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Investment in Agrophotovoltaics: Efficient Solutions from Switzerland

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Abstract: ***The agrophotovoltaics innovative technology (APV) is a staged culture that combines photovoltaic power generation and agricultural production on the same land. The coexistence of solar panels and crops implies a sharing system of sunshine between these two types of production. It opens new horizons by making drylands cultivable while producing clean energy for local populations. APV lies at the heart of a global energy transformation, increasing world energy demand, negative global warming effects, and global water scarcity, and offers a promising investment to farmers and new opportunities for ecologically sustainable livelihoods. As a renewable energy investment, it meets the sustainability demand by reducing climate concerns but it also opens the door to significant socioeconomic benefits. However, the final outcome of the investment depends on government policies, environmental conditions, technical progress and what materials are used in solar power systems.***

This paper answers three questions: Why is the agrophotovoltaics an important technology today? What are the advantages and disadvantages of agrophotovoltaics use? And what are the economic risks related to this kind of investments? By analyzing Penthéréaz solar panels power generation example in Switzerland, the research illustrates the success factors to the investment and inherently provides recommendations regarding future investments.

Keywords**:** ***Fraunhofer, Solar energy, Ground-mounted photovoltaic systems (GMPV), Global warming, Land productivity, Renewable energy, Food production, Water scarcity.***

I. INTRODUCTION

The vulnerability of food, energy and water systems to climate change make the search for 'resilience' fundamentally challengeable. An innovative hybrid system called agrophotovoltaic (APV) linking between local agriculture and photovoltaics is able to exploit the solar potential without removing useful land for food production.

Plants and crops thrive in the shade under the solar panels thanks to a significant change in humidity. The idea is to grow food and produce clean energy by using the land for both solar panels and agriculture simultaneously. Scientists found an increase of the plants mass by 90% under the solar panels while shaded soil have shown an efficiency of about 328% in terms of moisture retention (Adeh et al., 2018).

In 1982, Adolf Goetzberger and Armin Zastrow showed Crops can be cultivated underneath elevated solar panels since they receive sufficient solar radiations for their development.

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This Solar-Dual-Use system has been revived in the 2000s when photovoltaic market had rapidly grown first, due to the dramatic decrease in solar technology costs (see Fig. 1.), and second, due to an increase in land-use conflicts (Brohm and Khanh 2018). In recent years, this photovoltaic agriculture concept gained global popularity with the increasing world energy demand (International Energy Agency, 2019), negative global warming effects (Azione per il clima - European Commission, n.d.), and global water scarcity (UN-Water, n.d.).

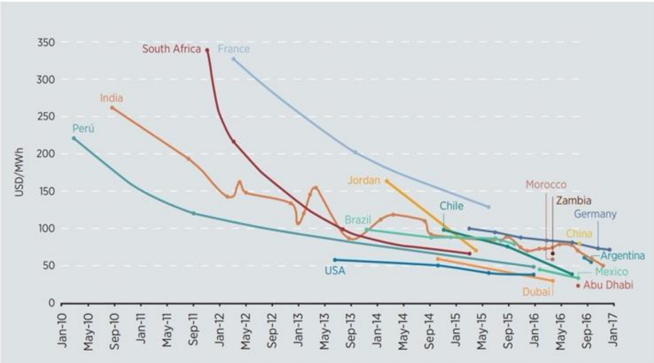

Fig.1. Evolution of average auction prices for solar panels around the world (Source: Irena.org)

APV allows the production of photovoltaic energy on arable land without impacting agricultural productivity. It is quite possible to combine photovoltaic electricity production and agricultural cultivation on the same farmland without having to choose between them.

The main objective of the dynamic agrivoltaics is to optimize the regulation of the microclimate received by the crops (La Tribune, 2017).

With the negative effects of global warming, crops are subjected to three levels of stress (La Tribune, 2017):

- radiative
- thermal
- and hydric

To regulate them, it is necessary to constantly adjust the levels of sunshine and shade to which it is subjected. The dynamic photovoltaic panels rotate according to plants physiological needs, considering the different stages of growth of plants, and the meteorological parameters (La Tribune, 2017).

Given the seventeen sustainable development goals that were set for 2030 (United Nations, 2015) and the urgent need to exit the fossil fuel dependency, this new technology should be studied and evaluated.

In fact, the use of portions of some agricultural land could then be taken into consideration, especially if we begin to evaluate, in several cases, a combination of solar panels and agriculture could bring benefits to both clean energy and agricultural production.

II. OPTIMIZED INFRASTRUCTURE

An optimum dynamic agrivoltaics infrastructure allows good agricultural productivity, circulation of agricultural machinery and good clean energy production. The innovative form of agronomy is based on the understanding of the four elements shown in Fig 2. These agrivoltaics elements allow us to control plants maturation process with the controlled sunshine reaching it (Optimum Tracker, 2016) – improving it, slowing it or stopping it.

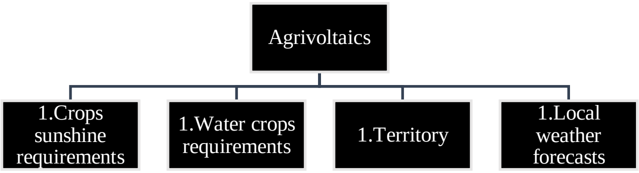

Fig. 2. The four elements of agrivoltaics

The photovoltaic modules are mounted on a metallic structure of 8 meters height from the ground allowing the free passage and circulation of all kind of agricultural machinery as shown in Fig 3 and Fig 4; usually only 5 meters are necessary (Huart, 2017), facilitating field maintenance, and in some cases helping to protect the crops by allowing anti-hail nets, irrigation systems or trellis installation (Optimum Tracker, 2016).

Fig. 3. Agricultural machinery under the agrophotovoltaics structure (Photo Credit: IdeeGreen)

Without any concrete foundations, the superstructure rest on pillars spaced 18 meters between each other's. The rows are aligned southwest or southeast and the solar modules are fixed with an inclination of 20 degrees (*Ibid.*), but a shading strategy can be adopted by making a smart photovoltaic panels tracking the sun using an innovative algorithm for a maximum energy production and shading efficiency, see Fig 4 (Optimum Tracker, 2016). Compared to a power plant on the ground, the space between the rows is larger (+ 40%) (Huart, 2017). The loss of agricultural land is reduced to less than 5% (*Ibid.*).

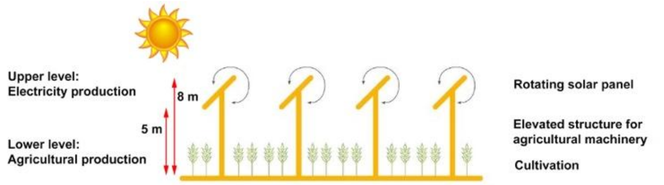

Fig. 4. Agrivoltaics structural system

III. ADVANTAGES AND DISATVANTAGES OF AGROPHOTOVOLTAICS

Agrophotovoltaics are still at an early stage of development, hence they are still under technical progress and quality improvements. Nevertheless, APV applications already show considerable potential in serving environmental concerns and achieving both sustainable agriculture and rural development. Table 1 shows the major advantages and disadvantages of the use of agrophotovoltaic systems.

Table 1. Advantages and disadvantages of agrophotovoltaics

Advantages	Disatvantages
CO_2 mitigation	Agrivoltaics do not yet work with greenhouses
Renewable energy production	Negative visual impact on the natural landscape. Sur-elevated agrophotovoltaic systems are highly visible from distance
Arable land use mitigation for non-food biofuel crops growing	The swarm of levitating solar panels raised few meters from the ground can fall due to wind hazards.
30% increase in economic value	Does not work for sunshine addicted plants
Protection against extreme temperatures: frost or heat wave	The swarm of levitating solar panels may increase humidity ratio and favoring growth of parasitic plants
Hail protection	Potential agricultural production decline due to solar radiation reduction for solar addicted crops
Water consumption reduction from 20 to 30% by reducing the evapotranspiration of plants by shading crops.	Increased infrastructure costs due to height
Increase in agricultural yields by 60-70%	5% reduced energy output if oriented SE/SW
Livestock radiation exposure reduction (shaded refuge)	Societal acceptance
Secondary source of income to land owners beside their primary agricultural activity.	-
Significant increase in late-season plants growth.	-
Increase pasture fields production on dry, unirrigated farmland	-
Soil hydrometry, sunlight, and plants physiological needs might be controlled via innovative sensors and swing PV.	-
Source of income at a long-term	-
Contribution to rural and off-grid electrification	-
Land-use increased output	-
Decreasing land-use competition/conflict between energy and agriculture	-
328% more efficient in terms of soil moisture retaining during summer heat (for shaded area)	-

Because of the few disadvantages listed above, there are some countries who stopped operating the APV systems, but there are also others who kept adapting innovatively to new challenges these systems impose. Agrophotovoltaics has proven to be a promising solution when adequately managed and regulated. Its main advantage is being a resource efficient increasing land use efficiently by 60-70% and opening up a valuable source of income for farmers.

IV. PLANTS CATEGORY FOR THE AGRIVOLTAICS

Fig 1. Shows the classification of the three different agri-food plants category according to their need in sunlight for the German context (Obergfell, 2016).

Most favorable vegetables for agrivoltaics production are the one preferring to grow in the shades: potatoes, hops, spinach, salads and beans. On the other hand, cabbages, peas, asparagus, carrots, onions, zucchini, rapeseed, etc. are indifferent to sunlight presence or shading, however corn, wheat, sunflowers, etc. So, the production can be reduced considerably in the agrophotovoltaics system due to their solar radiation addiction, see Fig 5.

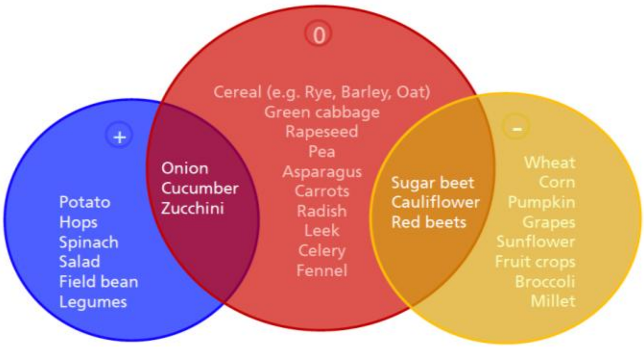

Fig. 5. Suitable species for agrivoltaics in the German context (Obergfell, 2016)

In general, the sunshine reaching the plants and the grounds is sufficient for photosynthesis thanks to the gap between the PV modules installed in rows.

V. SOLAR ENERGY INVESTMENT RISKS

The experiences in Switszerland outline some important factors that stand out in solar farms or even agrivoltaics projects and that may be found in other countries.

In 2009, the Swiss government promoted photovoltaic installations in the country as a partial initiative to reduce nuclear energy dependency (Mise au Point, 2018) by launching an incentive program called cost-covering remuneration for feed-in to the electricity grid (CRF). The CRF guarantees the purchase of the produced green energy at an advantaged price for 25 years (*Ibid*). Many Swiss farmers, looking for a secondary source of income, were particularly interested in this perspective and invested hundreds of thousands of dollars in the deployment of solar panels on the large roofs of their warehouses in the hope to get subsidies and take advantage of the purchase of their produced green electricity. However, the program rapidly failed because of farmers' unexpected huge subvention requests and insufficient funding resources (Mise au Point, *Op. cit.*). Consequently, the government revised their contract with the investors, policy makers adjusted price volatility and altered price distribution and hence reduced the buying price of the produced green energy from US$0,31 per kWh to US$0,084 per kWh (Mise au Point, 2018; Muller, 2018; Actu Vaud, 2019). Price volatility leads to big changes in investors' realized profit, and therefore the investors were not even able to sell to end-users their electrical production due to restricted governmental laws.

In 2012, approximately US$600.000 were invested to install 890 solar panels on a farmer warehouse, see Fig 6. (Pillonel, 2014; Mise au Point, 2018) in a small municipality called Penthéréaz of Gros-de-Vaud District in the canton of Vaud in Switzerland (Actu Vaud, 2019; Muller, 2018). The investment was shared by approximately 10% of the total village population. The installation had an estimated output of 250.000 kWh corresponding of the electrical consumption of approximately 70 households (Pillonel, 2014).

Fig. 6. The transparent photovoltaic panels replaced the cancerogenic Eternit of the farmer warehouse adding brightness to the interior space (from: Mise au Point, 2018)

The investors' idea was to make their village autonomous in electrical energy but more importantly to be able to profit from the government incentive program RPC and repay all bank loans and return of capital. The idea failed at the bottom as the legislation was no longer in its favor listing a series of technical standards and rules, and imposing on them to sell their energy to a local network with a very low price without even having the possibility to use it locally or to distribute it to end-users; the reason is the presence of public domain (a public car road) between the PV warehouse and local factories and major households as shown on Fig 7. (Mise au Point, 2018).

After almost 6 years of negotiations, the Swiss authorities upgraded the federal legislation allowing the investors to use a win-win solution which consists in the creation of a local network of consumers. This allowed the private company Penthéréaz Photovoltaic Energy (PEP) to sell its electricity production directly to its neighbors at a price of US$0,21 per kWh instead of US$0,084 granted by the official energy supplier Romande Energie (Muller, 2019).

The energy sold to users was cheaper by US$0,041 per kWh compared to the actual pricing offered by Romande Energie (Mise au Point, 2018).

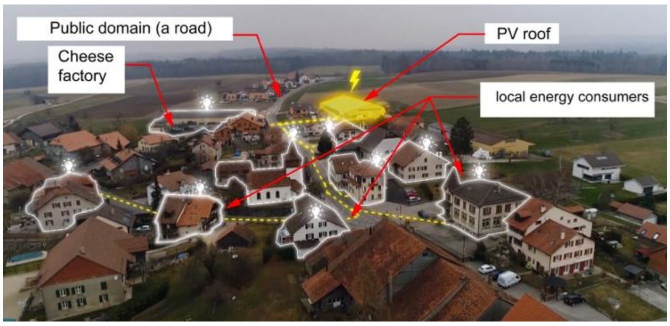

Fig. 7. PV installation and the village (from: Mise au Point, 2018)

To achieve this solution, more than US$100.000 were added to the initial investment by local villagers to contribute for the creation of a new local network. This additional investment allowed them to build (Muller, *Op.cit.*):

1. An electrical panel to manage the production and the consumption and
2. Trenches and cable layouts to connect to users

VI. CONCLUSION

Beside the fact that the agrophotovoltaics systems have a great success potential, they are still at the experimental level. Even if many of these experiments are already showing a concrete increasing in food and renewable energy production, it remains that some investment risks are present and may compromise the attractiveness of the agrivoltaics projects.

This paper describes the case of Penthéréaz in Switzerland illustrating the important roles of investors and policy makers and highlights the most current risks with PV or APV innovative technologies. Many other countries are facing similar barriers in the investment project hence it is important to list the success factors that can be applied everywhere. The case studies analyzed in this paper demonstrate that promoting collective self-consumption around large PV facilities and the creation of small electric network are the only main solutions to keep the attractiveness of the solar energy. Governments and investors can deal with key investment risks by taking action targeted at renewable energy using appropriate policies, effective facilities, and cost-effective mechanisms. Governments, investors (or investment institutions investment institutions that provide investment funds) public finance institutions, and developers have all a role to play in increasing or mitigating risks and building either a failed or strong project. Proactive collaborative measures are a key to successfully scaling up private sector investment in an innovative APV system technology.

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