Diffuse Optimization:
Strategy To Enhance Photovoltaic Yield In Tracked Systems

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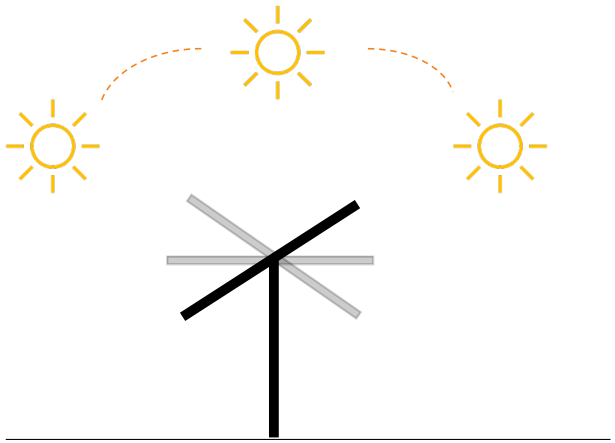
Agenda

- Introduction
  - Horizontal Single-Axis Trackers (HSAT)
  - HSAT Limitations & Research Question
- Methodology
  - Flowchart
  - Main Assumptions
- Results
  - Daily Gains
  - Optimized Tilt Profile
- Conclusions & Future Developments

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Introduction

Horizontal Single-Axis Trackers



- Surge in the global adoption of horizontal single-axis trackers (HSATs)

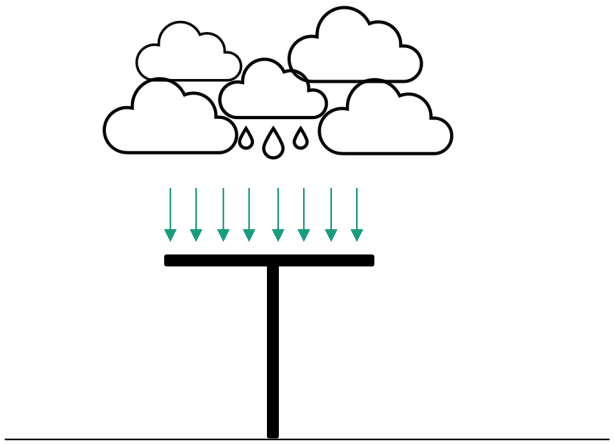
Boost in annual yield from 10% to 30% compared to standard ground-mounted systems

Backtracking strategy adopted to minimize shadowing between different rows of the system

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Introduction

HSAT Limitation & Research Question



Traditional tracking methods do not consider the share between direct and diffuse radiation

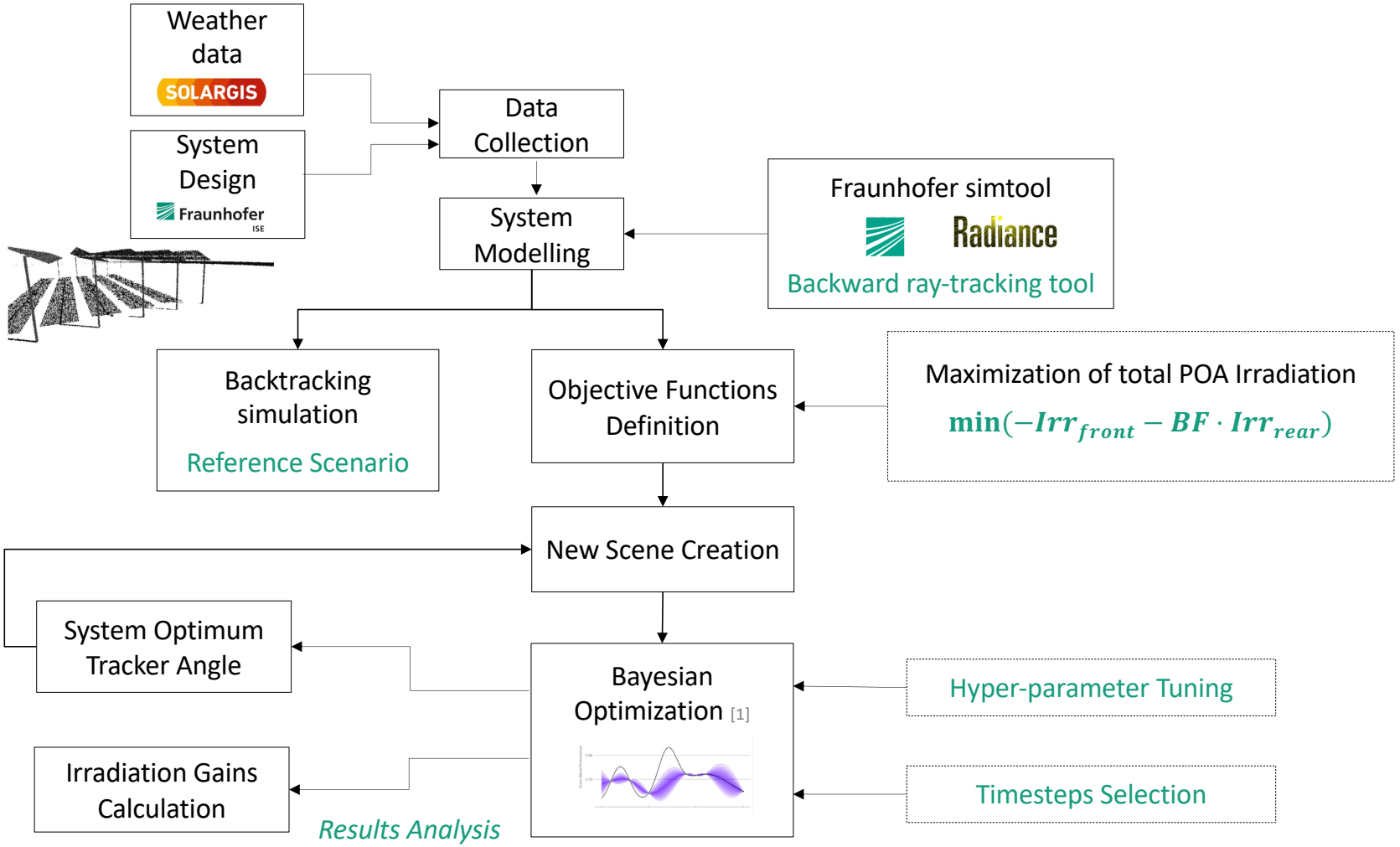
- The benefits of HSATs diminish at higher latitudes
  - Prevalence of overcast days with an isotropic distribution of the solar radiation

How can the POA irradiation be increased compared to backtracking strategy?

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Methodology

Flowchart

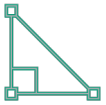


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[1] Wikimedia Commons. *File:GpParBayesAnimationSmall.gif* — Wikimedia Commons, the free media repository. [Online; accessed 22-May-2023]. 2022.URL: https://commons.wikimedia.org/w/index.php?title=File:GpParBayesAnimationSmall.gif&oldid=714971054

Methodology

Main Assumptions



Geometric simplification adopted for system modelling



Bayesian Optimization chosen for its computational efficiency



Selection of optimization timesteps to further reduce the computational effort

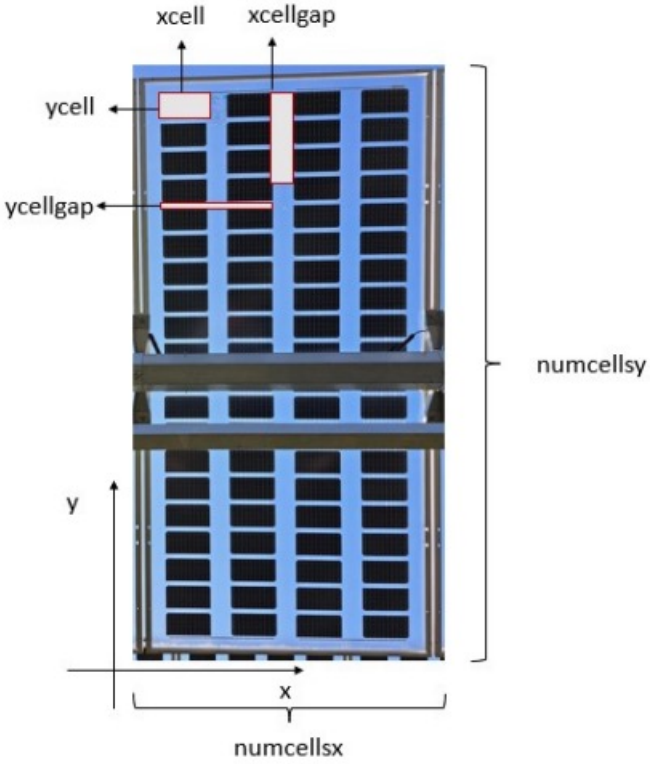


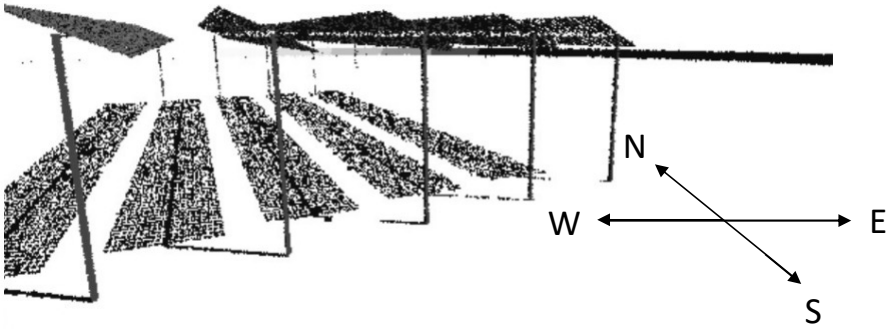
Approximate estimation of the trackers motor consumption

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Methodology

System Geometry





- Portion of the system that guarantees periodic boundary conditions
- Model detailed at the cell level
- Substructure and torque tube included
- Geometric properties obtained from the datasheet
- Trackers properties from the datasheet

Compromise between runtime and accuracy

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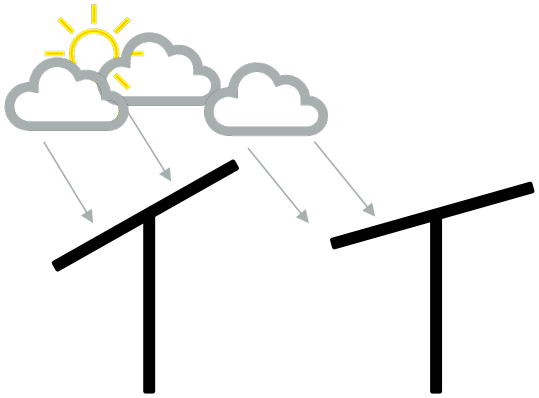
Methodology

Bayesian Optimization

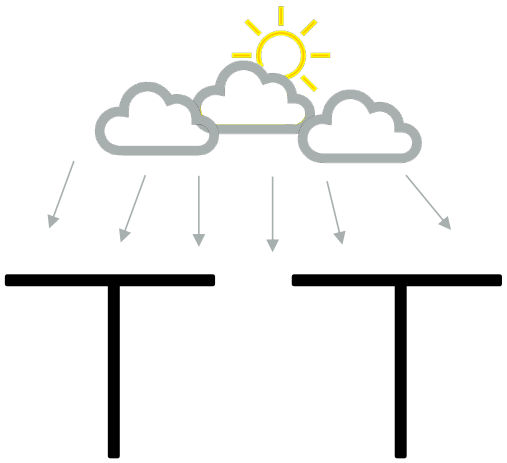
Objective function: $min(-Irr_{front} - BF \cdot Irr_{rear})$

Space between backtracking tilt and horizontal position

Study performed only in terms of irradiation and light distribution, not photovoltaic yield



Backtracking Tilt



Stow Position

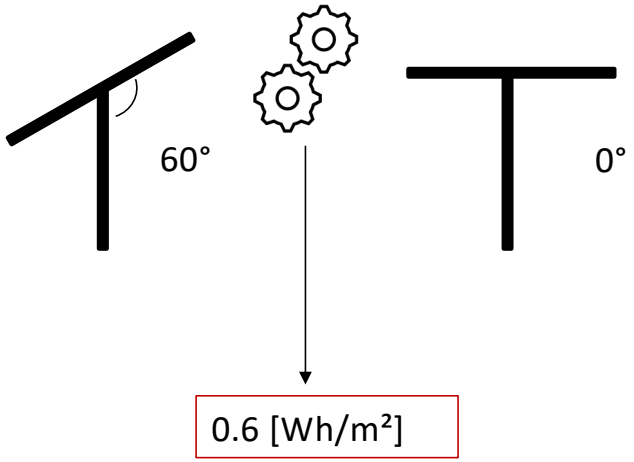
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Methodology

Motor Consumption

- The *Diffuse Optimization:*
  - Run every 15 min
  - System rotatation to new optimized angle
- Maximum rotation occurs from the maximum tilt angle of the system to the stow position
- For a typical 1500 [V] system and a motor with an average power of 72 [W] :
  - **0.6 [Wh/m²]** increase of the POA irradiation to compensate a 60° rotation

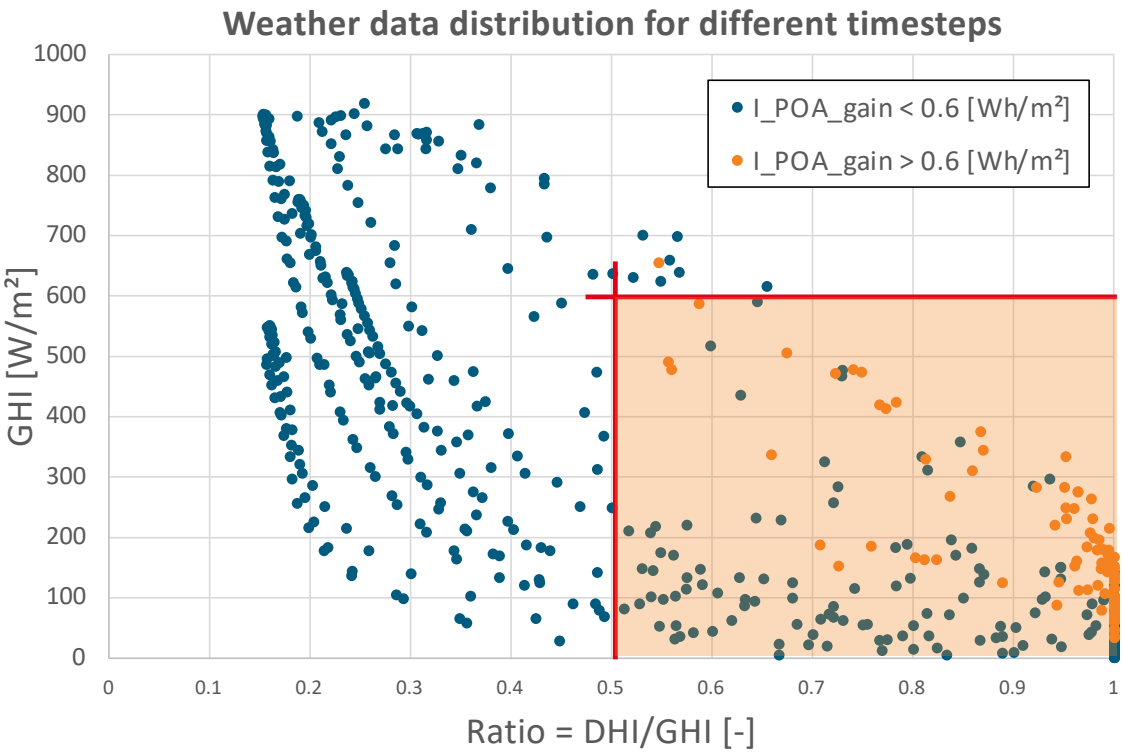


Worst case analysis motor consumption

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Methodology

Timestep Selection



- Slected GHI and Ratio thresholds
  - Exclude timesteps POA-Irradiation gains lower than estimated motor consumption

GHI < 600 [W/m²]

Ratio > 0.5

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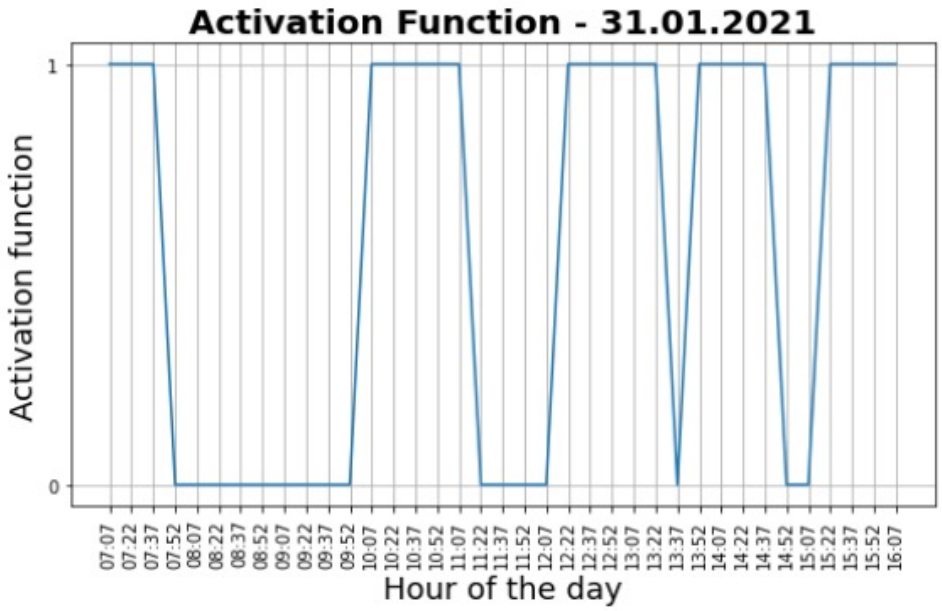
Bruno, M. (2023). *Tracking Optimization in Agrivoltaic Systems : A Comparative Study for Apple Orchards* (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-333634

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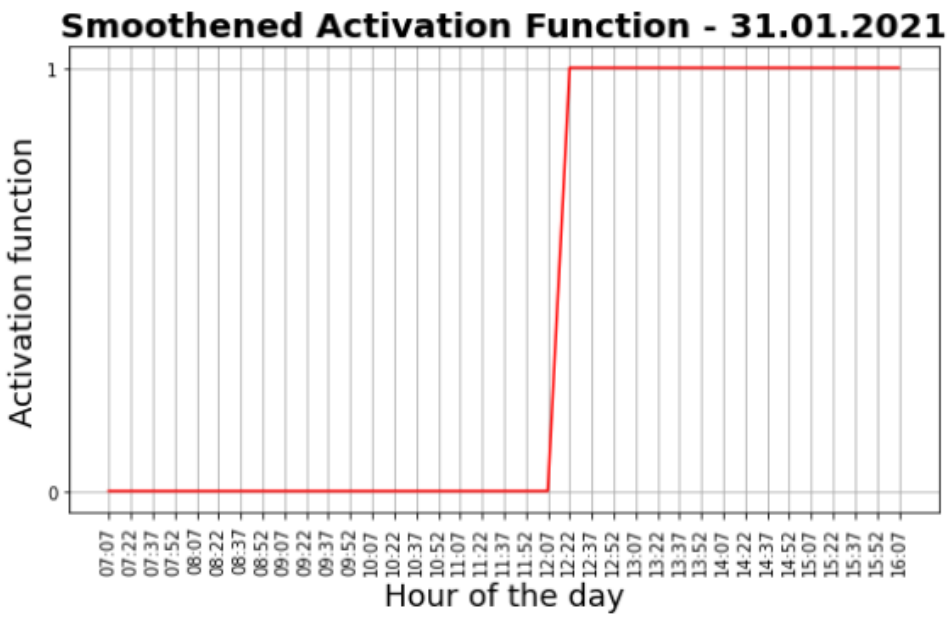
Methodology

Timestep Selection

- Defined an Activation function (AF) based on the tresholds



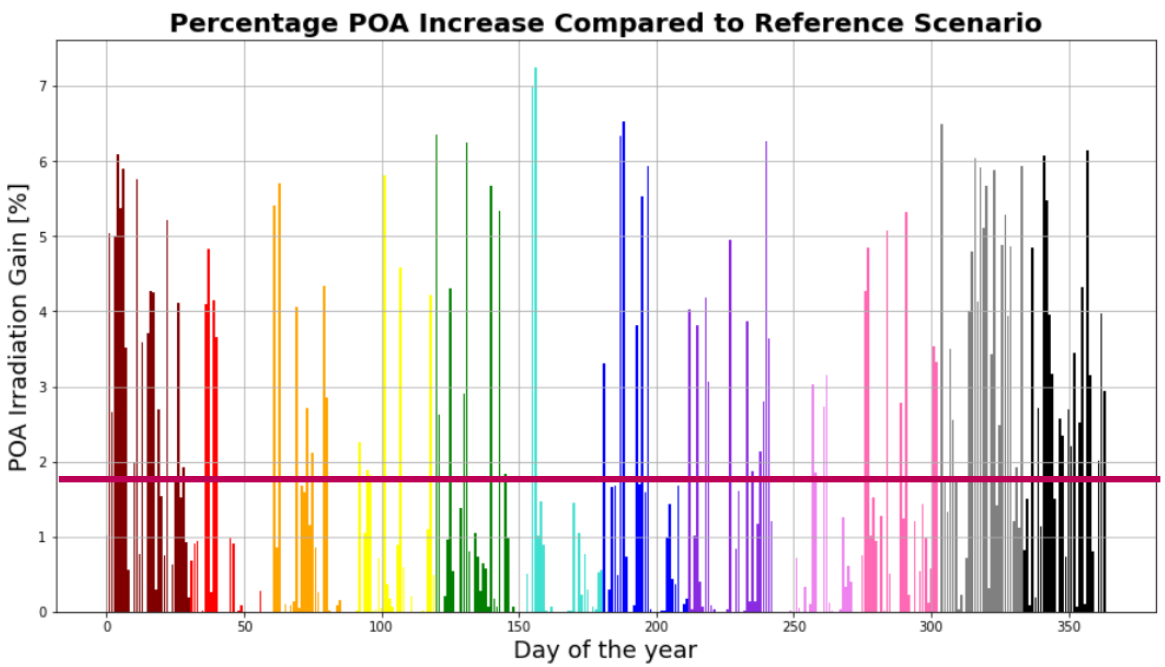
- Smoothened the AF to limit components fatigue and mechanical stress



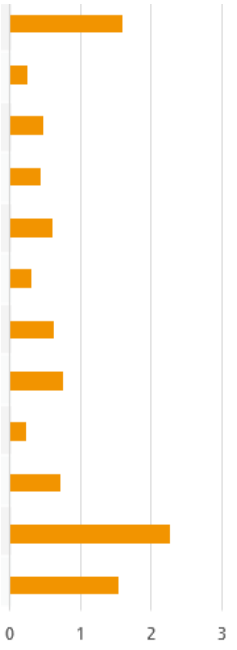
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Results

Daily Gains



Month in year 2021	POA Irradiation Gain [%]
Jan	1.60
Feb	0.25
Mar	0.48
Apr	0.43
May	0.61
Jun	0.31
Jul	0.63
Aug	0.75
Sep	0.23
Oct	0.72
Nov	2.26
Dec	1.54



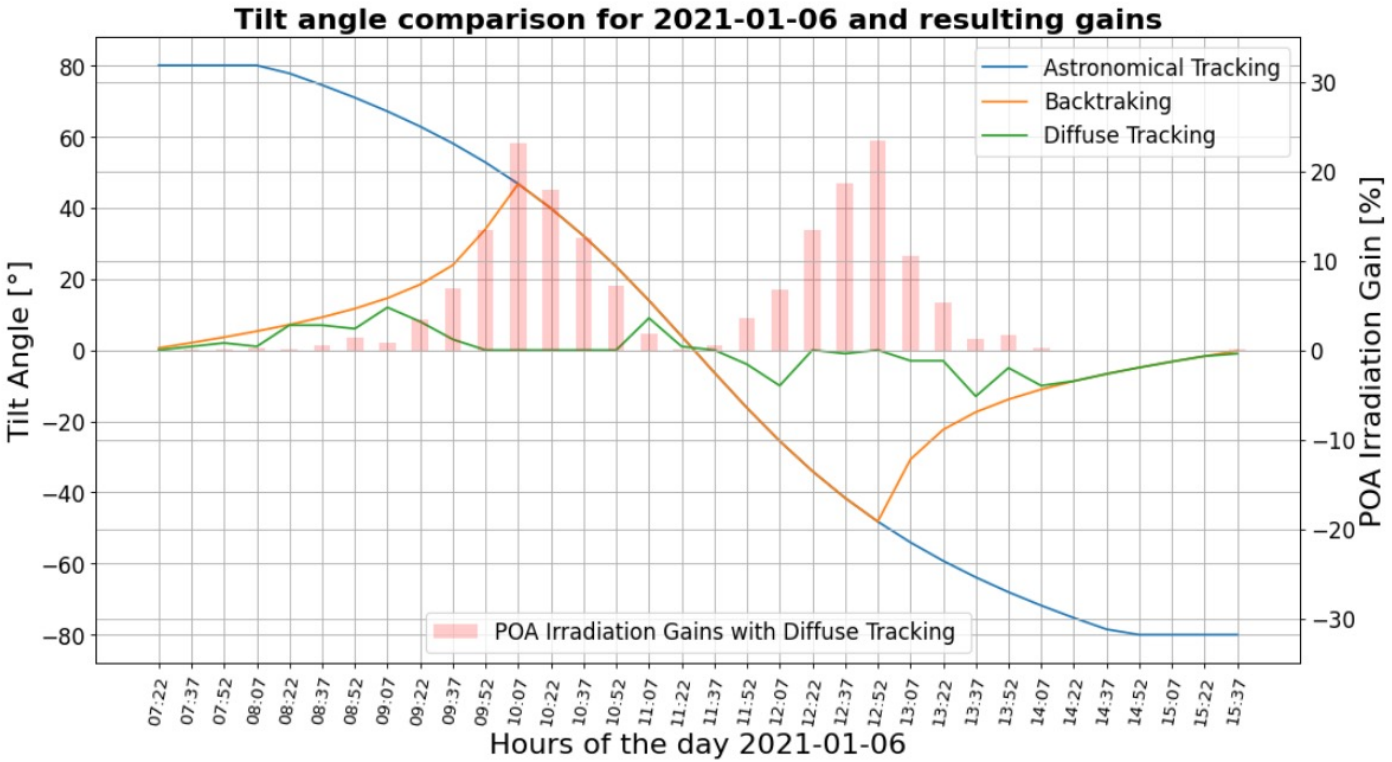
The average daily POA irradiation gain is 1.7 %

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Results

Optimized Tilt Profile



Overall in a year:

- Instantaneous irradiation gains up to **46%**
- Yearly POA irradiation capture **0.6% ↑**

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Conclusions

Advantages & Limitations



- Demonstrated the potential of diffuse tracking strategy
- Daily POA irradiation gains up to 7% even in summer months
- Defined a methodology applicable to different systems and locations



- Computationally heavy
- Results only for selected timestep (58% of the year)
- Selection based on estimation of motor consumption

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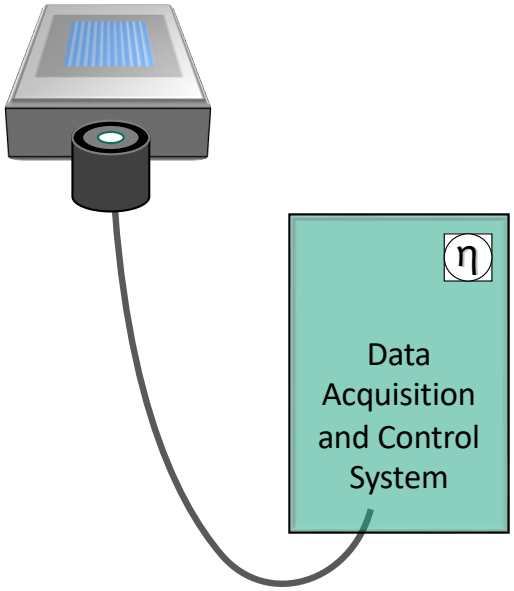
Conclusion

Future Developments



- Deep learning meta-model integration
- Weather forecast integration
- Field testing and validation

Rotating POA Irradiation Sensor



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Thank you for your attention

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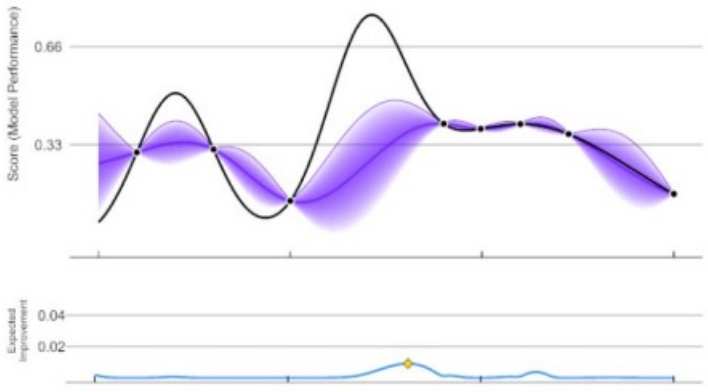


Figure 1: Bayesian Optimization [1]

- Efficient black-box optimization
- A ***Surrogate Model*** is created to mimic f(x) behaviour in a less costly manner
- Based on *Gaussian Process Regression (GPR)*
- Maximization of the *Acquisition Function*
- Compromise between exploration and exploitation
- *skopt.gp_minimize* from Scikit-Optimize 0.8.1 python library

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