# AGRIVOLTAICS FOR ARID AND SEMI-ARID CLIMATIC ZONES

## Technology transfer and lessons learned from Japan and Germany


Max Trommsdorff

Fraunhofer Institute for Solar Energy Systems ISE

*International Webinar Series on Agrivoltaics in Africa*

**Time**: 9:00-10:00 UTC / 18:00-19:00 JST

Thursday, May 13, 2021

www.ise.fraunhofer.com



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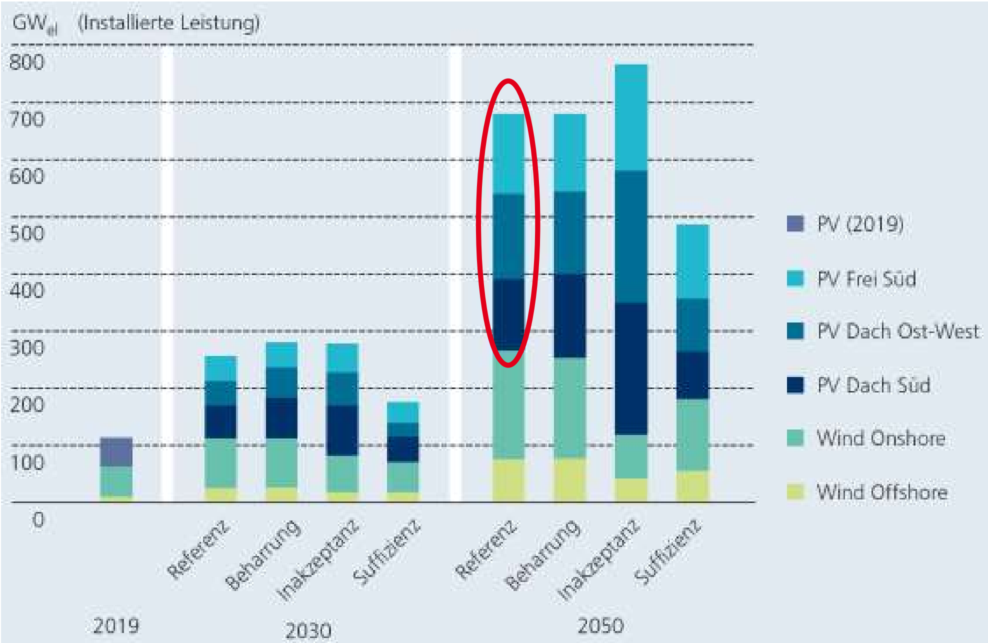
# Agenda

- Introduction: Background, History and Definition of Agrivoltaics
- R&D Results from Germany and Experiences from Japan
- Water-Energy-Food Nexus and Potential for Africa
- Running R&D-Projects of Fraunhofer ISE in Africa

# Challenges of the Energy Transition in Germany
## Political Objectives, Reality, and Demand

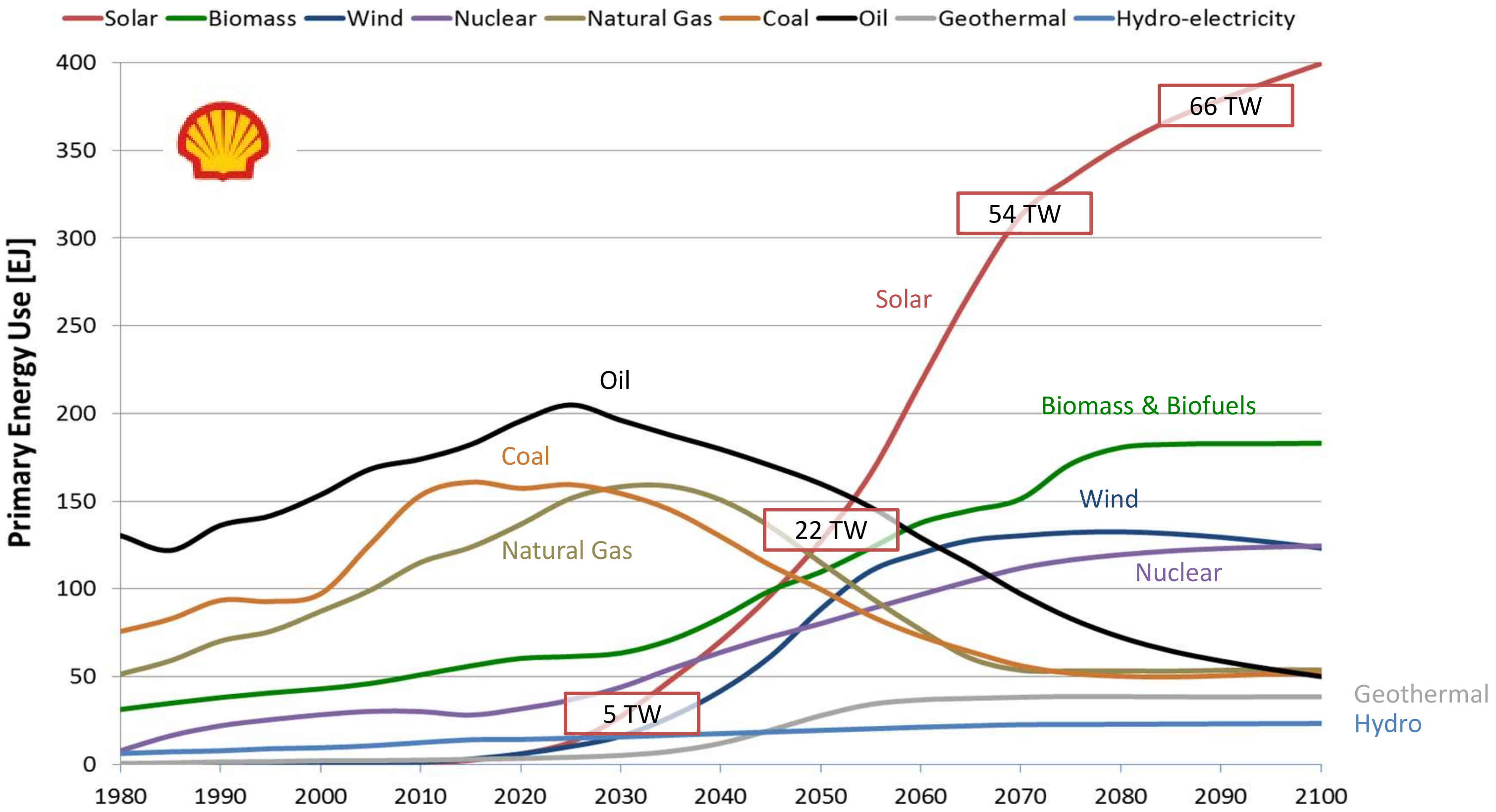
- Greenhouse gas emissions by 2030: -55%
  by 2050: ca. -100%
- Share of Renewable Energy in the electricity consumption by 2030: 65%
- **Electricity demand by 2050: up to 1000 TWh**
- PV-Expansion target by 2030: 98 GW
- PV-Increase 2013-2018 on average: 1,8 GW/a
- PV-Increase 2019: 3,9 GW
- PV-Increase demand by 2030: 5 – 10 GW/a
- **PV-Increase demand by 2050: 400-500 GW**




Cumulative installed capactiy of PV and wind power for four examined scenarios, Fraunhofer ISE Febr. 2020

# Challenges of the Energy Transition - Worldwide

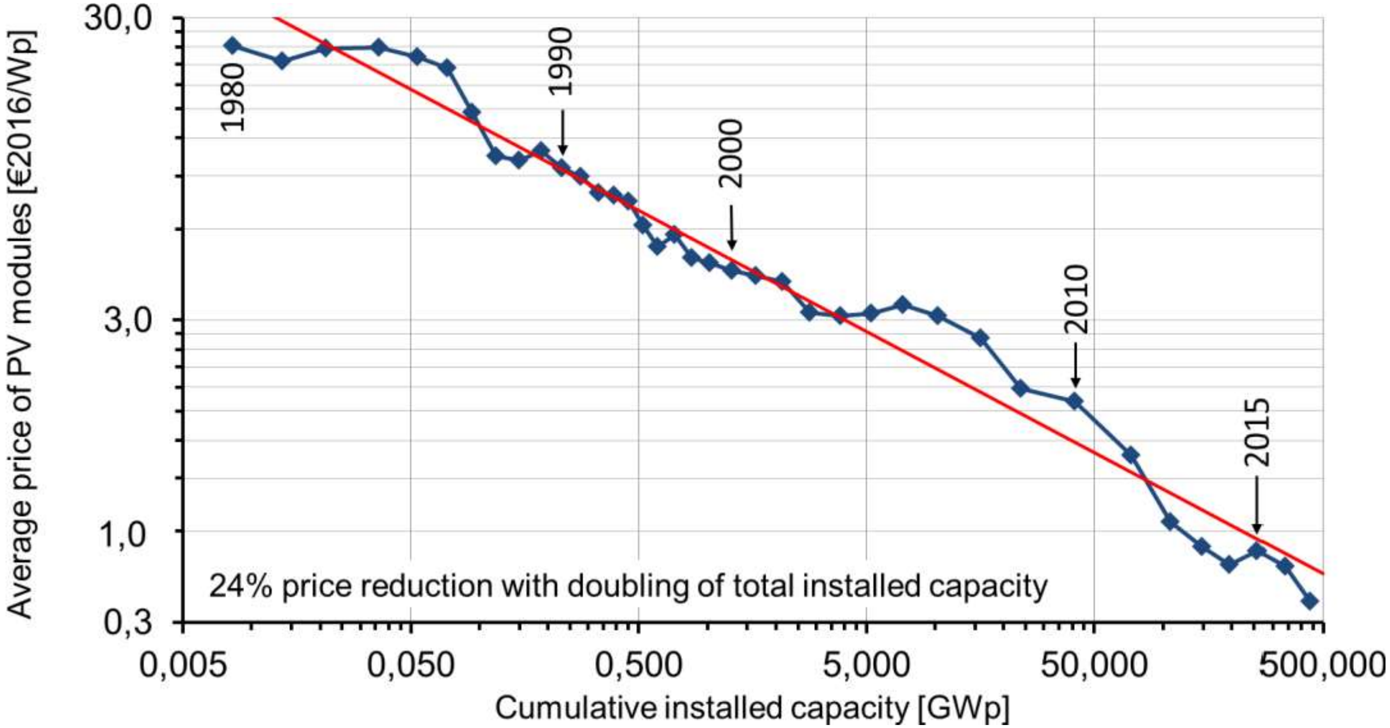
## Energy Market Scenario by Shell: PV dominating




https://www.carbonbrief.org/in-depth-is-shells-new-climate-scenario-as-radical-as-it-says

# Challenges of the Energy Transition - Worldwide

## Photovoltaics: Price Development of Modules







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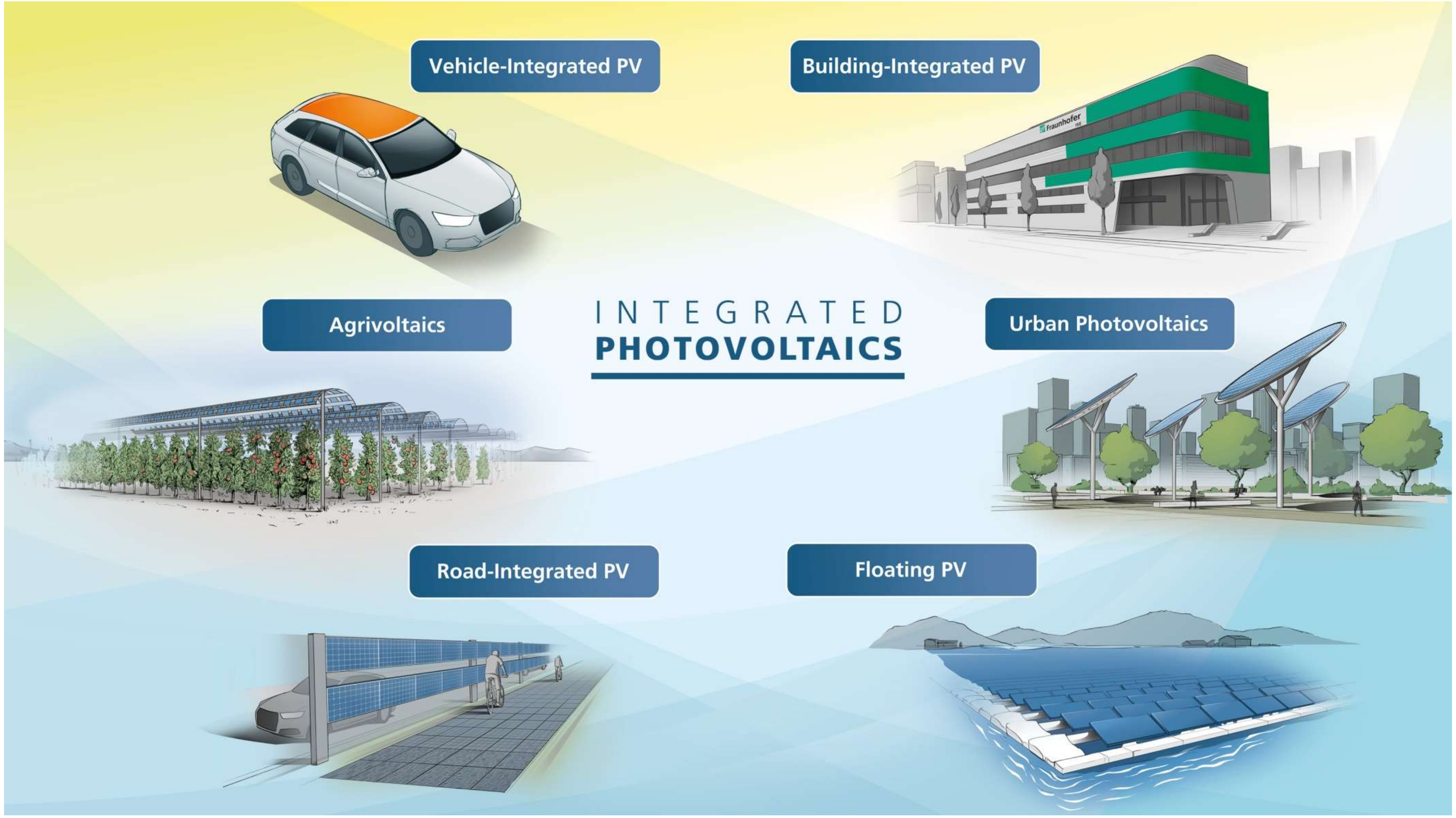
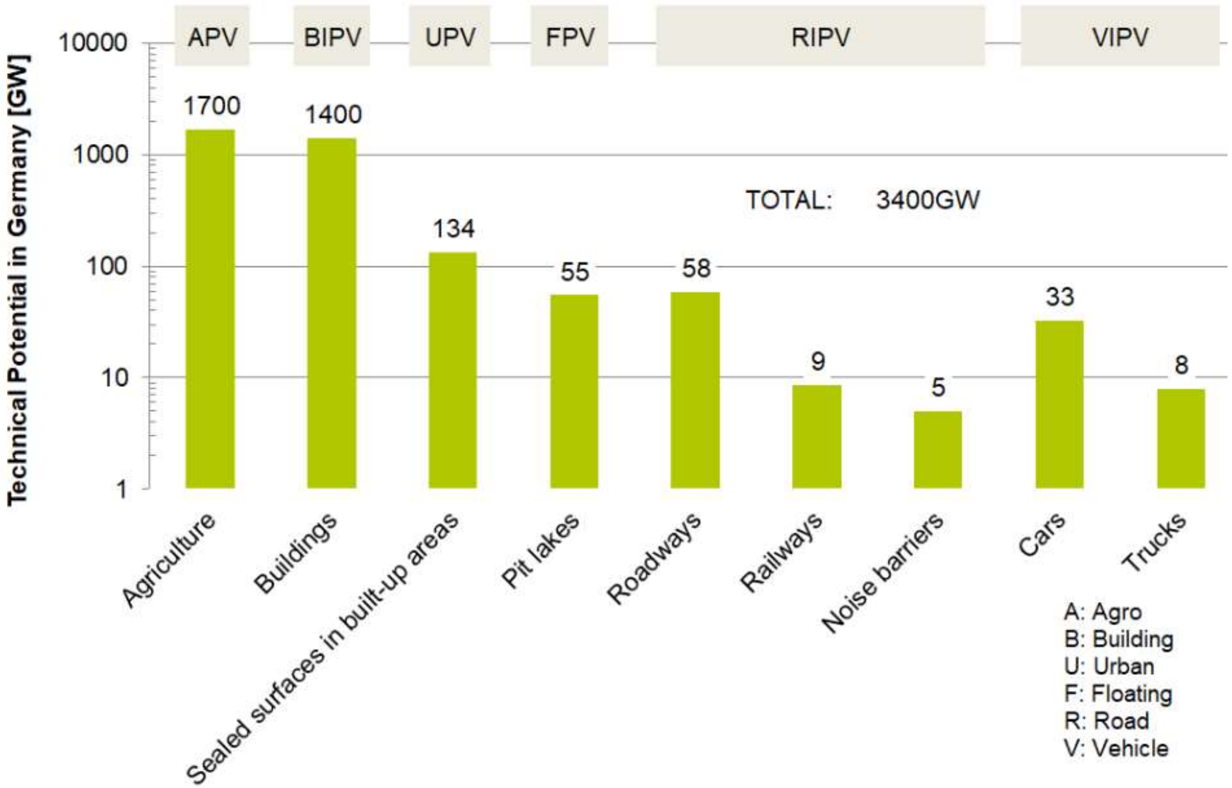
# Examples of Integrated Photovoltaics



# Challenges of the Energy Transition
## Technical Land Potential in Germany

**Technical Potential**

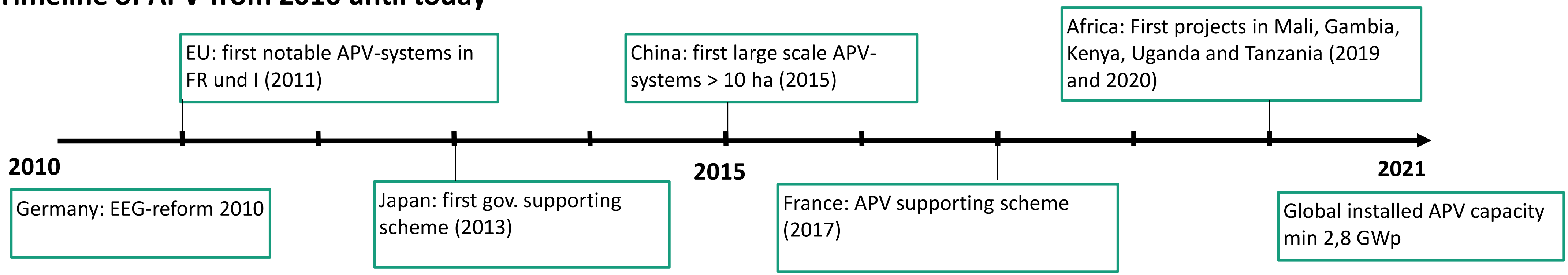
Consideration of technical, infrastructural and ecological constraints



# Agrivoltaics – From the Idea to the Implementation
## Brief History

- From 2000 EEG feed-in tariffs for Renewable Energies
- PV „revolution“
- First large scale ground-mounted PV plants (PV-GM)
- EEG-reform 2010: PV-GM only in exceptional cases on arable land
- The time has come for agrivoltiacs

### Timeline of APV from 2010 until today



What is agrivoltaics?

# Definitions, Classifications, and Standards of Agrivoltaics

## Diversity of Agrivoltaics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## Diversity of Agrivoltaics


Source: Corditec


Source: Green Source Technology



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# Definitions, Classifications, and Standards of Agrivoltaics

## Diversity of Agrivoltaics


Source: NREL


Source: ÖKO-HAUS GmbH

# Definitions, Classifications, and Standards of Agrivoltaics

## Diversity of Agrivoltaics






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# Definitions, Classifications, and Standards of Agrivoltaics
## Diversity of Agrivoltaics

Source: Ourjiangsu

Source: CVE

# Definitions, Classifications, and Standards of Agrivoltaics

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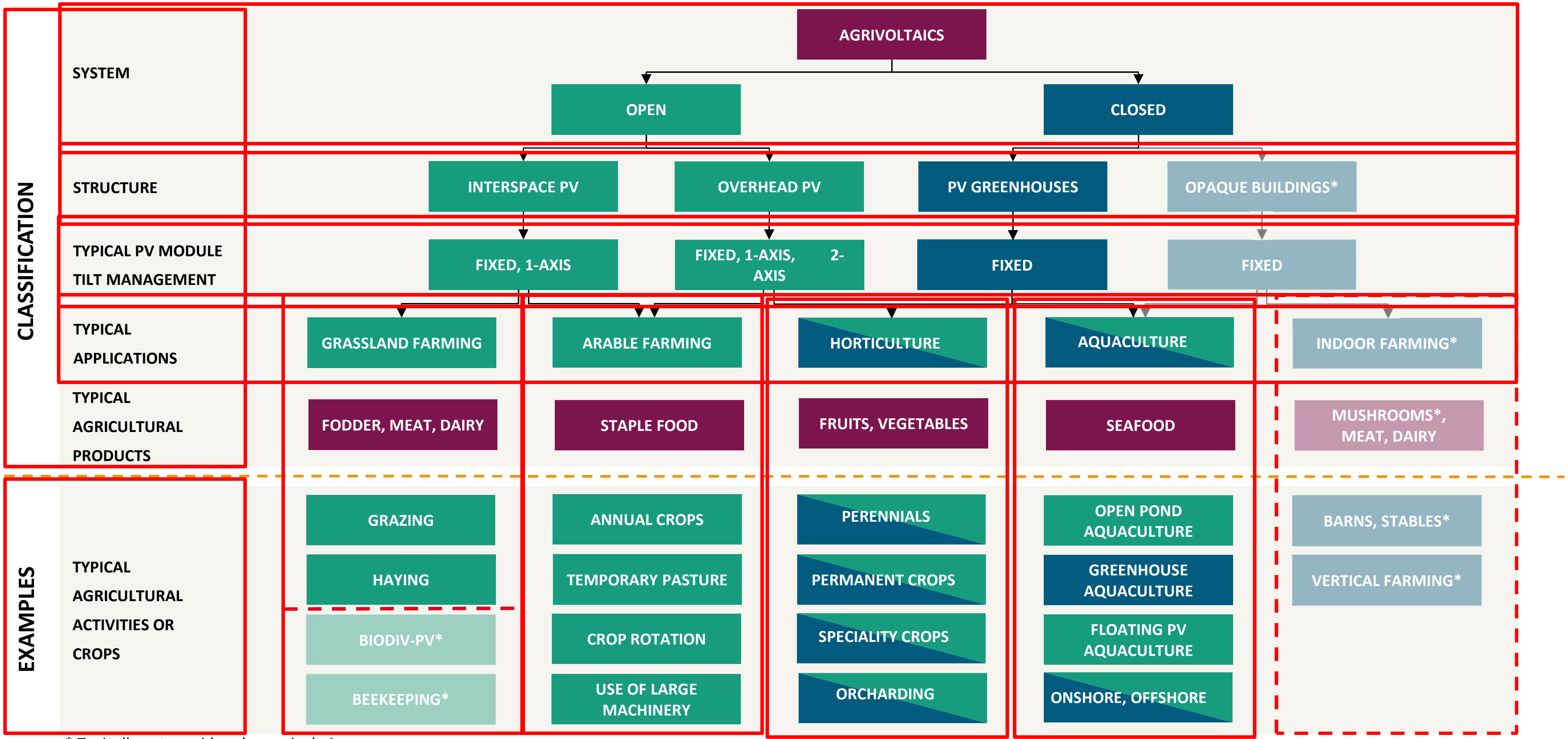
# Definitions, Classifications, and Standards of Agrivoltaics

## Photosynthesis as a Criterion for Agrivoltaics

- Japan: Term “solar sharing” suggests that agricultural production in agrivoltaics relies on direct solar insulation
- Fraunhofer ISE: “Agrivoltaics is a combined use of an area for agricultural crop production (photosynthesis) and PV electricity production (photovoltaics).”

# Classification of Agrivoltaic Systems




* Typically not considered as agrivoltaics



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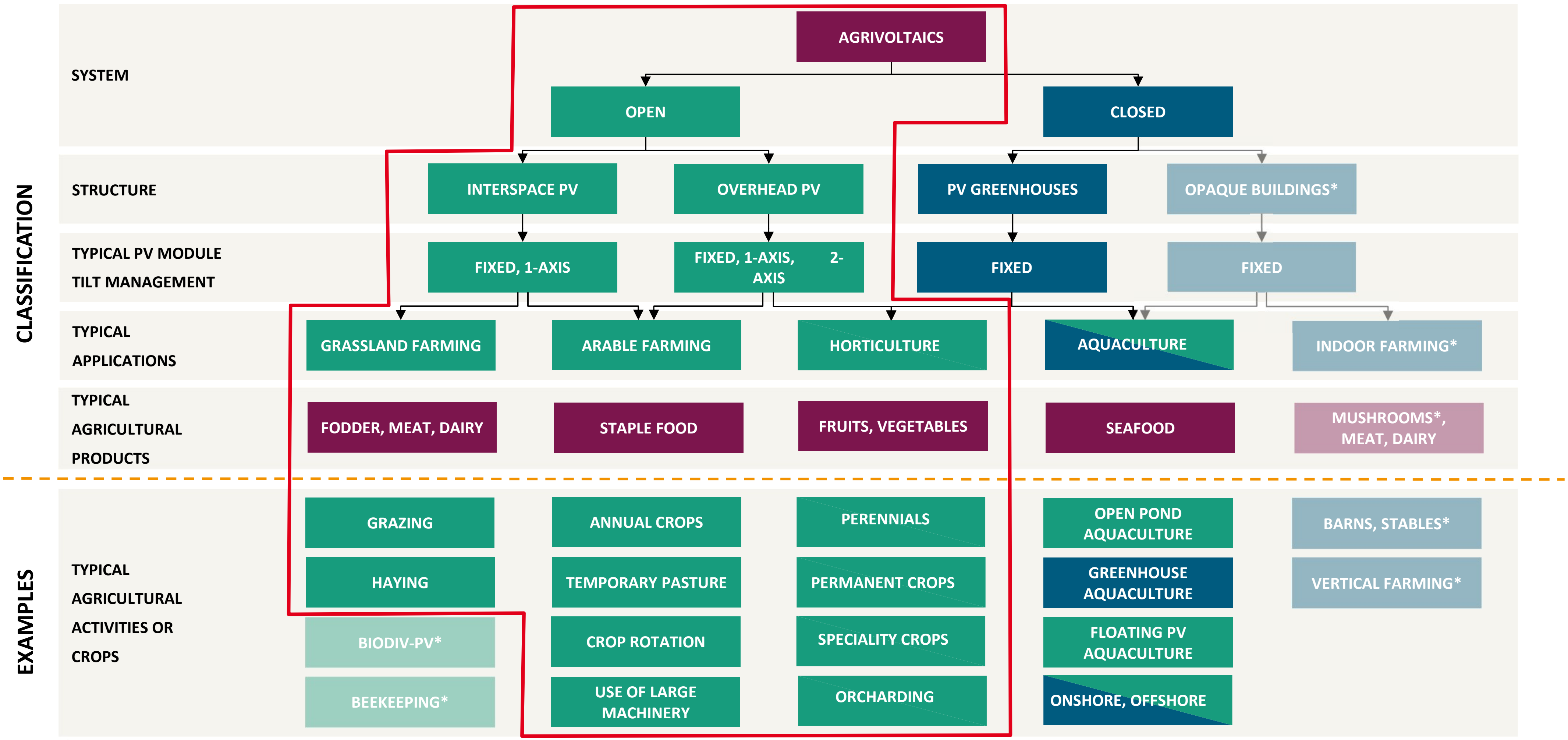
# Narrow Classification Open Systems without Aquaculture




* Typically not considered as agrivoltaics



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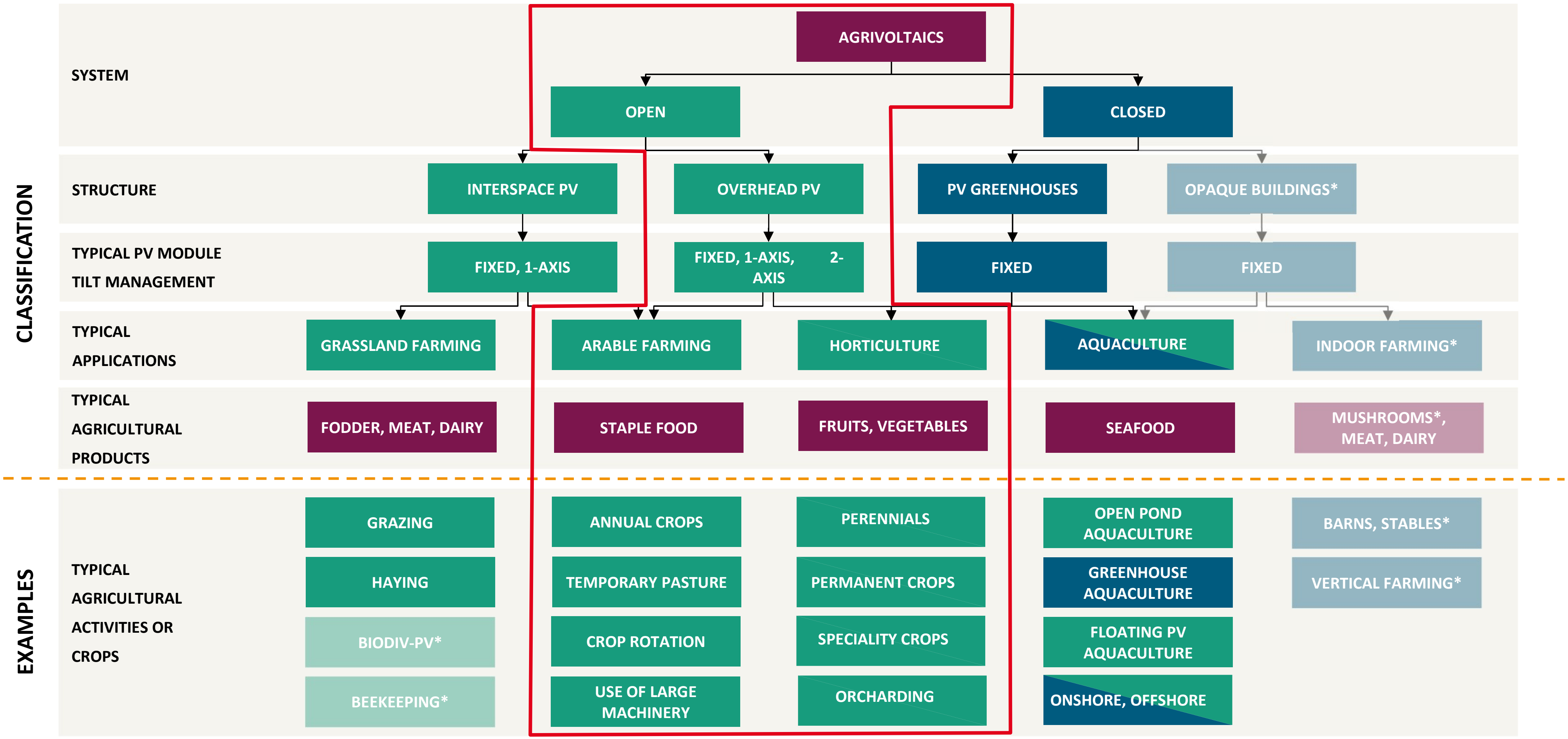
# Narrow Classification Open Overhead Systems without Aquaculture




* Typically not considered as agrivoltaics

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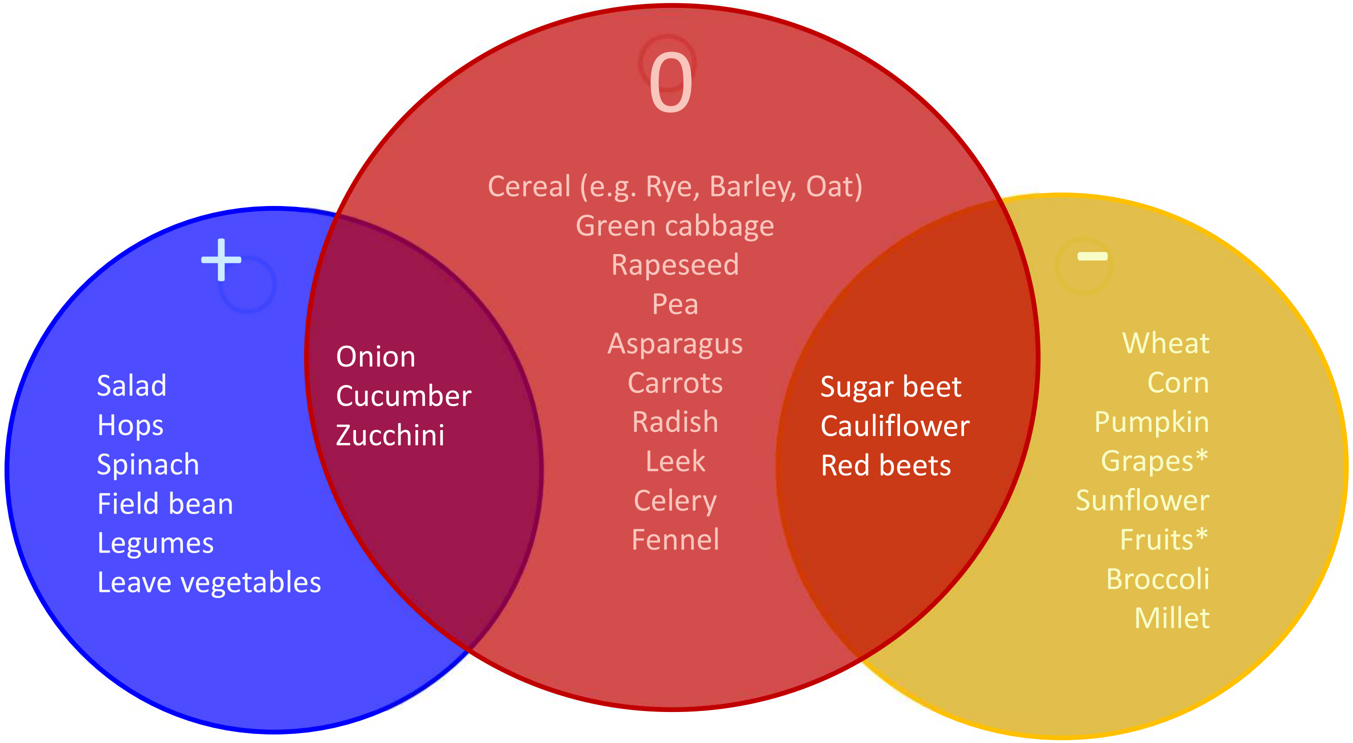
# Research Results from Germany/APV-RESOLA

## Shade Tolerance: Classification of the Most Relevant Crops in Germany




Source: Fraunhofer ISE

* Dependent on species and type



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FONA Forschung für nachhaltige Entwicklungen BMBF
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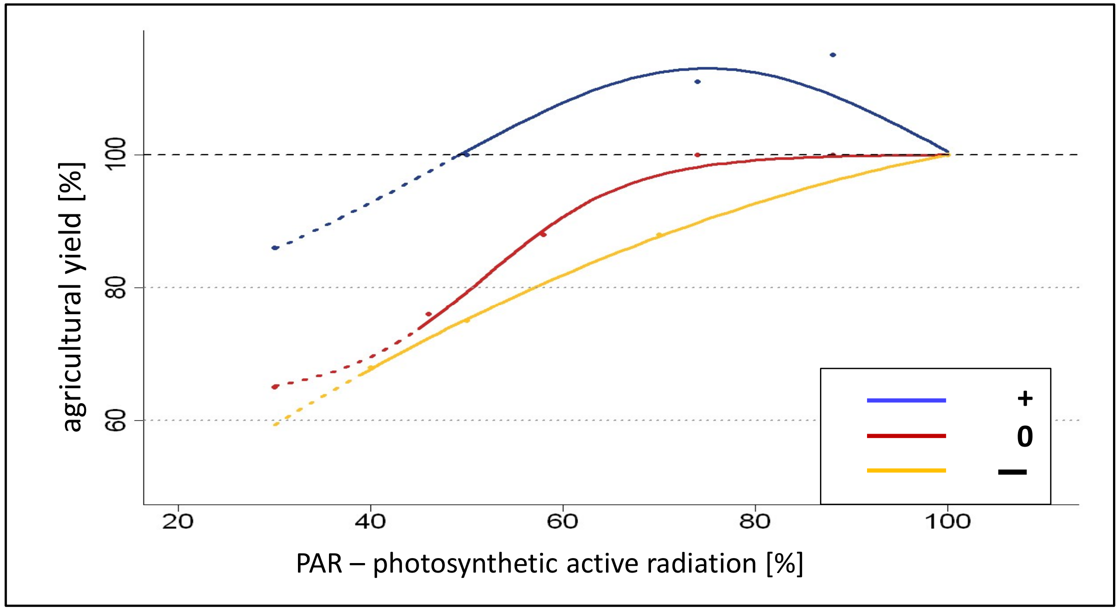
# Research Results from Germany/APV-RESOLA

## Selection of the „right“ Arable Crops or Crop Rotations




| Kategorie | Referenzart |
|---|---|
| + | Berries, Leaf Vegetables |
| 0 | Rape & Barley, Potatoes |
| - | Corn |

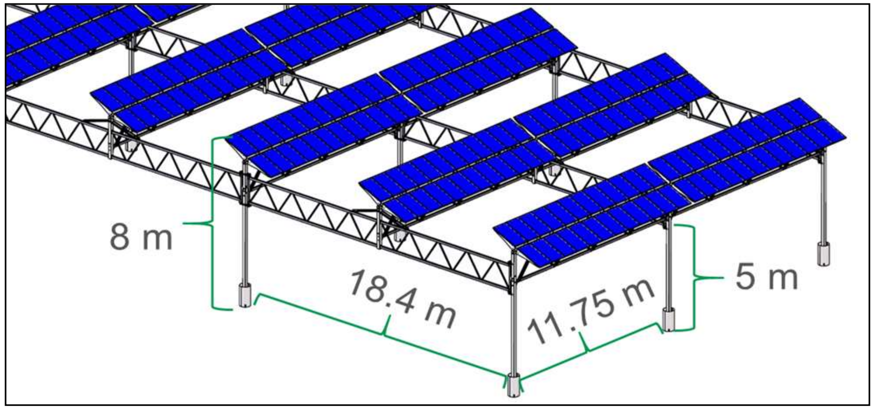
Source: Fraunhofer ISE

- Shade tolerant arable crops exist
- Many arabale crops suffer from to high solar radiation
- Increase in yield and quality improvement through shading is possible
- Reduction of water shortages

# Research Results from Germany/APV-RESOLA

## Pilot Plant in Heggelbach: Facts and Figures I

- Installed: 2016 in Heggelbach
- Region: Bodenseekreis
- Length: 136m
- Width: 25m
- Height: 8m
- Area: ~ 1/3 ha
- Vertical clearance : 5m
- Installed capacity : 194 kWp
- Crops: clover, celery, potatoes and winter wheat




Source: Hilber Solar

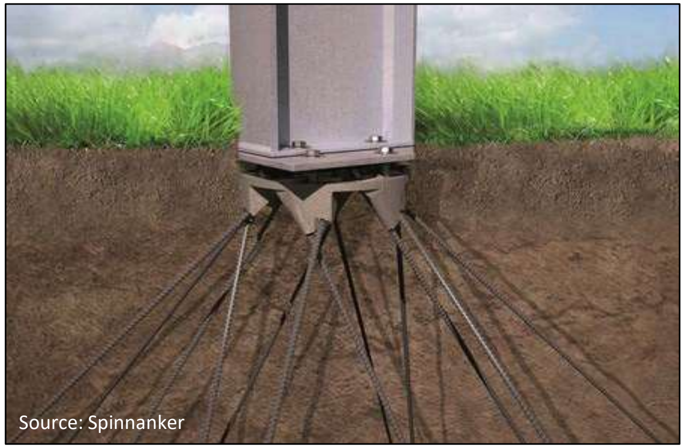
# Research Results from Germany/APV-RESOLA

## Pilot Plant in Heggelbach: Facts and Figures II

- Light management
- Fixed-tilt towards southwest
- Bifacial glas/glas  PV-modules
- Yield monitoring
- Passageway for agricultural machinery
- Rain water distribution
- Spinnanker fundaments
- Ram protection
- No fence
- Cross Compliance: high environmental sustainability


Source: BayWa r.e.


Source: BayWa r.e.


Source: Spinnanker



BayWa r.e.
Gefördert vom Bundesministerium für Bildung und Forschung
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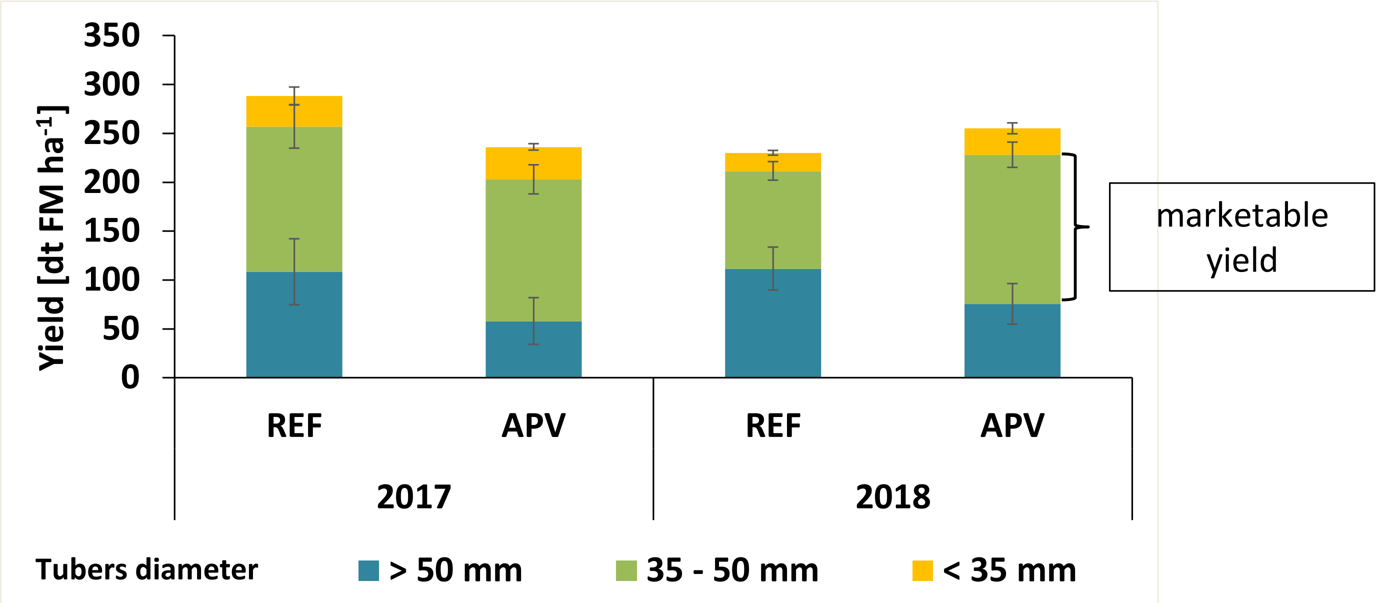
# Research Results from Germany/APV-RESOLA

## Agriculture: Example Yield Potatoes




Source: Universität Hohenheim



- 2017: Yield under agrivoltaic reduced by 18 %
- 2018: Yield under agrivoltaic increased by 11 %
- Higher share of tubers with diameter 35 - 50 mm under agrivoltaic in both harvests



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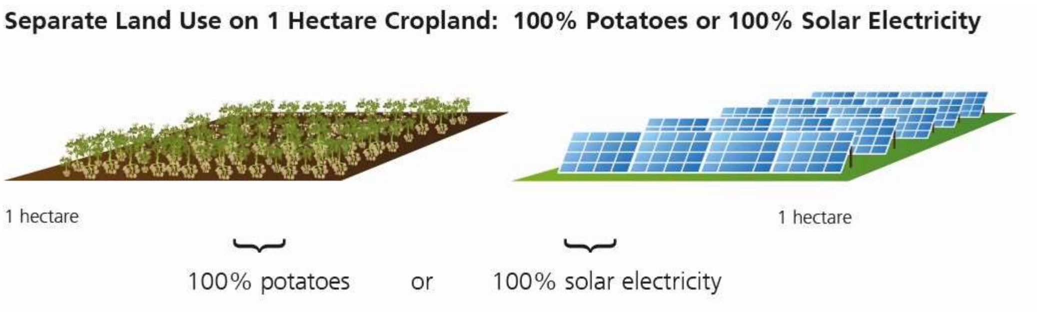
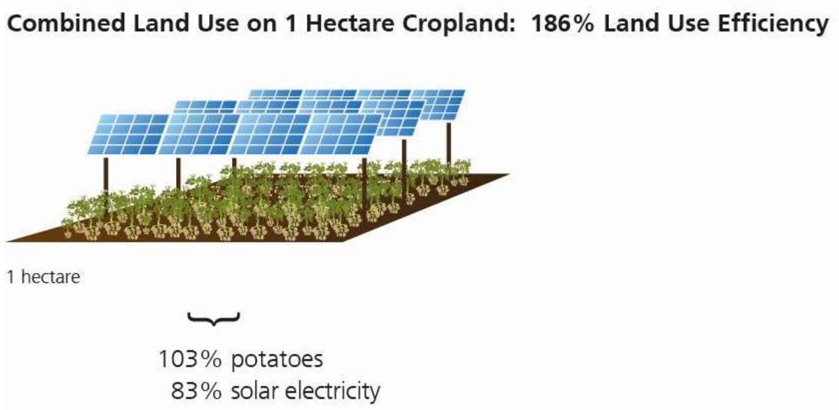
# Research Results from Germany/APV-RESOLA

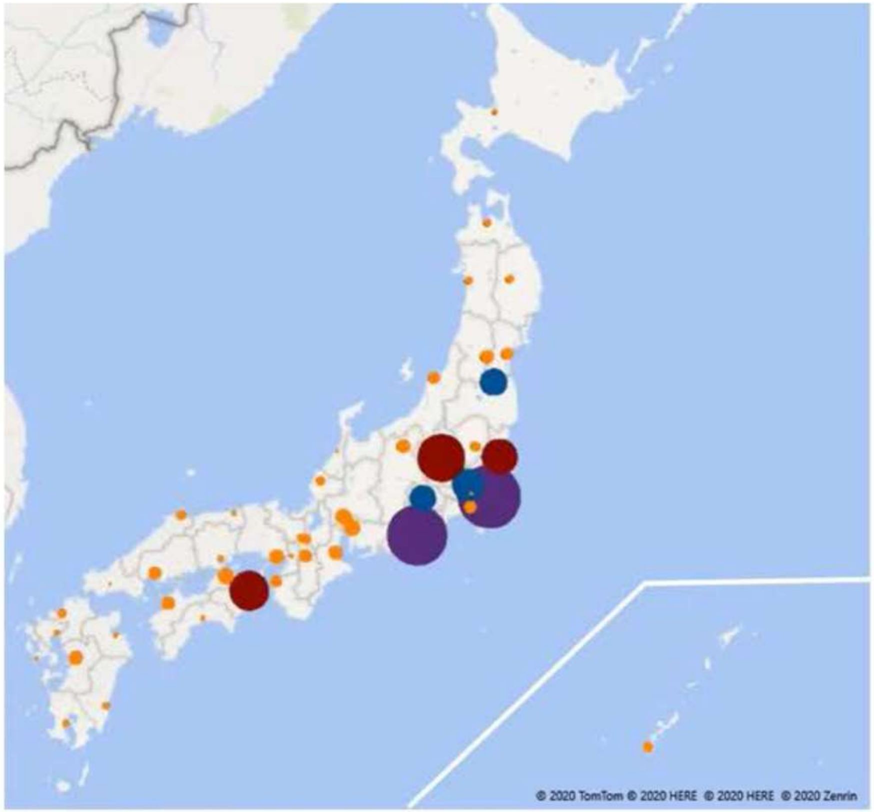
## LER: Potatoe Yield 2018




- Crop: potatoes
- $LER\ 2018 = \dfrac{255{,}26\,\frac{dt}{ha}\,(dual)}{230{,}02\,\frac{dt}{ha}\,(mono)} + \dfrac{249.857\,\frac{kWh}{a}(dual)}{301.032\,\frac{kWh}{a}(mono)} - 0{,}083\ = 1{,}86$
- Extension of potential PV area without land use conflicts
- Improvement of land use efficiency between 60 – 90 % possible in Germany
- Large potential in regions with land scarcity and in arid / semi-arid climate zones

# Agrivoltaics in Japan
## Development and Distribution of Agrivoltaic Systems (by 2019)




Over **1,992 farms** in all 47 prefectures but Toyama

| | Prefecture | # farms |
|---|---|---|
| Purple circle (large) | Chiba<br>Shizuoka | 298<br>264 |
| Red circle | Gunma<br>Tokushima<br>Ibaraki | 196<br>131<br>111 |
| Blue circle | Saitama<br>Fukushima<br>Yamanashi | 100<br>75<br>67 |
| Orange dot | 38 other prefectures | < 50 |

Source: Ministry of Agriculture, Forestry and Fisheries, About the permission record to install agrivoltaic facilities (as of the end of March 2019), 2019.



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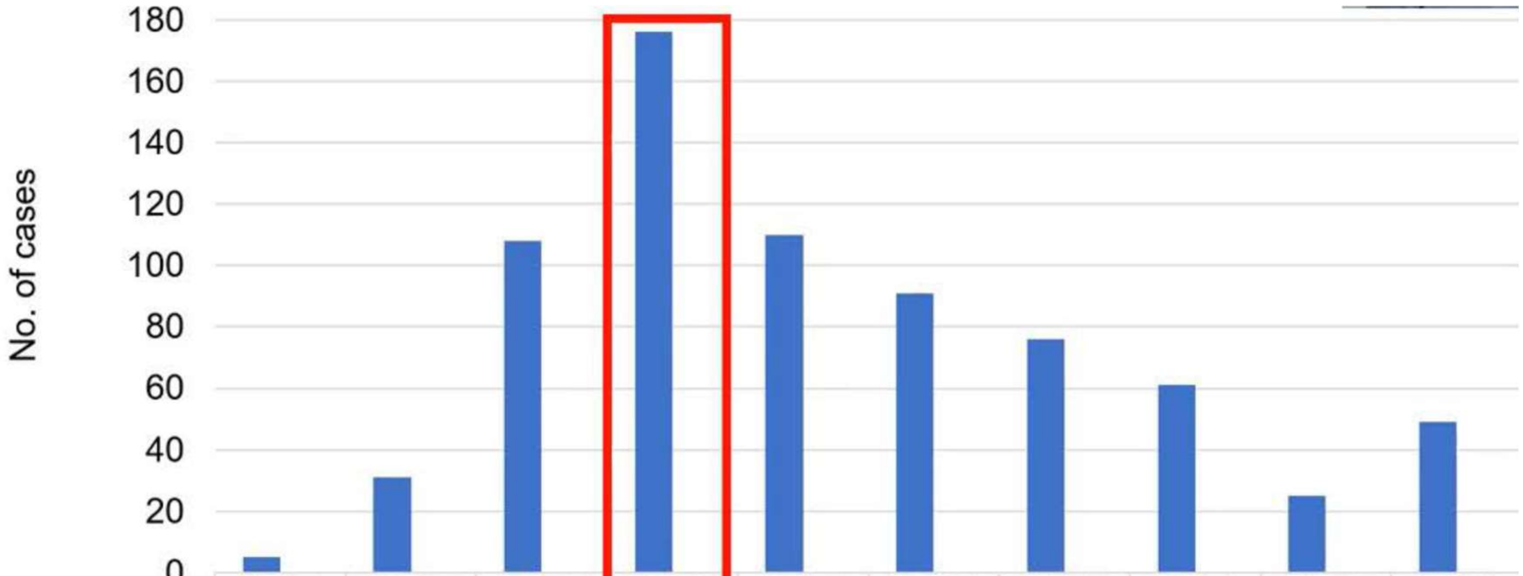
# Agrivoltaics in Japan
## Main Cultivated Crops in Agrivoltaic Systems

| Agrivoltaic Crops |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| **Common name** | *mioga* ginger | Japanese cleyera | paddy rice | shiitake mushroom | blueberry | *fuki* / butterbur |
| **Scientific name** | *Zingiber mioga Rosc.* | *Cleyera japonica* | *Oryza sativa* | *Lentinula edodes* | *Cyanococcus spp.* | *Petasites japonicus (Siebold et Zucc.) Maxim.* |
| **No. of AV farms** | 65 | 41 | 35 | 31 | 20 | 18 |
| **Average shading rate (%)** | 60.2 | 65.9 | 35.1 | 73.4 | 35.9 | (shade tolerant) |

Source: Chiba University Kurasaka Laboratory and NPO Regional Sustainability Research Institute, Report on the results of nationwide survey on solar sharing, 2019.
H. Kurasaka, Journal of Japan Solar Energy Society **45** (6), 14-18 (2019).
Ministry of Agriculture, Forestry and Fisheries, Current status of agrivoltaic facilities, 2018.

# Agrivoltaics in Japan
## Main Cultivated Crops in Agrivoltaic Systems




| | 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% |

Source: Ministry of Agriculture, Forestry and Fisheries, Current status of agrivoltaic facilities, 2018.



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# Water-Energy-Food Nexus
## Synergies and Potentials

Highest benefits in hot and sunny arid and semi-arid regions

- High insolation throughout the year
- Shading leads to less crop water requirements, less heat stress
- Improved working conditions through shadowing
- Effective measure against desertificat

Source: Sahara Forrest Project SFP Jordan

Source: Sahara Forrest Project SFP Jordan



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# Water-Energy-Food Nexus
## Synergies and Potentials

- Low evaporation (approx. 20%)
- Dual use of water for module cleaning and irrigation
- Integration of irrigation devices in substructure
- Availablility of electricity for
  - Water pumps (good match of generation and consumption)
  - Desalination / water treatment
- Rainwater Harvest
- Revegetation of the desert


Source: Solar Research Center Jodhpur, India


Source: Solar Research Center Jodhpur, India



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# Water-Energy-Food Nexus
## A third harvest: Rainwater

Concept

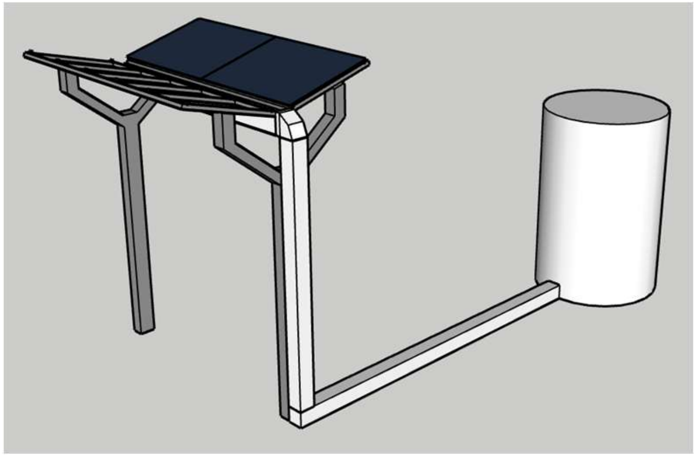
Rainwater harvesting (RWH) integrated into agrivoltaics mounting structure

Research

Simulations - rainwater harvesting capacity, effect of V-shape design on electrical yield and solar irradiation below PV modules

Findings & Benefits

- Opposite facing PV modules may result in greater volumes of rainwater collected
- V-shape has minimal impact on electrical yield particularly in equatorial areas
- Low impact on light transmission to crops
- Material cost savings



Conceptual design of rainwater harvesting APV with storage

# Food-Energy-Water Nexus

## Potential of RWH: Case study India

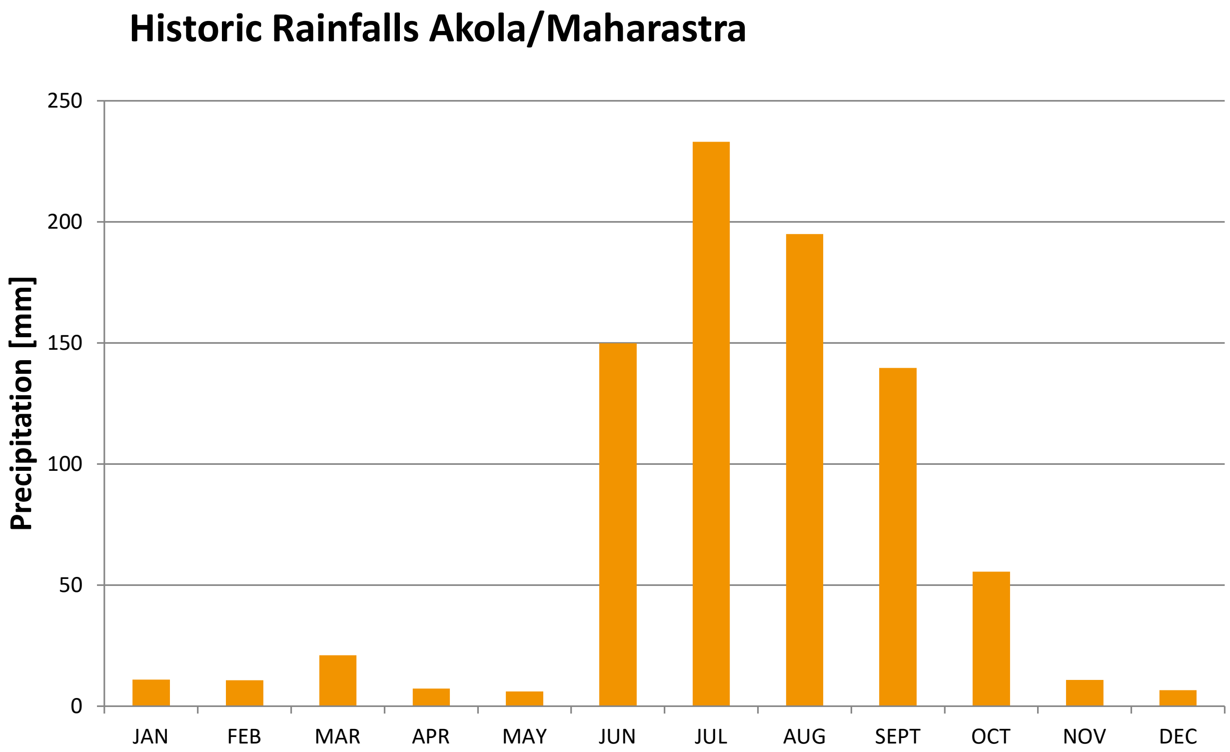



Illustration: Fraunhofer ISE

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# Food-Energy-Water Nexus

## Potential of RWH: Case study India

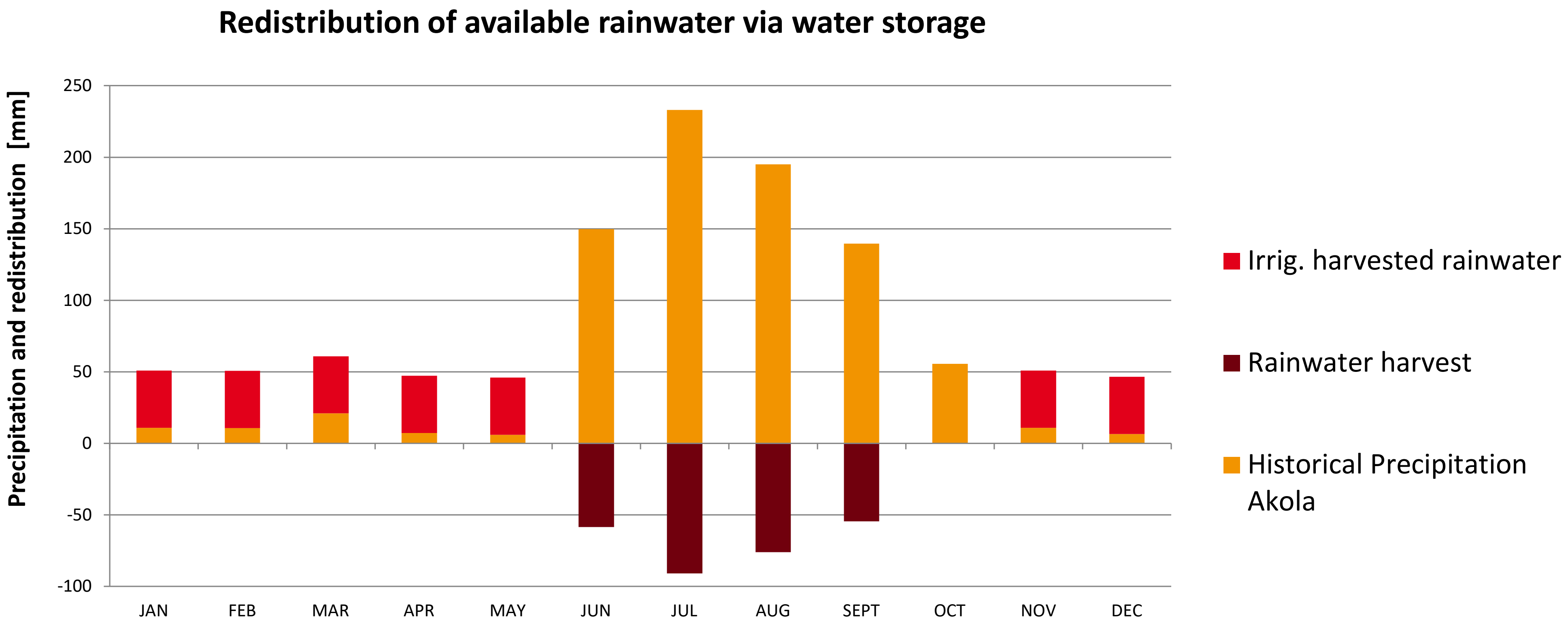


Illustration: Fraunhofer ISE




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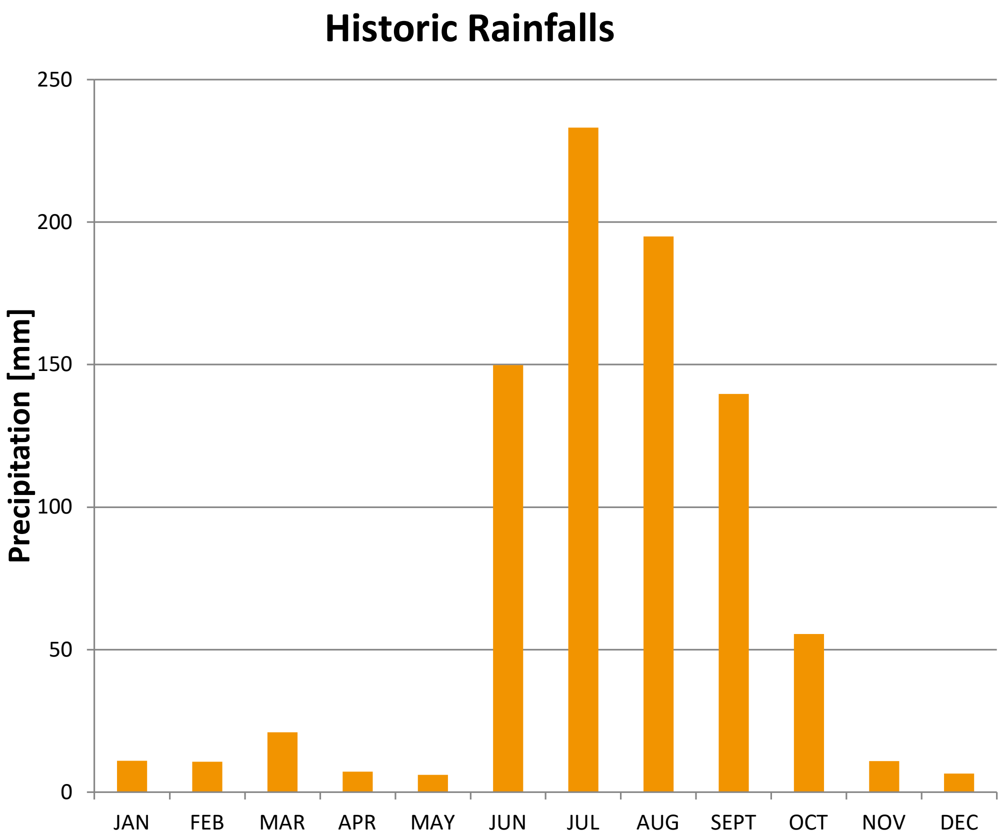
# Food-Energy-Water Nexus
## Potential of RWH: Case study India



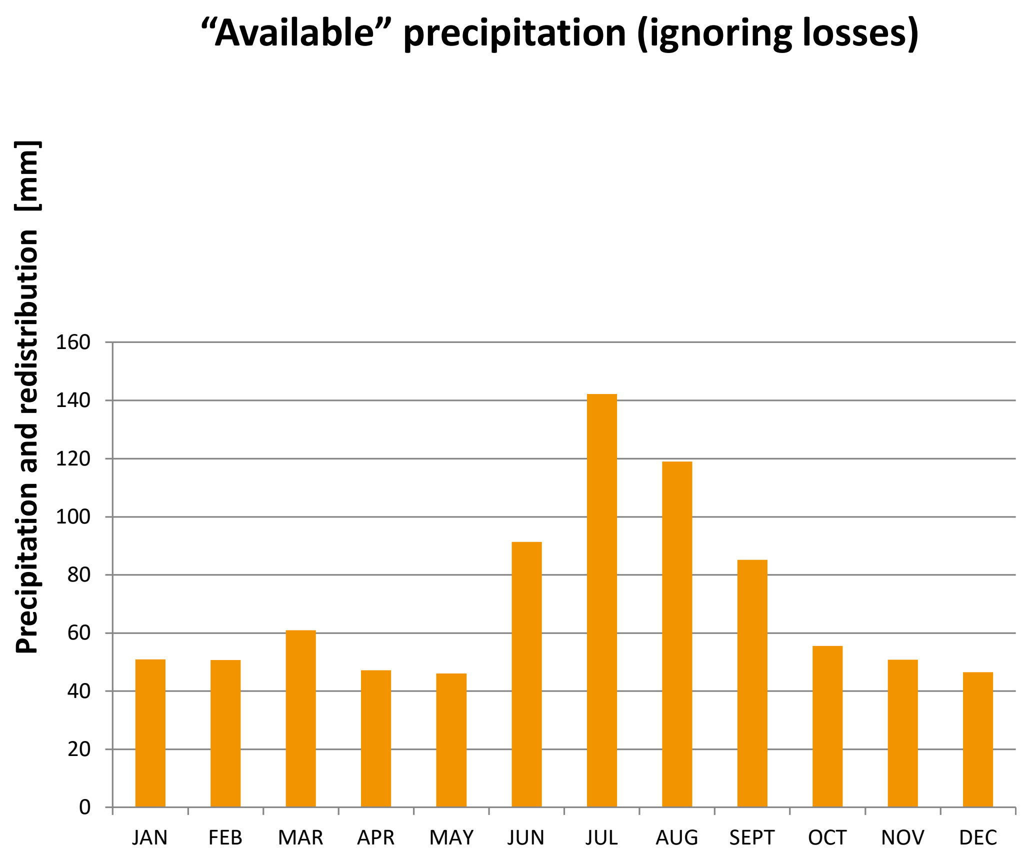




Illustration: Fraunhofer ISE



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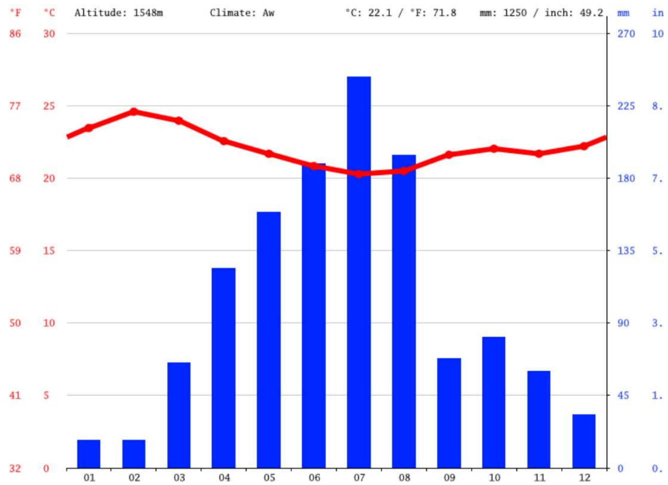
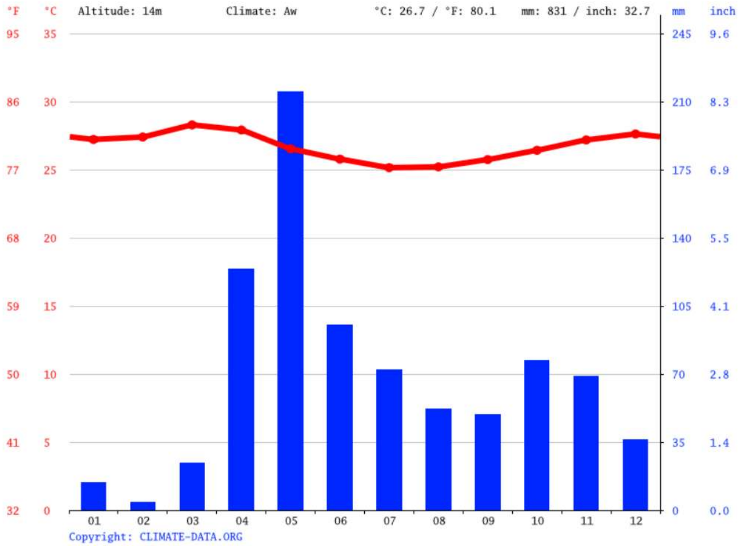
# Water-Energy-Food Nexus

## Historic Precipitation Patterns in East Africa

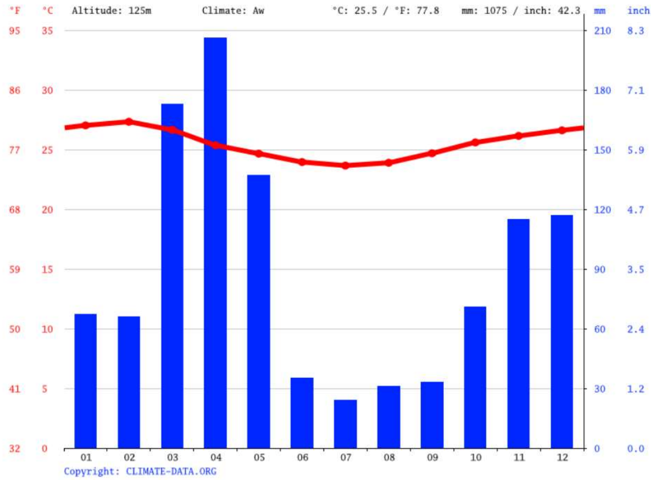
Kaabong, North Uganda




Shela, East Kenya




Kibaha, East Tanzania







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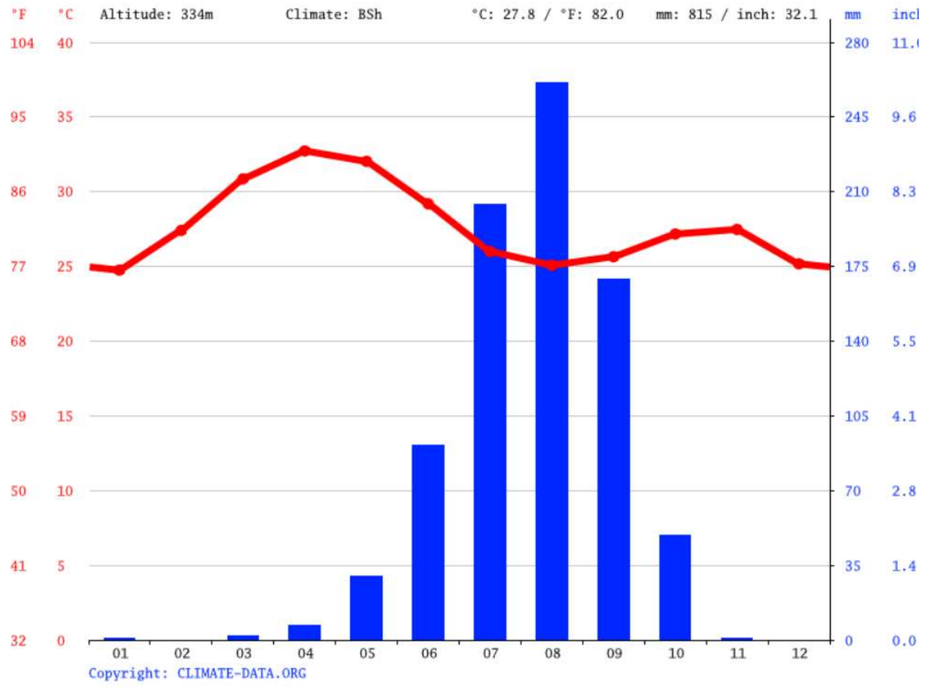
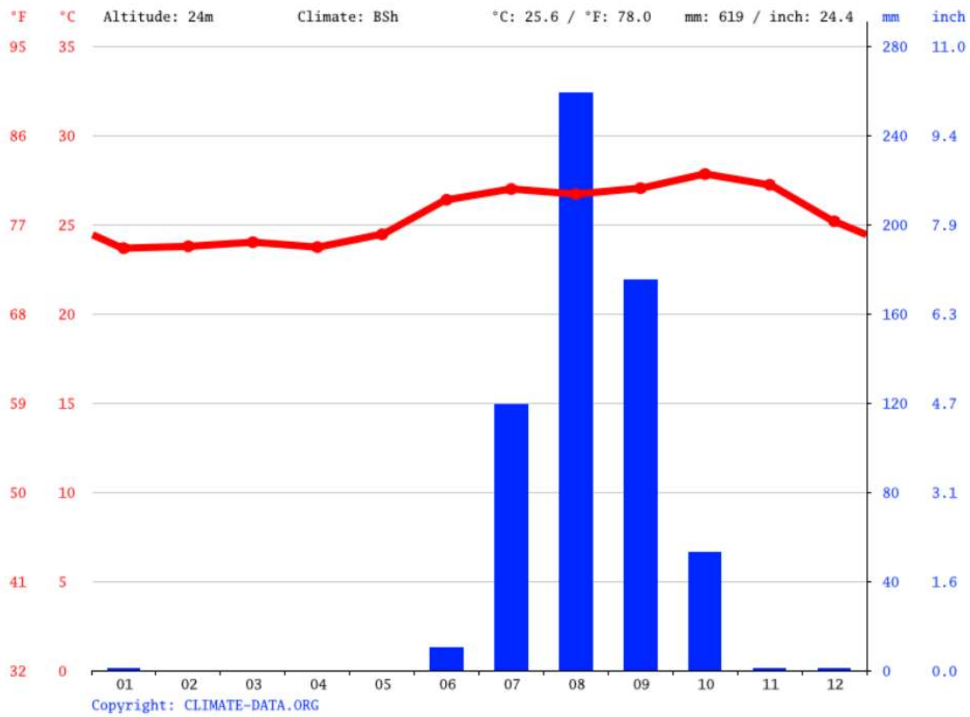
# Water-Energy-Food Nexus
## Historic Precipitation Patterns in West Africa

Bamako, Mali




Sukuta, The Gambia



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# Running Projects of Fraunhofer ISE in Africa

## WATERMED4.0, Algeria: Background

- WATERMED 4.0 – Efficient use and management of conventional and non-conventional water resources through smart technologies applied to improve the quality and safety of Mediterranean agriculture in semi-arid areas
- Duration: June 2019 - May 2022
- Contracting Authority/ Sponsors: PRIMA (Partnership for Research and Innovation in the Mediterranean Area) programme supported under Horizon 2020, the European Union's Framework Programme for Research and Innovation.
- Project Partners: University of Murcia; Central Board of Users of Vinalopó Basin, L'Alacantí and Water Consortium of Low Marina; Spanish National Research Agency CEBAS –CSIC; University of Oran1, Ahmed Ben Bella. LAPECI laboratory; University of Djilali Bounaama Khemis Miliana. Research laboratory of agricultural production and sustainable development of natural resources; Arvum Agriculture & Technological Services S.L.; Turkish Water Institute SUEN

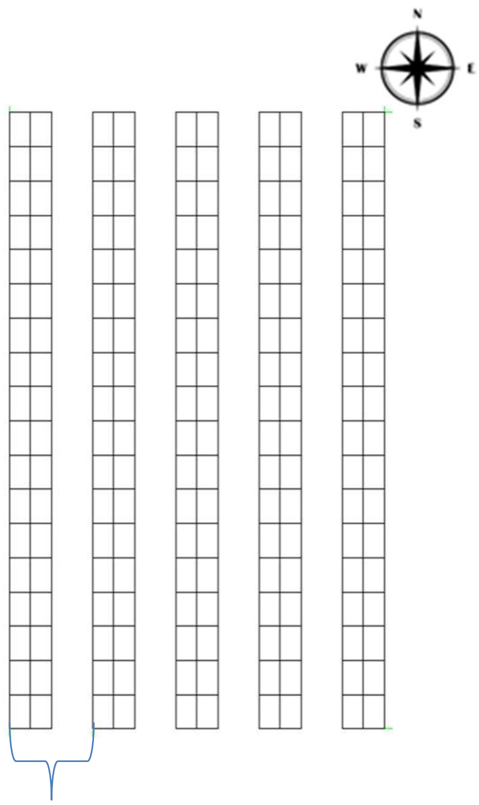
# Running Projects of Fraunhofer ISE in Africa
## WATERMED4.0, Algeria: Pilot Goals

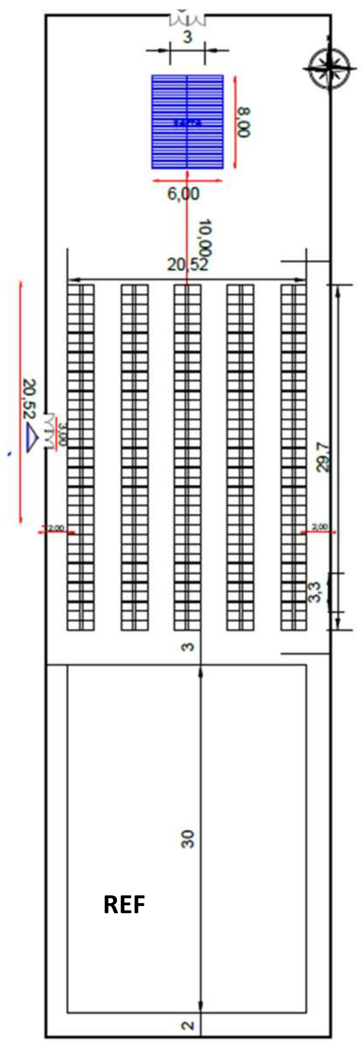
- To set up a system for the monitoring of low-quality water uses (high salinity groundwaters) and the application of modern irrigation practices to save water and nutrients.
- To increase crop productivity >25% controlling quantity of nutrients and fertilizers.
- To improve soil quality and environmental effects of a more efficient water management in agriculture, including treated wastewater.
- To ensure the regulatory feasibility (organoleptic and sanitary studies) with a view to obtaining technical and economic dimensioning data in order to allow the transfer of technology to end-users and professionals.
- **To analyze the potential of agrivoltaics applications with respect to provision of energy to isolated areas and to reduce irrigation needs through shadowing and test opportunities to integrate smart irrigation systems into the mounting structure of the agrivoltaics system.**
- Contribute to public awareness regarding the use of wastewater applied to agriculture.

# Running Projects of Fraunhofer ISE in Africa

## WATERMED4.0, Algeria: System Layout

| Agrivoltaic system parameters | Caracteristics |
|---|---|
| Crops | Potatoes and Strawberries |
| Ground Coverage Ratio | 44% |
| Module length | 1.65m |
| Module width | 1m |
| Modules per string | 18 |
| Total number of strings | 10 |
| Total modules | 180 |
| Total module surface area | 297m² |
| Table height (from ground to the lowest part of module) | 2.5 |
| Module tilt angle | 15° |
| Pitch distance (distance between rows) | 4.57m |
| Module orientation (north=0°, east=90°, south=180°, west=270°) | EW |
| Field area | 604m² |



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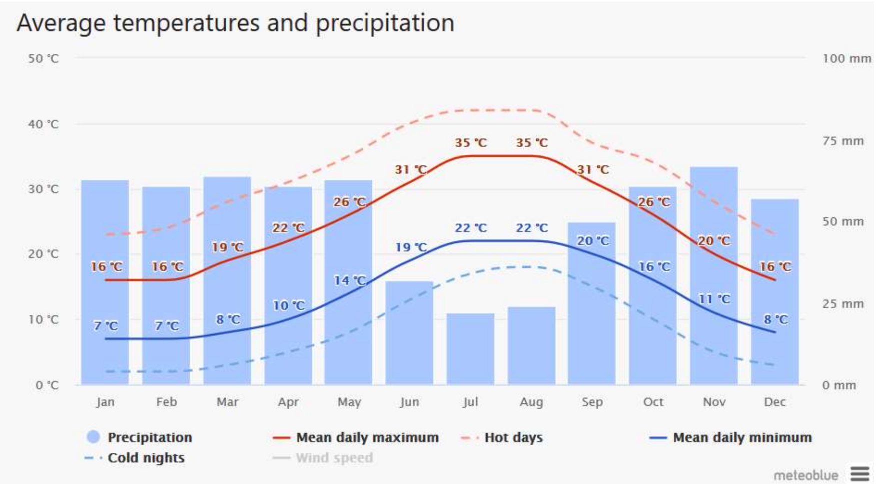
# Running Projects of Fraunhofer ISE in Africa

## WATERMED4.0, Algeria: Location and Climate

- Location: Khemis Miliana, North Algeriy
- Area of University of Djilali Bounaama Khemis Miliana
- Agricultural experiments to be conducted by the University of Djilali Bounaama, research laboratory of agricultural production and sustainable development of natural resources







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# Running Projects of Fraunhofer ISE in Africa

## WATERMED4.0, Algeria: Installation April 2021

- Location: University of Djilali Bounaama Khemis Miliana. Research laboratory of agricultural production and sustainable development of natural resources
- **Budget limitations:** Real PV modules only for the central module row, the rest covered by dummies
- To increase crop productivity >25% controlling quantity of nutrients and fertilizers.

PV controller, inverter and batteries

| Source | Type | Number | Rating |
|---|---|---|---|
| Solar PV array | Mono-facial Polycrystalline (mSi) Si 275W | 36 (2 strings of 18 modules) | 9,9 kWp |
| Battery bank | Gel | 4 | Battery of 400Ah, 12V |
| Battery Controller | With MPPT controller | 1 | 48V |
| DC-AC Inverter | Single phase | 1 | 48V/230V |
| Pump | Pump HP | 1 | 4kW |



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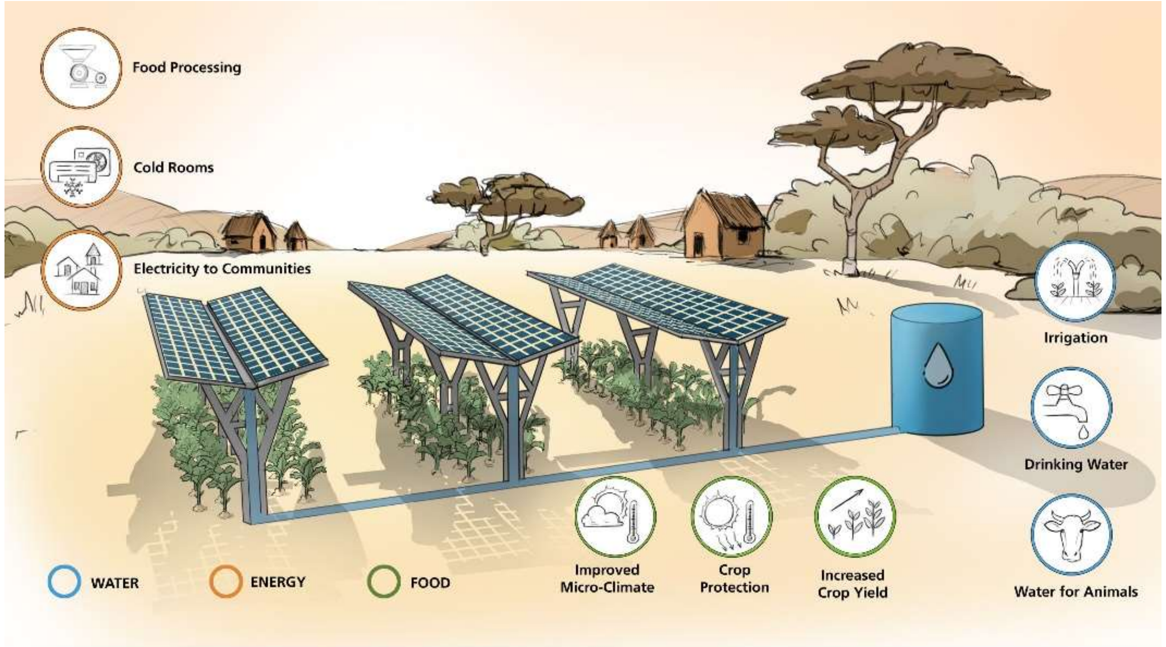
# Running Projects of Fraunhofer ISE in Africa

## APV-MaGa: Key Facts

**“Agrivoltaics for Mali and The Gambia: Sustainable Electricity Production by Integrated Food, Energy and Water Systems (APV-MaGa)”**

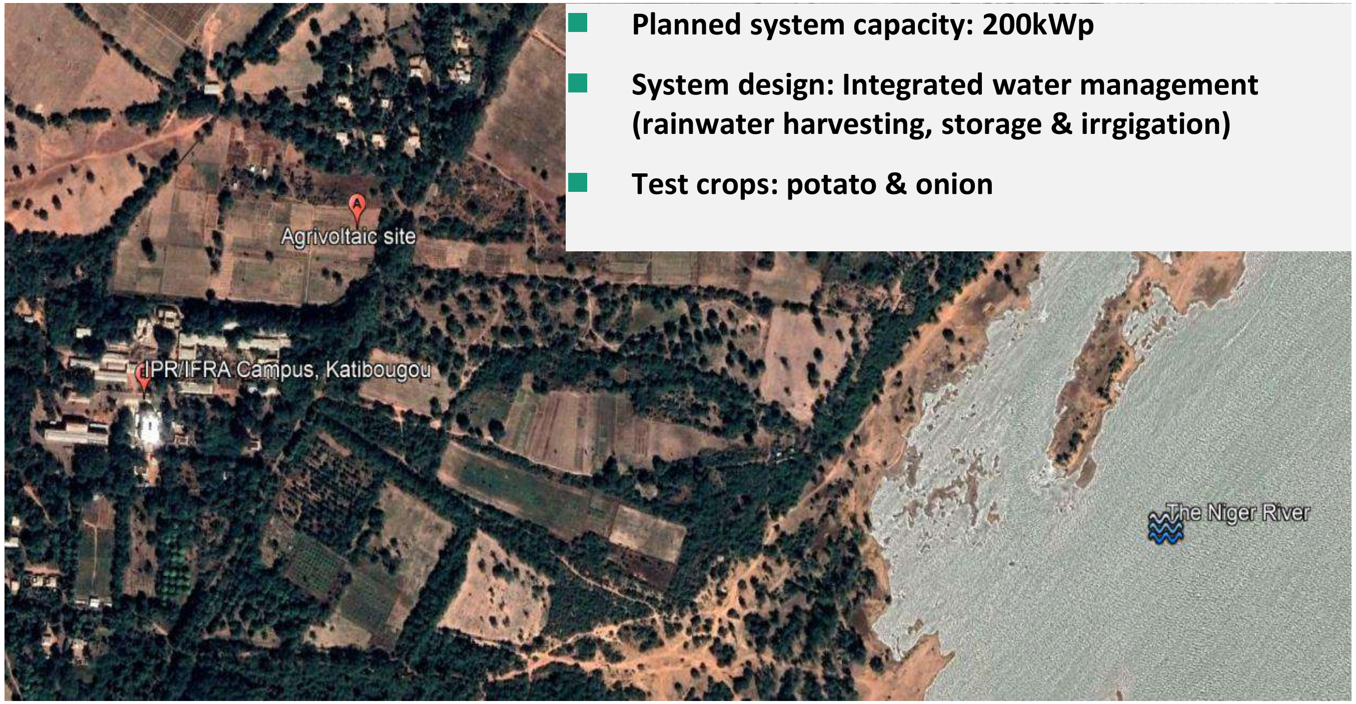



- Duration: 08/2020 - 07/2023
- Funding Scheme: CLIENT II (BMBF)
- 15 partners (including associate partners)
- Five agrivoltaics demonstrators planned
  - One in Mali
  - Four in Gambia
- Research technical and economic viability of an integrated triple land-use system

# Running Projects of Fraunhofer ISE in Africa
## APV-MaGa: Location Malian Pilot

**Katibougou, Mali**

- Site visit planned end of May (deea solutions) to collect data, assess proposed site and confirm exact location
- Small workshop to be held with Malian partners
- Kick-off meeting and workshop planned – as soon as permissible




- **Planned system capacity: 200kWp**
- **System design: Integrated water management (rainwater harvesting, storage & irrgigation)**
- **Test crops: potato & onion**



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# Running Projects of Fraunhofer ISE in Africa

## APV-MaGa: Location Gambian Pilots

### Location at the University of The Gambia

- **Planned system capacity: approx. 62.5kWp**
- **System design: TBD**
- **Test crops: TBD**




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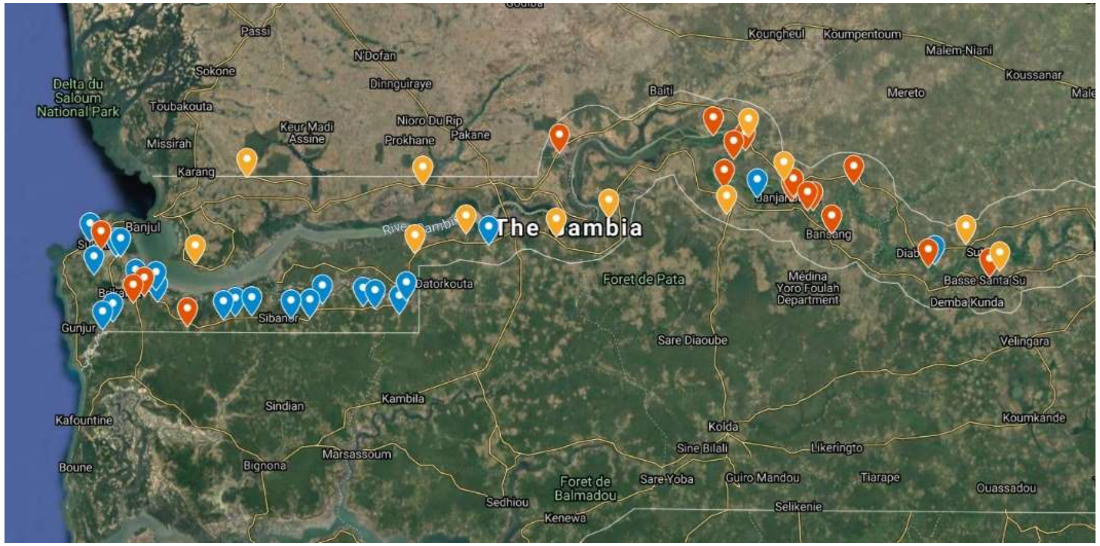
# Running Projects of Fraunhofer ISE in Africa

## APV-MaGa: Future Location of Gambian Pilots

- Remaining 3 sites to be identified
- Shortlist of 36 potential sites pre-screened by local partner
- Shortlist of 10 sites suggested
- Site visit planned in June (deea solutions) to assess the 10 sites for agrivoltaic feasibility, visit University of the Gambia campuses and hold workshop with project partners



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# Thank you very much for your attention!






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