AGRIVOLTAICS – DUAL HARVESTING OF FOOD AND ELECTRICITY

R&D Activities at Fraunhofer ISE

Kawan Amelung

American Farmland Trust

07.04.2022

Fraunhofer Institute for Solar Energy Systems ISE

www.ise.fraunhofer.com

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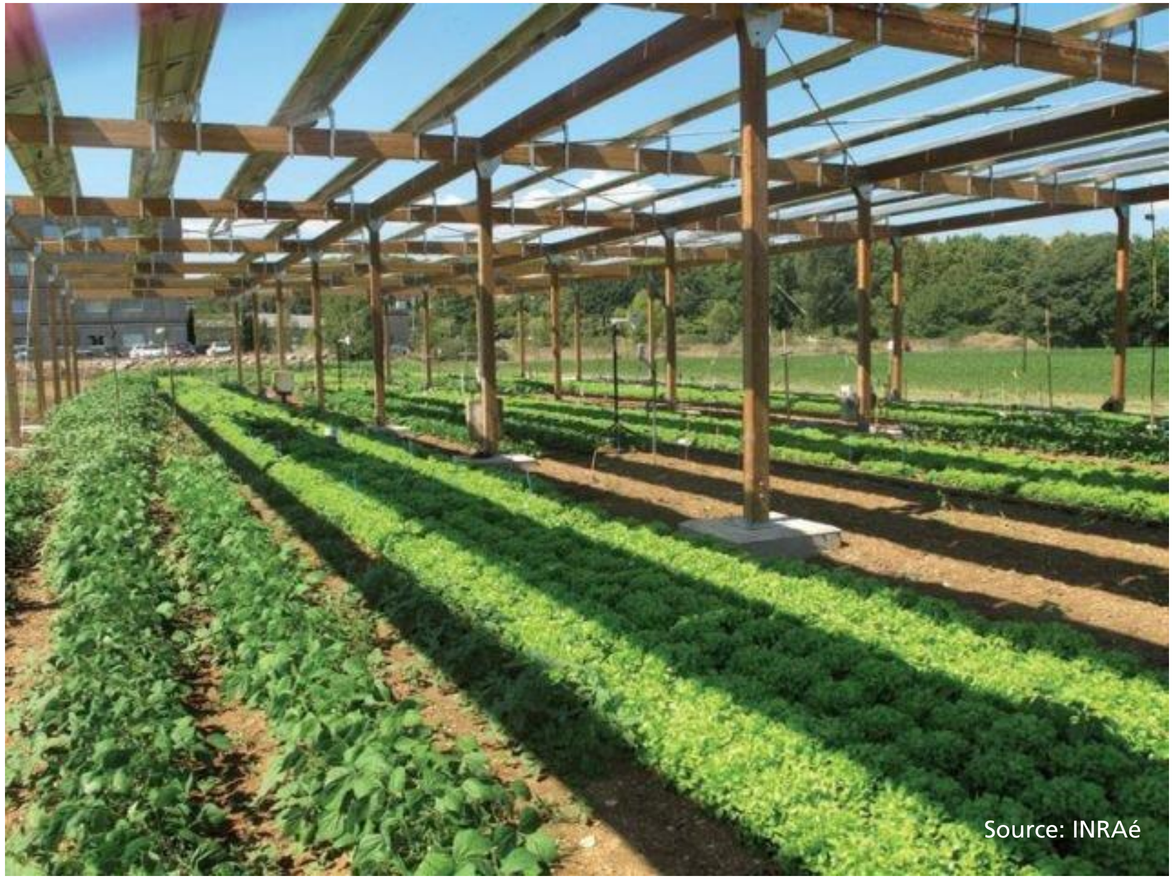
Integrated Photovoltaics at Fraunhofer ISE

What is agrivoltaics?

Definitions, Classifications, and Standards of Agrivoltaics

Diversity of Agrivoltaics



Definitions, Classifications, and Standards of Agrivoltaics

Diversity of Agrivoltaics

Definitions, Classifications, and Standards of Agrivoltaics

Diversity of Agrivoltaics

Source: NREL

Source: Fraunhofer ISE

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Definitions, Classifications, and Standards of Agrivoltaics

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Diversity of Agrivoltaics

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Definitions, Classifications, and Standards of Agrivoltaics
Diversity of Agrivoltaics

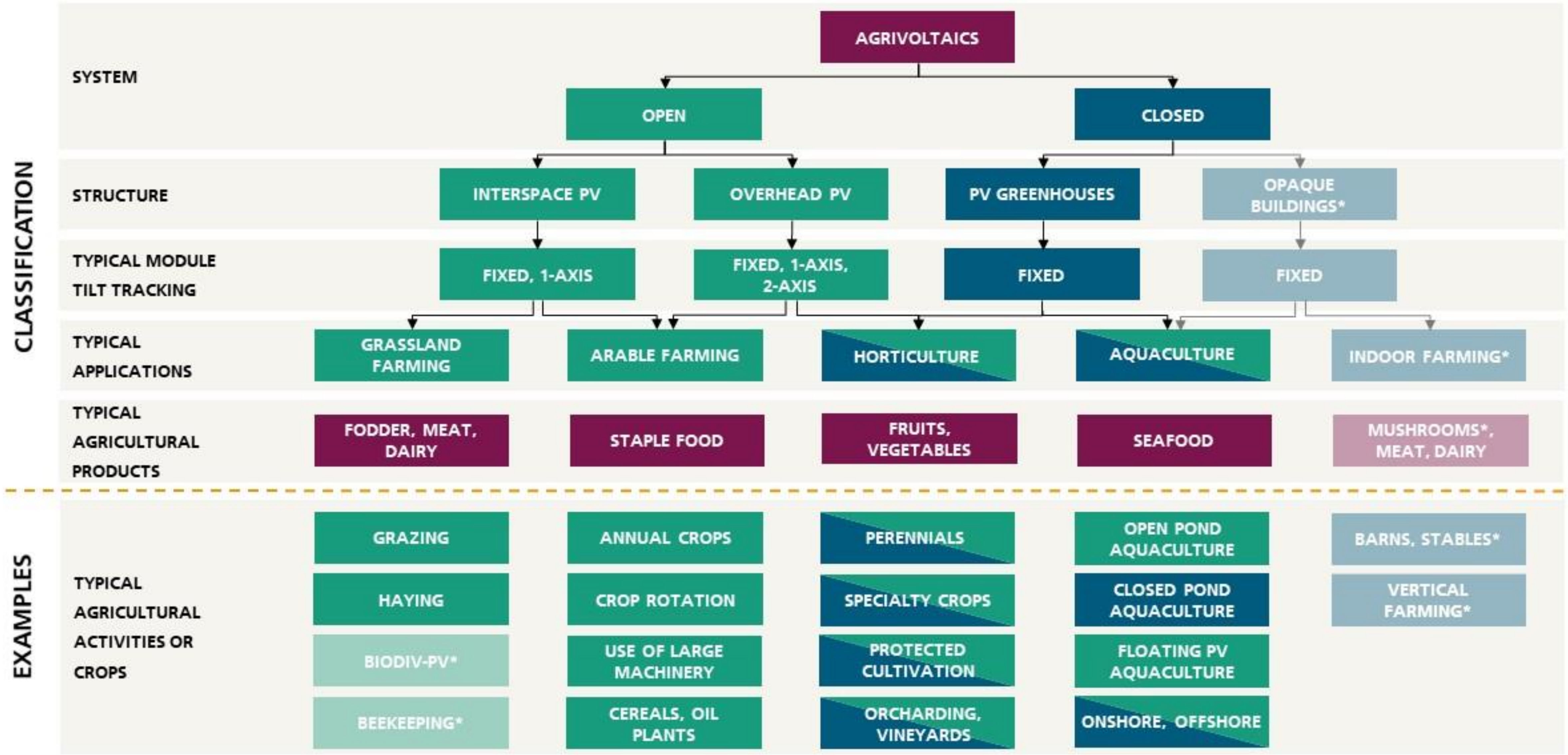

Source: Oregon State Universtiy, Mark Floyd


Source: Next2Sun

Definitions, Classifications, and Standards of Agrivoltaics

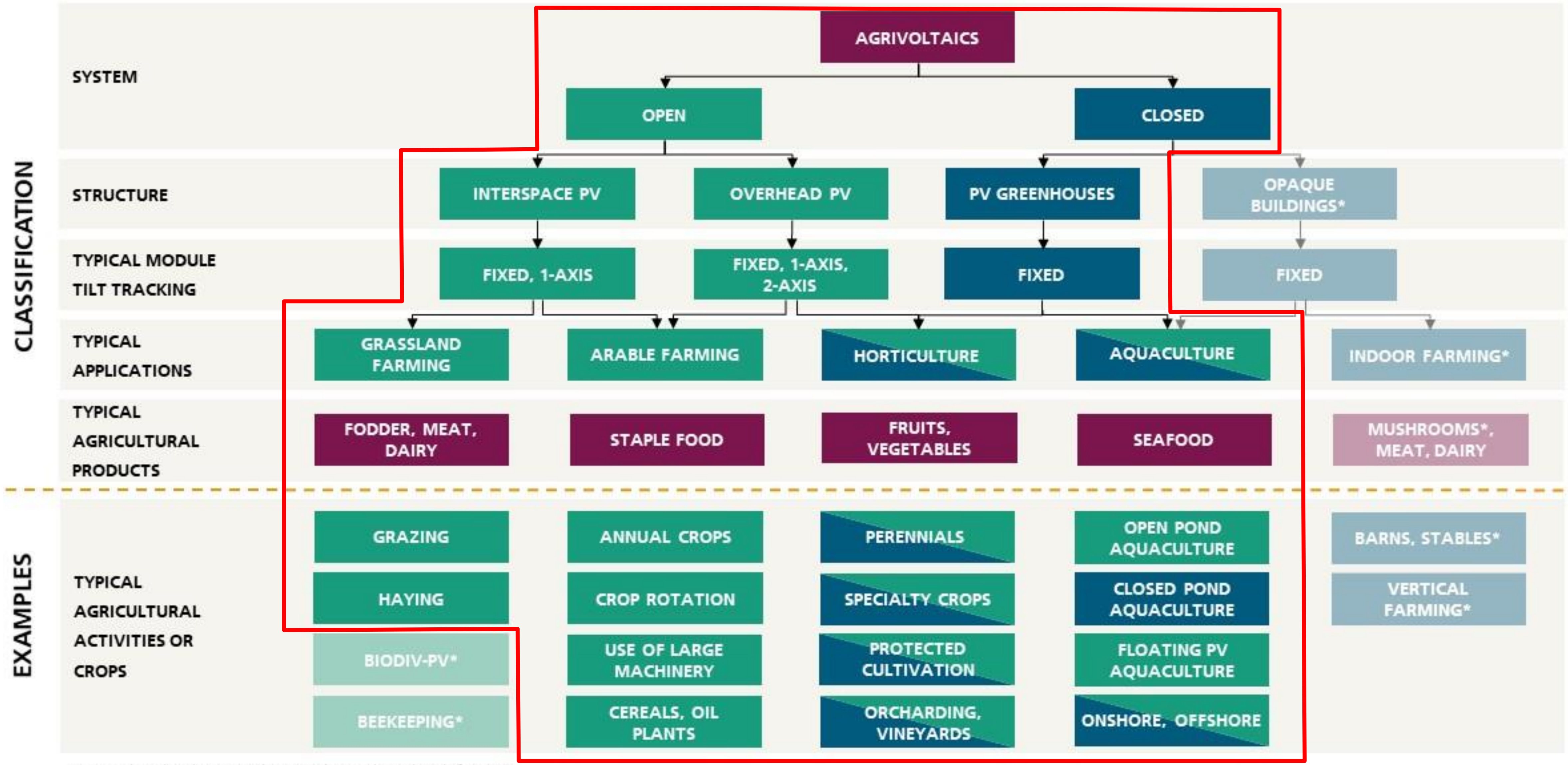
Diversity of Agrivoltaics

Classification Scheme for Agrivoltaics



* Considered to be agrivoltaics only in a broader definition

Classification Scheme for Agrivoltaics



* Considered to be agrivoltaics only in a broader definition

Definitions, Classifications, and Standards of Agrivoltaics
German DIN SPEC 91434: New German Standard for Agrivoltaics

Definition of agrivoltaics according to DIN SPEC 91434

“Agrivoltaics is the combined use of the same land area for agricultural production as the primary use and for electricity PV production as the secondary use.”

Definitions, Classifications, and Standards of Agrivoltaics
German DIN SPEC 91434

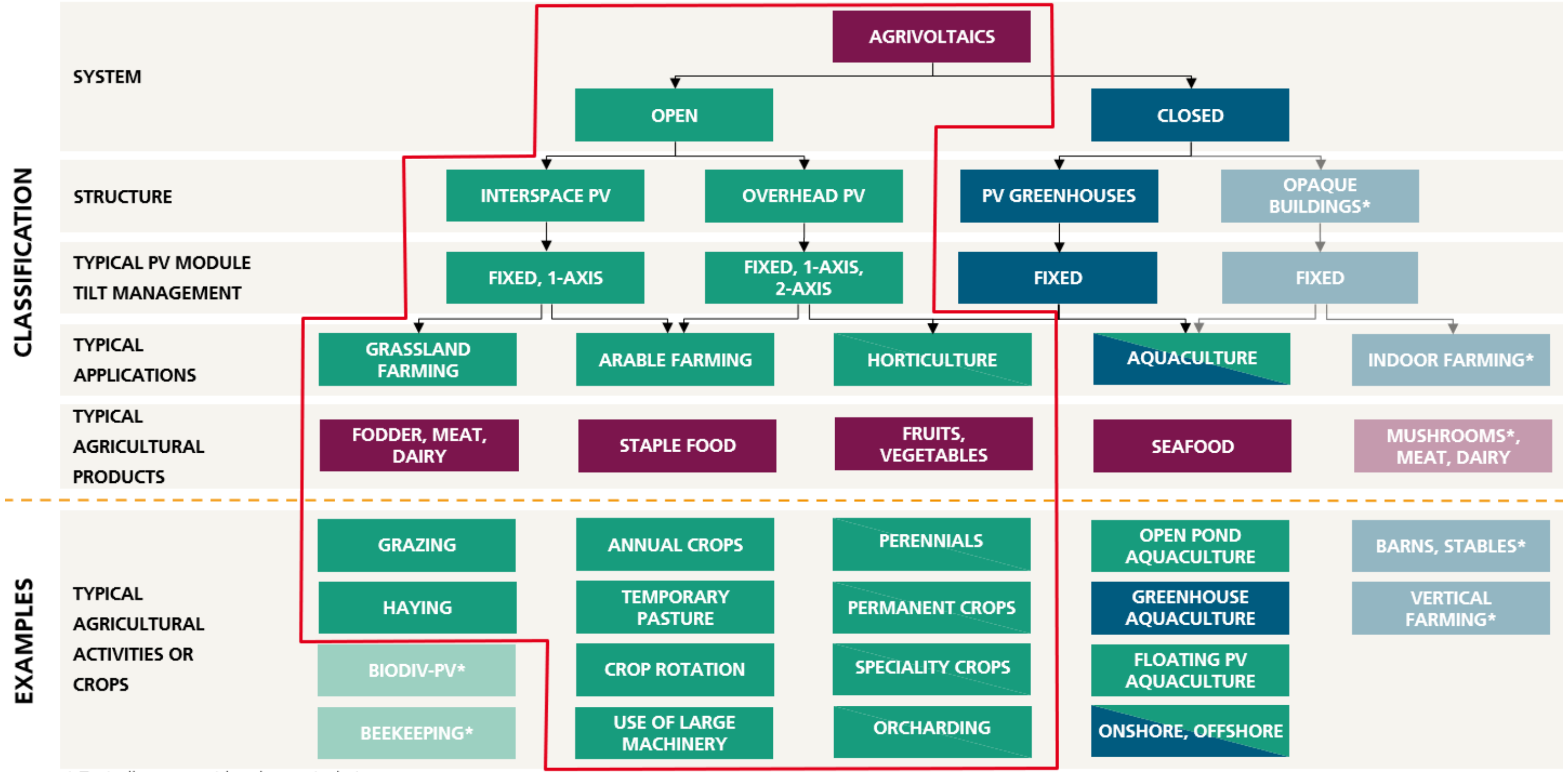
Key Facts

- Published on 16. April 2021
- Process according to preliminary standard (SPEC PAS) of the German Institute for Normisation (DIN)
- Public announcement of process in September 2019
- Kick-off meeting in December 2019
- 15 partners in the consortium, most from PV sector, only 3 from agriculture sector
- Lead: Fraunhofer ISE and University of Hohenheim
- Main goal: Set requirements for primary agricultural use to assure quality of agrivoltaics

Definitions, Classifications, and Standards of Agrivoltaics
German DIN SPEC 91434

Scope

- Only open systems
- No aquaculture
- Interspace PV is considered within a separate category (Cat. II)



* Typically not considered as agrivoltaics

Definitions, Classifications, and Standards of Agrivoltaics
German DIN SPEC 91434

Core Requirements & Criteria

- Agricultural yield of at least 66% of the reference yield
- Agricultural use of the land must be guaranteed
- Land loss after installation of system maximum 10% (Cat. I) or 15% (Cat. II)
- Avoid soil erosion and damage (construction, anchoring, and water management)
- Dismantling must be possible without any larger damages to soil and constructional residues

Definitions, Classifications, and Standards of Agrivoltaics

German DIN SPEC 91434

Category I – Overhead PV

Agrivoltaic System	Use	Example
Category I: Vertical clearance >2,1m	1A: Permanent and multi-year crops	Fruits, berries, viticulture, hops
	1B: Single-year und long-term crops	Arable crops, vegetables, alternating grassland, fodder
	1C: Grassland with mowing	Intensive and extensive commercial grassland
	1D: Grassland with pasture	Pasture, pasture rotation (e.g. cattle, poultry, sheep, pig, and goat)

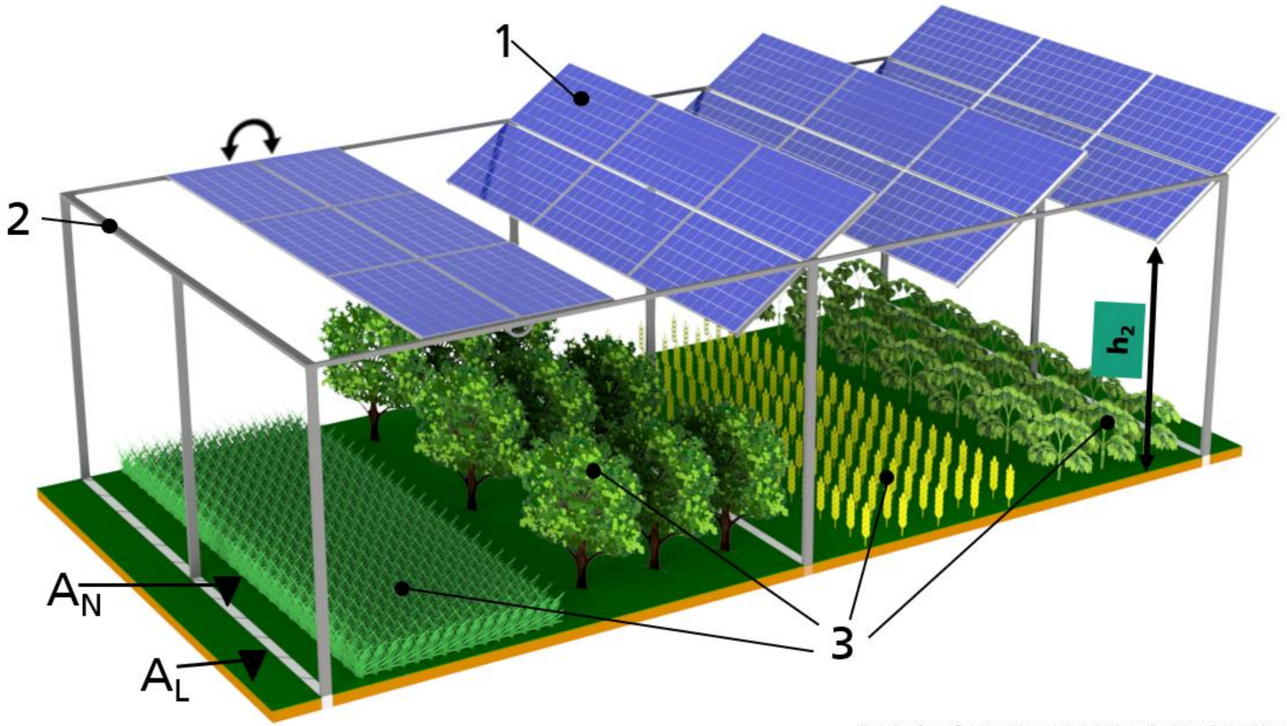


Illustration of crops © shutterstock.com / Ulvur, BlueRingMedia, Pisut tarding, Ice AisberG

Legend:

A_L	Cultivatable agricultural areas	
A_N	Uncultivatable agricultural areas	
h_1	Clearance height below 2.10 m	
h_2	Clearance height above 2.10 m	
1	Examples of solar modules	
2	Mounting structure	
3	Examples of crops	

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Definitions, Classifications, and Standa

German DIN SPEC 91434

Category II – Interspace PV

Agrivoltaic System	Use	Example
Category II: Vertical clearance <2,1m	2A: Permanent and multi-year crops	Fruits, berries, viticulture, hops
	2B: Single-year and long-term crops	Arable crops, vegetables, alternating grassland, fodder
	2C: Grassland with mowing	Intensive and extensive commercial grassland
	2D: Grassland with pasture	Pasture, pasture rotation (e.g. cattle, poultry, sheep, pig, and goat)

Legend:

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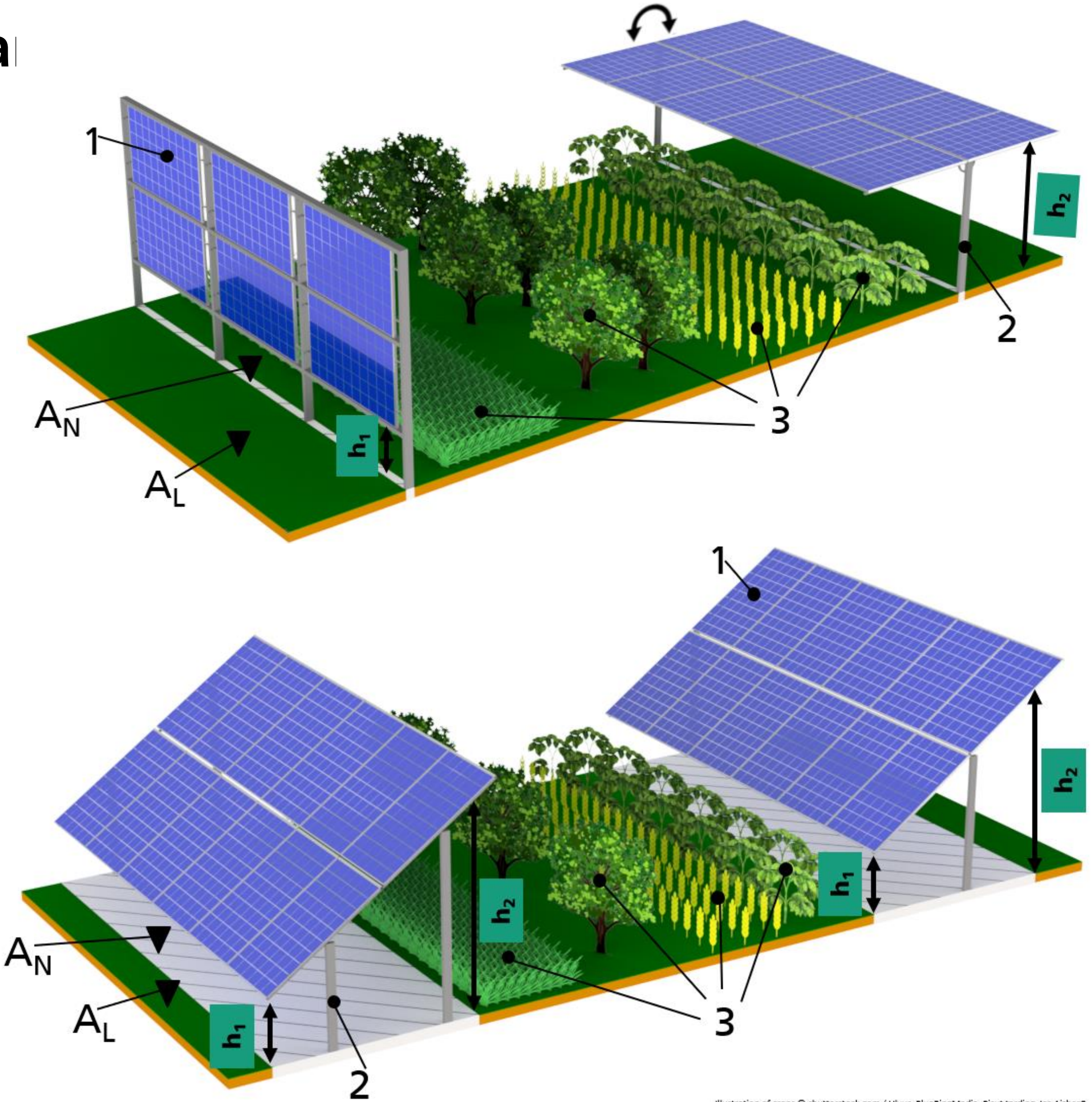

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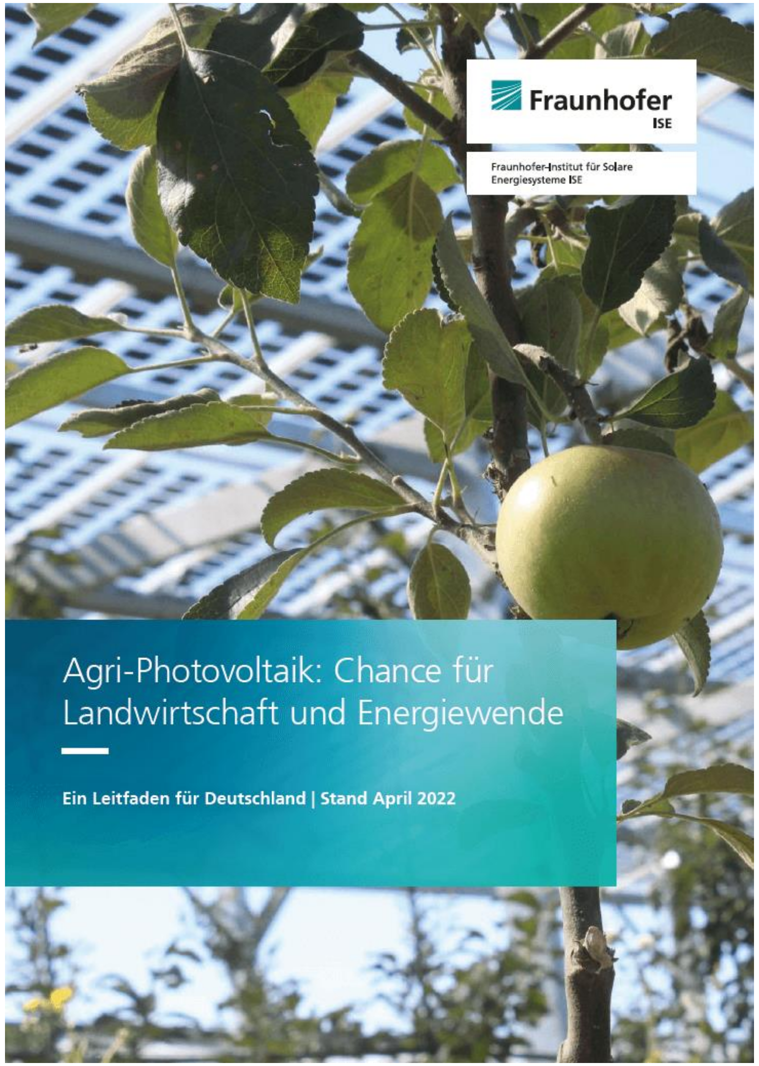
Fraunhofer ISE Agrivoltaics Guideline for Germany



April 2022

Only DE

EN Pending

https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/agri-photovoltaik-chance-fuer-landwirtschaft-und-energiewende.html

October 2020

DE/EN

https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/APV-Guideline.pdf

AgriVoltaics2022
15-17th June 2022

AgriVoltaics2022
Conference & Exhibition
15-17 June Piacenza, Italy & Online

- April 23, 2022: End of Early Bird period
- https://www.agrivoltaics-conference.org/

Thank you very much for your attention!





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Germany
Innovation Tenders

- Deadlines:
  - April 1st 2022
  - August 2st 2022
- 150 MWp for “Special Solar Systems”
  - Floating PV, carport PV, and agrivoltaics
- Vertical PV already within the EEG
  - Limited approved areas (adjacent to railways and highways)
  - Not competitive with ground mounted PV

- Maximum 2MWp
- Maximum 7.5 ¢/kWh “adder”
- Must adhere to the DIN SPEC 91434
- Must be a “combination system”
  - Wind/solar energy source
  - and/or storage system

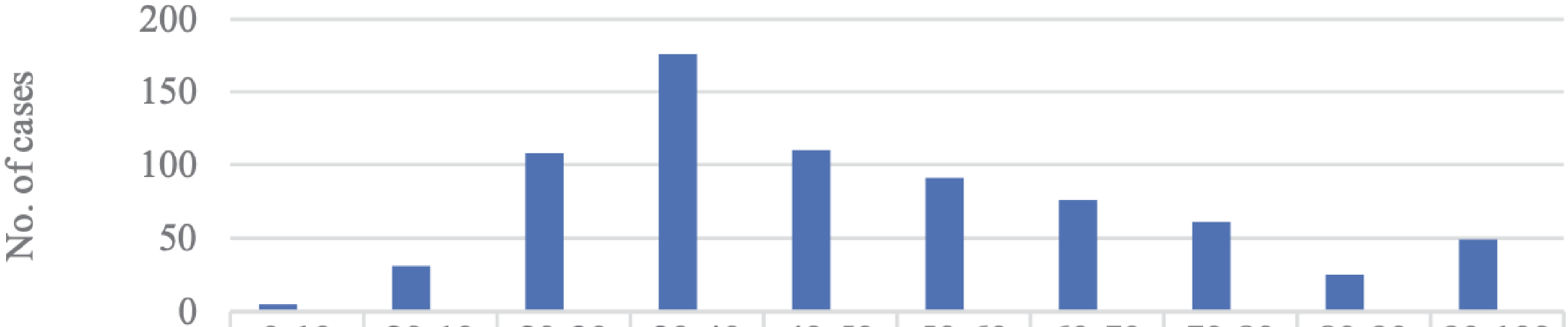
- Mixed response to the DIN SPEC requirement

Japan
Solar Sharing

- Introduced in 2004 by Akira Nagashima
- By 2019, roughly 2000 farms
  - 89% less than 0.3 ha
- Feed-in-tariff introduced in 2012
  - Clear farming plan and the continuation of farming activities must be ensured.
  - Ample light for crop production and the mounting structure must have an elevation of about 2 meters to make sure it does not hinder the use of agricultural machinery.
  - No effect on the neighboring farmlands
  - The crop yield must reach 80 % of local standard yield and an annual report must be provided as evidence to prove the same
- Agrivoltaic systems must be removed and the land must be restored if conditions are not met

Japan
Solar Sharing

- Shading rates (2018)



	0-10	20-10	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
No. of cases	5	31	108	176	110	91	76	61	25	49
Ratio	0.7%	4%	15%	24%	15%	12%	10%	8%	3%	7%

Makoto Tajima and Tetsunari Iida

France
A focus on vineyards

- The Agency for Ecological Transmission (ADEME)
- French Energy Regulatory Commission (CRE)

- Three rounds from 2017 – 2019 (15 MWp)

- Larger agrivoltaics tender for 2021
  - 31 projects for 81 MWp
- 2021/2022 tender for 140 MWp
  - Projects up to 3 MWp
- Tenders to continue until 2026

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AGRIVOLTAICS – DUAL HARVESTING OF FOOD AND ELECTRICITY

R&D Activities at Fraunhofer ISE


Copyright: BayWa r.e.

Dr.-Ing. Matthew Berwind (he/him)

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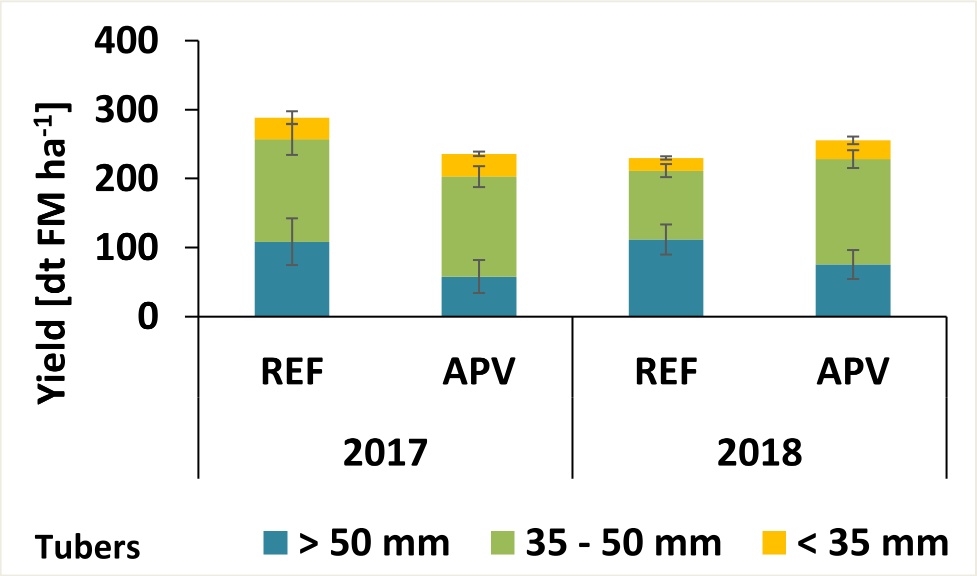
APV-RESOLA
First pilot in arable farming in Germany

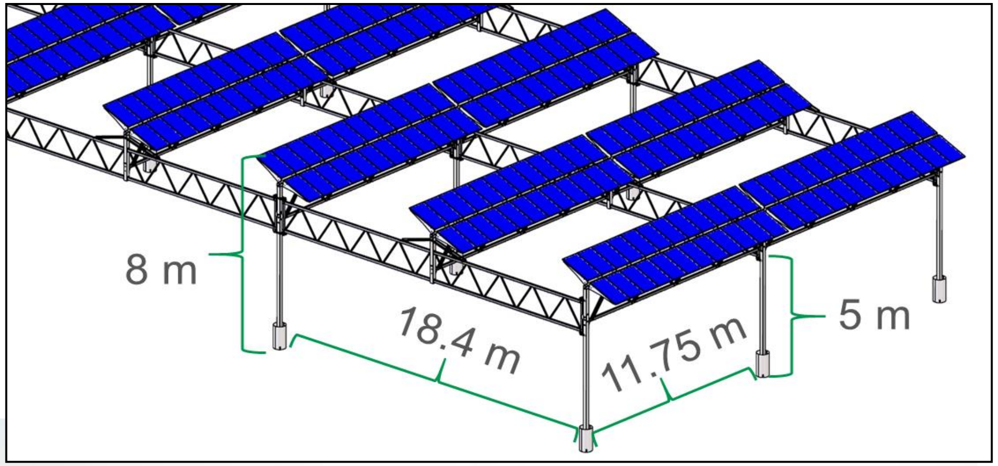
Project duration: March 2015 – Juli 2021

Topic: Field trials on clover grass, potato, winter wheat and celery

Installed capacity: 194 kWp

Budget: ca. 3,5 Mio Euro





Source: Hilber Solar

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APV-Obstbau

First pilot in apple farming in Germany

Project duration: April 2020 – April 2025

Topic: Field trials on 8 different apple cultivars

Budget: ca. 1,3 Mio Euro

Installed capacity: 258 kWp

Technology: transparent PV modules with two different cell layouts, tracked vs. non-tracked. First agrivoltaic apple harvest in August.

WATERMED4.0

Efficient use and management of water resources through smart technologies

Project duration: June 2019 – Dec 2022

Topic: Management of the water cycle in agriculture and measure of economic, energy, social and governance factors that influence the water use efficiency in Mediterranean (Algeria) agricultural production areas.

Budget: ca. 1.8 Mio €

Installed capacity: 10 kWp

Technology: V-Shaped rainwater harvesting

APV-MaGa

Agrivoltaics for Mali and The Gambia: Sustainable Electricity Production by Integrated Food, Energy and Water Systems

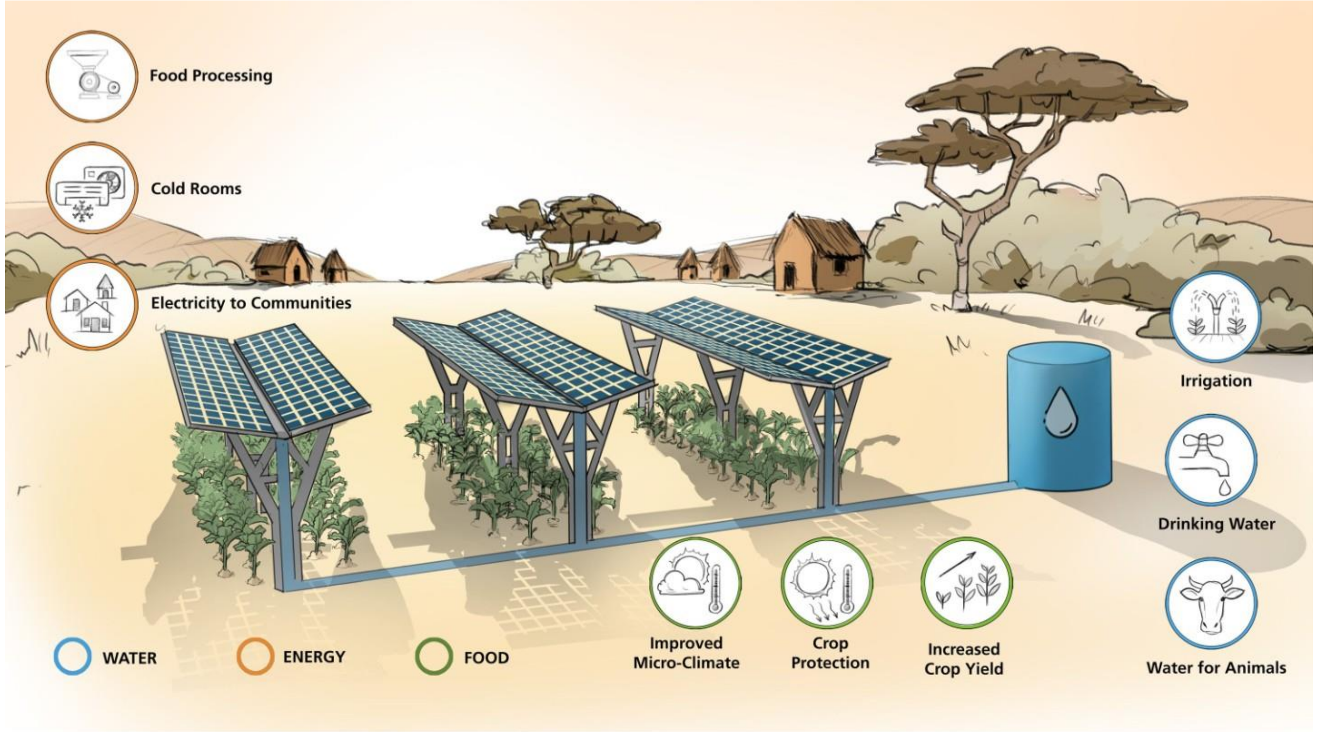
Project duration: August 2020 – Juli 2023

Topic: Rainwater harvest systems, socio-economic barriers, WEF-nexus

Budget: ca. 1,9 Mio Euro

Installed capacity (5 prototypes): 4x50 kWp, 1x150 kWp

Technology: V-shape, focus more robust, off-grid capable technologies with high system reliability



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SHRIMPS

Solar-Aquaculture Habitats as Resource-Efficient and Integrated Multilayer Production Systems

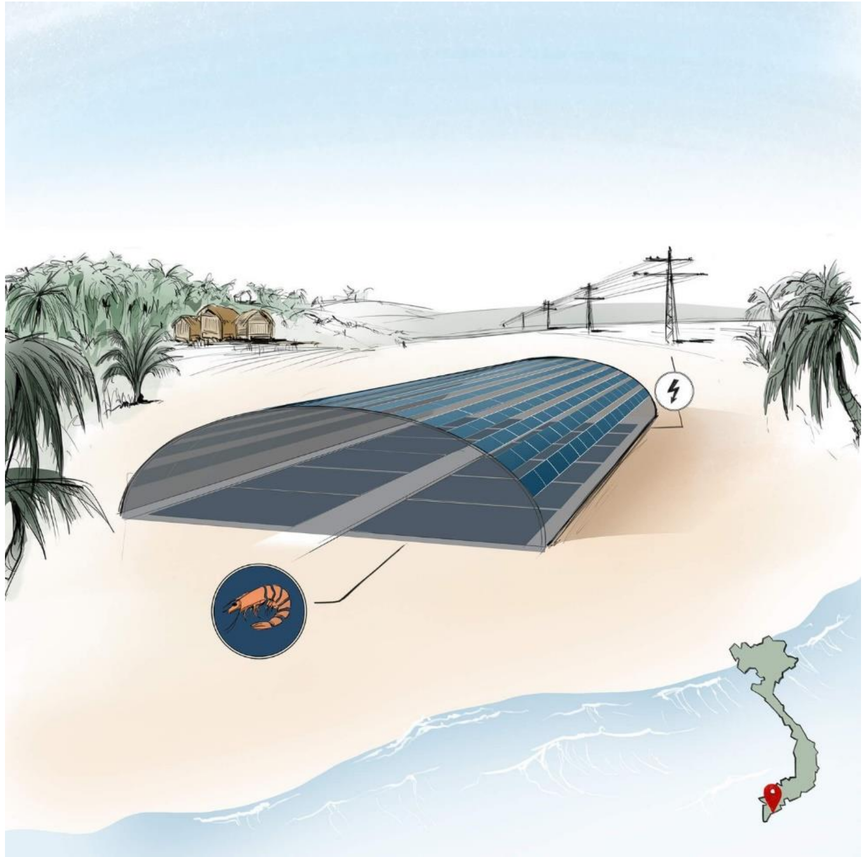
Project duration: June 2019 - May 2023

Topic: Aquaculture, bio-floc, shrimp

Budget: ca. 1.7 Mio Euro

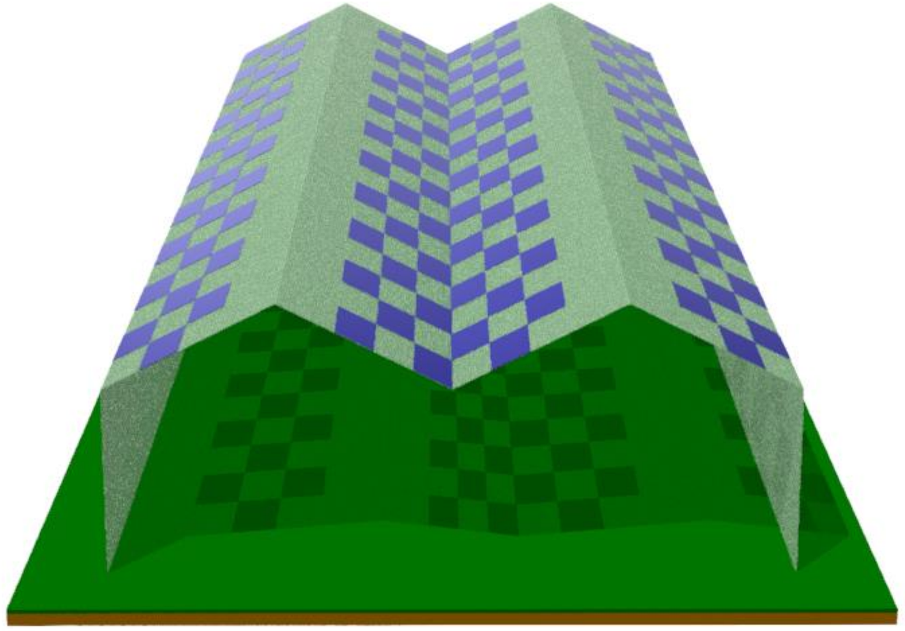
Installed capacity: 100 kWp

Approach: Different shading rates and their impact on shrimp production. How do varying light levels impact algae growth and reduce bio-floc necessities?



SusMedHouse

Sustainability and Competitiveness of Mediterranean Greenhouse and Intensive Horticulture



Project duration: January 2020 – February 2023

Topic: : Efficient, eco-friendly, sustainable Mediterranean greenhouse with integrated artificial intelligence, hi-tech automation and control system

Budget: 1.5 Mio €

Installed capacity: 48,6 kWp

Approach: Evaluation of light distribution effects on PV greenhouse plant development for horticultural cultivars (tomato, lettuce, pepper). Phenotypic monitoring and analysis via image correlation

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION
IN THE MEDITERRANEAN AREA

HyPErFarm

Hydrogen and Photovoltaic Electrification on Farm

Project duration: January 2020 – December 2023

Topic: The integration of farm-colocated renewable energy production in the hydrogen economy

Budget: ca. 5.2 Mio €

Installed capacity: 300 kWp

Approach: 1. Development of material efficient single-axis tracked APV systems

2. Electrolysis and bio-waste pyrolysis for hydrogen production

3. Examination of bio-char soil effects on agricultural activity

Prototype of Krinner Carport GmbH

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APV 2.0

Agrivoltaics 2.0: Coupling crop production and photovoltaics in Strukturwandel

Project duration: January 2020 – December 2021 (extension to 2025)

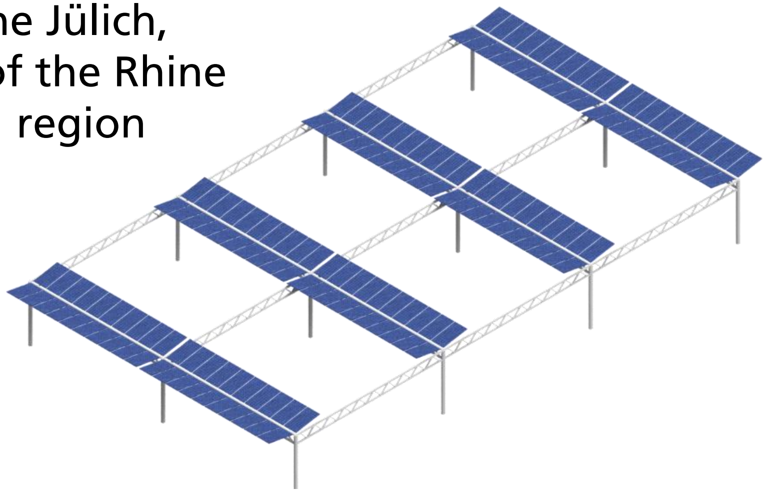
Topic: Bio-economy based structural transition of traditional coal-mining regions

Budget: ca. 2,5 Mio Euro

Installed capacity: 300 kWp

Approach: In-situ phenotypic monitoring of various crops for the development of plant growth models suitable in heterogeneous light conditions. Development of plant/PV/water digital twin framework for the control of optimized agrivoltaic tracking systems.

Test site in the Jülich, Germany area of the Rhine coal-mining region



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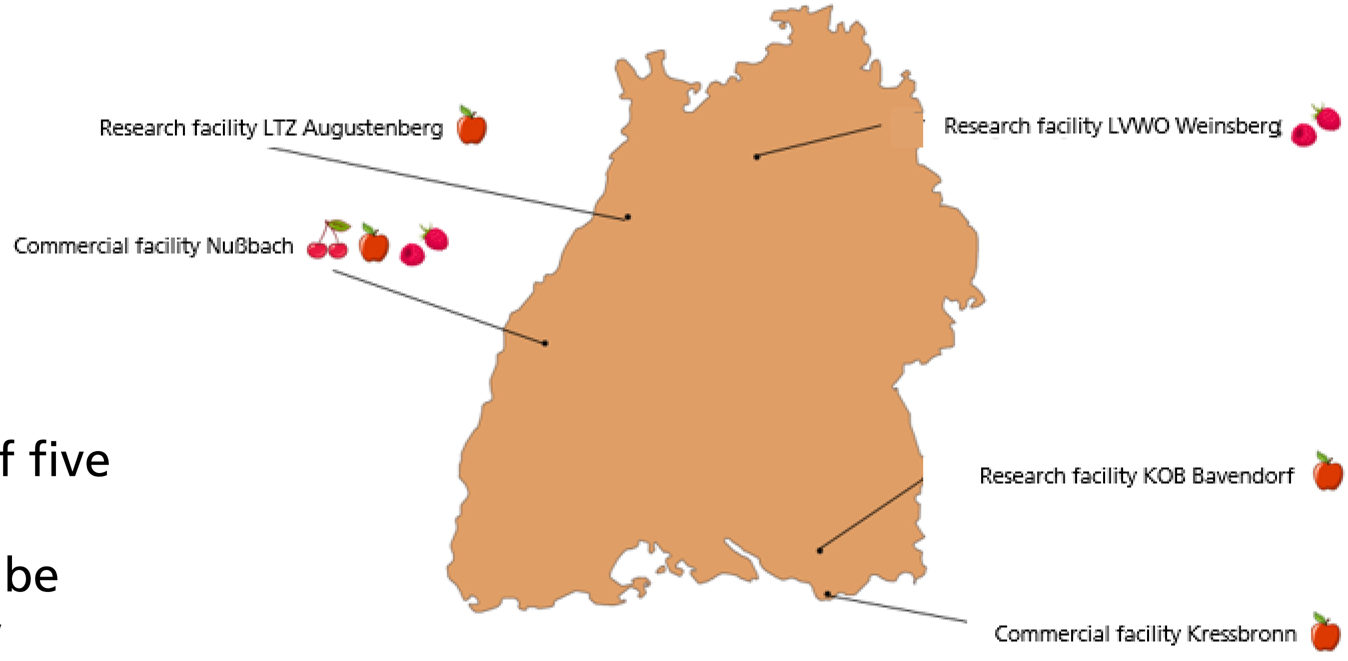
Modellregion Agri-PV-BaWü
Baden-Württemberg



Project duration: Still in conception phase

Topic: With the construction and analysis of five pilot plants in Baden-Württemberg, the potentials and difficulties of Agri-PV are to be identified and the development of the new technology is to be advanced statewide

→ Strong focus on pome fruit

Budget: ca. 4.6 Mio €; ISE 2,5 Mio €

Installed capacity: 1,700 kWp

Approach: Examining suitability of regionally relevant specialty crops as well as their accompanying economic models in the German state of B-W. Provide guidelines for farmers and regulatory authorities.

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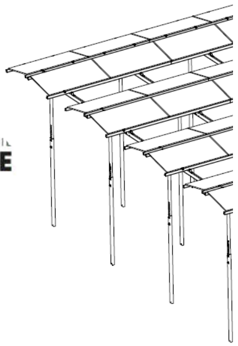
ltz Landwirtschaftliches Technologiezentrum Augustenberg
LVWO Weinsberg
KOB Kompetenzzentrum Obstbau-Bodensee
Hochschule Kehl University of Applied Sciences Verwaltung - Gestalten & Entwickeln
INTECH Clean Energy
Obsthof Vollmer
Obsthof Bernhard
tws
regionalwerk Bodensee
Stadtwerke Oberkirch
Regionalverband Bodensee-Oberschwaben
Regionalverband Südlicher Oberrhein Planen. Beraten. Entwickeln.
Baden-Württemberg Ministerium für Ländlichen Raum und Verbraucherschutz
Baden-Württemberg Ministerium für Umwelt, Klima und Energiewirtschaft



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AGRICULTURAL OPPORTUNITIES AND OBSTACLES

40 YEARS
FRAUNHOFER ISE
#CreatingTheEnergyFuture

Julia Riedelsheimer

07.04.2022

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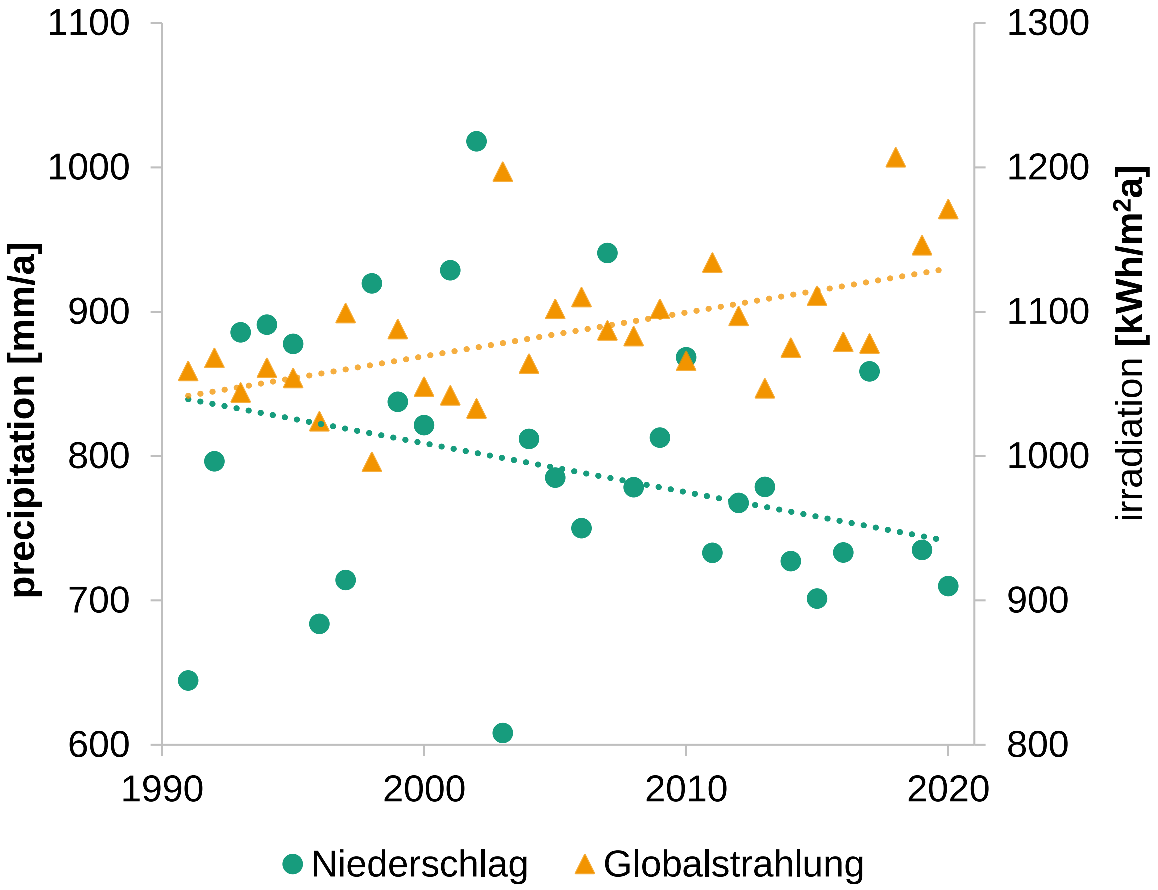
Opportunities
Current Challenges

- Land use conflict (Germany/Europe)
  - Growing damand of population, Increasing need for renewable energy, Decreasing arable land

    → **Increase land use efficiency required**
- Global: climate change issues
  - Increasing temperature, global irradiance and hours of sunshine
  - Heterogenicity of rain events
    - Frequent and long droughts → Reduced precipitation in spring months
    - Heavy rain events
  - Crops need to be protected from sun and rain

    → **Strategies to avoid yield losses/fluctuations needed**



DWD

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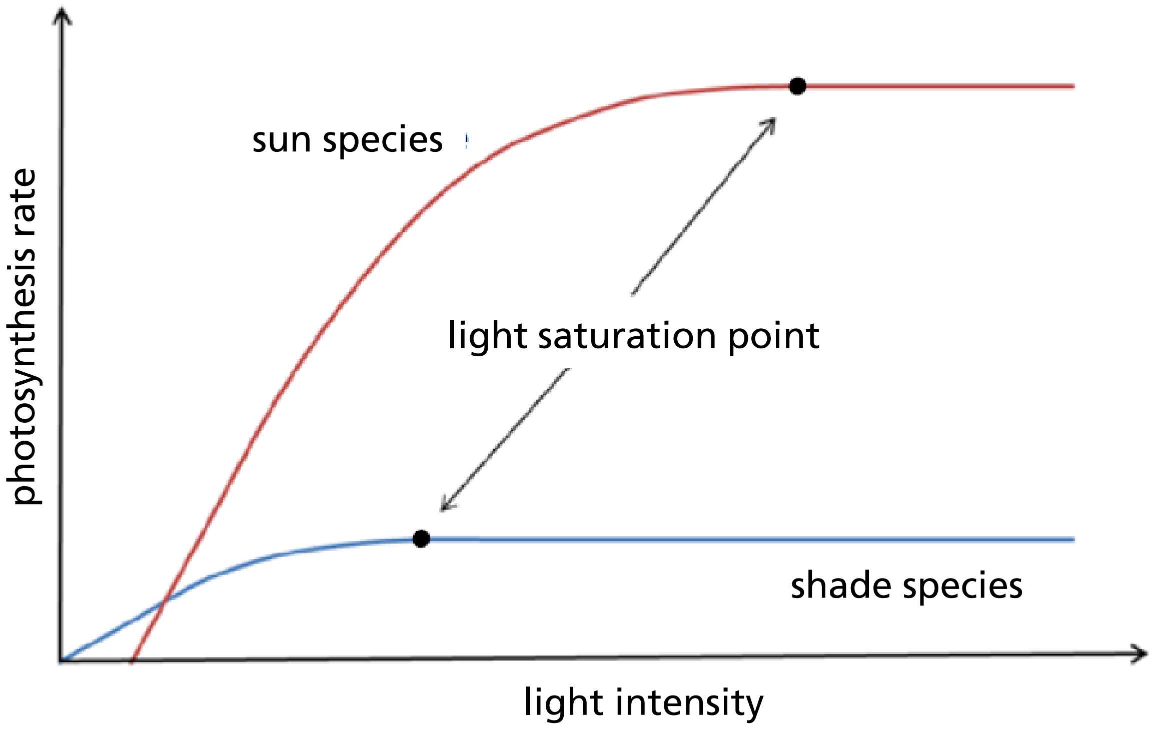
Theoretical Effects of Agrivoltaics
on the Microclimate and the Crops

- Microclimatic changes and the crop's reaction variable
    - Set up of PV construction and crop selection
    - Environmental conditions

- **Light**
    - Dynamic shading reduces crop available radiation
    - Effect on photosynthesis
    - Theoretical relationship between light and photosynthesis rate: light response curve
        - Not linear → shading doesn't necessarily mean yield reduction
        - Impact of shade highly crop specific
        - The light saturation point of C3-plants ranges from 640 W/m² to 790 W/m² (1)



(1): Lambers et al. 2008, Diepenbrock et al. 2016

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Theoretical Effects of Agrivoltaics
on the Microclimate and the Crops

- **Rainwater Distribution**
  - Heterogeneous at surface
  - In deeper layers research needs to be done
- **Air Temperature**
  - Panels buffer daily occurring fluctuations
    - Decrease heat input during day
    - Better retain thermal reflection at night
  - Effect on phenological development
- **Soil Moisture**
  - Decreased Evapotranspiration
  - Effect on drought stress level

Marrou, Guilioni et al. 2013, Elamri et al. 2018 ; Weselek et al. 2021

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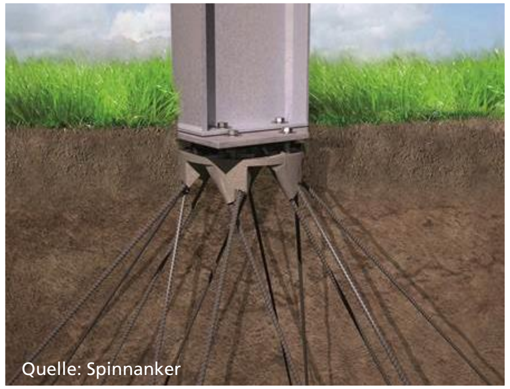
Experiences – arable land
APV RESOLA – Project overview

- Installation: 2016 in Heggelbach, South Germany
- Length/Width: 136 m/ 25 m
- Area: ca. 1/3 ha
- height: 8 m → max. machinery : 5 m
- Installed capacity: 194 kWp
- Crop rotation (S16/17 u. 17/18): Clover grass, Celery, Winter wheat, Potato)


Quelle: BayWa r.e.


Quelle: Spinnanker

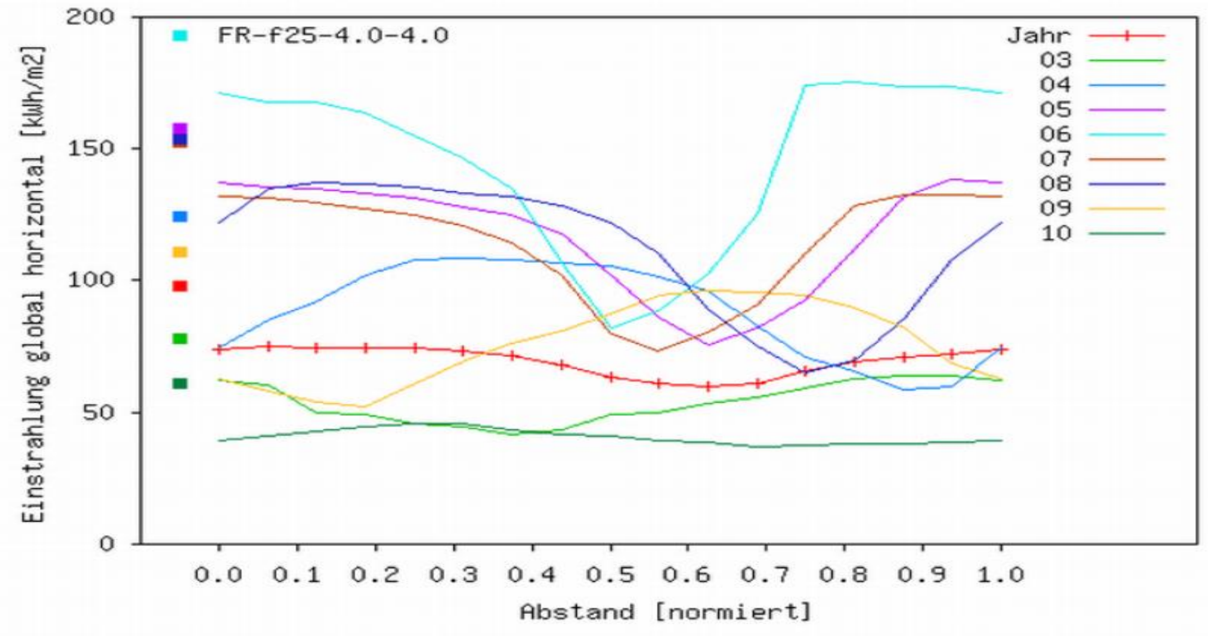

© Fraunhofer ISE

Experiences – arable land

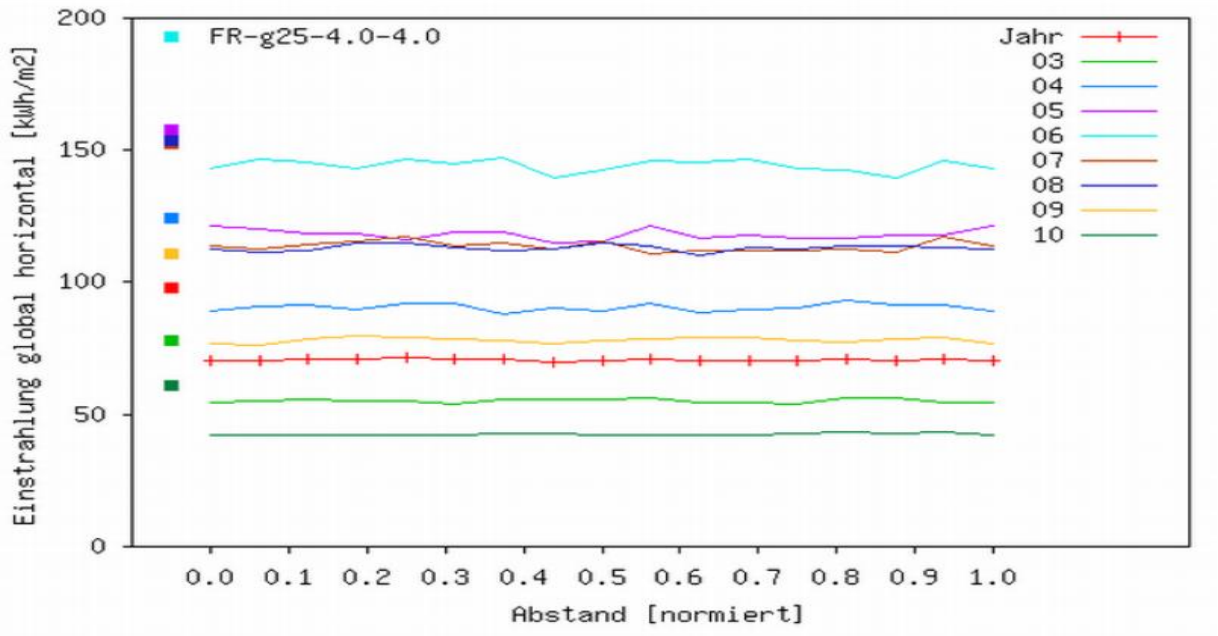
APV RESOLA – Project overview

- Orientation

Towards South



Towards South West

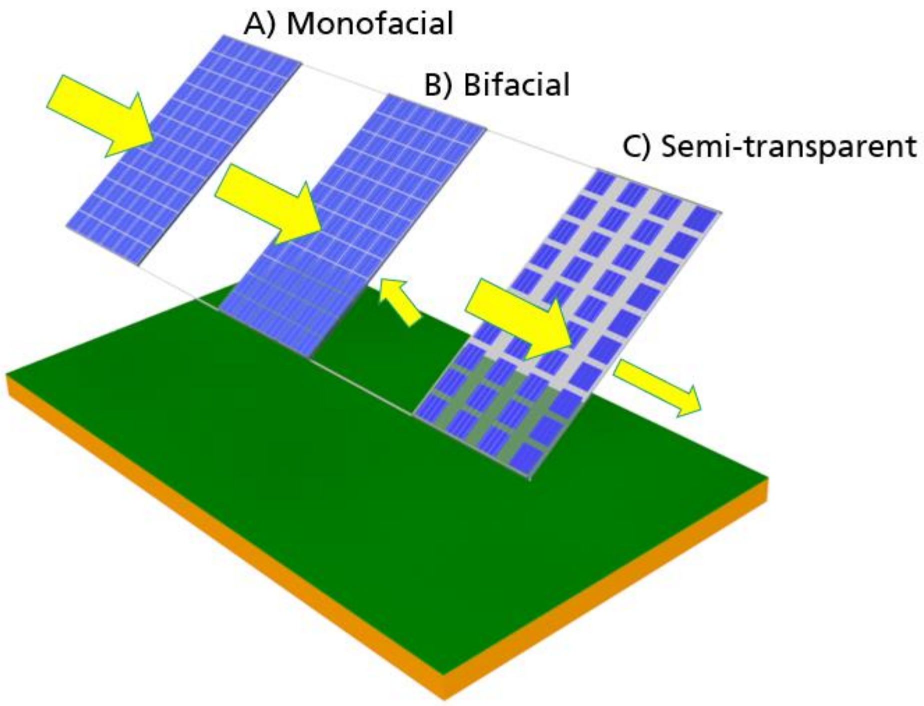


Fraunhofer ISE, Beck et al 2012

Experiences – arable land

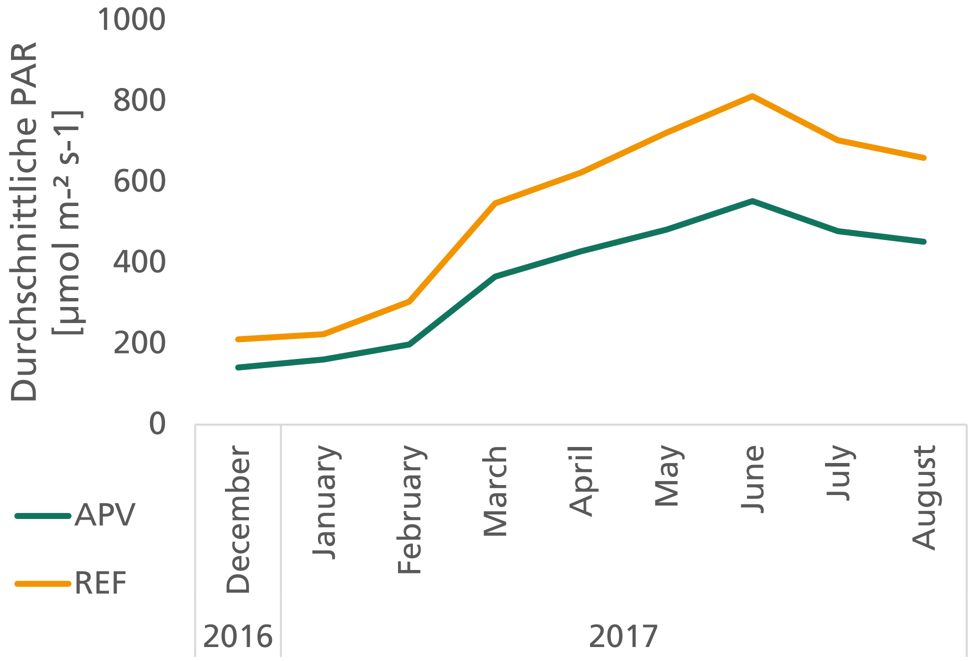
APV RESOLA – Project overview

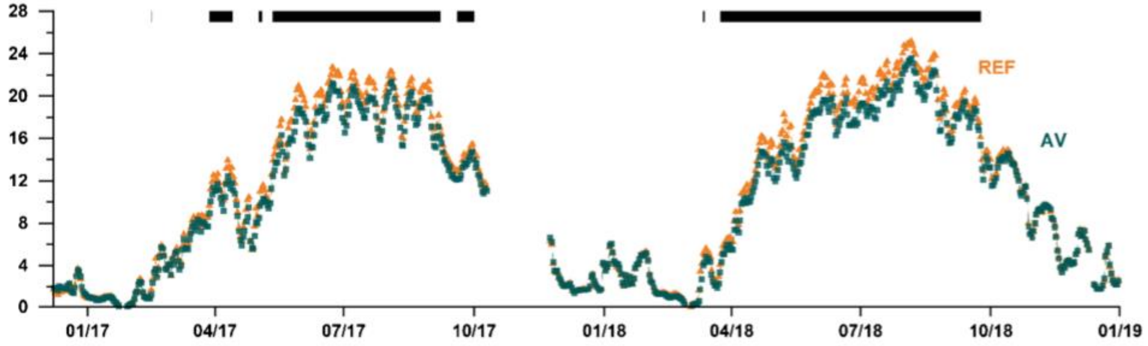
- Modules:
  - Monofacial:
    - Biggest market share
  - Bifacial:
    - Two-sided power generation
    - Double-glas design
    - Stronger yield increases in Agri-PV due to height and row spacing
  - Semi-transparent:
    - c-Si cells with larger spacing
    - Degree of transparency can be adjusted
  - OPV:
    - Specral selective



Experiences – arable land
APV RESOLA – Project overview

- Changes
  - Microclimate: reduced soil temperature, increased soil moisture, reduced PAR





Universität Hohenheim, Weselek et al. 2021

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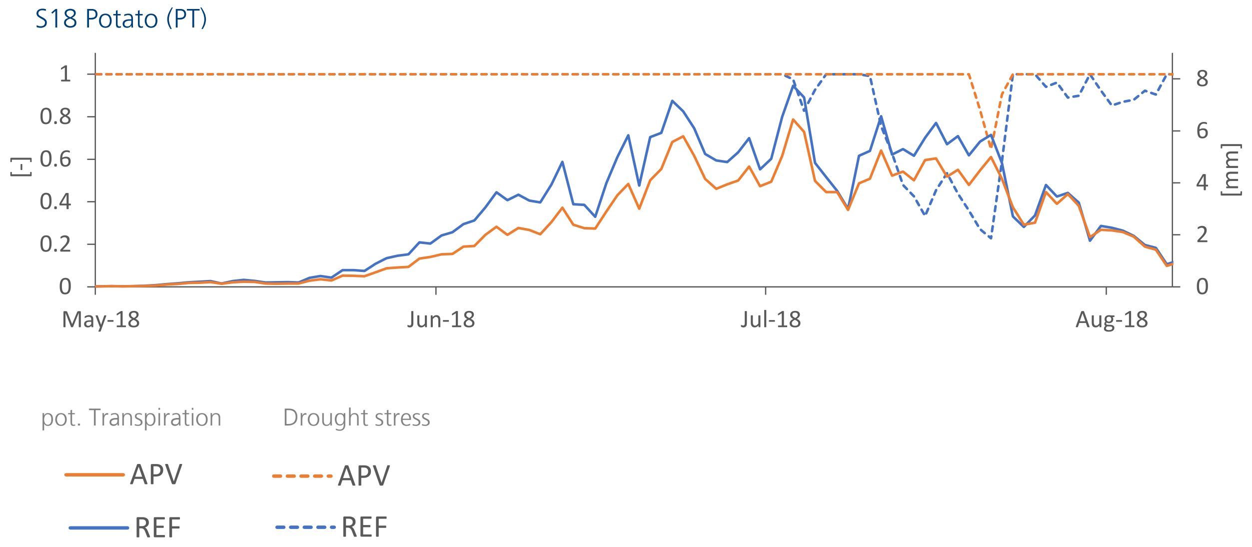
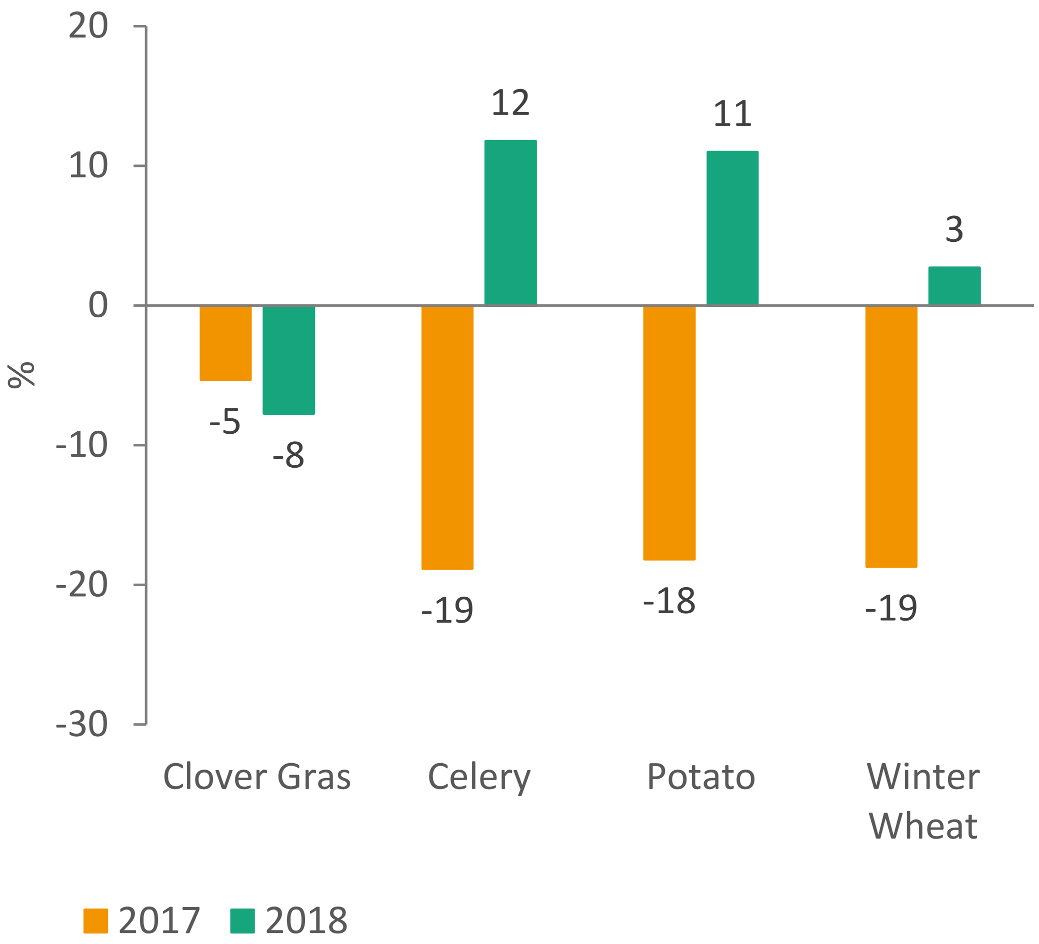
Experiences – arable land

APV RESOLA – Project overview

- Changes
  - Microclimate
  - Yield





Universität Hohenheim

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Speciality crops

Facts

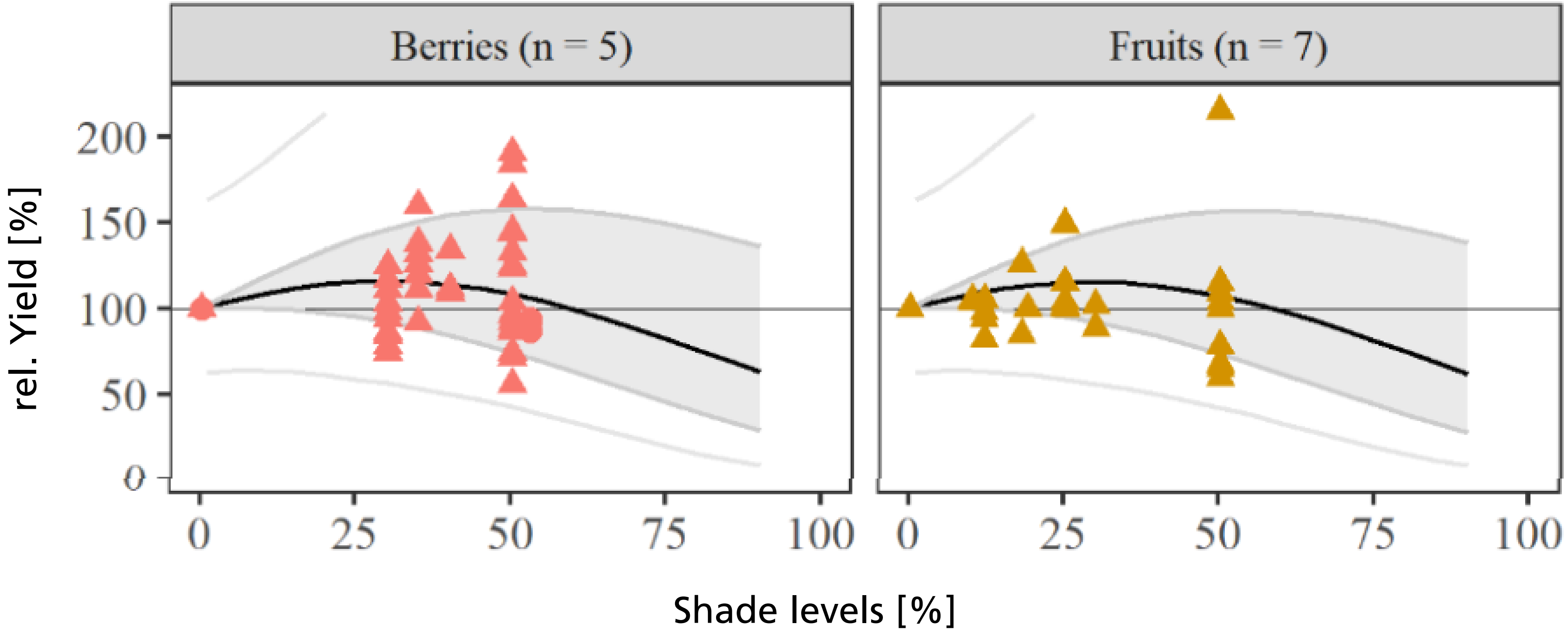
- High demand for protective measures
  - Hail/Heat
    - 2015: 30% of apple fruit area in South GER under hail nets
    - Trend towards Protected cultivation: example raspberry in GER: 9% (2012) to 27% (2017).
- Additional synergies/benefits:
  - Replacement of hail protection nets by Agri-PV.
    - Reduction of plastic
    - Increased acceptance by the population
  - Possibility to reduce pesticides
  - Lower clearance requirements
- Disadvantages: Land potential

- Vineyards
- Berries
- Apples, pears, cherries etc.
- Hops

Garming et al., 2018

Fraunhofer ISE

Speciality crops
Shade tolerances



- Berries: blackcurrant, blackberry (2x), blueberry, strawberry
- Fruits: grapevines, apple (4x), navel orange, lemon

Laub et al., 2022

Speciality crops
Shading potential explained

- Drought
  - Waterstress/ Irrigation need can be reduced
- Temperature
  - F.e. blackberries: Primocane varieties bloom during hottest periods → damage
  - Vineyards: Increase in temperature lead to a change in the quality of vine (change in acid-sugar ratio, alcohol content)
  - Agrivoltaic systems have the potential to lower temperatures
- Late frost
  - Vineyards: Climate change promotes premature budding and flowering → crop failure or even plant damages
  - Agrivoltaic systems have the potential to reduce the risk
- Extreme weather events: Hail/ irradiation (Sun burn)
- Fungal infection
  - Apple: reduced risk of apple scrab


Spätfrostschäden, © LVWO Weinsberg


Sonnenbrand, © LVWO Weinsberg

APV Greenhouses

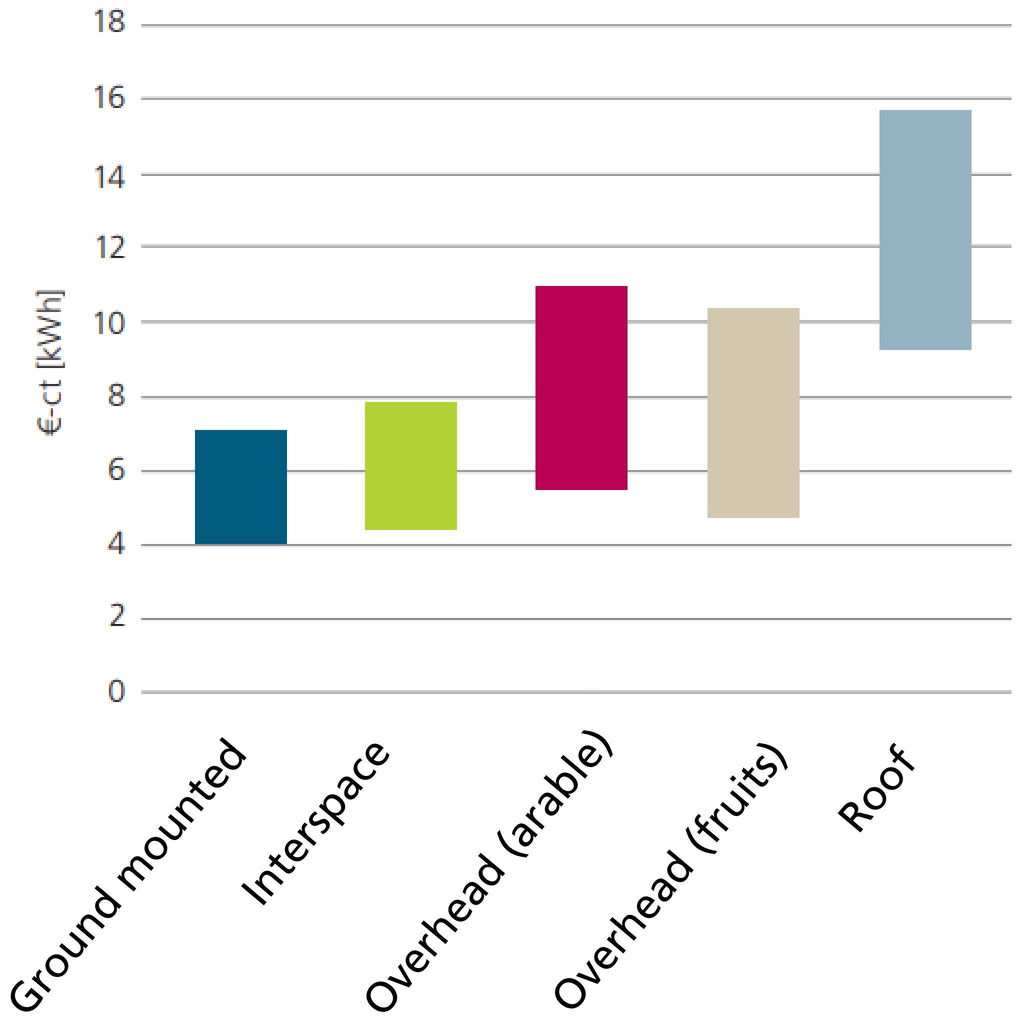
Results from Italy

- Floriculture crops tolerate high light reductions
- Horticulture crops:
  - Rather shade tolerant: max. 10- 25% yield reduction (minus 35-50% PAR)
    - Asparagus
    - Spinach
    - Basil
    - Strawberry
    - Lettuce
  - Very senstive: -20 to -40% yield reduction
    - Tomato
    - Cucumber

Cosu et al., 2020

Challenges

- Identification of suitable crops and shade tolerances
  - Knowledge on how single leaves react to shading
  - Results are difficult to generalize → dependency on: region, variety, weather conditions (year) and developmental stage:
    - F.e. apples require between 60 and 80% of light → tracking system
  - Research needs to be done
- Construction in existing orchards
- Economy: 6ct/kWh vs. 7 to 10 ct/kWh
  - PV-Modules, Subconstruction, preparation/protection of the soil



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Thank you for your Attention!

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Sources:

Beck, M., Bopp, G., Goetzberger, A., Obergfell, T., Reise, C., & Schindele, S. (2012). Combining PV and Food Crops to Agrophotovoltaic – Optimization of Orientation and Harvest. Advance online publication.

Cossu, Marco; Yano, Akira; Solinas, Stefania; Deligios, Paola A.; Tiloca, Maria Teresa; Cossu, Andrea; Ledda, Luigi (2020): Agricultural sustainability estimation of the European photovoltaic greenhouses. In European Journal of Agronomy 118, p. 126074. DOI: 10.1016/j.eja.2020.126074

Diepenbrock, W., Ellmer, F., & Léon, J. (2016). Ackerbau, Pflanzenbau und Pflanzenzüchtung (4th Edition). UTB: Vol. 2629. Verlag Eugen Ulmer, Stuttgart

DWD – Deutscher Wetterdienst: Zeitreihen und Trends https://www.dwd.de/DE/leistungen/zeitreihen/zeitreihen.html?nn=344886#buehneTop

Elamri, Y., Cheviron, B., Mange, A., Dejean, C., Liron, F., & Belaud, G. (2018). Rain concentration and sheltering effect of solar panels on cultivated plots. Hydrology and Earth System Sciences, 22(2), 1285–1298.

Fraunhofer ISE (2020). Agri-Photovoltaik: Chancen für Landwirtschaft und Energiewende. https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/agri-photovoltaik-chance-fuer-landwirtschaft-und-energiewende.html

Garming, H., Dirksmeyer, W. & Bork, L. (2018). Entwicklungen des Obstbaus in Deutschland von 2005 bis 2017: Obstarten, Anbauregionen, Betriebsstrukturen und Handel (Thünen Working Paper), No. 100.

Laub, Moritz; Pataczek, Lisa; Feuerbacher, Arndt; Zikeli, Sabine; Högy, Petra (2021): Contrasting yield responses at varying levels of shade suggest different suitability of crops for dual land-use systems. A meta-analysis.

Lambers, H., Chapin, F. S., & Pons, T. L. (2008). Plant Physiological Ecology. Springer New York, New York.

Marrou, H., Guilioni, L., Dufour, L., Dupraz, C., & Wery, J. (2013). Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels? Agricultural and Forest Meteorology, 177, 117–132.

Marrou, H., Wery, J., Dufour, L., & Dupraz, C. (2013). Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. European Journal of Agronomy, 44, 54–66

Rheinland-Pfalz Kompetenzzentrum für Klimawandelfolgen (o.J.). Weinbau in Rheinland-Pfalz. Abrufbar unter: https://www.kwis-rlp.de/klimawandelfolgen/landwirtschaft/weinbau/

Weselek, A., Bauerle, A., Hartung, J., Zikeli, S., Lewandowski, I., & Högy, P. (2021). Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate. Agronomy for Sustainable Development, 41(5), 1-15.

Bilder:

https://lvwo.landwirtschaft-bw.de/pb/,Lde/Startseite/Fachinformationen/Sonnenbrand+ein+einmaliges+Sonderereignis_?LISTPAGE=669634

https://lvwo.landwirtschaft-bw.de/pb/,Lde/Startseite/Fachinformationen/Checkliste+-+Was+tun+nach+Spaetfrostschaeden+im+Weinberg_?LISTPAGE=669634