Agrophotovoltaic – Agricultural production below optimized elevated photovoltaic systems.

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(1) Overview

In the last two decades many states introduced renewable energy policies to support climate change mitigation[2]. For this reason the global photovoltaic (PV) market has grown substantially. In particular the market share of ground mounted PV installations is globally increasing and already today considerable large (REN21, 2012; EPIA, 2012)[3]. Through this development a conflict in land use between the energy and agricultural sectors emerged, where food production/security competes with energy production/security.

With increasing renewable energy deployment, awareness of the energy-food-conflict is increasing, too, and yet, a vast majority of studies available focus on electricity production from biomass when assessing this conflict. Hardly any studies can be found on the conflict between PV and agriculture, even though this issue had been addressed already long ago (Goetzberger, 1982).

In this paper, we suggest developing an innovative PV system technology allowing simultaneous production of solar electricity and agricultural goods. We suggest calling this new technology an Agrophotovoltaic (APV) system. Optimized elevated APV systems permitting agricultural production will effectively and efficiently endorse sustainable land use and thus diminish (or even eliminate) the aforementioned conflict between the energy and agricultural sectors. 2010, in Germany, to solve this intersectoral conflict, PV dissemination regulation was altered by the legislator and support for ground mounted PV limited to land areas in conversion, such as former military bases or former landfill areas, as well as to land areas along transportation routes, such as railway lines or motorways. APV may relieve the PV industry by bringing ground mounted systems out of the niche, back into the mainstream PV market.

(2) Methods

In the paper at hand, we analyze feasibility of APV systems in Germany from a technological and agricultural perspective. Furthermore, we conduct a CAPEX and OPEX analysis of APV-systems and evaluate impacts APV might has on domestic energy policy making in future, under the

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[2] Further reasons for introducing renewable energy dissemination policies are knowledge society and innovation, employment, energy security, other environmental advantages (reduction of fine dust) to name only a few. However, this study's focus mainly on APV impacts on the nexus between energy and climate policy instruments.

[3] There is a diversified trend in market share development for ground mounted PV-systems. For instance, in the EU there is a negative trend, with an annually decreasing share of ground mounted PV and in contrast an increasing share of roof-top PV, while in other regions of the world, mainly in the USA and South-East Asia, ground mounted PV shows largest market growth rates of all PV segments.

assumption that it is agricultural and socially feasible to unlock the APV market potential in Germany.

The applied methods include (i.) development of an irradiation simulation tool based on the ray tracing software radiance, which simulates direct and diffuse radiation reaching any point at ground level; (ii.) identification of suitable crops for the cultivation in APV systems in Germany based on a literature review; (iii.) analysis of the productivity measured by the Land Equivalent Ratio (LER); (iv.) calculations of Levelized Cost of Electricity (LCOE); (v.) capital budgeting techniques for the economic analysis, such as Net-Present-Value (NPV), Internal Rate of Return (IRR) reflecting different investment decisions and business cases including discounted cash flows; and (vi.) estimate of technically feasible potential in Germany.

(3) Results

Irradiance simulations showed that optimal PV module orientation towards south results in uneven distribution of radiation on ground level. However, optimized APV orientation from a plant's perspective towards southeast/-west provides homogeneously distributed irradiation. Deliberate southeast/-west facing PV systems shift solar electricity supply from midday towards mornings and afternoons and therewith increase energy security as needs to manage residual load within grid operation is reduced. Food crops could be categorized into three groups in respect to the needed irradiation level and diverse promising species have been identified. Land productivity of APV increases by 55 to 75 % compared to a separated generation of PV electricity and food. The economic analyses clarified that APV can be financially profitable, compete with low LCOE of other renewable energies (i.e. biomass and off-shore wind energy) and therefore be an attractive investment option. Technically feasible APV potential is estimated to be approximately 50GWp in Germany.

(4) Conclusions

The study clarifies, that at given appropriate suitable political and economic framework conditions, the considerable potential of APV could make an important contribution to the future energy supply. Further research of possible impacts on the energy policy making in Germany is necessary. Finally, this paper ends by opening the perspective on application options in arid climate zones and off-grid installations[4].

References

EPIA (2012) Global Market Outlook for Photovoltaics until 2016, Brussels European Photovoltaic Industry Association Secretariat

Goetzberger A., Zastrow A. (1982) "On the coexistence of solar-energy conversion and plant cultivation", *International Journal of Solar Energy,* 55 – 69.

REN21 Renewables Global Status Report, http://new.ren21.net/default.aspx (last visited: 15.03.2013)

[4] Especially these two factors – solar irradiance level and off-grid vs. on-grid (incl. investment incentives from energy policy) – have tremendous impact on the economic analysis and thus the business case for APV.