State of the art of Agrophotovoltaics in Germany

Stephan Schindele
Fraunhofer ISE

Agrovoltaics in
France and Germany

OFATE DFVEW Seminar

Paris, 12.10.2018

www.ise.fraunhofer.de
AGENDA

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

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

![Share of RE 1990 – 2015 and goals by 2050](image)

*Source: AGEE-Stat, BMWi / own layout*
Problem
Arable land is scarce, Crops suffer from too much sun

PV-Ground Mounted
- Reduction of (precious!) arable land
- Impact on landscape
- Germany is a net energy importer
- Energy sector accounts for 85 % of CO2-emissions
- Energy transition implemented too slow due to NIMBY

Agriculture
- Many crops suffer from too much sunlight
- Environmental impact from pesticide and fertilizer use is steadily increasing
- „Fuel, Fiber or Food“ Discussion
- Germany is a net food importer
- Agricultural sector accounts for 7.5 % CO2-emissions

- Policy innovation: no to biogas, mildly yes to PV-GM since 2014
- Nuclear phase-out by 2022 → coal phase out by 20?? → Land getting scarce!
- Farmers as the key to the energy transition and successful climate protection

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

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

Other IFES exist (FAO 2014):
- Agrofuels with cascading use
- Agroforestry
Solution

APV-Prototypes of Fraunhofer ISE and Fraunhofer Chile

- **Germany, 2016:**
  - APV-Prototype in Hegelbach, Southern Germany
    - 194.4 kWp, bi-facial PV-Modules
    - Spinnaner-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

Source: Fraunhofer CSET

Source: Hofgemeinschaft Hegelbach
Solution
Optimization of PV and Photosynthesis Yields

- 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 %

Source: Fraunhofer ISE
Solution

Shade Tolerant Crops Exist

- 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

<table>
<thead>
<tr>
<th>Category</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Salad</td>
</tr>
<tr>
<td>0</td>
<td>Rape &amp; Barley</td>
</tr>
<tr>
<td>-</td>
<td>Corn</td>
</tr>
</tbody>
</table>

Source: Fraunhofer ISE
Solution

Suitable crops: Case study Germany

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

- Cereal (e.g. Rye, Barley, Oat)
  - Green cabbage
  - Rapeseed
  - Pea
  - Asparagus
  - Carrots
  - Radish
  - Leek
  - Celery
  - Fennel

+ Potato
  - Grapes*
  - Fruits*
  - Hops
  - Spinach
  - Ginseng
  - Salad
  - Field bean
  - Legumes

- Onion
  - Cucumber
  - Zucchini

Sugar beet
- Cauliflower
- Red beets

Wheat
- Corn
- Pumpkin
- Grapes*
- Sunflower
- Fruits*
- Broccoli
- Millet

*depending on the type

Source: Fraunhofer ISE
AGENDA

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

APV-Projects between 1981 and 2018

- (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 Spargel, 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
AGENDA

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


- **(H) Korea**, Korea Hydro & Nuclear Power Corporation, 78, kWp, 2018
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
AGENDA

- Problem
- Solution
- Germany
- International
- R&D Outlook
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
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
Thank you very much for your attention!

Save-the-Date: 06. May 2019 / APV-Workshop in Berlin

Stephan Schindele, Fraunhofer ISE

stephan.schindele@ise.fraunhofer.de
www.agrophotovoltaik.de
www.ise.fraunhofer.de