



Photovoltaics and Electrification in Agriculture

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1. Introduction: The Importance of Electricity for Agriculture

The editorial introduces a Special Issue entitled “Photovoltaics and Electrification in Agriculture”. Agriculture requires not only tillage and fertilization but also water supply and, in some cases, heating and cooling. These needs go hand in hand with the use of energy, which, increasingly, is electrical energy. An option that has dropped a lot in price in recent years is photovoltaic energy. This type of energy has experienced an explosion in terms of its expansion worldwide and has been revealed as a viable solution to rapidly increase the electrical power of non-fossil origin. However, the use of panels must compete with the use of the soil for cultivation, and in many cases, it could displace the use of the soil for cultivation, something that would not be desirable either from a production point of view or from an ecological point of view. For this, a new concept of soil sharing for crops and energy production is being developed in what is called “agrovoltatics”. This shared production model is analyzed in this document. In addition, the electrification of agriculture allows the introduction of elements, such as sensors, the IoT, and intelligent control. The internet connection opens the doors to technologies such as those based on data, digital control, and what is called precision agriculture, both for cultivation in greenhouses and for regular cultivation. This would not be possible without an electrical energy source that allows powering the inter-connected elements, photovoltaics being the best candidate again. However, above all, we must not forget the issue of CO₂ emissions due to the use of energy in agriculture. In this sense, photovoltaic energy can reduce the carbon footprint and provide one of the cheapest energy sources available. All these topics are analyzed in this Special Issue, focusing on photovoltaics and its uses and impact on agriculture.

Energy is inherent in ancient and modern agriculture, in one form or another. It is necessary for tillage, for pumping, and for the transport and transformation of the products. Modern agriculture manages to produce enough food for the growing world population (even though it is not correctly distributed, and this generates famines in many areas of the planet). This is possible thanks not only to the use of new agriculture techniques but also to the help of the energy necessary to carry out these techniques. In most cases, the origin of this energy could be electrical, even more and more in transport, with electric vehicles, and without any doubt, for pumping, heating, cooling and in the powering of the control systems associated to the new agriculture based on expert systems.

The origin of the energy must be renewable to guarantee the achievement of neutrality of greenhouse gas emissions and therefore, probably the most important source will be photovoltaic energy. According to Eurostat [1] areas such as EU, agriculture poses around 3.3% of the final energy consumption. From it, 55% comes from fossil fuel sources, despite the global consumption decreased by 8.1% in the past two decades. Besides this, it must be pointed out that globally, electricity is only around 20% of the energy consumed, but it has been increasing in the past decades, when it was less than 10% fifty years ago, according to IEA [2].



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Electricity also makes it possible to technify crops in so-called precision agriculture. In this way, agriculture optimizes the resources used, reduces the carbon footprint and the environmental impact, and manages to produce more, better, and more efficiently. Precision agriculture is the evolution of agriculture towards sustainability. All of this requires efficient technology and energy with the least possible impact, such as photovoltaic energy.

2. Special Issue Overview: General Topics

2.1. *The Use of Photovoltaics in Greenhouses*

The new context of climate change, in turn, generates new forms of production where the environmental parameters in which it takes place must be controlled more and better. The paradigm of this type of system is greenhouse cultivation. In this type of cultivation, not only the interior temperature is controlled, or parameters such as relative humidity, the amount of CO₂ and the nutrients applied in the case of hydroponic cultivation but also the amount of radiation that reaches the plants. In countries with high insolation, shading is used either by means of meshes or by “liming” the roof. Photovoltaic solar energy as an energy source in greenhouses can also be used as a shading element for certain crops. However, the analysis of the impact of the solar panels on the crop is a topic being studied nowadays and a topic of great interest for the future development of solar energy applied to greenhouses.

The use of alternative systems, such as semi-transparent photovoltaic panels, can add value to greenhouse cultivation. This type of panel lets a part of the radiation pass through, as it does not include a reflective layer on the back. Consequently, the panel may lose a small percentage of efficiency, which is offset by the benefits to the crop. In the work of Aira et al. [3], the influence of radiation loss on production and crop quality is analyzed. In their conclusions, the shaded crop adapted to the new conditions, partially compensating for the decrease of radiation.

The application of agrovoltaic technology in arid areas, such as the southwestern United States, using organic solar panels, was carried out by Waller et al. [4] in a study exploring the influence of certain photovoltaic materials that do not completely block so-called photo active radiation (PAR), applied to hydroponic cultivation under greenhouse, something that makes it a very interesting case and with a great future for its high efficiency not only in terms of energy but also in the application of water and nutrients. Their conclusions show that, as in other cases of similar studies, the crop adapts to the decrease in radiation so that finally, the amount of harvest by weight is similar.

In greenhouse cultivation, fixed-plane surfaces are available with a certain orientation. The estimation of radiation on such plane, depending on the location, must be carefully analyzed to determine the impact and viability on the crop and on the photovoltaic production itself, something that has been considered in the work of Díez et al. [5], applying new methodology, including anisotropic models of the sky. The model is able to calculate the incidence angle of the radiation at any time besides the irradiation of a considered placement, with increased accuracy. As one of the conclusions, it allows predicting the hourly radiation reaching the crop and then the expected production.

2.2. *Viability of Photovoltaics Coexisting with Traditional Agriculture*

An agrovoltaic system has certain benefits in terms of the temperature of both the panels and the crop itself. In the study by Othman et al. [6], it is analyzed how the crop itself, with its evapotranspiration, reduces the temperature of the solar panels, which, as is known, is the main responsible for their loss of efficiency. Likewise, the placement of panels reduces the evapotranspiration itself and therefore, the hydric stress of the crop, especially in areas with high solar radiation. All these topics are currently the object of analysis and research, and each new study contributes to the improvement of the knowledge in this area.

The areas in countries with desert climates in Africa and the Middle East present peculiarities that make the analysis of the viability of photovoltaic systems on crops interesting. The case of Africa is especially interesting since, on the one hand, climate change can affect

this continent much more intensely and, on the other, population growth is significantly higher than on the rest of the planet. Therefore, optimizing the use of resources is extremely necessary in order to achieve the necessary social and political stability for a region where the only option many young people find is to emigrate. The Srijana et al. study [7] shows how traditional farming systems based on the use of diesel for irrigation and those that only use rainwater are at a clear disadvantage compared to agrovoltaic systems that use solar energy for irrigation. Moreover, the concept of land equivalent ratio (LER) is calculated with positive results that demonstrate how the combination of photovoltaics and agriculture results in better use of land.

In the Moreda et al. study [8], an exhaustive theoretical study was carried out, including nine types of rotating crops on a surface of 24 ha on the hypothesis of crops in the southern area of Spain, one of the most representative areas of Mediterranean agriculture. Two systems for obtaining irrigation water were compared: Surface water and extracted from wells. The conservative analysis of the profitability of the shared use of the land for solar panels and rotary cutters was carried out in periods of four years. The conclusion is moderately optimistic, however, the rise in fossil electricity prices, as well as the emission reduction targets, make the results more than reasonable.

Not only the regions that until now were classified as arid, but also those semi-arid or even those that were less warm, are affected by the increase in temperatures due to climate change as well as the decrease in average rainfall. This forces other regions like the rest of the Mediterranean areas to adapt their crops to this new situation.

The economic feasibility of agrovoltaic systems is an issue depending not only on the type of crop and photovoltaic system but also on the area of the analysis. Pascaris et al. [9] analyzed the agrovoltaic systems from a human point of view, interviewing north-American farmers and detecting in their conclusions how farmers are concerned not only with the present situation but also the long-term issues like productivity, market potential, just compensation, and system flexibility, in order to decide to implement or not the new energy systems over their crops. Although the lifetime of the systems has been extended to 25 or 30 years, and the reliability has been increased, there are other considerations related to the market that can affect the profitability and therefore, the viability of these systems. However, this is an issue that affects not only agrovoltaic systems but everything that concerns the agricultural market in general, generating increasing uncertainties that do not have to do with technology itself but also with the geopolitical situation and global market tensions.

We can also find studies in areas with high humidity, such as central Europe. In the study by Wexellex et al. [10], trials were carried out for two different years with the cultivation of celery under solar panels in irrigated cultivation. Although the years were not conducive to the analysis, it can be observed that in any case, the agrovoltaic system does not pose a significant problem for the crop, which would allow concluding that the use of the soil can be shared with the consequent improvement in efficiency of land use.

2.3. Precision Agriculture and Photovoltaics

The electrification of the tasks associated with agriculture encompasses not only the more traditional methods, such as tillage or pumping, but also those related to the so-called precision agriculture.

There are many activities that benefit from the application of intelligent systems, such as selective spraying and fertilization, which can be applied with robots that include an internet connection (internet of things IoT), and which benefit from autonomy that provides them with a photovoltaic power system like the one proposed by Chand et al. in their study [11]. The document concludes that this field still has a long way to go and that there are still few experiences, which is why it is an area of great interest for research and the application of results to the automation of cultivation tasks and the improvement of precision in agriculture.

In agricultural applications, an important aspect is the remoteness from the connection points when implementing the Internet of Things (IoT), which influences the energy consumption of transmission systems and forces to study strategies to optimize the use of data and power. This aspect is addressed by Swain et al. in their work [12], where they study a long-range system applying Matlab algorithms. In their conclusions, they determine the improvement that occurs by including hybrid systems in terms of range and then addressing real-time systems. All this is applicable to the new generation of agriculture 4.0.

2.4. Research in Electrification Applied to Rural Areas

Not only photovoltaics is covered in this Special Issue, but also cases of research in electricity production and transport applied to rural areas. This is the case of Pindado et al. in the work about the importance of a precise selection of the protections as fuses [13] in the context of a rapid growth of renewable connected plants with a distributed scheme. In this kind of topology, the fault of one of the plants can affect the others and, with the increasing number of plants, the adequate selection of the fuses to operate when necessary is of vital importance.

Rural electrification is not yet complete in many areas, such as areas in Palestine, limiting local development that is fundamentally agronomic. The contribution of photovoltaic energy to solve the problem of rural electrification is crucial due to lower prices, modularity, and increased reliability, something that is reflected in the Ibrik study [14], something also reinforced by the low impact on greenhouse gas emissions of this solution (which we remember is not null, since it exists in the manufacture, installation, and dismantling of the plant). In addition, electrical micro-grids are a boost both to local development in rural areas and to the elimination of the need for new power lines.

3. Conclusions

The electrification of the tasks associated with agriculture is an unstoppable and necessary process. The use of photovoltaic energy will be one of the energy sources with the greatest impact on this process. In the context of the decarbonization of all sectors, including agricultural and livestock production and the rural world, photovoltaic energy is undoubtedly one of the mechanisms with the easiest implementation.

In summary, the abovementioned works demonstrate in their analysis and conclusions that:

- Photovoltaic energy is the most competitive electrical energy option for the agricultural sector at the present time due to the drastic drop in component prices.
- The cultivation can be developed under photovoltaic panels coexisting in the so-called “agrovoltatics” with an increase in profitability or land use.
- Precision agriculture or agriculture 4.0, based on the Internet of Things (IoT), benefits from the use of photovoltaic solar energy for its purposes.
- Greenhouses are an ideal agricultural production system for the integration of photovoltaic panels of different technologies, such as organic, semi-transparent, or amorphous silicon panels.

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