SIMULTANEOUS PHOTOVOLTAIC PRODUCTION AND CROP GROWTH: FUNDAMENTALS AND APPLICATIONS OF AGRIVOLTAICS

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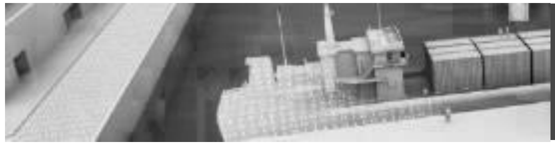
Agenda

- About DLR
- Introduction and fundamentals of Agrivoltaics
  - Background and motivation
  - Definition and history
  - Advantages of Agrivoltaic Systems
  - Contribution to the SDGs
  - Potential of Agrivoltaics
  - Classification of Agrivoltaic Systems
  - Research lines and current challenges of Agrivoltaics
- Agrivoltaics research in Almería, Spain

0. ABOUT DLR

German Aerospace Center
Research Centre + Space Agency + Project Management Agency

AERONAUTICS	SPACE	ENERGY	TRAFFIC
			



SECURITY
Civil & Defence Security Research

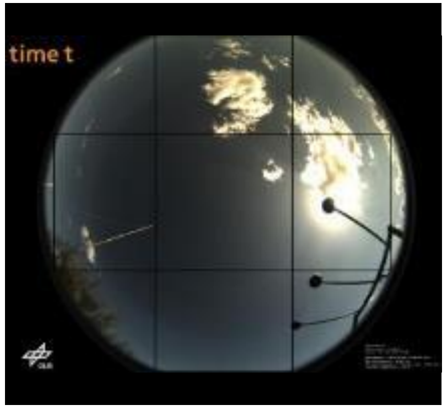
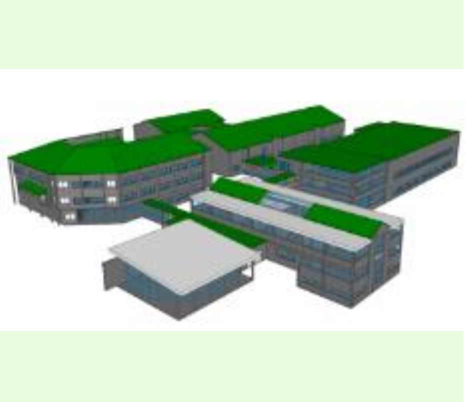
DIGITALISATION
Quantum Technologies & Systems Modelling

DLR in numbers

- 55 institutes in 30 sites.
- > 11,000 employees, including > 1,300 PhD students.
- > 40 spin-offs created in the last 10 years.
- Cooperation with > 500 partners organizations from 110 countries.

Institute of Solar Research

Research focus

Solar heat production	Autonomous operation	Defossilization of the chemical industry	Condition monitoring	Districts and Buildings
				

PLATAFORMA SOLAR DE ALMERÍA

OWNER AND OPERATOR: CIEMAT

Qualification Department – Institute of Solar Research (Almería – Spain)

5 research teams in the field of CSP and PV energy systems

Optical Condition Monitoring

Optical qualification of solar fields of tower and parabolic trough systems

Thermal Condition Monitoring

Thermal qualification of components and systems in industrial and commercial plants

Materials

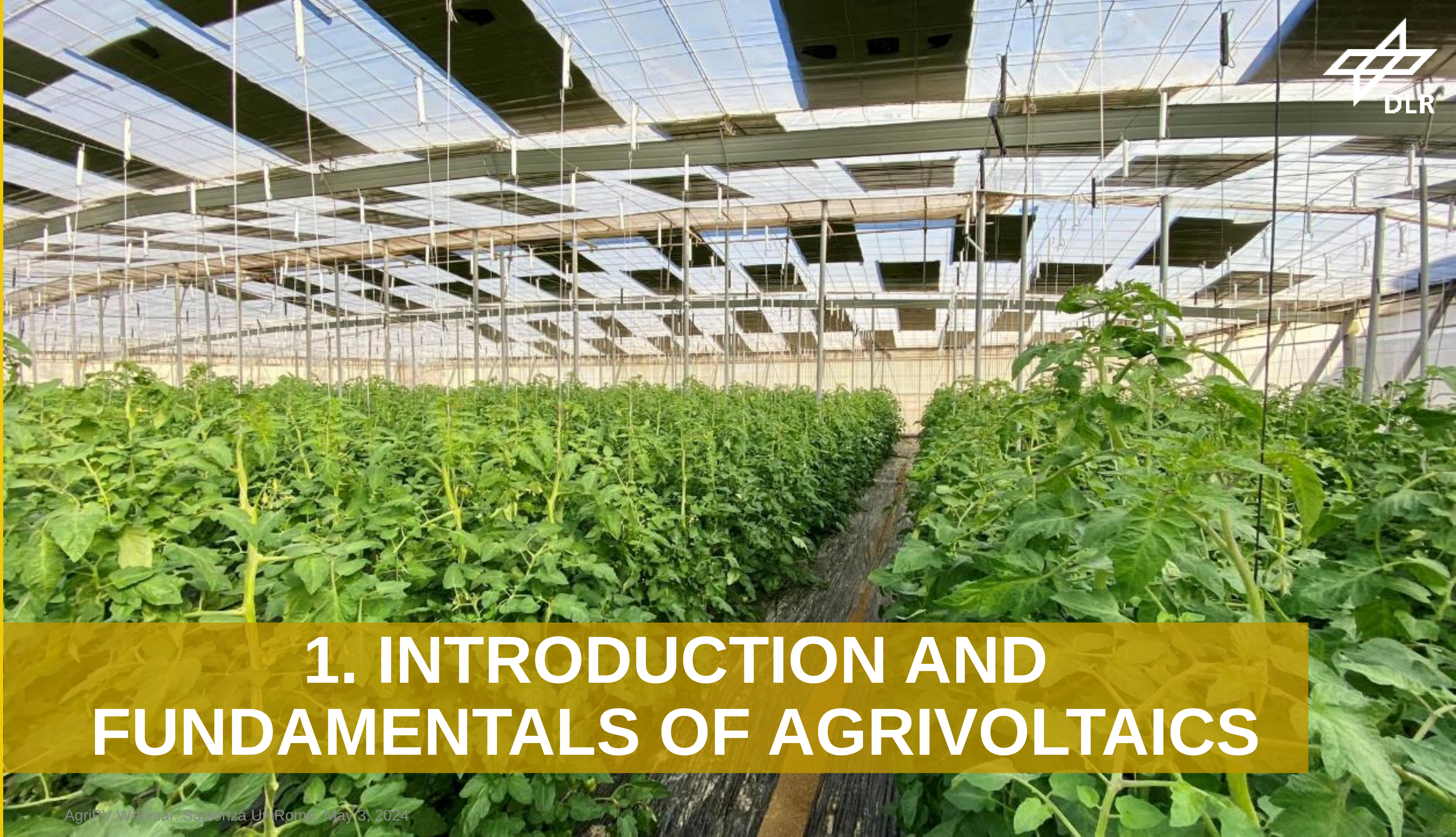
- Development of coatings.
- Testing of materials under different climates and conditions.

Meteorology

- Measurements and Modelling of meteorological conditions and all parameters relevant to the development and operation of facilities

Agrivoltaics

- Modelling and measurement of the influence of meteorological parameters for the investigation of options for dual use of land



1. INTRODUCTION AND FUNDAMENTALS OF AGRIVOLTAICS

Introduction to Agrivoltaics

Background and Motivation

Sustainable Agriculture

- *x2 since early 1960s*
- *9.8 billion people by 2050*

Rapid increase of global population

Food security

Global and Societal Challenges

Exhaustion of fossil fuel resources

Water scarcity

Renewable Energy Sources

AGRIVOLTAICS

Motivation

- More efficient use of resources
- Lower carbon footprint in agriculture
- Adaptation of agriculture to climate change

Growth in the agriculture sector is said to be 3 times more effective in reducing poverty than growth in other sectors.

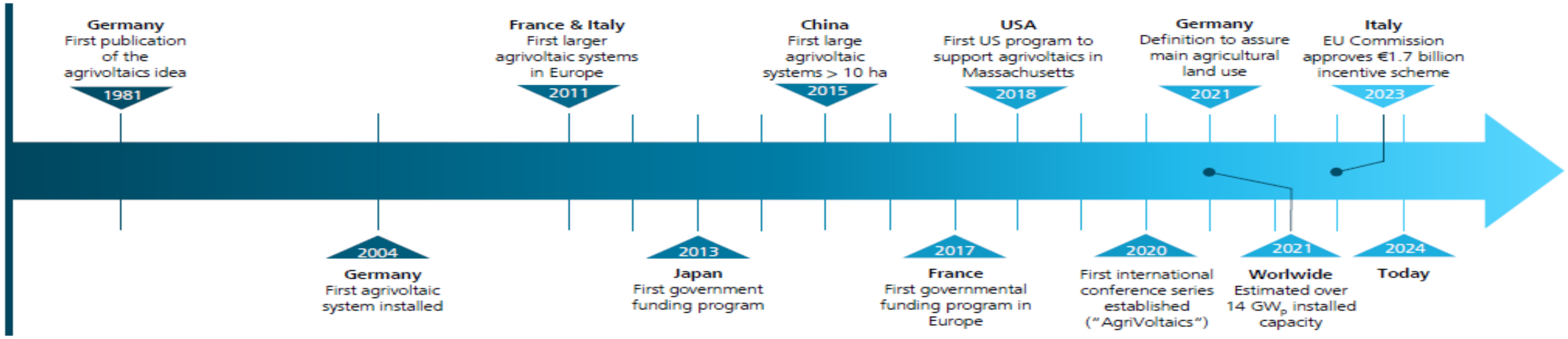
Introduction to Agrivoltaics

Definition and history

The term **Agrivoltaics** represents the dual use of land for both crop production and solar energy generation, being agriculture the main activity.

The concept of agrivoltaics emerged in the early 1980s, when Goetzberger and Zastrow [1] mentioned the possibility of combining plant cultivation and solar energy production to alleviate the competition for the use of arable land between agriculture and energy generation.

In 2011, the term ***"Agrivoltaics"*** first appeared in research by Dupraz et al. [2]. However, the concept is also known as 'agri-photovoltaics' (APV), 'agrophotovoltaics', 'solar sharing', 'agrisolar', or 'agri-PV':



Timeline for the development of agrivoltaics. Source: Fraunhofer ISE

[1] Goetzberger, A.P., & Zastrow, A. (1982). On the coexistence of solar-energy conversion and plant cultivation. *https://doi.org/10.1080/01425918208909875*
[2] Dupraz, C. et al. (2011). "Combining Solar Photovoltaic Panels and Food Crops for Optimising Land Use: Towards New Agrivoltaic Schemes. *https://doi.org/10.1016/j.renene.2011.03.005*

Introduction to Agrivoltaics

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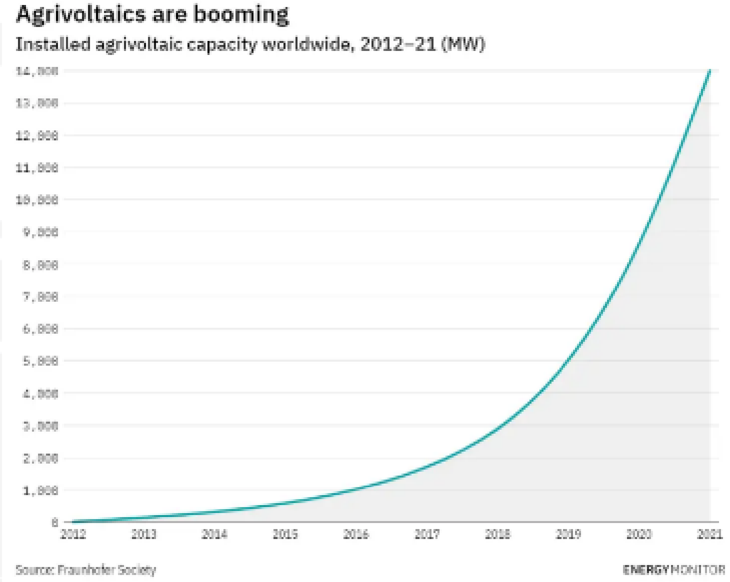
Since 2011, the deployment of agrivoltaic systems has experienced an **exponential growth**.

Research agrivoltaic facility in Germany.
Source: Fraunhofer ISE.



Commercial agrivoltaic facility in France.
Source: Sun'Agri.

[1] Goetzberger, A.P., & Zastrow, A. (1982). On the coexistence of solar-energy conversion and plant cultivation. https://doi.org/10.1080/01425918208909875
[2] Dupraz, C. et al. (2011). "Combining Solar Photovoltaic Panels and Food Crops for Optimising Land Use: Towards New Agrivoltaic Schemes. https://doi.org/10.1016/j.renene.2011.03.005

Introduction to Agrivoltaics

Advantages of Agrivoltaic Systems

1. Reduce the competition for the use of land

Source: Fraunhofer ISE.

2. Protect the crops against extreme weather events

Vineyard damaged by hail.
Source: Adobe stock.

3. Reduce evapotranspiration → Less water for irrigation is required

Source: Adobe stock.

4. Reduce the carbon footprint of agriculture

Source: Adobe stock.

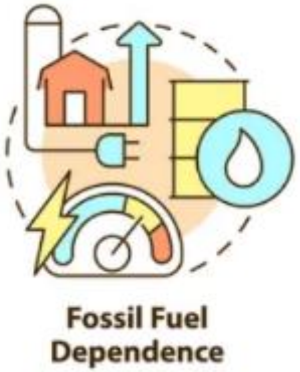
Introduction to Agrivoltaics

Advantages of Agrivoltaic Systems

5. Promote the preservation of ecosystems and biodiversity

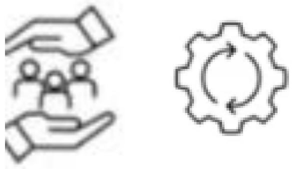
Sheep grazing within a PV system.
Source: Adobe stock.

6. Reduce the dependence on fossil fuels

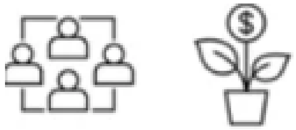


Source: Adobe stock.

7. Foster the welfare of rural communities

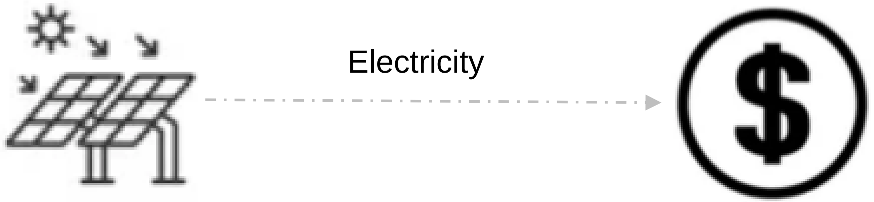


Job creation



Higher incomes

8. New source of revenues for farmers: Energy production



Introduction to Agrivoltaics

Contribution to the Sustainable Development Goals (SDGs)

- **SDG No. 2 – Zero Hunger**

✓ Achieve food security
✓ Sustainable agriculture

- **SDG No. 6 – Clean Water and Sanitation**

✓ Sustainable management of water for irrigation

- **SDG No. 7 – Affordable and Clean Energy**

✓ Access to renewable PV energy

- **SDG No. 13. Climate Action**

✓ Agrivoltaic systems can help to combat climate change challenges

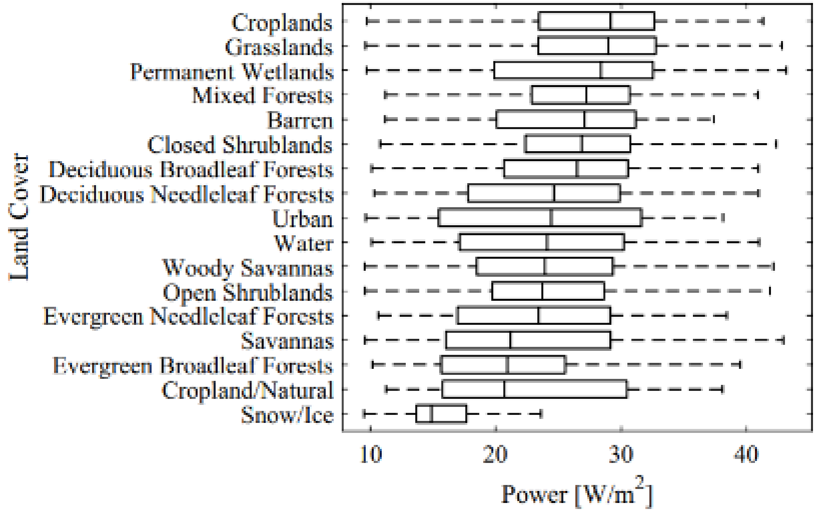
Introduction to Agrivoltaics

Potential of Agrivoltaic Systems

- Nowadays, it is difficult to estimate the global PV capacity installed in Agrivoltaic installations.
  - **Lack of databases and of a unified definition of Agrivoltaics**.
  - **In 2021**, Fraunhofer ISE estimated a total **agrivoltaics capacity > 14 GWp**.

- Along with the deployment of agrivoltaic systems worldwide, several studies have been conducted in recent years to highlight the massive potential they present:
  - In 2019, Adeh et al. [1] indicated that:
    - **Croplands have the greatest median solar potential** → Power density of ~28 Wp/m².
    - The **global energy demand would be offset by PV production if ~1% of croplands were converted to agrivoltaic** installations.

[1] Adeh, E. et al. "Solar PV Power Potential Is Greatest over Croplands.“. *Scientific Reports 9, no. 1 (2019): 11442.* https://doi.org/10.1038/s41598-019-47803-3



Solar power potential ranked by land cover classification

Introduction to Agrivoltaics

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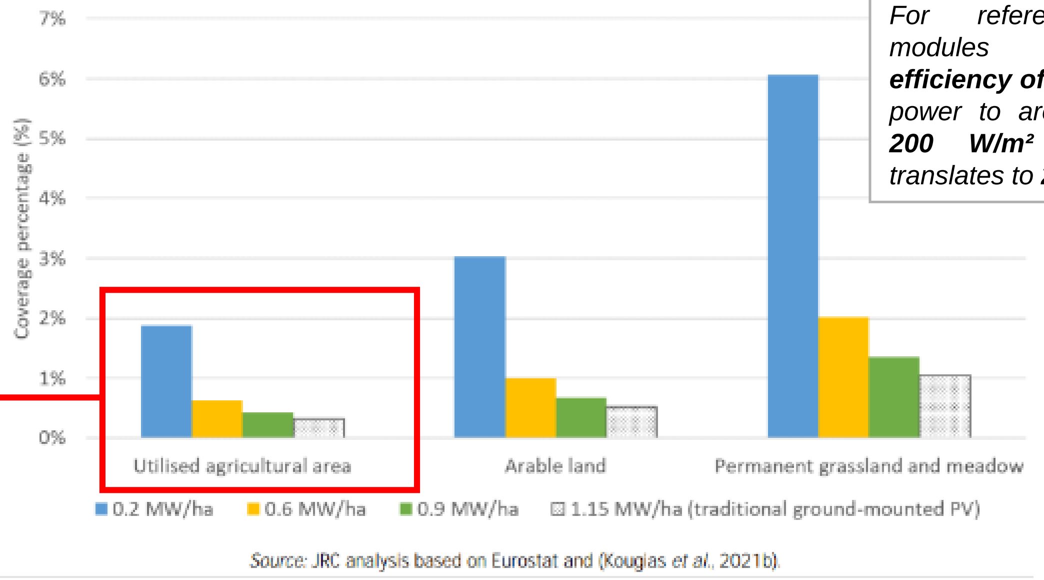
❖ Along with the deployment of agrivoltaic systems worldwide, several studies have been conducted in recent years to highlight the massive potential they present:
  - In 2023, a report from the European Commission [1] highlighted the huge potential of Agrivoltaics in the EU:
    - **A coverage of just 1% of Utilised Agricultural Area (UAA) with Agri-PV systems would translate into 944 GW of new capacity additions** (assuming a PV power density of 0.6 MW/ha).

*For reference, PV modules with an **efficiency of 20 %** have power to area ratio of **200 W/m²**, which translates to **2 MW/ha**.*

Required % of different land coverage for Agri-PV systems for the accomplishment of the PV capacity EU's 2030 targets for different assumed power density values



Less than 2% even for the lowest PV density

[1] Chatzipanagi, A. et al. (2023), "*Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union*", doi:10.2760/208702.

Introduction to Agrivoltaics

Potential of Agrivoltaic Systems

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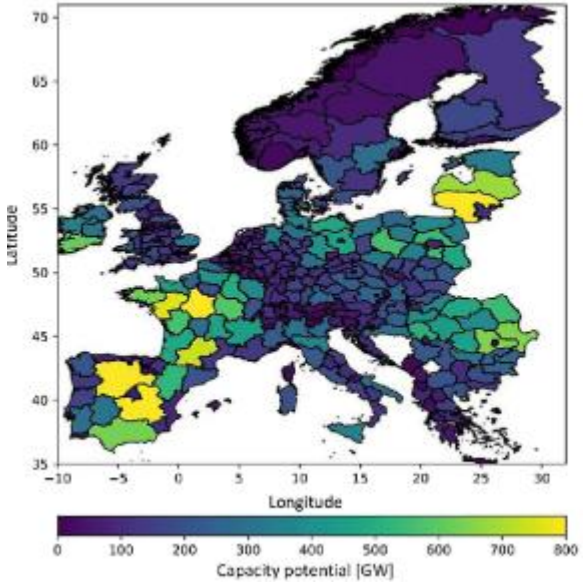
- Along with the deployment of agrivoltaic systems worldwide, several studies have been conducted in recent years to highlight the massive potential they present:
  - Also, in 2023, Khan and Victoria [1] evaluated the capacity potential of Agrivoltaics in the EU by region:

Suitable eligible land for agrivoltaics deployment in Europe

- **16.2% area of EU (170 million ha) is suitable for agrivoltaics.**
- **Potential capacity of 51 TW in Europe.**
- **Highest potential in flat Spanish and French regions and in Eastern Europe.**

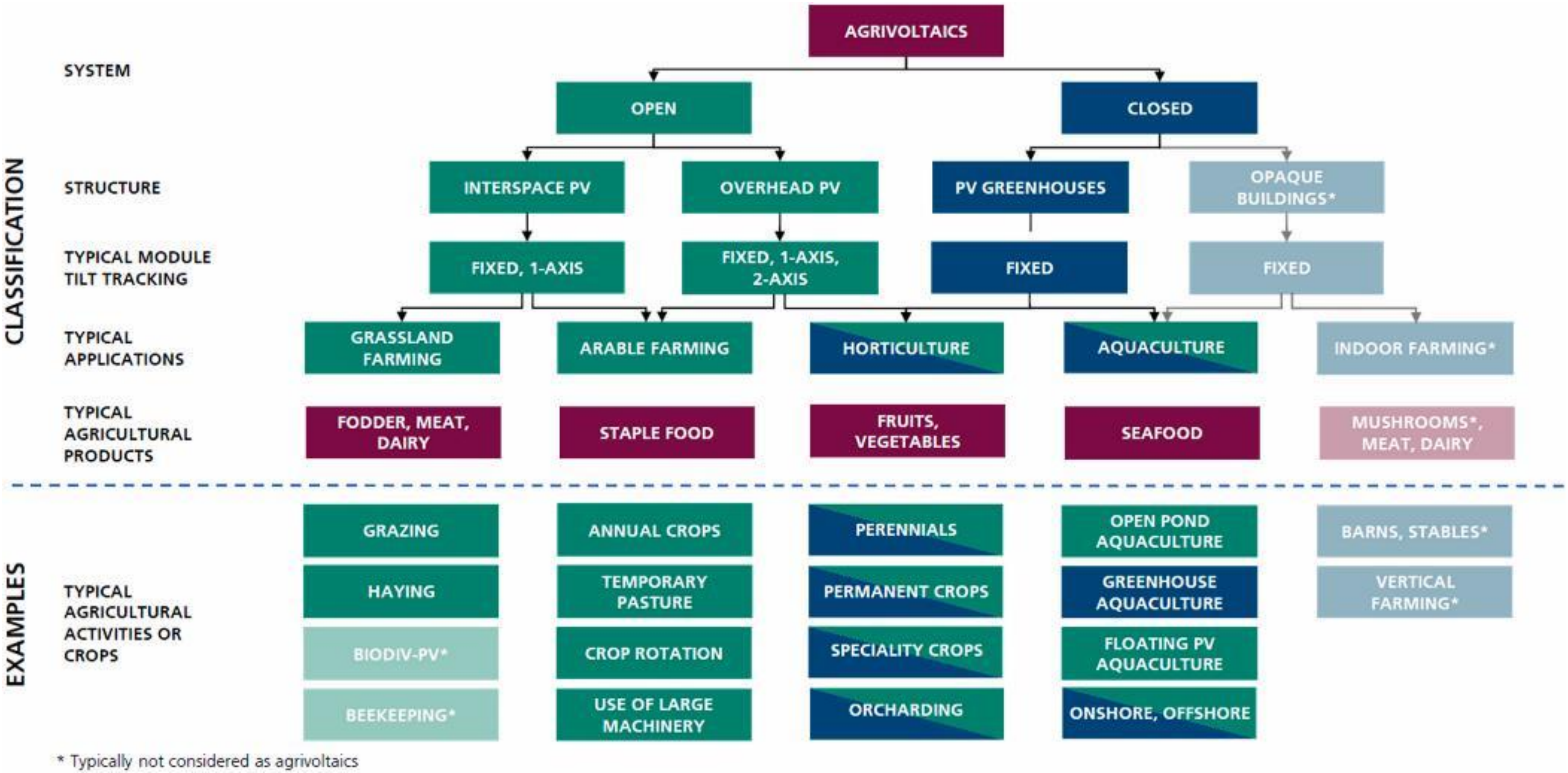


Maximum capacity potential for agrivoltaics systems
Capacity density = 0.3 MW/ha

[1] Ali Khan Niazi, K., and M. Victoria (2023). "Comparative Analysis of Photovoltaic Configurations for Agrivoltaic Systems in Europe." https://doi.org/10.1002/pip.3727

Introduction to Agrivoltaics

Classification of Agrivoltaic Systems



Broad classification of agrivoltaics systems according to Gorjian et al. [1]

[1] Gorjian, S. et al. (2022), "Progress and Challenges of Crop Production and Electricity Generation in Agrivoltaic Systems Using Semi-Transparent Photovoltaic Technology".
DOI: 10.1016/j.rser.2022.112126.

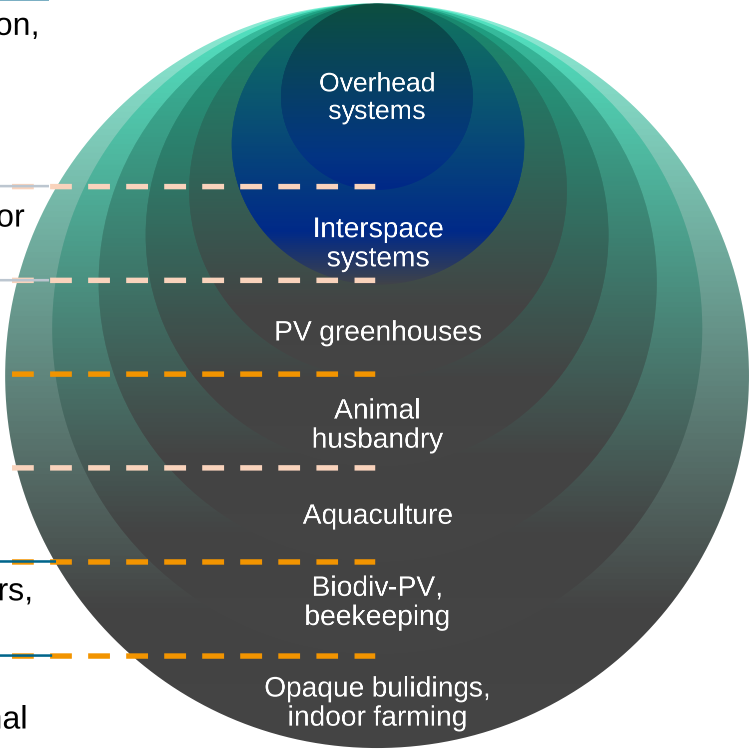
Introduction to Agrivoltaics

Classification of Agrivoltaic Systems

- Nowadays, there is not a set of universal definitions for agrivoltaic systems.
- A wide diversity of activities can then be considered as Agrivoltaics.
  - Sheep grazing.
  - Beekeeping.
  - Fish farming.
  - …

Narrow → Wide

Crop production	High elevated agrivoltaics on crop production, horticulture or arable farming applications
	Ground-mounted with interspace cropping or permanent greenland
	Closed PV greenhouse systems
Animal husbandry	Diary, meat, or poultry farming in open agrivoltaic systems
	Aquaculture in open or closed ponds or swimming off-shore applications
Eco Services	Biotops for increased biodiversity, pollinators, and beekeeping
Others	Closed applications without direct photon sharing, e.g indoor crop production or animal husbandry



Definition hierarchy of agrivoltaics systems according to the experts of IEA Task 13. Source: [1]

[1] IEA PVPS Task 13 report (to be published), "Dual Land Use for Agriculture and Solar Power Production".

Introduction to Agrivoltaics

Classification of Agrivoltaic Systems (Narrow definition) - Examples

Grassland, interspace

Arable farming, interspace

Arable farming, overhead

Horticulture, overhead

PV Greenhouse

Introduction to Agrivoltaics

Classification of Agrivoltaic Systems (Wide definition) - Examples

Grazing

Beef cattle husbandry

Pollinators

Solar Beekeeping

Aquaculture Shrimp PV greenhouse

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

- Identification of suitable crop species
- Development of novel PV systems and technologies
- Modelling
- Performance assessment
- O&M of Agrivoltaic systems
- Legal frameworks for agrivoltaics
- Social acceptance

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Identification of suitable crop species

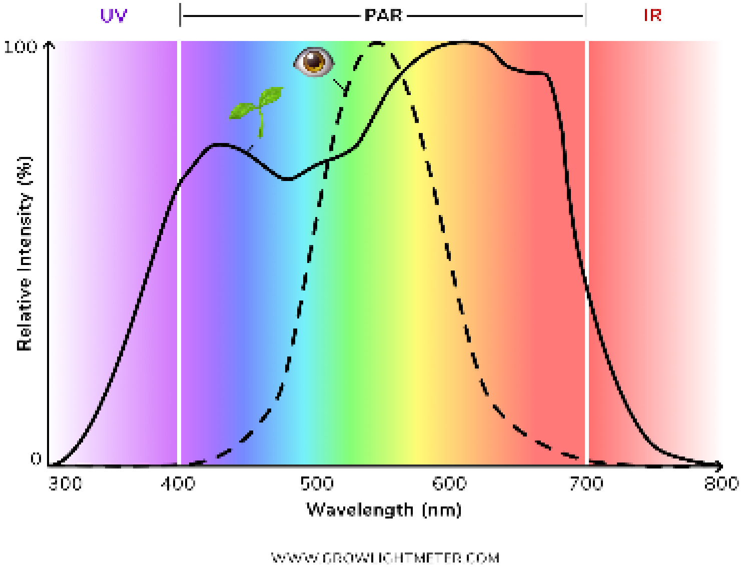
Not all crops are suitable for Agrivoltaics!

- Each crop has a maximum light threshold, and excessive light can be harmful to its growth.

- Some basic concepts of biology:

    - **PAR radiation**: Solar radiation within the 400 nm to 700 nm range of the spectrum. Plants use the photons within this range in the photosynthesis process.

        - PPFD = PAR → No. of photons within the 400 nm – 700 nm range received by a surface during a certain amount of time [umol/m²/s].



Introduction to Agrivoltaics

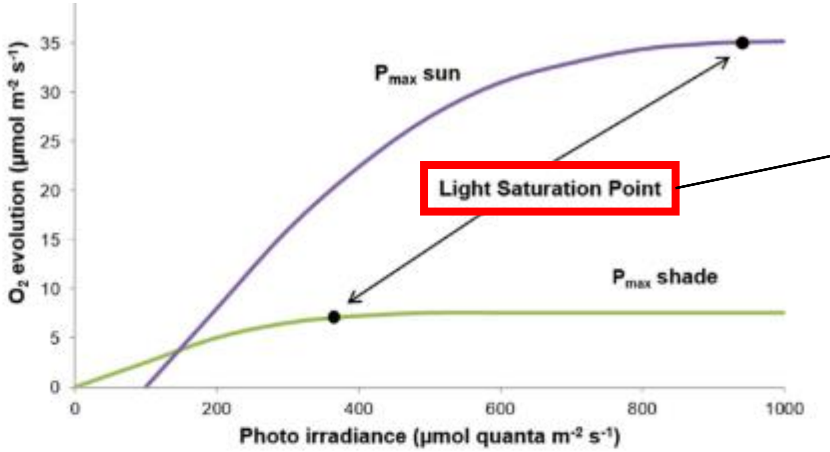
Research lines and current challenges of Agrivoltaics

Identification of suitable crop species

Not all crops are suitable for Agrivoltaics!

- Each crop has a maximum light threshold, and excessive light can be harmful to its growth.
- Some basic concepts of biology:
  - **Light response curve**: It represents the correlation between the amount of PAR received by the plant and the photosynthesis rate.

Light response curve of a sun-loving (purple) and shade-tolerant (green) plants



Further increases in light intensity do not cause a change in the photosynthesis rate.

- ✓ **The light saturation point is crucial for optimizing the shading ratio of an agrivoltaic system for determining the suitability of crops to be cultivated in the system.**
- ✓ **The lower the light saturation point the more shade can be given to a crop without experiencing yield losses.**

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Identification of suitable crop species

- An accurate knowledge of the light requirements of crop species contribute to:
  - Optimizing the design of the agrivoltaic system.
  - Implementation of smart light management approaches → Dynamic agrivoltaic systems

$$DLI = Daily\ Ligh\ Integral = \int PAR\ dt$$

Species	DLI crop requirements		
	Insufficient	Sufficient/Good	Optimal
High light demanding crops (DLI_{opt} > 30 mol m^{-2} day^{-1})			
Cucumber	< 12	12 – 30	> 30
Tomato	< 15	15 – 30	> 30
Medium light demanding crops (10 mol m^{-2} day^{-1} > DLI_{opt} > 20 mol m^{-2} day^{-1})			
Strawberry	< 12	12 – 19	> 19
Spinach	< 8	8 – 17	> 17
Low light demanding crops (5 mol m^{-2} day^{-1} > DLI_{opt} > 10 mol m^{-2} day^{-1})			
Kalanchoe	< 4	4 – 8	> 8
Poinsettia	< 6	6 – 10	> 10

Source: https://doi.org/10.1016/j.eja.2020.126074

- Other aspects, such as plant dimensions, climate conditions and irrigation needs, can also determine the configuration of the agrivoltaic installation:
  - Overhead PV systems are particularly suitable for perennial crops (fruit orchards and vines) and for the cultivation of berries.
  - Interspace PV systems are suitable for arable or grassland farming.

Overhead PV for strawberries cultivation. Source: Baywa r.e.

Interspace PV in arable farming. Source: Fraunhofer ISE

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

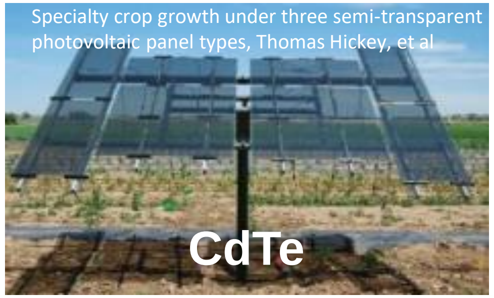
Development of novel PV systems and technologies

Semi-Transparent PV modules

Gaps between rows of opaque PV cells

- Mature m-Si technology.
- High reliability.
- Non-uniform light distribution.
- Glass - Glass – High weight.

Thin-film (CdTe, DSSC, a-Si) semitransparent



- Uniform light distribution on the ground.
- Low efficiency.
- High cost.
- Lifetime.

Organic PV modules

- Photo-selective PV materials.
- Uniform light distribution.
- Flexible and lightweight.
- Low efficiency.
- Not commercially available yet.
- Lifetime.

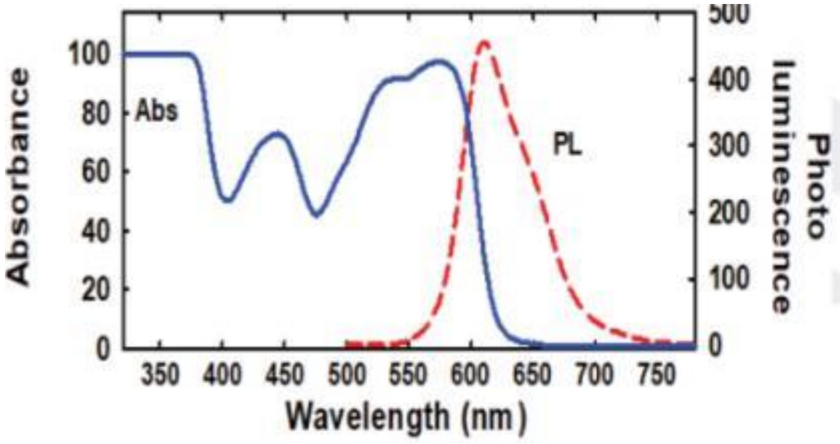
Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Development of novel PV systems and technologies

Semi-Transparent PV modules

Luminescent PV These modules have coatings that modify the incident solar spectrum (e.g. they can convert UV light into visible light)



Source: DOI 10.1002/2016EF000531

Characteristics

- Customized transparency.
- High reliability.
- Increase the useful light for plants.
- High cost.
- Only commercially available in USA.

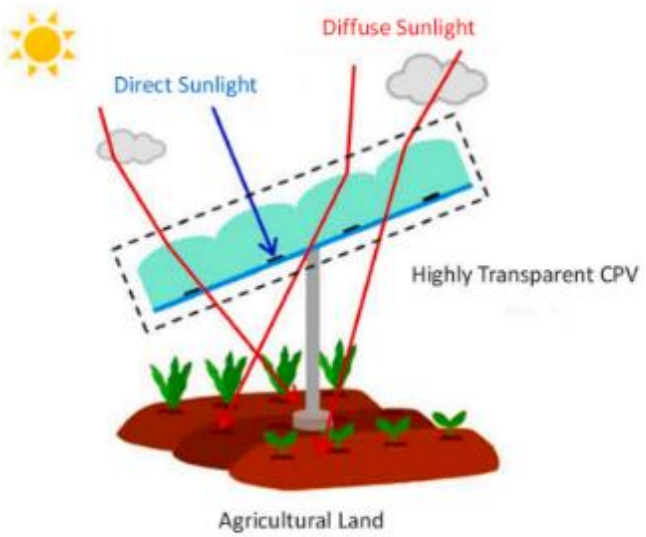
Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Development of novel PV systems and technologies

Semi-Transparent PV modules

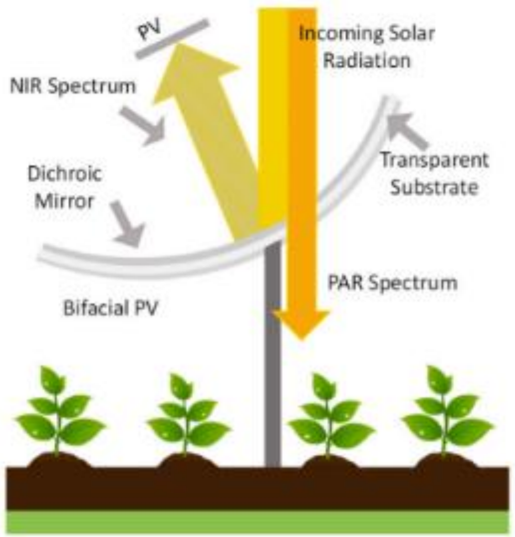
Concentrating PV module using Fresnel lens



https://doi.org/10.1002/ese3.550

- Less PV area is required.
- Diffuse sunlight can pass through the modules and reach the plants.

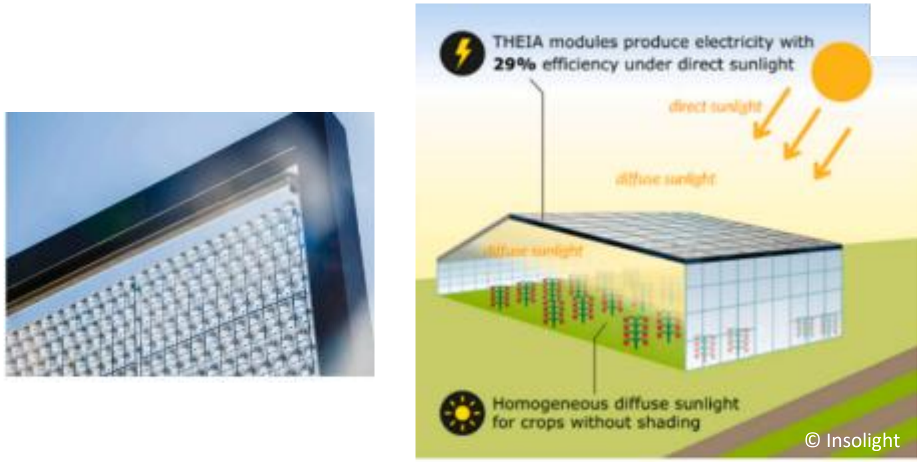
Dual-axis tracking dish type CPV + beam filter



https://doi.org/10.1038/s41893-019-0388-x

- Wavelength-selective transparency.
- NIR wavelengths are reflected to the PV cells.
- PAR light can pass through the mirror and reach the plants.

CPV modules with optical micro-tracking technology



- No tracking systems are required.
- Use of small lenses and micro PV cells.
- Homogeneous diffuse sunlight at plant level.

Introduction to Agrivoltaics

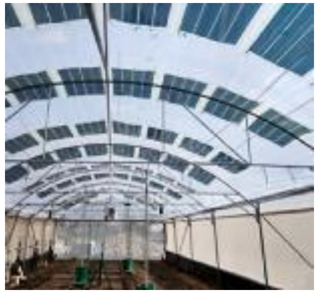
Research lines and current challenges of Agrivoltaics

Development of novel PV systems and technologies

Flexible and lightweight PV modules

Integration into greenhouse covers

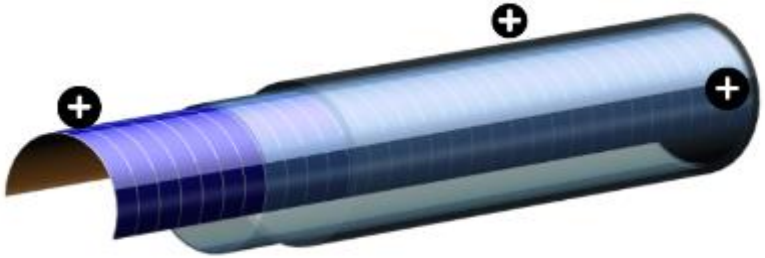
Organic and flexible PV modules



Source: https://doi.org/10.1016/j.seta.2020.100641

Source: ASCA ©

Tubular PV modules



Source: Tubesolar AG

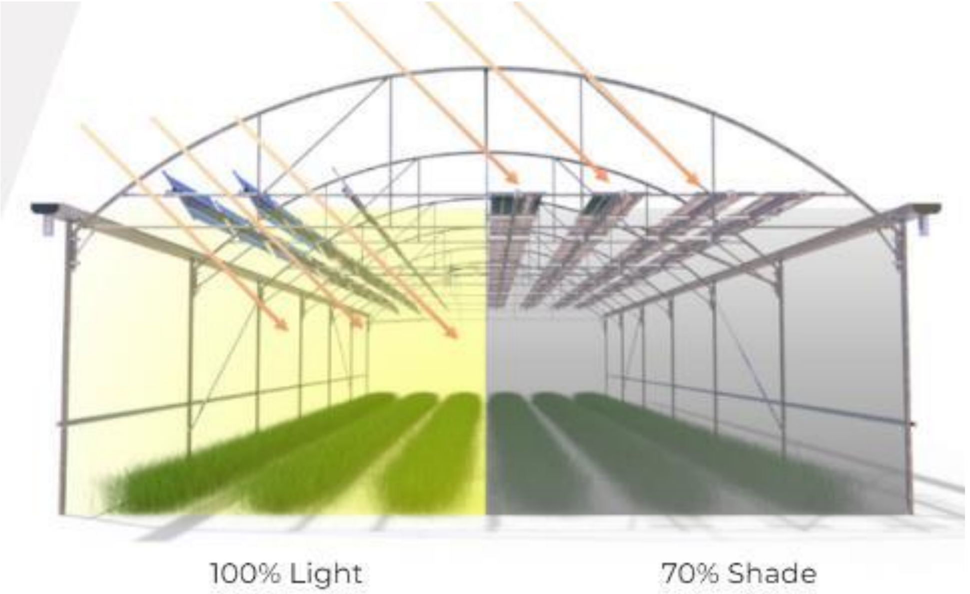
Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Development of novel PV systems and technologies

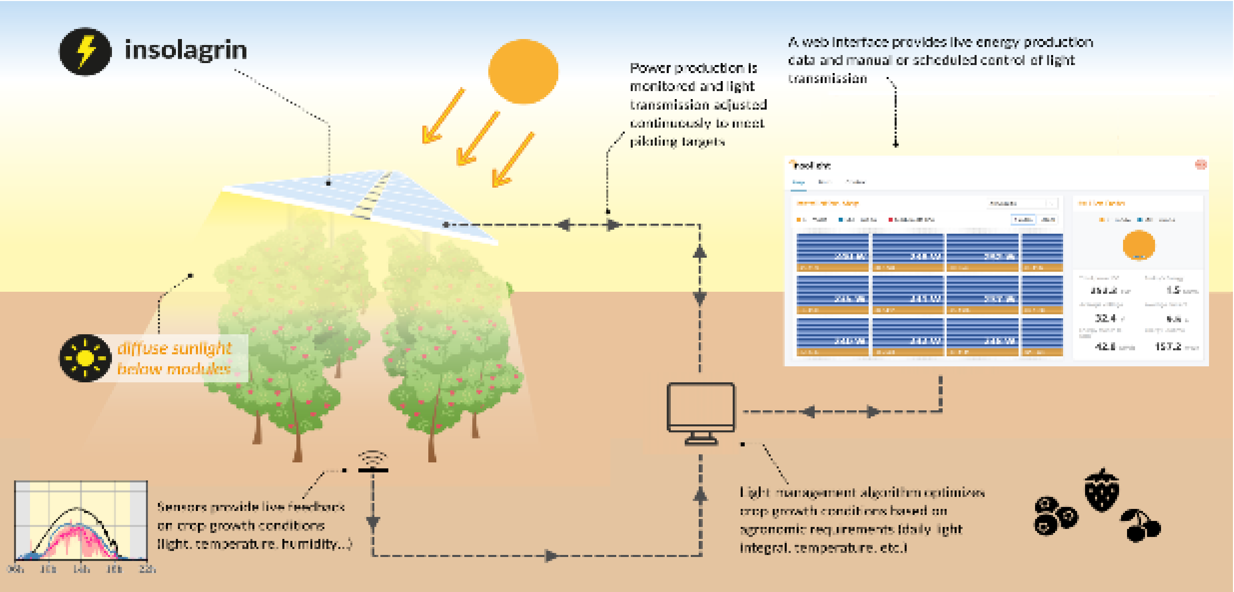
Smart integrated systems for Agrivoltaics

Trisolar - Israel



- The adjustable modules allow to control light and shade at crop level.
- Real-time monitoring of light and crop conditions → Tracking system.

Insolight - Switzerland



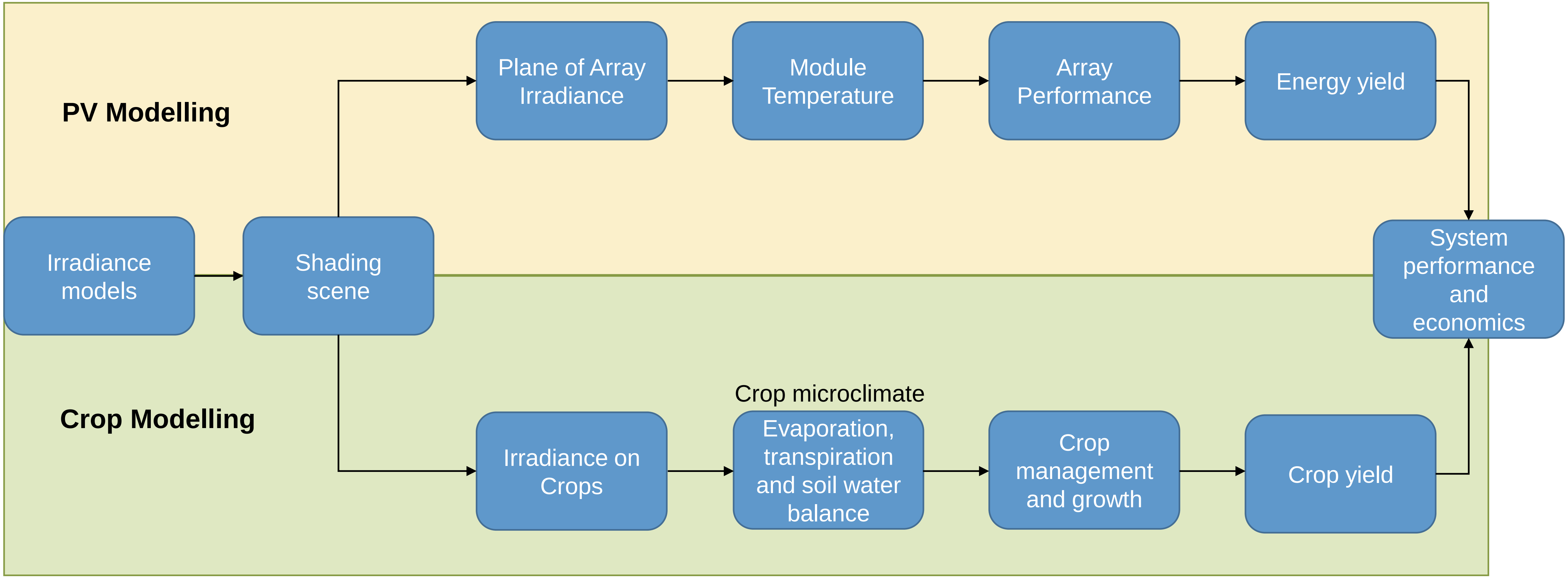
- Semi-Transparent PV modules.
- Optical layer for shading.
- Centralised control system.

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Modelling in Agrivoltaics

Flowchart – Simulation & Modelling



Introduction to Agrivoltaics

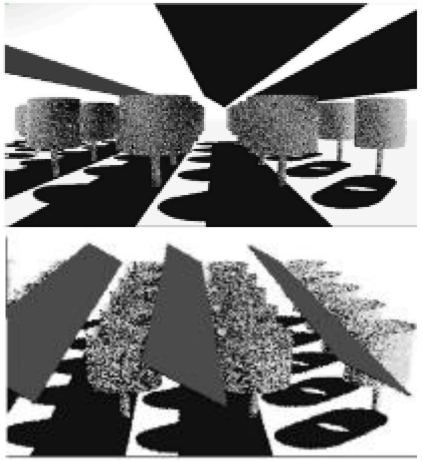
Research lines and current challenges of Agrivoltaics

Modelling in Agrivoltaics

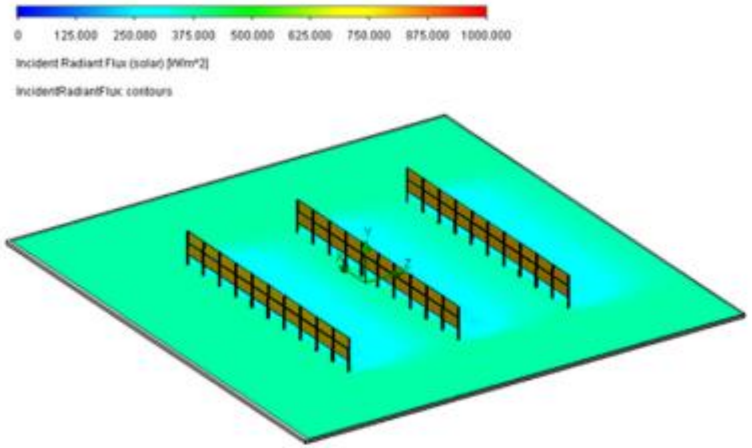
Irradiance Modelling

1. Evaluation of the light distribution at PV module and ground levels.
2. Shading modelling → View-factor equations or Ray-Tracing.
3. Decomposition of solar irradiance components.
4. Irradiance transposition models → Different surfaces and only one sensor.
5. PAR modelling.

- ❑ Use of Typical Meteorological Year (TMY) data
- ❑ Typical softwares and models
  - PVSYST
  - Radiance
  - SketchUp
  - CDF models
  - 3D models
  - SMARTS → Solar spectrum generator.



Scene of an Agrivoltaic system within an olive grove Bifacial created with Radiance Raytracing Tool [1]



Irradiance simulation of a vertical Agrivoltaic system using a CFD model [2]

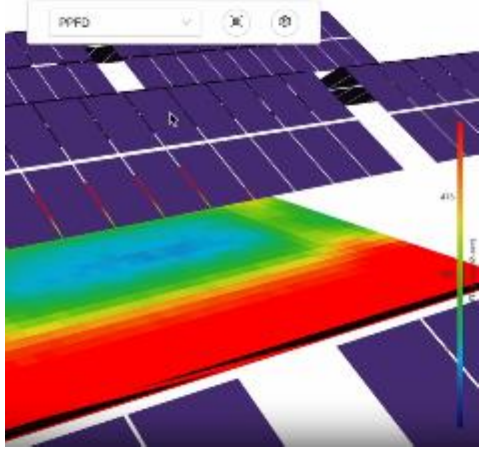


Illustration of the results provided by Spade software

[1] Mouhib, E. et al. (2024), "*Enhancing land use: Integrating bifacial PV and olive trees in agrivoltaic systems*", https://doi.org/10.1016/j.apenergy.2024.122660
[2] Zainali, S. et al. (2023), "*Computational fluid dynamics modelling of microclimate for a vertical agrivoltaic system*" **https://doi.org/10.1016/j.nexus.2023.100173**

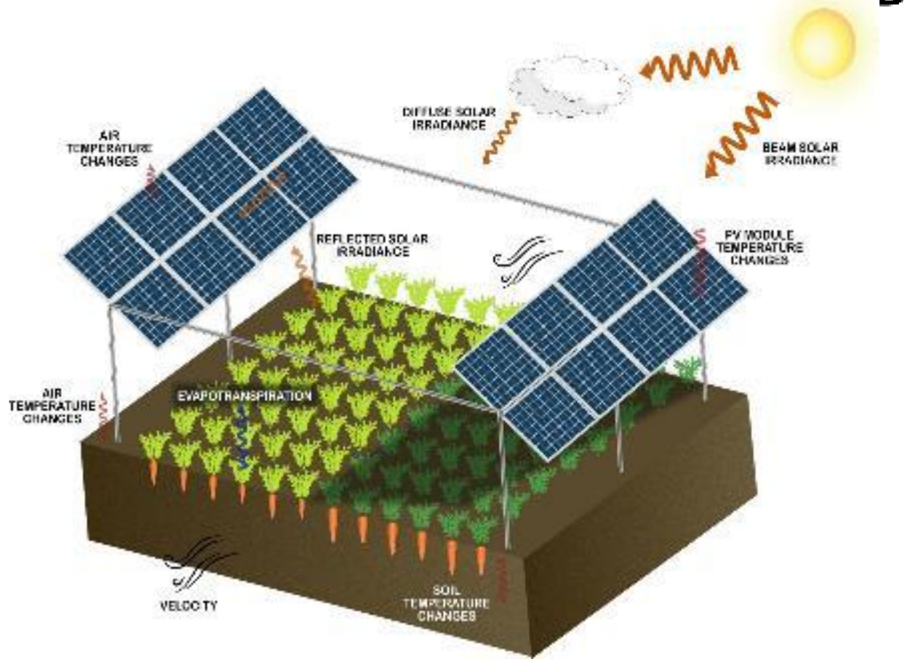
Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Modelling in Agrivoltaics

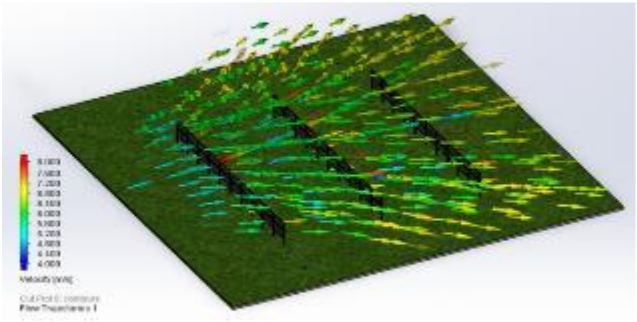
Microclimate Modelling

1. Thermal assessment through analytical and data-driven models.
   - Energy balance and heat transfer models.
2. 3D temperature and wind dynamics modelling through CFD tools or multiphysics models (ANSYS, COMSOL, …).
3. Modelling of 3D moisture transport through CFD techniques.
4. Water balance models → Evaporation and evapotranspiration rates.
5. Rainfall distribution on the ground → Interception and redistribution of rain by PV modules.

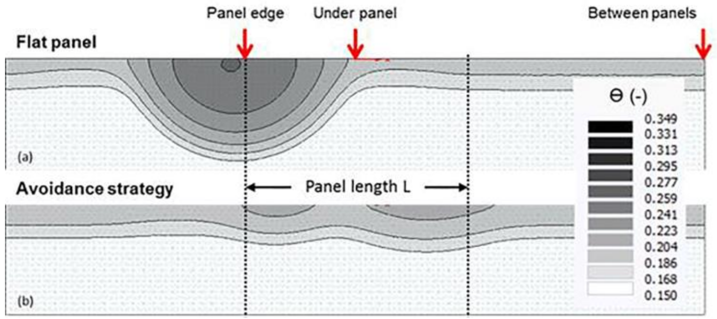


Microclimate interactions within an Agrivoltaic system

CFD model computation of wind speed and direction [1]



Simulation of soil water patterns – Hydrus 2D [2]



[1] Zainali, S. et al. (2023), "*Computational fluid dynamics modelling of microclimate for a vertical agrivoltaic system*" https://doi.org/10.1016/j.nexus.2023.100173
[2] Elamri, Y. et al. (2018), "*Rain concentration and sheltering effect of solar panels on cultivated plots*" https://doi.org/10.5194/hess-22-1285-2018

Introduction to Agrivoltaics

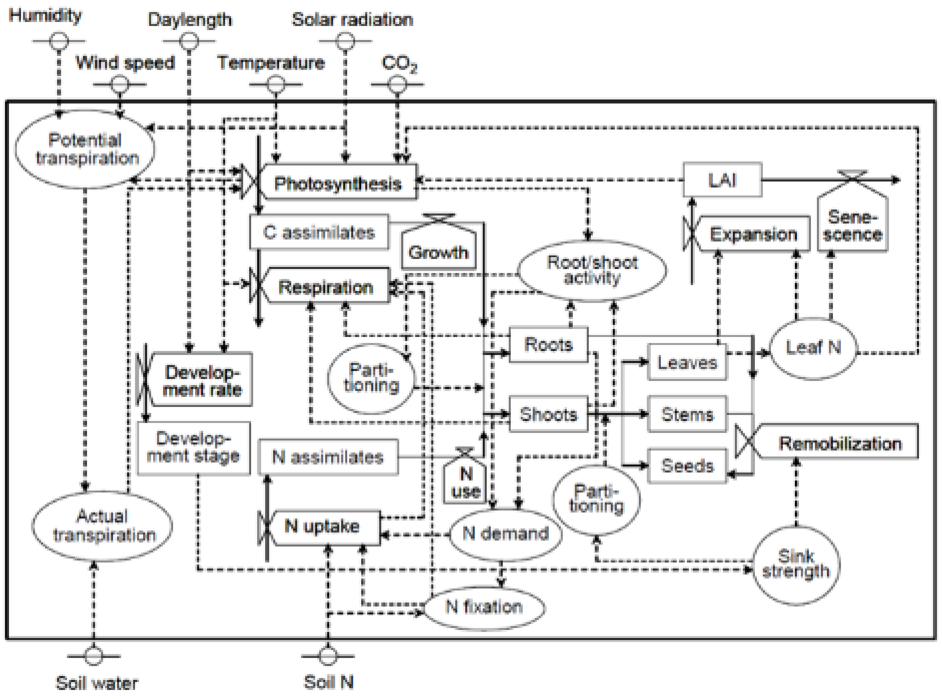
Research lines and current challenges of Agrivoltaics

Modelling in Agrivoltaics

Crop Modelling

- **Up until now, there are no crop models tailored to Agrivoltaic systems**.
- **In some research articles, traditional crop growth models have been applied. However, their complexity and the high number of inputs required to run them does not make suitable their application within the agrivoltaics field.**

Flowchart of the GECROS crop model



There is a pressing need for dual (PV yield + Crop yield) models adapted to Agrivoltaics

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Performance Assessment – Key Performance Indicators (KPIs)

In Agrivoltaics, KPIs allow to quantitatively evaluate the system performance, thus leading e.g. to a potential optimization of their design and/or operation to maximize the final incomes for the farmers.

KPIs related to light/solar irradiance

KPI	Description
Homogeneity of Light (LHI)	Measures the uniformity of PAR distribution within the APV area.
Light Use Efficiency (LUE)	Relates total agricultural yield to the total amount of light reaching the system.
Light Productivity Factor (LPF)	Evaluate the efficiency of solar irradiance sharing for a particular crop and APV system configuration.
Light Distribution in PV Greenhouses (G_{GR})	Calculates the incident global irradiance within a PV greenhouse [99].

KPIs related to PV

KPI	Description
Power Conversion Efficiency (PCE_n)	Measures the performance and stability of PV modules over time.
Energy Yield (Y_{el})	Connects yearly electrical power generation to the land area of the APV system.

Agricultural KPIs

KPI	Description
Crop Yield (Y_{ag})	Represents the quantity of agricultural produce harvested per unit of land area.
Energy Yield (Y_{el})	Connects yearly electrical power generation to the land area of the APV system.

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Performance Assessment – Key Performance Indicators (KPIs)

In Agrivoltaics, KPIs allow to quantitatively evaluate the system performance, thus leading e.g. to a potential optimization of their design and/or operation to maximize the final incomes for the farmers.

Land-related KPIs

KPI	Description
Ground Coverage Ratio (GCR)	The ratio of the area occupied by PV modules to the total area of the agrivoltaic system.
Land Equivalent Ratio (LER)	Evaluates the productivity of land for APV systems compared to traditional PV installations.
Land Productivity Factor (LPF)	Assesses APV system productivity based on relative yields for PV electricity production and PAR reaching the crop level.

$$LER = \frac{Y_{c,APV}}{Y_{c,ref}} + \frac{Y_{PV,APV}}{Y_{PV,ref}}$$

LER > 1 indicates that the **land productivity** of an **APV** system is **higher than** the **productivity** of a **separate PV** or **agricultural system**

Water-related KPIs

KPI	Description
Water Productivity (WP)	Relates total agricultural yield to the total water needed for the crop.
Water Consumption (WC)	Measures the volume of water consumed per unit area of the crop.
Water Use Efficiency (WUE)	Relates total agricultural yield to the total amount of reference evaporation.

Economic Metrics

KPI	Description / Why relevant?
Net Present Value (NPV)	Determines a project's profitability by considering cash inflows and outflows.
Levelized Cost of Electricity (LCOE)	Actual cost of generating electricity by an APV system.

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Operation and Maintenance

Monitoring

Irradiance/PAR measurements

Pyranometers

PAR sensor

Meteo/Microclimate measurements

- Air temperature, RH, wind speed and direction, barometric pressure, and precipitation.

MetSens600 – Campbell Scientific

Soil measurements

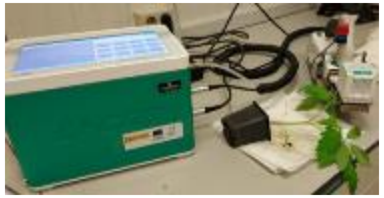
- Soil temperature
- Soil moisture
- Soil EC conductivity

Crop measurements

- Photosynthesis rate.
- Leaf wetness.
- Morphological measurements (steam length, number of leaves, Leaf Area,…)
- Fresh and dry mass.
- Fruit quality.

Leaf Wetness Sensor

Photosynthesis rate



Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Operation and Maintenance

Soiling mitigation

Action: Periodical cleaning of PV arrays to remove built-up soiling (dust, dirt, pollen, debris, etc).
Importance: Boost of energy production and prevent follow-up failures (hot spots → mismatch effects).

Soiling impact on an Agrivoltaic installation in Chile [1]. (a) Cleaning of the modules. (b) Plowing with a tractor below the modules. (c) Soiled vs Clean modules.

Monitoring of the impact of soiling on the Performance Ratio (PR) of the agrivoltaics installation in Chile [1]. The green bars represent the daily PV energy. The yellow line represents the daily POA radiation. The black line shows the evolution of the PR.

[1] Jung, D. et al. (2022), "*Effects of soiling on agrivoltaic systems: Results of a case study in Chile*" https://doi.org/10.1063/5.0107943

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Operation and Maintenance

Vegetation management

Action: Periodical vegetation management under and around the PV modules and their mounting structures.
Importance: Prevent seasonal shading + Ensure proper light exposure for crops.

Preventive maintenance – Check of Balance of System (inverter, cabling, mounting structures, etc.)

Action: Routine checks of inverters, other electrical components and mounting structures.
Importance: Ensure normal operation + identify potential issues to prevent downtime and ensure safety.

Irrigation system maintenance

Action: Maintenance and inspection checks of the irrigation system for proper functioning.
Importance: Ensure that crops receive enough water, especially in drought periods, to support healthy growth.

Agronomic practices

Action: Implementation of integrated pest management strategies, planting patterns and harvesting approaches, etc. customized to the configuration of the Agrivoltaic system
Importance: Maximize land use efficiency and maintain a harmonious coexistence between land/crops and PV systems.

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Legal Frameworks for Agrivoltaics

There is not a common EU framework for Agrivoltaics systems

- So far, only a few countries have established regulatory laws and decrees about agrivoltaics systems, being Germany the first country in Europe to do that following the **"Agriculture First" approach**.

> ***"Agriculture First"***: Strategic framework that aligns solar power generation with the needs and objectives of agricultural production by considering that **agriculture is the main use of the land**.

Regulatory requirements – Agrivoltaics policies of different countries

Country	Maximum lost areas*	Minimum relative crop yield	Reference crop yield has to be recorded?	Maximum GCR	Minimum clearance height	Minimum relative PV yield	Rate of agricultural subsidies	Reference
France	Not considered	90%	Yes (5% area of the APV system, max. 1 ha)	40%	-	-	100% if GCR ≤ 40%	Decree No. 2024 -318 (2024)
Germany	• Cat.1 - Overhead APV: 10% • Cat. 2 - Interspace APV: 15%	66%	-	-	• Cat.1: 2.1 m • Cat 2. Not applicable	-	85%	DIN SPEC 91434 (2021)
Italy	30%	Not defined	-	40%	• 1.3 m with animals • 2.1 m with crops	60%	Undecided	Guidelines issued by the Italian Ministry of Environment and Energy Transition (2022)
Japan	Not considered	80%	-	-	-	-	Unknown	https://doi.org/10.1063/5.0054674

*Lost areas are zones that cannot be occupied by crops due to the PV installation

Introduction to Agrivoltaics

Research lines and current challenges of Agrivoltaics

Social acceptance

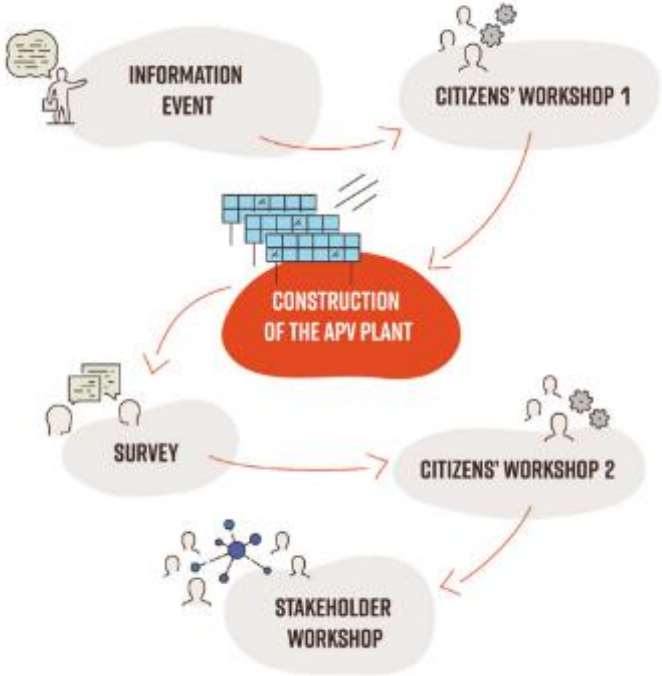
Opposition of locals and farmers to the deployment of PV installations in rural areas

→ It is crucial to evaluate the social acceptance of agrivoltaics systems and to promote awareness of their benefits

↓ Local workshops and dissemination events

The US's largest solar farm is canceled because Nevada locals don't want to look at it

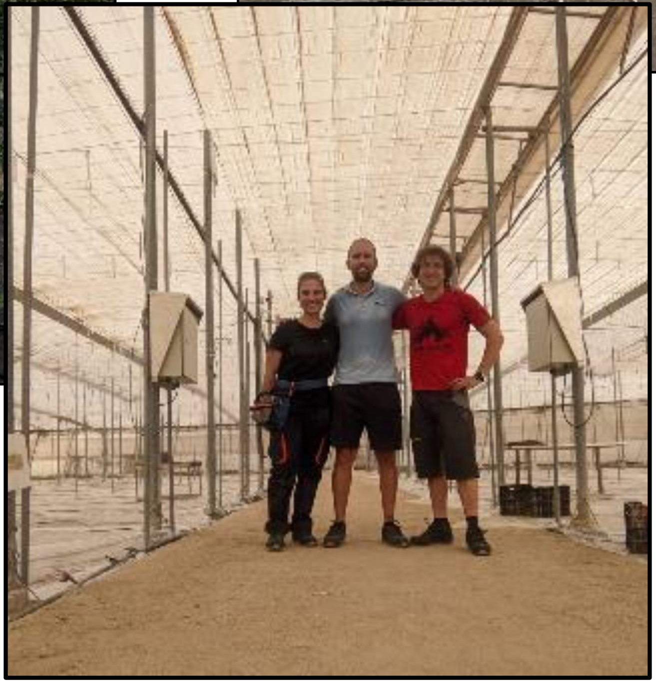
Michelle Lewis | Jul 26 2021 - 10:37 am PT | 0 Comments



Multi-stage educational approach [1]

[1] Trommsdroff, M. et al. (2022), "Agrivoltaics: solar power generation and food production" https://doi.org/10.1016/B978-0-323-89866-9.00012-2

Students welcome!!



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