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SOLELFORSKNINGS
CENTRUM SVERIGE

Integrated modelling of agrivoltaic systems

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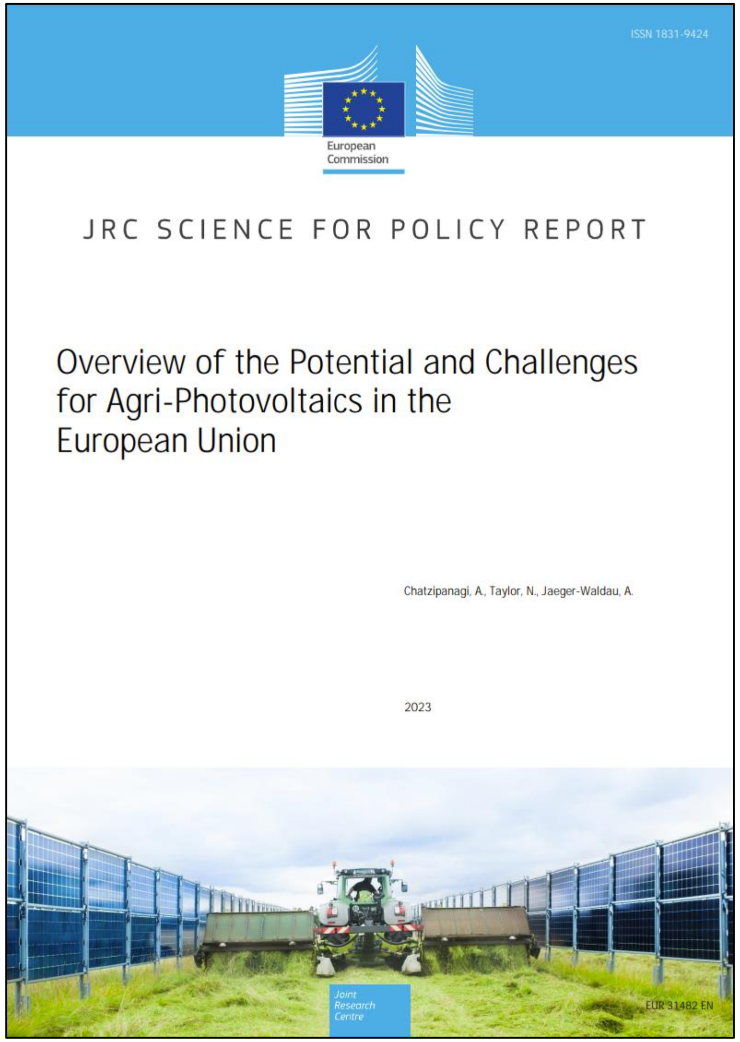
AGRIVOLTAIC SYSTEMS DEFINITION

*“Solar PV system located on the same area as the agricultural production, and it impacts the agricultural production by providing, without any intermediary, one of the **services** listed below, **without inducing any significant degradation of the agricultural production (both qualitatively and quantitatively), or any farm income loss:***

- *Climate change adaptation*
- *Hazard protection*
- *Animal welfare*
- *Specific agronomic service (e.g., lower temperature stress)”*



https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/4992-caracteriser-les-projets-photovoltaiques-sur-terrains-agricoles-et-l-agrivoltaisme.html
https://publications.jrc.ec.europa.eu/repository/handle/JRC132879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SIMILAR CONCEPT TO AGROFORESTRY OR INTERCROPPING

Climate-ADAPT. (2022). Available at: https://climate-adapt.eea.europa.eu/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier
https://wikifarmer.com/how-to-use-cover-crops-in-vineyards-and-their-advantages/

MICROCLIMATE AND SYNERGIES IN AGRIVOLTAIC SYSTEMS

Photo credit: Julienbrustudio, 2023

- Shadings from PV systems affects
  - the quantity and quality of light received to the ground
  - energy balance on the ground and thus soil evapotranspiration and soil moisture and temperature
- Microclimate affects both electricity and crop production
- Crop evapotranspiration can reduce solar cells operating temperatures
- Albedo (light reflected by the crops) affects PV system electricity → crop selection become important for the energy conversion

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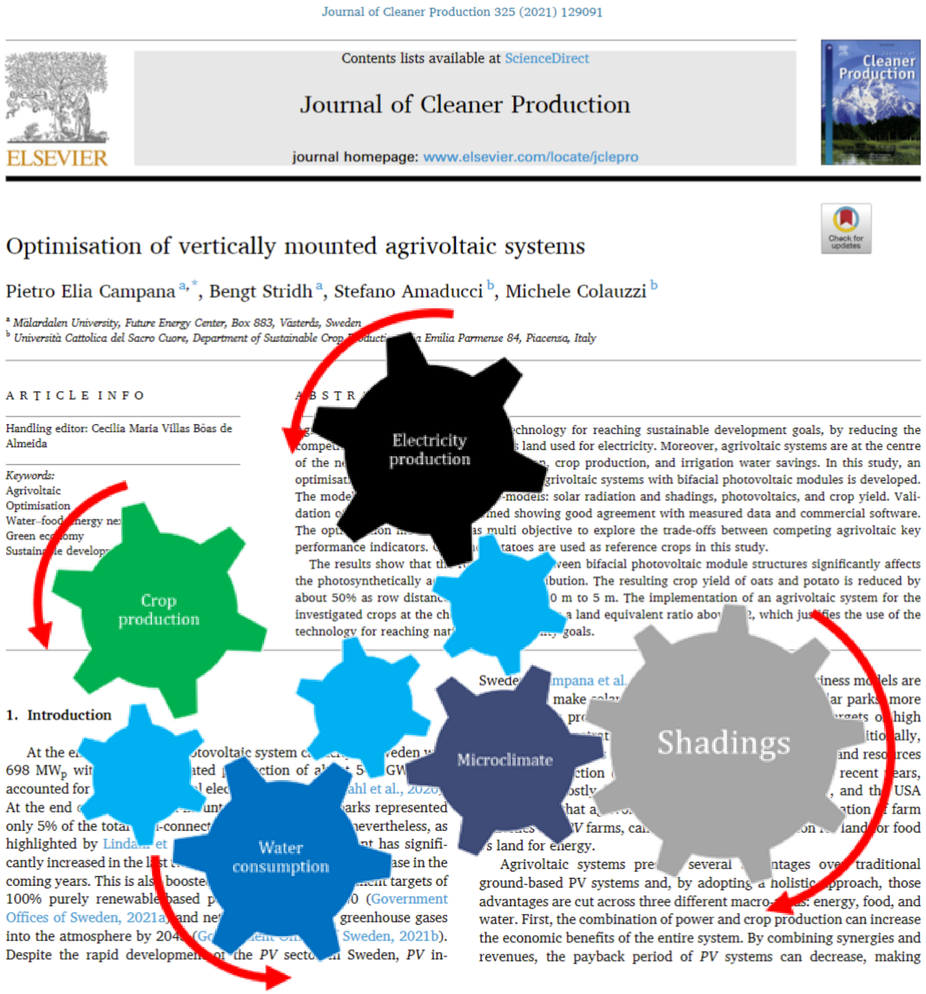
AgriOptiCE® MODEL

Optimization is a complex task due to conflicting sectors targets!!!



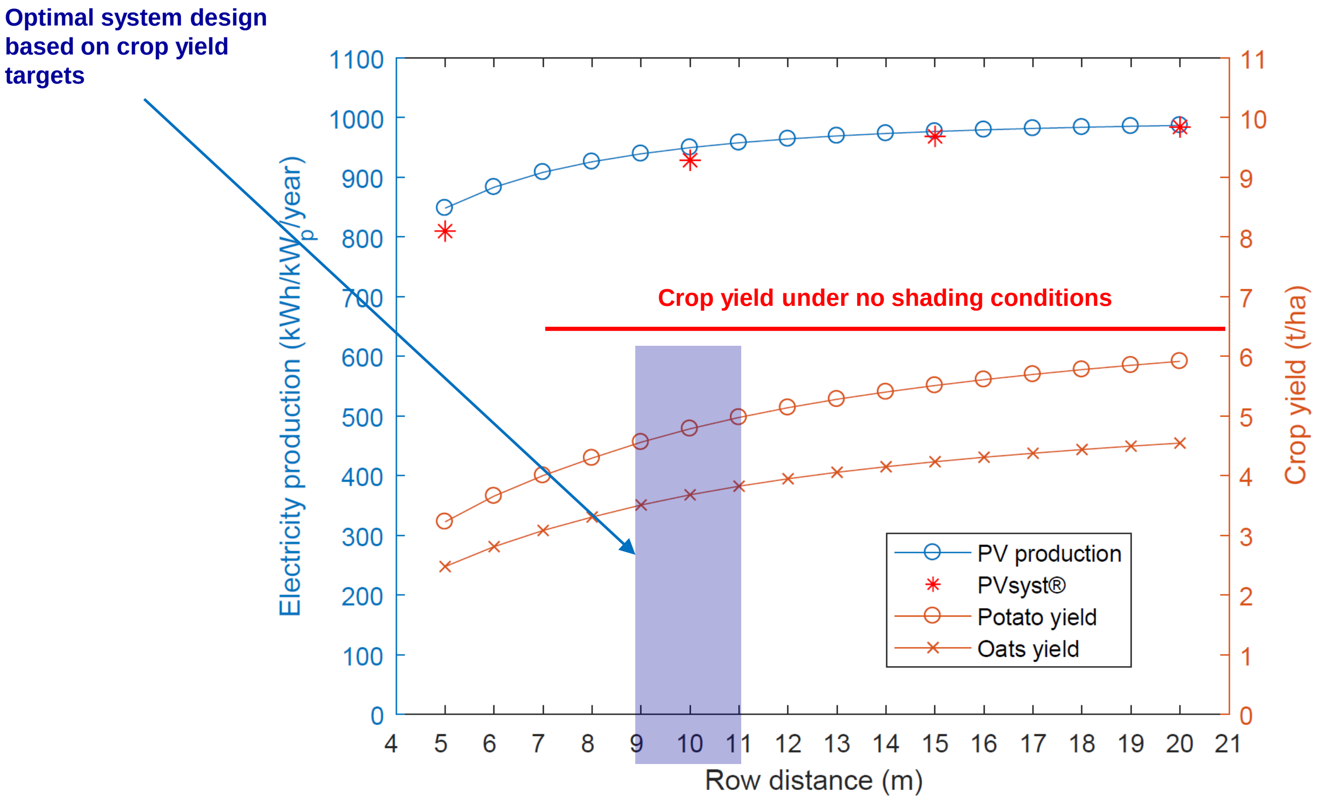
Campana, P. E., Stridh, B., Amaducci, S., & Colauzzi, M. (2021). Optimisation of vertically mounted agrivoltaic systems. Journal of Cleaner Production, 325-129091

WHY A SIMULATION AND OPTIMISATION MODEL?

To meet policy targets concerning crop production under agrivoltaic systems!!!

- **Japan ≥ 80% (NEDO)**
- **Germany ≥ 66% (DIN SPEC 91434)**
- **France ≥ 90% (AFNOR Label)**
- **Italy ≥ 70% (UNI/PdR 148)**

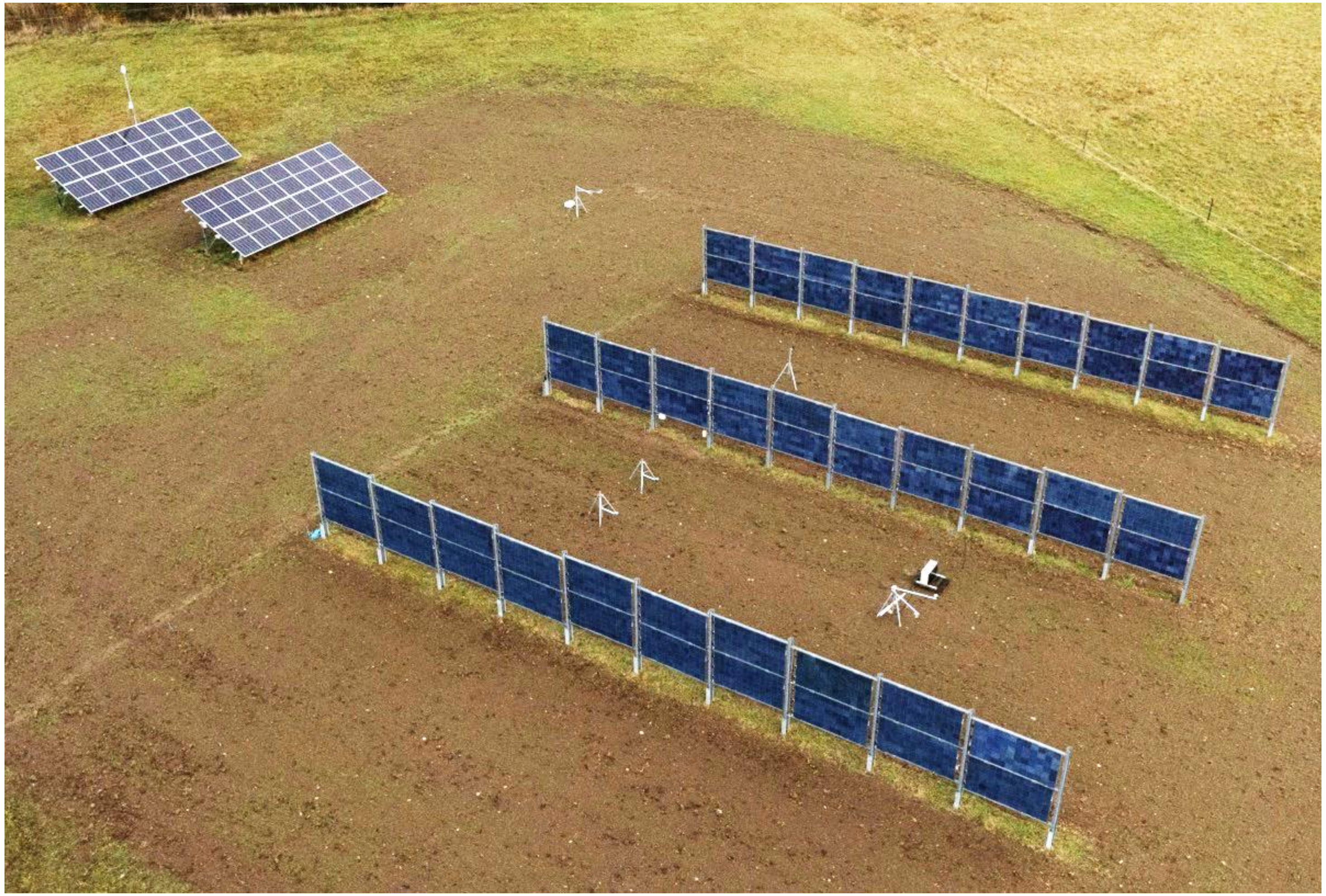
No policy targets exist yet in Sweden!!!



Integrated modelling can estimate the crop yield reduction, and other performances in agrivoltaic systems at a design stage

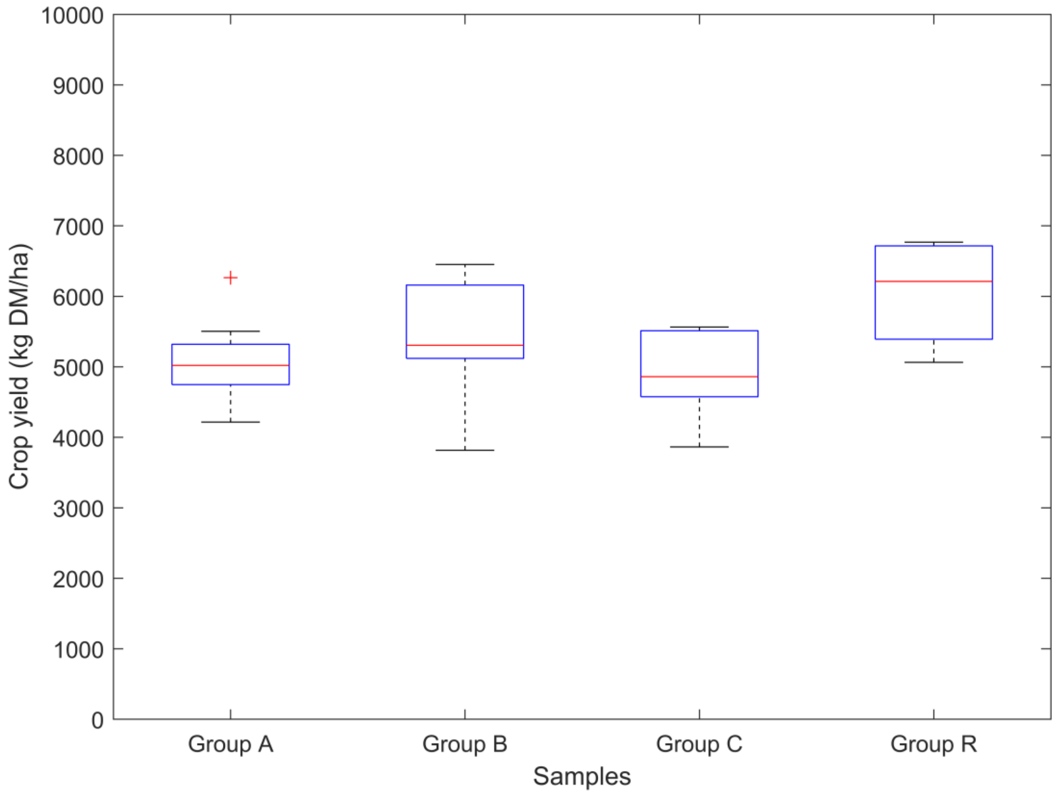
http://www.i-sis.org.uk/Japanese_Farmers_Producing_Crops_and_Solar_Energy.php
Trommsdorff, M., Kang, J., Reise, C., Schindele, S., Bopp, G., Ehmann, A., ... & Obergfell, T. (2021). Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. Renewable and Sustainable Energy Reviews, 140, 110694.
Fraunhofer Institute for Solar Energy Systems ISE (2022). Agrivoltaics: Opportunities for Agriculture and the Energy Transition
Campana, P. E., Stridh, B., Amaducci, S., & Colauzzi, M. (2021). Optimisation of vertically mounted agrivoltaic systems. Journal of Cleaner Production, 325-129091
https://store.uni.com/uni-pdr-148-2023

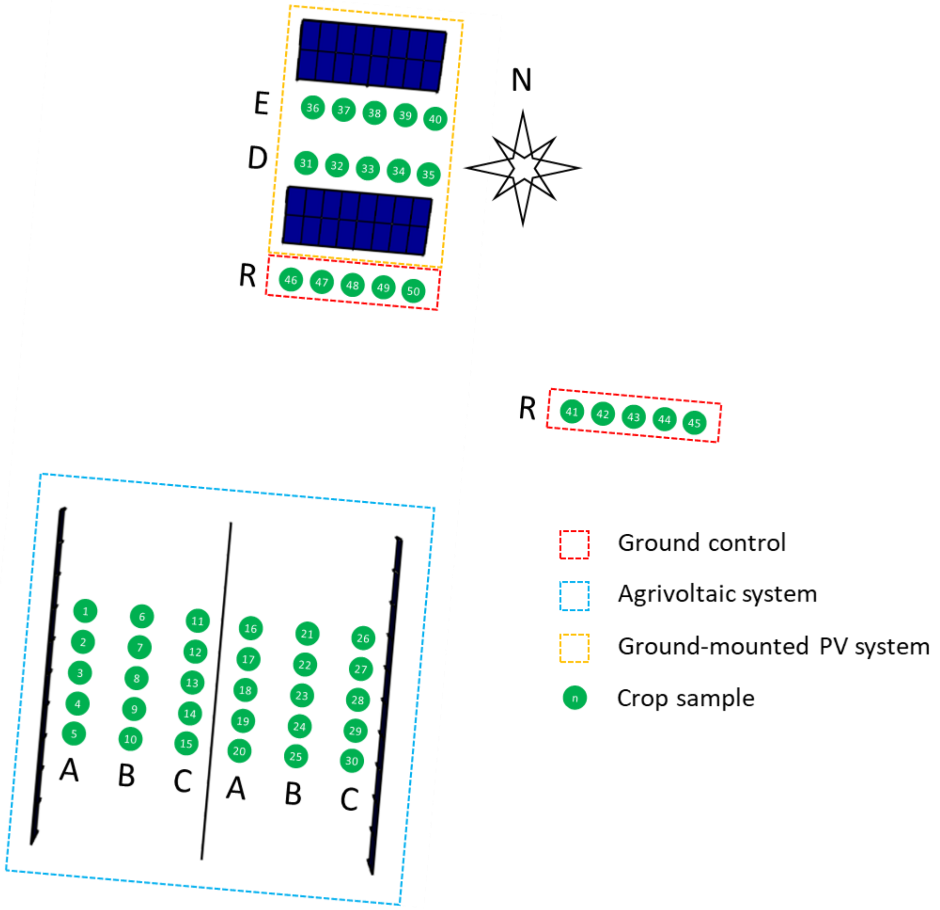
FIRST AGRIVOLTAIC SYSTEM IN SWEDEN



Mälardalens universitet · SLU Sveriges Lantbruksuniversitet · SOLKOMPANIET · Kärrbo prästgård · Energimyndigheten

CROP YIELD RESPONSE IN SHADING CONDITIONS

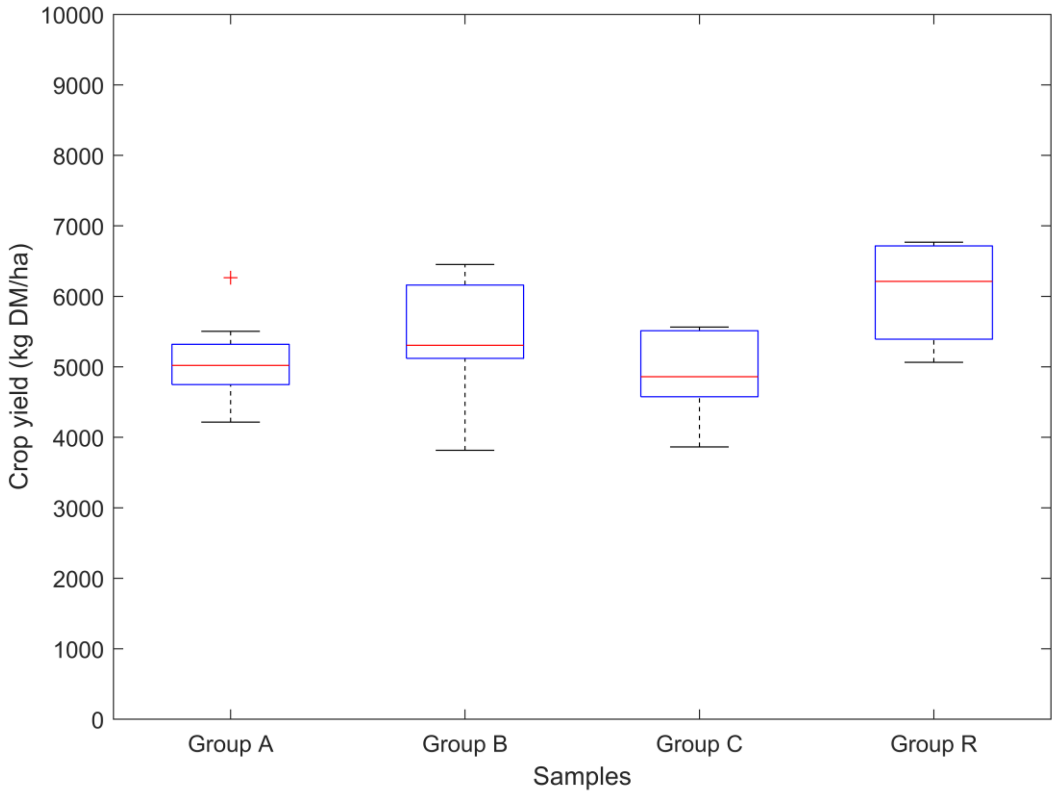


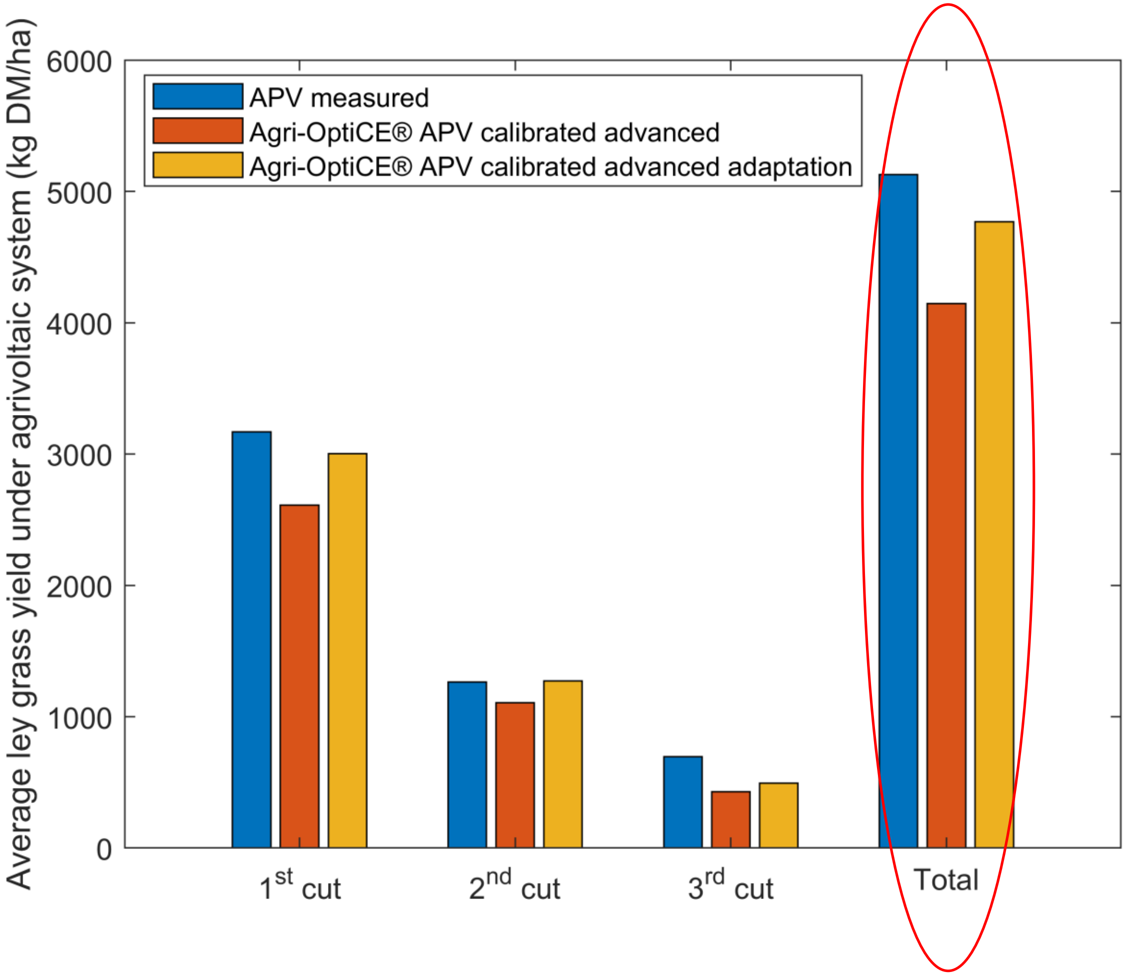


No statistical difference between ley grass under the agrivoltaic system versus open field conditions. The yield refers to the samples, a 10% reduction should be applied due to the land loss for the supporting structures

Campana, P. E., Stridh, B., Hörndahl, T., Svensson, S. E., Zainali, S., Lu, S. M., ... & Colauzzi, M. (2023). Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes. https://eartharxiv.org/repository/view/5747/

CROP YIELD RESPONSE IN SHADING CONDITIONS





Validation of the integrated modelling platform

Campana, P. E., Stridh, B., Hörndahl, T., Svensson, S. E., Zainali, S., Lu, S. M., ... & Colauzzi, M. (2023). Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes.
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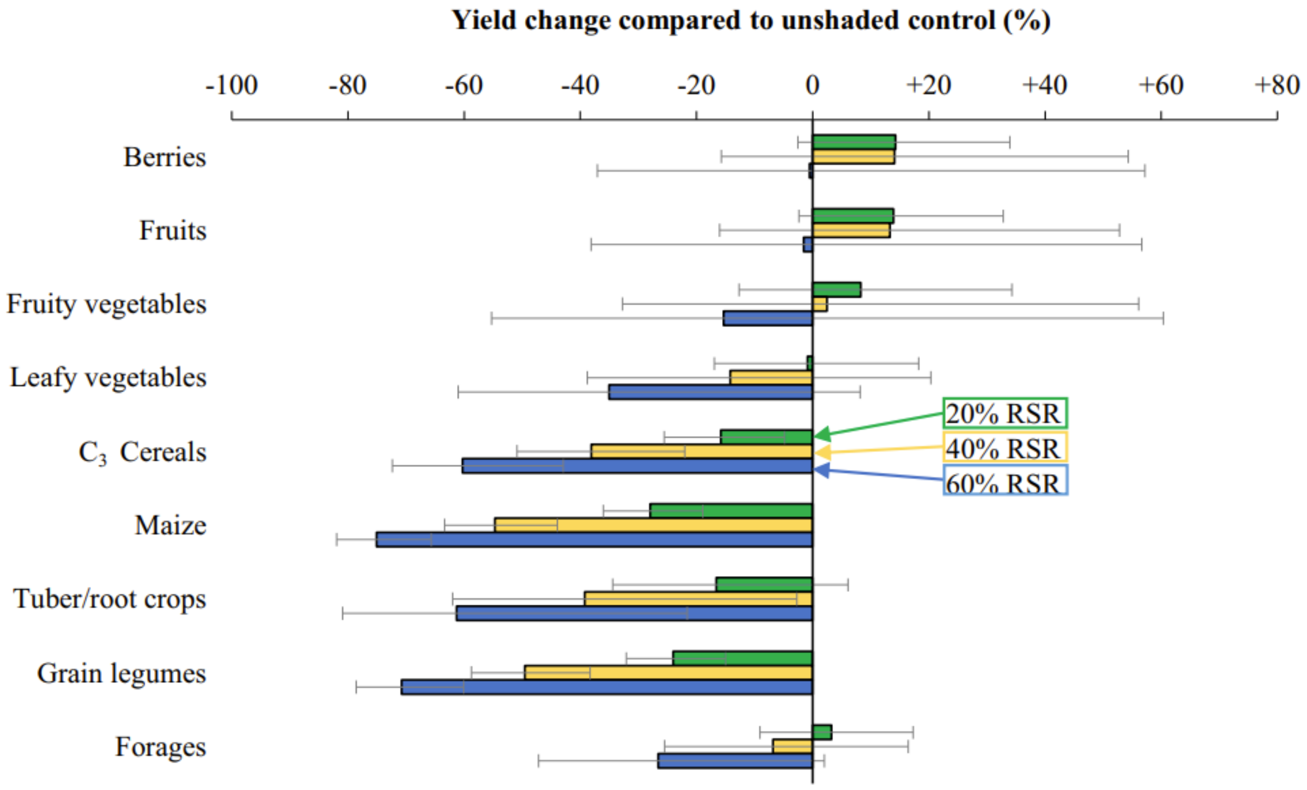
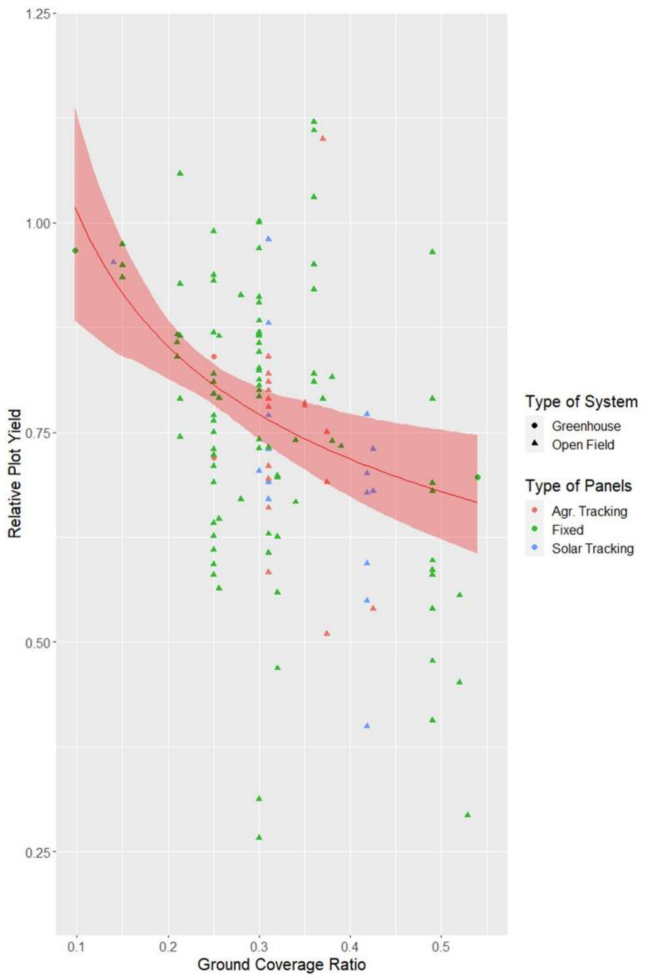
BEST CROPS FOR AGRIVOLTAIC SYSTEMS?



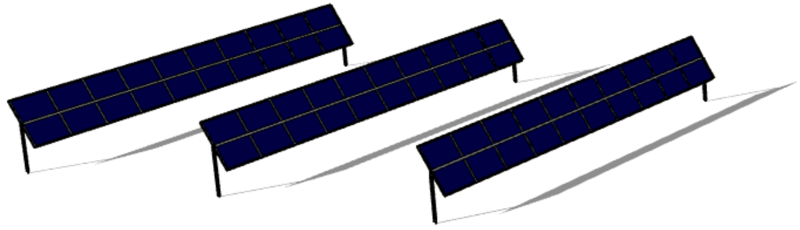
Crop yield reduction versus irradiation reduction

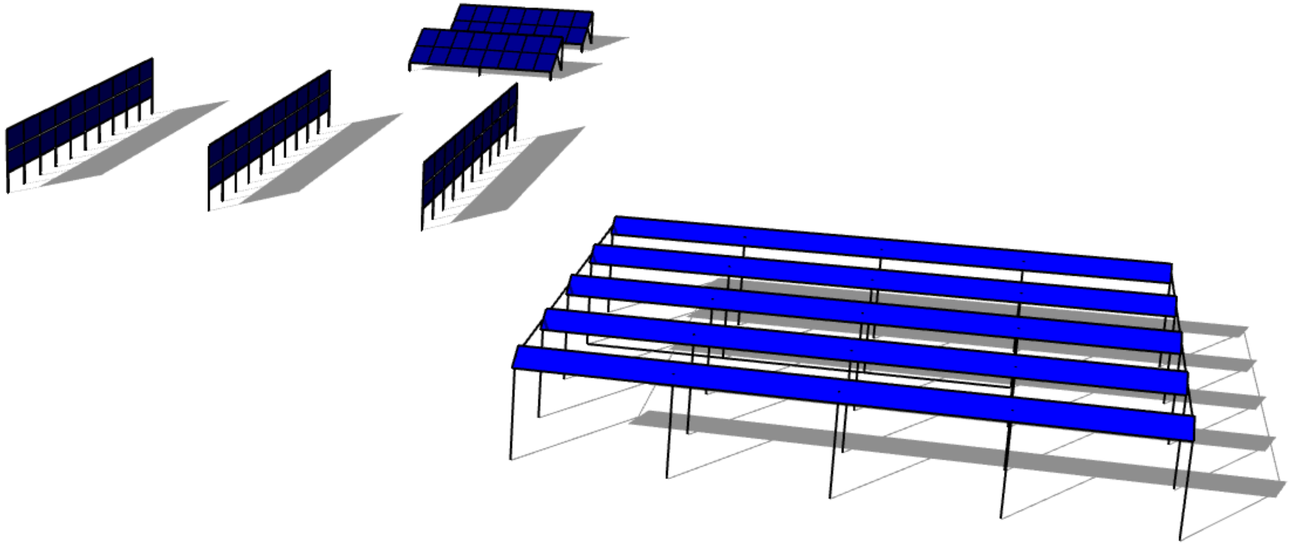


Crop yield reduction versus ground coverage ratio

Laub, M., Pataczek, L., Feuerbacher, A., Zikeli, S., & Högy, P. (2022). Contrasting yield responses at varying levels of shade suggest different suitability of crops for dual land-use systems: a meta-analysis. *Agronomy for Sustainable Development*, *42*(3), 51.
Dupraz, C. (2023). Assessment of the ground coverage ratio of agrivoltaic systems as a proxy for potential crop productivity. *Agroforestry Systems*, 1-18.

BETTER APPROACHES





Plant	Recommended		
	PPFD μmol/m²/s	Light ON Hours	DLI mol/m²/Day
Coriander,Chives,Cilantro	300~463	12~14	15~20
Honey Dew	386~600	14~18	25~30
Kale	325~444	10~12	14~16
Lavender, Strawberry	298~579	12~14	15~25
Leafy Greens	238+	12~14	12+
Lemon Balm	200~463	12~14	10~20
Lavender	298~579	12~14	15~25
Mint	230~556	8~12	10~16
Oregano	298~463	12~14	15~20
Parsley	231~556	8~12	10~16
Pea	250~382	8~10	9~11
Pumpkin	386~695	14~18	25~35
Rosemary	232~556	8~12	10~16
Spearmint	200~695	8~14	10~20
Spinach	298~394	12~14	15~17
Swiss Chard	278~370	12~14	14~16
Thyme	198~463	12~14	10~20
Watercress	243~579	12~16	14~25
Watermelon, Zucchini	386~595	14~18	25~30

Recommended illumination requirements

Our approach:

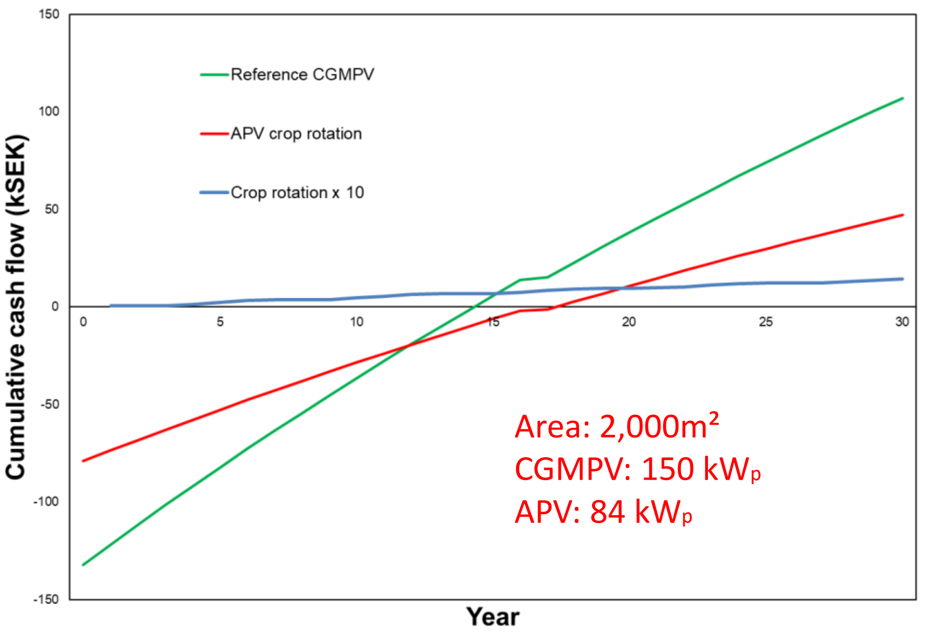
- Develop mechanistic models to simulate performances
- Create a MATRIX of agrivoltaic systems layout and test different crops simultaneously towards a more robust database

https://koraylights.com/how-much-light-do-different-plants-need-for-photosynthesis-dli-ppfd-ppf-par-lcp-lsp/
https://www.mdu.se/en/malardalen-university/research/research-projects/matrix---evaluation-of-the-first-agrivoltaic-systems-facility-in-sweden

ENERGY AND ECONOMIC PERFORMANCES

4.86 kWh/m²/year

30 kWh/m²/year
+ food!



Lower profitability of agrivoltaic (APV) systems compared to conventional ground mounted PV (CGMPV) systems

The land profitability with APV systems can be 30 times higher as compared to only farming

Policies required to maintain farming!!!

Campana, et al. (2023). Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes. https://eartharxiv.org/repository/view/5747/
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- Agrivoltaic systems combines solar photovoltaic and agricultural activities on the same land with synergistic effects
- The shading produced by the PV modules on ground create a microclimate that affects crop production
- Integrated modelling fundamental for meeting current and future policy targets
- No statistical difference between agrivoltaic and open field conditions for ley grass
- Agrivoltaic system are a key technology to support farmers incomes
- Legal aspects are fundamental to set the scene

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Thank you for the attention! Questions?

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