV system without farming, although the number of PV panels for the agrivoltaic system is only half of that of the optimised HSAT system. The combined relative crop and electricity yield is always larger than 100%. The next step will be to also optimise the tracker strategy to adapt to local conditions, e.g., allowing more light on the crops during low temperature humid conditions, but shading crops during hot and dry conditions, taking into account actual crop models instead of soil irradiance.

Data availability statement

The contribution is based on simulations using proprietary software. Details of the solar park design and climatic data are included in the paper. Parties with legitimate interest in the data can contact the corresponding author to discuss access.

Author contributions

ARB: Methodology, Software, Writing – review & editing. ET: Writing – review & editing. CK: Writing – review & editing. BBVA: Formal analysis, Writing – original draft.

Competing interests

The authors declare no competing interests.

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