FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

State of the art of Agrophotovoltaics in Germany

Boris Farnung, Stephan Schindele

Fraunhofer ISE

PVPMC Workshop

Weihai, China, 04.12.2018

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AGENDA

- Problem
- Solution
- Germany
- International
- R&D Outlook

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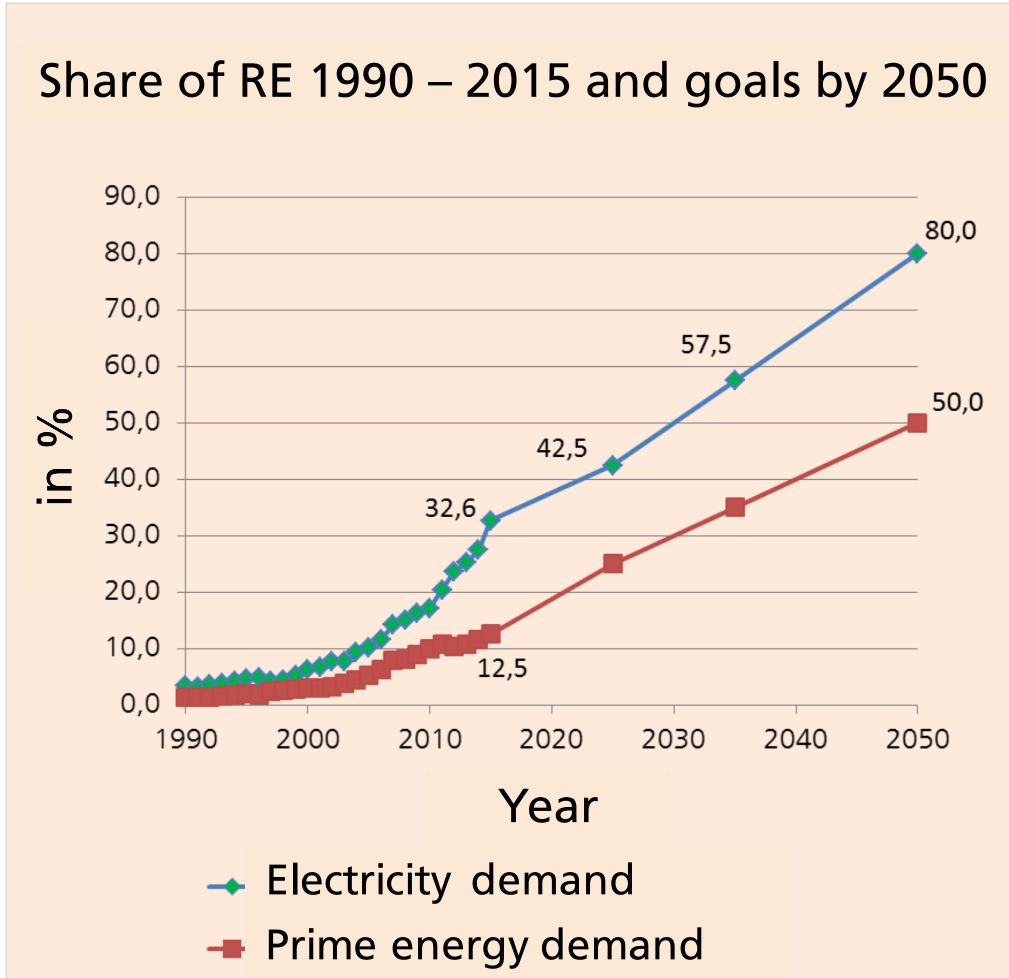
Problem
Ambitious Renewable Energy (RE) Targets in Germany

- Energy Transformation has only recently started
- Best sites for RE-implementation are already taken
- Demand for land continues to be high
- Sector coupling: electricity sector merges with heat/cooling and transport sector
- Paris Agreement: binding climate policy targets
- Limit increase of arable land occupation to 30 ha/day by 2030 (GSDS)



Source: AGEE-Stat, BMWi / own layout

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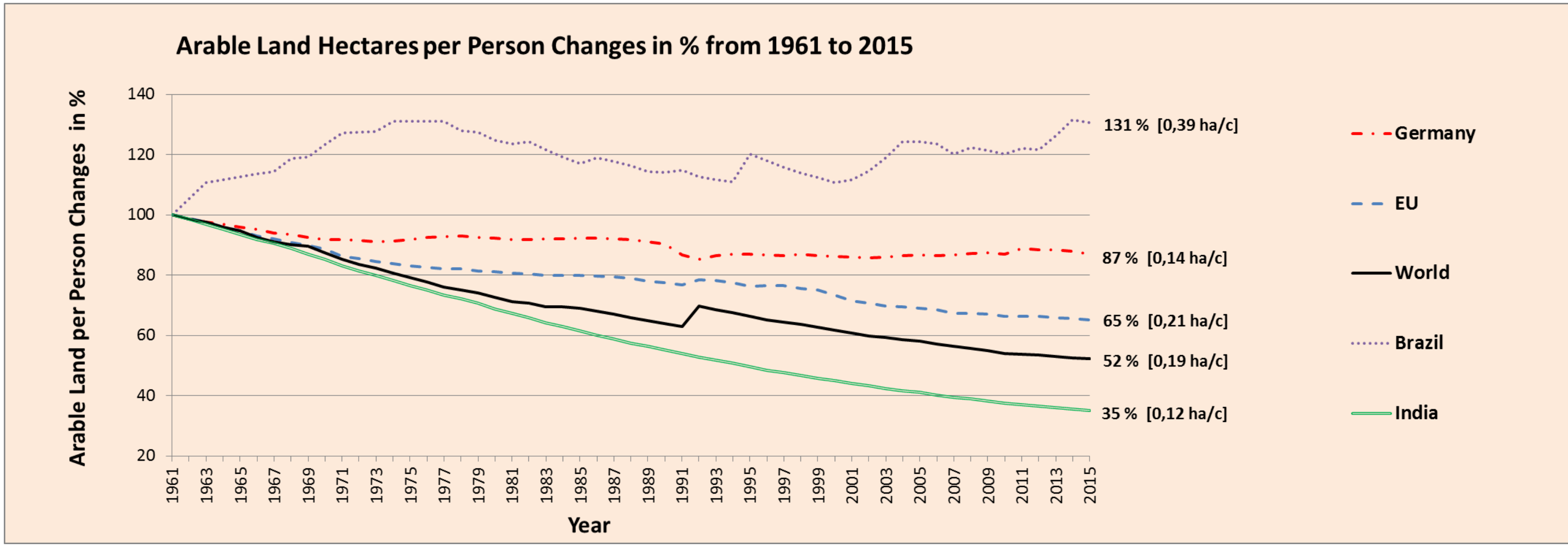
Problem

Scarcity of arable land, Crops suffer from too much sun



Agriculture

- Globally arable land available per capita has decreased by 48 % (!) since 1961
- Many crops suffer from too much sunlight
- „Fuel, Fiber or Food“ Discussion
- Agricultural sector accounts for 7.5 % CO2-emissions

➡ Resource efficient land use → Dual use of land → multiple cropping

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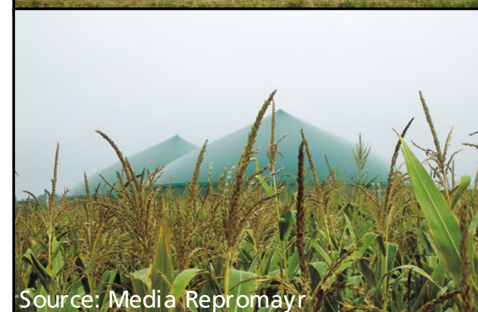
Solution
Integrated Food-Energy Systems: Agrophotovoltaics (APV)

- Definition of Agrophotovoltaics:

"APV is a system technology that enables the simultaneous *main* agricultural production and *secondary* solar power generation on the same area *and* which seeks to optimally utilizing synergy effects and potentials of both production systems."



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Solution

APV-Prototypes of Fraunhofer ISE and Fraunhofer Chile

- Germany, 2016:

- APV-Prototype in Heggelbach, Southern Germany
  - 194,4 kWp, bi-facial PV-Modules
  - Spinnanker-foundation, Soil protection during installation
  - Own power consumption
  - Potato, winter wheat, celery, clover

- Chile, 2017:

- 3x APV-Prototypes in Metropolitan Region Santiago de Chile
  - each 15 kWp, si-PV
  - Technology Transfer
  - Social integration
  - Broccoli, cauliflower, herbs

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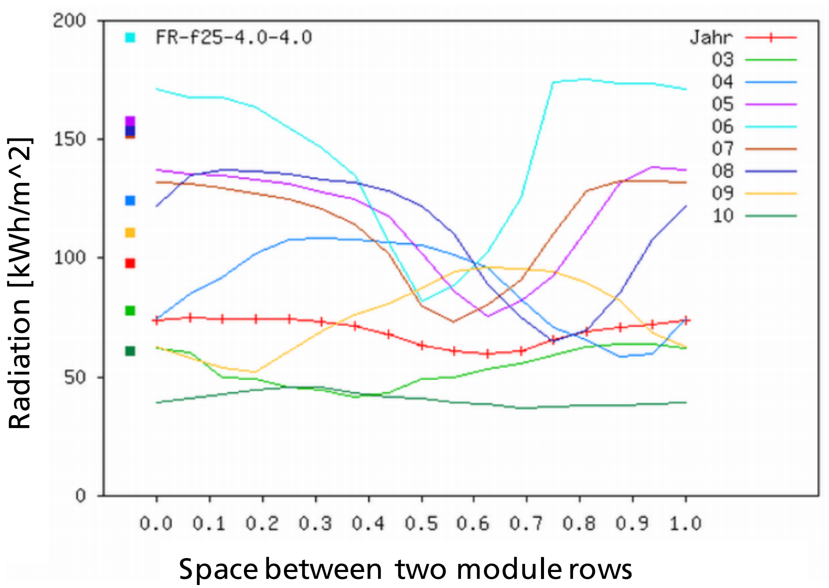
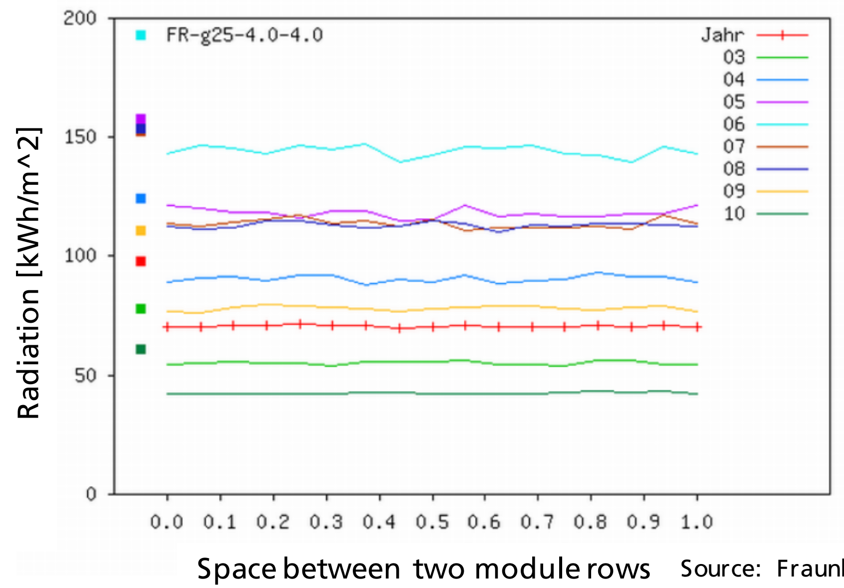
Solution
Optimization of PV and Photosynthesis Yields

Orientation: South



Orientation: South-east or South-west



Source: Fraunhofer ISE

- Fraunhofer ISE patent on APV-design and lightmangement: simulation of radiation on ground level under APV
  - *Homogeneous* distribution of radiation underneath APV possible
  - *Sufficient* radiation during vegetation phase of crops feasible
  - Electricity losses compared to South orientation are low: -5 %

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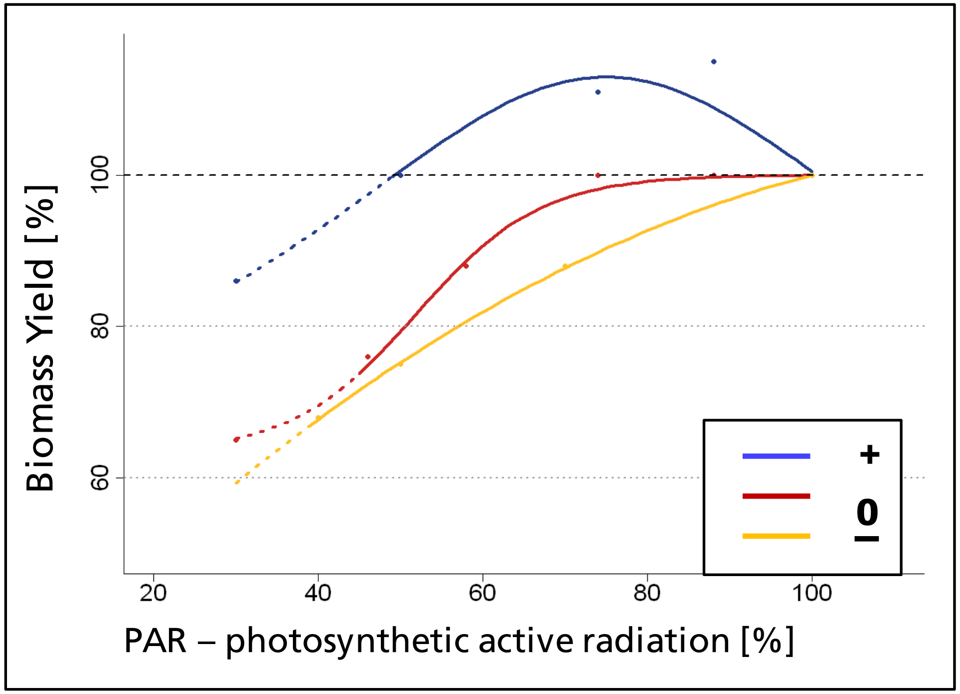
Solution
Shade Tolerant Crops Exist



Category	Crops
+	Salad
0	Rape & Barley
-	Corn

Source: Fraunhofer ISE

- Increase in yield and quality improvement through shading is possible
- Depending on crop rotation and average Light Compensation Point (LCP) site specific reduction in solar radiation feasible

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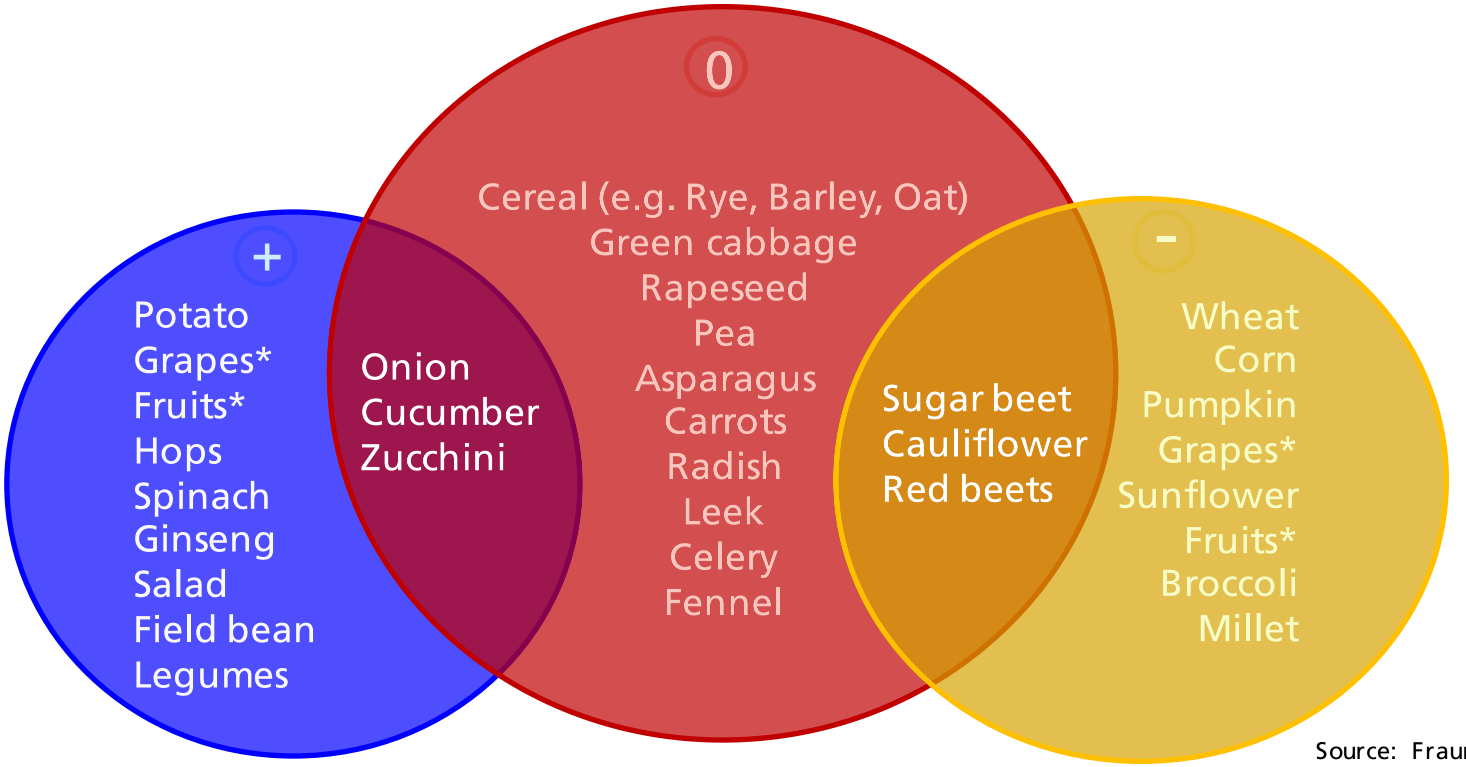
Solution

Suitable crops: Case study Germany

Classification of Germany's most relevant economic (food/feed) plants in agriculture with respect to shade tolerance:



Source: Fraunhofer ISE

*depending on the type

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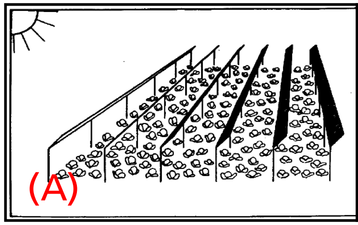
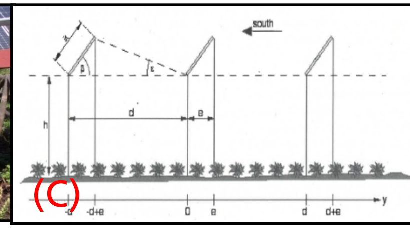
Germany

APV-Projects between 1981 and 2018





- (A) 1981, Fraunhofer ISE, Goetzberger A., Zastrow A., On the Coexistence of Solar-Energy Conversion and Plant Cultivation
- (B) 2004, Elektro Guggenmos, Warmisried, 70 kWp, Beetroot, barley, leek,…
- (C) 2006, FhG ISE, SunPower (USA), Prof. Yamaguchi (JP), Energy Farming
- (D) 2010, Gärtnerei Haller, Bürstadt, 1.200 kWp, Peony (Flower)
- (E) 2013, University Weihenstephan-Triesdrof, 30 kWp, Cabbage
- (F) 2013, Krug's Spargel, Lampertheim, 5.000 kWp, Ginseng
- (G) 2015, Krug's Sparge, Bürstadt, 5.000 kWp, Ginseng
- (H) 2016, Fraunhofer ISE, Heggelbach, 194 kWp, Wheat, potato, celery
- (I) 2018, University Dresden, 12,9 kWp, Spinach, peas, beans, radishes

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Agrophotovoltaic Project Germany
Technical Design

- Installed: 2016
- Region: near Lake Constance
- Surface: 136m x 25m (~1/3 ha)
- Direction: 80°

- Height: 8m
- Vertical clearance : 5m
- Installed capacity: 194 kWp

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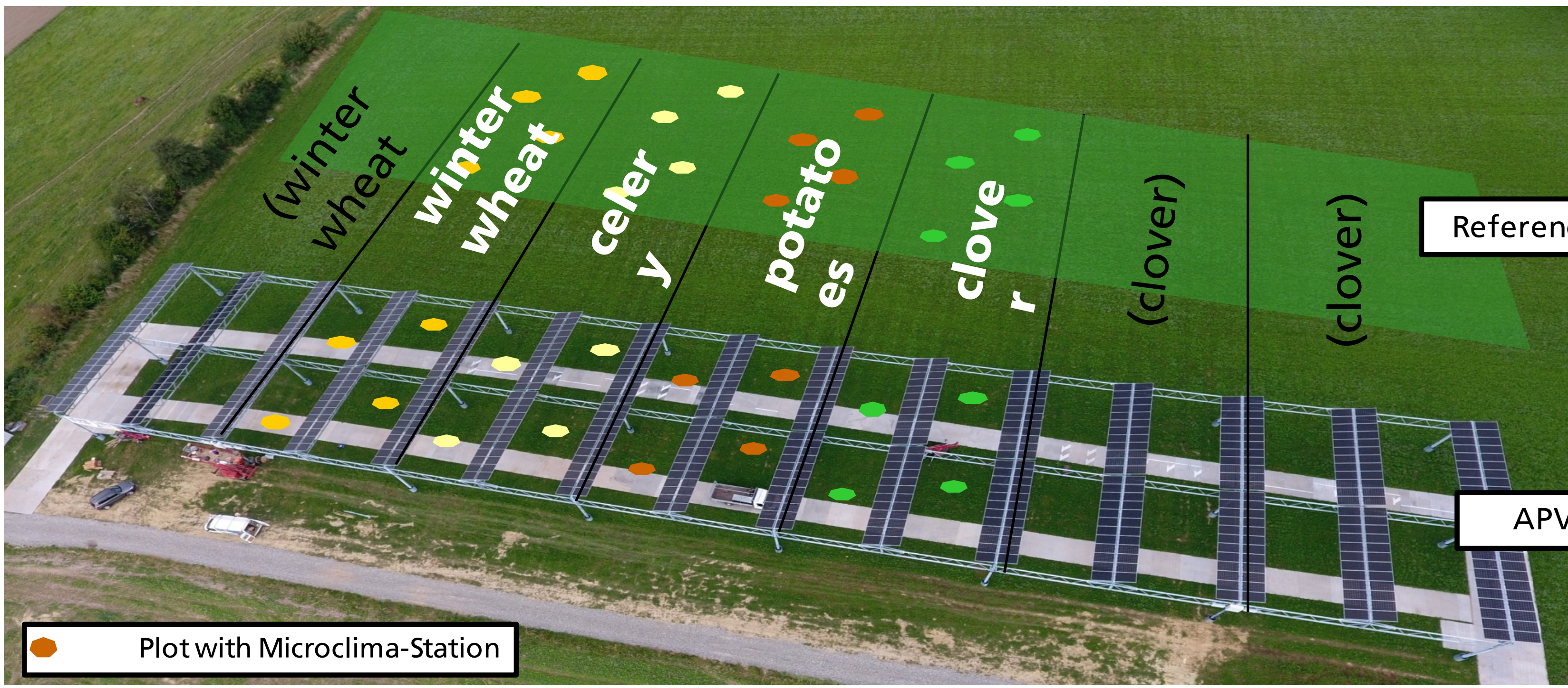
Agrophotovoltaic Project Germany
Technical Design

First year crops: winter wheat, celery, potatoes and clover



Source: BayWa

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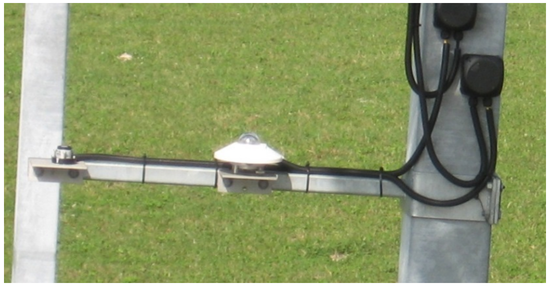
Agrophotovoltaic Project Germany
Sensor Equipment

- Irradiance:
  - Global tilted front 20°
  - Global tilted back 20°
  - Global & diffuse horizontal
  - Global horizontal shaded @1,5m
  - PAR (photosynthetic active radiation) Sensor shaded @1.5m

- T(mod), T(amb)



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Agrophotovoltaic Project Germany
Sensor Equipment

- DC Voltage and current
  - reference inverter (3 MPPTrackers)
- Energie/Power
  - AC reference inverter
  - AC overall production
  - AC to farm
  - AC from Utility

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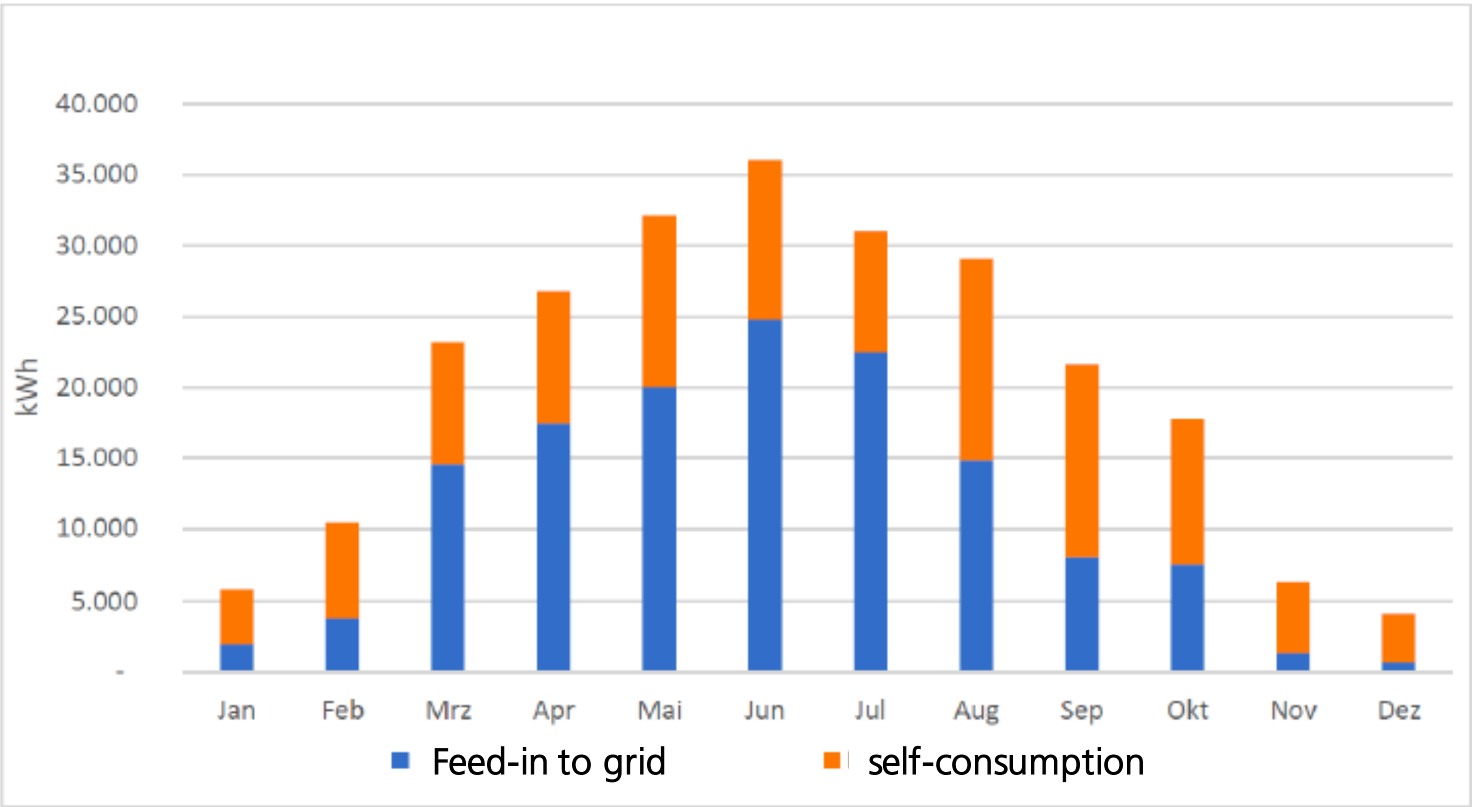
Agrophotovoltaic Project Germany
Monitoring Results 2017



Quelle:
BayWa/Fraunhofer ISE

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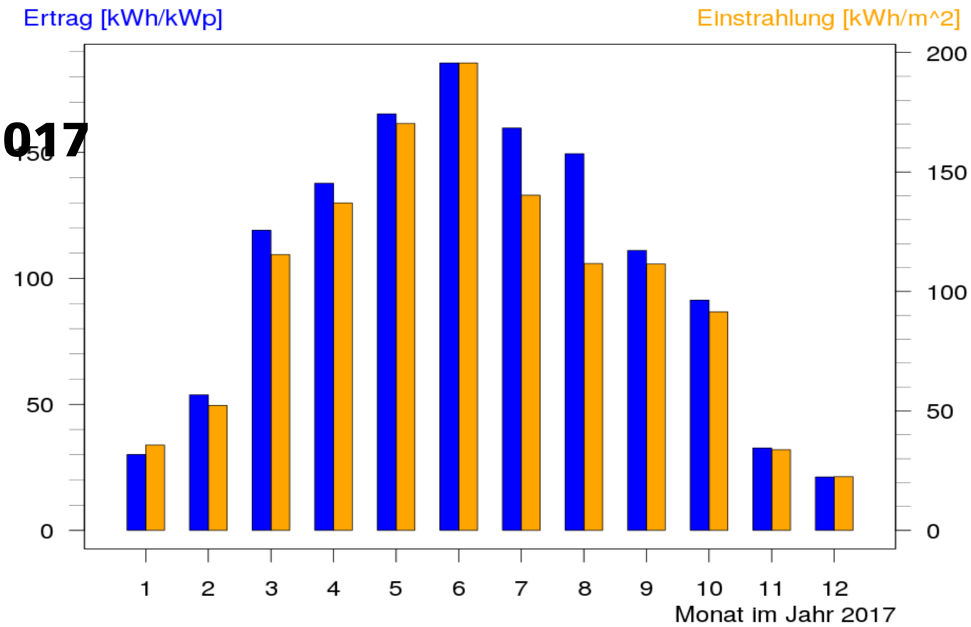
Agrophotovoltaic Project Germany
Monitoring Results 2017

First full year of operation: 2017

Specific Yield: 1257 kwh/kWp

Irradiance tilted: 1218 kWh/m2



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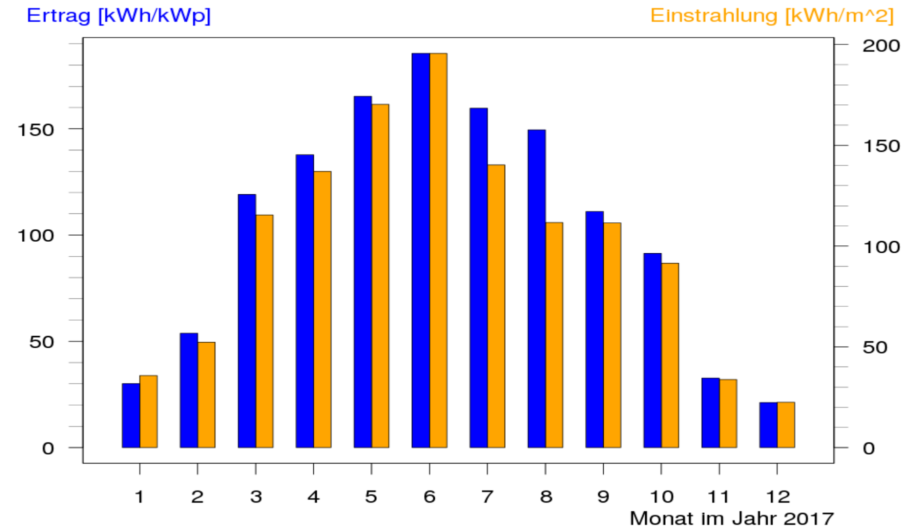
Agrophotovoltaic Project Germany
Monitoring Results 2017

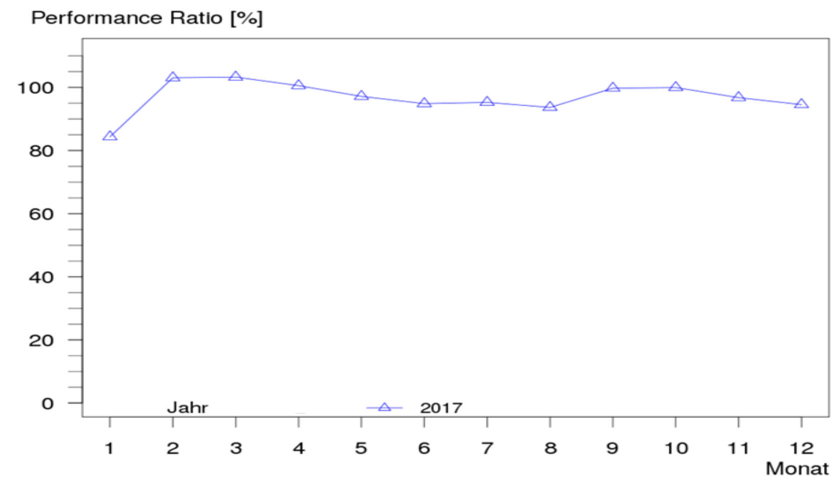


First full year of operation: 2017

Total Yield: 2444401 kWh

Specific Yield: 1257kwh/kWp

Irradiance tilted: 1218kWh/m2



Performance Ratio: 97,4%

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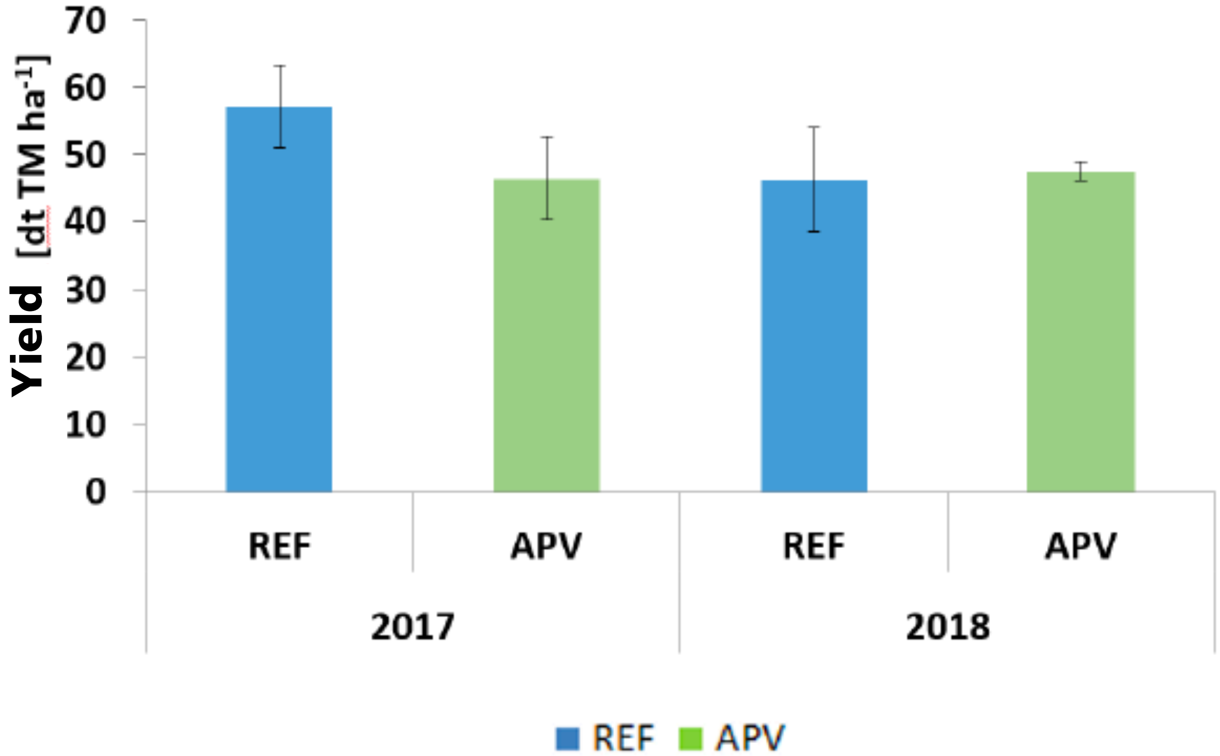
Agrophotovoltaic Project Germany

Harvest in 2017 and 2018: Winter Wheat



Quelle:
Universität Hohenheim

- 2017: yield -19 % under APV
- 2018: yield + 2 % under APV

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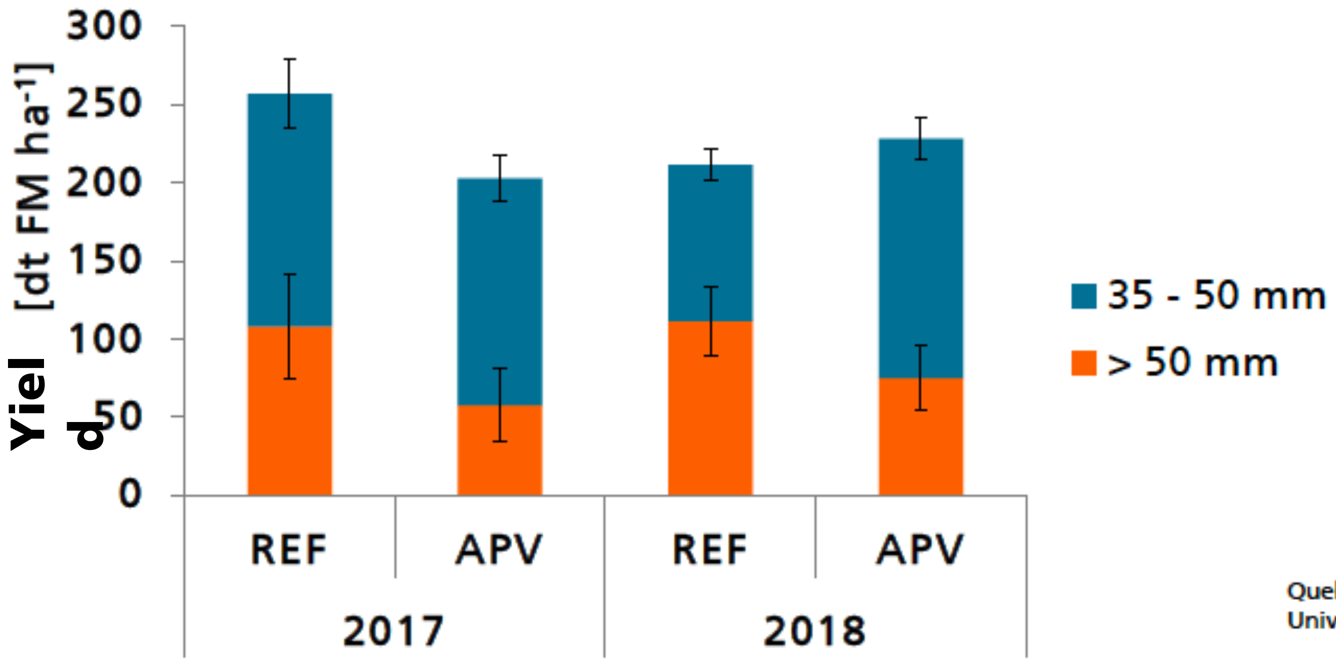
Agrophotovoltaic Project Germany

Harvest in 2017 and 2018: Potato



Quelle:
Universität Hohenheim

- 2017: total yield -18 % under APV
- 2018: total yield +11 % under APV
- Tubers > 50 mm smaller under APVsoil compaction?

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Agrophotovoltaic Project Germany

Increase of Land-use Efficiency by over 60 %

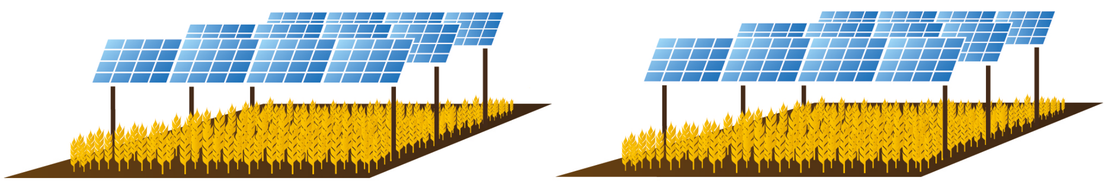
Separate Land Use on 2 Hectare Cropland

1 hectare + 1 hectare

100% wheat + 100% solar electricity = 100% wheat, 100% solar electricity

- LER Wheat:
  - 81,3 % yield
  - 74, 6 % yield inkl. land loss
  - 83 % electricity

Combined Land Use on 2 Hectare Cropland: Efficiency increases over 60%



1 hectare + 1 hectare

80% wheat, 80% solar electricity + 80% wheat, 80% solar electricity = 160% wheat, 160% solar electricity

LER Wheat = 149,2 %

LER PV = 166,0 %

LER APV = 157,6 %

Source: Fraunhofer ISE, University of Hohenheim

- PV-cropping is feasible and synergies generate additional income for farmers

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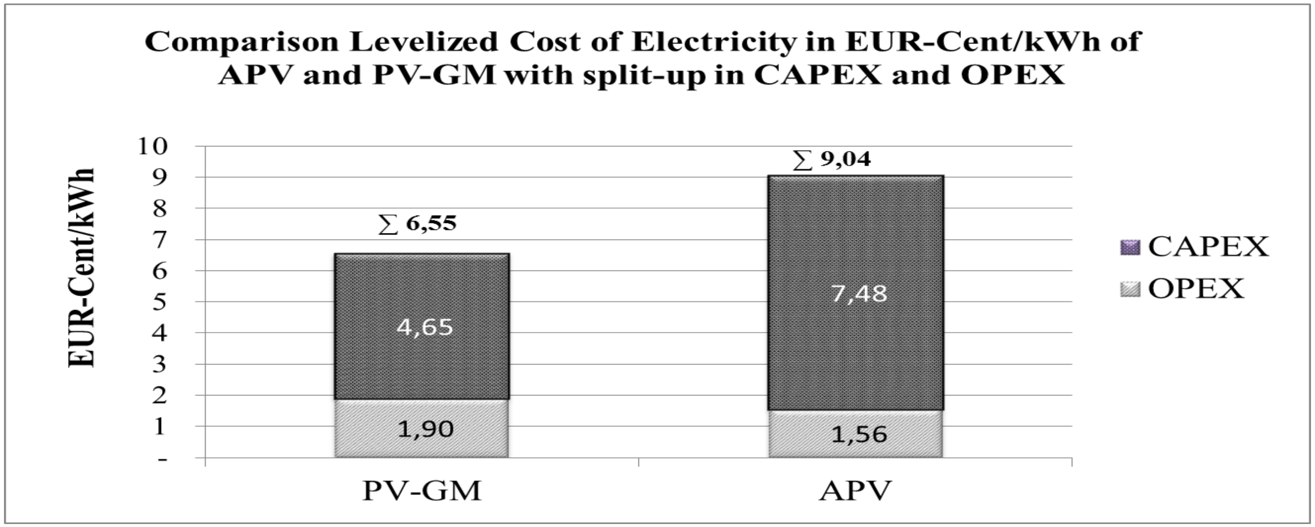
Agrophotovoltaic Project Germany
Economic Evaluation - LCOE



Source: Fraunhofer ISE

- APV-LCOE > approx. 1/3 than PV-GM
- APV-OPEX < than PV-GM due to synergy effects
- APV Learning curve? Economics of Scale?

- Constraints:
  - Land area: 2 ha
  - PV-GM: 1,38 MWp
  - APV: 1,04 MWp
  - Solar radiation:

  1.209 kWh/m2/a

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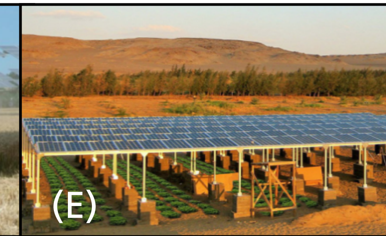
Proof of Concept worldwide – Part I



- (A) **Italy**, R.E.M. Tech Energy, 3 x APV systems since 2011
  - 3,2 MWp, 1,3 MWp, 2,15 MWp Agrovoltaico
- (B) **France**, University of Montpellier, 50 kWp, 2010
  - 2017 – 2019: 45 MWp Agrivoltaic and SolarGreenHouses
- (C) **Japan**, Solar Sharing, Ministry of Agriculture, Forest and Fishery, Akira Nagashima
  - 1.054 Solar Sharing 2013 - 2017, approx. 85 MWp
- (D) **Italy**, Corditec, Ahlers, 800 kWp, 2012
- (E) **Egypt**, SEKEM, Almaden, Kairo, 90 kWp, 2017
- (F) **USA**, University of Arizona, approx. 50 kWp, 2017
- (G) **Taiwan**, Green Source Technology, unknown kWp, 2016
- (H) **Korea**, Korea Hydro & Nuclear Power Corporation, 78, kWp, 2018

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Proof of Concept worldwide – Part II

- (I) **Italy**, Villa Crespia Muratorio, E. Gimbel, Wine yard, 2011
- (J) **France**, Straßburg, 300 kWp, E. Gimbel, 2016
- (K) **China**, Ningxia, 700 MWp, Huawai, 2016
- (L) **Chile**, 3x APV-systems, Santiago, Fraunhofer CSET, 2016
- (M) **China**, Changshu, Zhongli PV Agricultural Research Institute, Talesun, 9,8 MWp, 2016
- APV-systems intended in Vietnam, Israel, East Africa, India, USA…
- **Total installed APV capacity worldwide until 2018:** approx. 1,95 GWp

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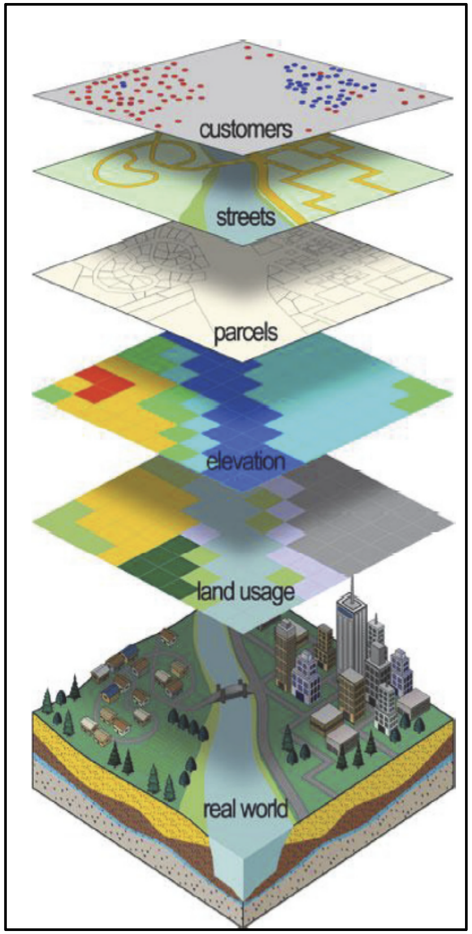
R&D Outlook – Part I
Next Steps at Fraunhofer ISE

- **GIS potential analysis**
  - Define site criteria, e.g.:
    - Next to farm for own power generation
    - Rural area with grid access
  - Define criterion of exclusion, e.g.:
    - Hillside situation
    - Cultural landscape heritage
  - Define parameter on how to manage and control APV area on local government level
- **Merge lightmanagement tool with biomass simulations**
- **Quality assurance, APV-Norm/-Standard, bankability**
  - Define Key Performance Indicators (KPI) of APV, e.g.:
    - Land use efficiency, e.g. energy output per area
    - Measure and proof synergistic effects



Source: GIS layers model
www.gembc.ca

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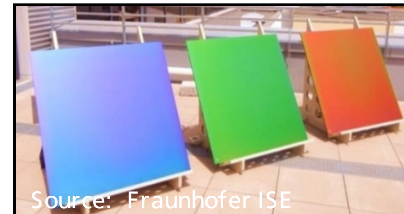
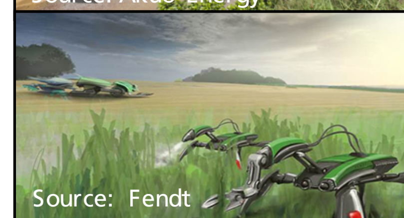
R&D Outlook – Part II
APV Innovation Process in Germany

- **Technology-push**
  - Horizontal Level: Diversification of APV applications
    - Fruits, berries, viniculture, herbs, animals, hop, aquacultures, crops, mushrooms, spices,…
  - Vertical Level: APV innovation potential
    - Spectral analysis, organic PV, construction, materials, colored PV, agrar-robotics, off-grid, storage, light management, indoor-farming,…
  - Environmental and Social Impact Assessment (ESIA)
- **Demand-pull**
  - Create a small APV-market, e.g. 60 MWp, triggering industry innovation investment, technical/scientific monitoring
  - Technology Transfer into EU & relevant markets





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   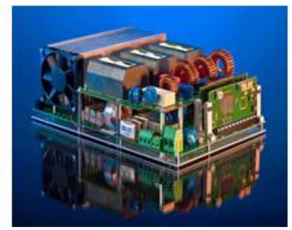 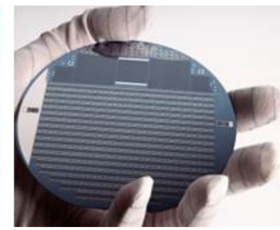 

Boris Farnung, Stephan Schindele, Fraunhofer ISE

Monitoring Data:
http://www.ise.solar-monitoring.de/system.php?system=apvh&untersystem=0&lang=en

Project Website:
http://www.agrophotovoltaik.de

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