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A PROTOTYPE AGRIVOLTAIC PLANT ON THE AREA IN THE EXPERIMENTAL FARM AT TUSCIA UNIVERSITY

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ABSTRACT

Agrivoltaic systems are a strategic and innovative approach to combine solar photovoltaic (PV) with agricultural production and for the recovery of marginal areas. The synergy between agriculture 4.0 models and the installation of latest generation photovoltaic panels will guarantee a series of advantages starting from the optimization of the harvest and livestock production, both from a qualitative and quantitative point of view, with a consequent increase in profitability and employment. This study aims to support farmers in understanding the factors that act on the choice of crop and/or farming system according to the plant design of the photovoltaic system, as today the investment of an agrivoltaic system is very expensive if three main variables are not considered: i) type of panel to be inserted (height from the ground, characteristics, tracker, etc.); ii) type of crop to be used including sustainable mechanization and suitable for design and maintenance and phytosanitary treatments; iii) authorizations and environmental regulations to be respected in order to proceed correctly with the installation of the panels.

Keywords: Agrivoltaic, Prototype, Environmental Law, Green Economy, Agriculture, Renewable Energy

INTRODUCTION

In September 2015, the UN adopted a global plan for sustainability called Agenda 2030 (Cristiani, 2018) which provides for 17 lines of action, including the development of agricultural plants for the production of renewable energy. The European Union immediately implemented the 2030 Agenda, obliging member states to comply with the provisions of the UN. On 10 November 2017, in Italy, the SEN 2030, National Energy Strategy until 2030, was approved. It contains more ambitious objectives of the UN 2030 agenda, in particular:

- The generation capacity of 30 GW of new photovoltaic;
- The reduction of CO_2 emissions;
- The development of innovative technologies for sustainability.

In 2018, the revised Renewable Energy Directive entered into force, as part of the 'Clean Energy for All Europeans' package, which aims to make the European Union the leading renewable energy sources and, more generally, to help the EU meet its emissions reduction targets under the Paris Agreement. The new directive sets a new target in terms of renewable energy for 2030, which must be equal to at least 32% of final energy consumption, with a clause on a possible upward revision by 2023. At the national level, in 2020 the MISE (Ministry of Economic Development) adopted the Integrated National Energy and Climate Plan (PNIEC), which represents a fundamental tool for turning our country's energy and environmental policy towards decarbonisation. More specifically, the National Integrated Energy and Climate Plan provides that in Italy, in order to achieve the set objectives, approximately 50 GW of photovoltaic systems should be installed by 2030, with an average of 6 GW per year and considering that the current annual installed power is less than 1 GW it is clear that alternative solutions need to be found to accelerate the pace; just think that in Italy alone the annual electricity requirement is equal to 320 TWh (Terna data) and only 24 TWh derive from photovoltaic systems. Different systems are in place and others are being tested to combat climate change (Gambella et al., 2021; Bianchini, 2021).

The PNRR (National Recovery and Resilience Plan, 2021) has recently been issued, in which the Italian government has allocated 1.10 billion euros to the installation of Agrivoltaic systems aimed at creating a winning combination between agriculture and green energy production. The aim of this work is to provide a framework for experimental photovoltaic projects and their evaluation systems with a focus on the area to be studied.

DEFINITION AND ORIGIN OF AGRIVOLTAIC

APV systems have been shown to improve land use, water use efficiency and improvement for some crops (Dinesh & Pearce, 2016). The concept of Agrivoltaic was first introduced in the early 1980s by Goetzberger & Zastrow (Weselek et al., 2019). They hypothesized that solar energy collectors and agriculture could coexist on the same ground with benefits for both systems. Photovoltaics still represent the simplest solution for the production of energy from renewable sources. The old ground-mounted plants still enjoy incentives from the various energy accounts developed in the past. The state of the art is as follows: for the plants there are no longer any incentives for the production of energy but the cost per unit of installed power has significantly decreased. This is the major push towards new plant installations. The current orientation for ground-mounted plants is as follows: there is a continuous search by investment funds for plots of land to be removed from agricultural practices for the installation of large plants. Of course, these are agricultural lands that are not subject to landscape, hydrogeological, or others restrictions. The request for land makes farmers only taxable subjects in the process as they are considered as owners of an asset (the fund) to be exploited both for rent (with the transfer of surface rights) and for sale for the installation of large plants. These potential plants are able to produce sufficient income to support all the various business plans drawn up for the verification of the economic feasibility of the plant itself.

This approach has limitations:

- Complete loss of agricultural income in the funds used for the construction of plants;
- Loss of the qualification of agricultural land due to the change of use that is made of the land (with consequent renunciation of the CAP and the related rural development plans);
- Income that goes to the exclusive advantage of the company that owns the plant to the detriment of the agricultural sector.

To change the view on this approach, it is believed to develop a new concept:

Agrivoltaic

This new approach would make it possible to see the photovoltaic system no longer as a mere means of income for the production of energy but as the integration of the production of energy from renewable sources with agricultural practice. To do this there is a need for a political and governmental change in the field of renewable energy deriving from Agrivoltaic plants and above all there is the need to legislate and regulate this new technology in order not to damage those who are willing to use it in own territories.

AGRIVOLTAIC IN THE EUROPEAN GREEN NEW DEAL

The Agrivoltaic systems fit perfectly with the objectives set by the Green New Deal. In fact, the possible large-scale installation of Agrivoltaic systems could lead to a reduction in carbon dioxide (CO_2) emissions equivalent to the removal of 71,000 cars from the road per year and the creation of over 100,000 jobs in rural communities (Proctor et al., 2021). In this regard, it is noted that agriculture 4.0 is able to offer a rare opportunity for a true synergy: more food, more energy, lower water demand, lower carbon emissions and more prosperous rural communities (Proctor et al., 2021). In order to encourage the use of Agrivoltaic technology, the European Union should modify the common agricultural policy regarding the use and destination of agricultural land: in fact, in the current state of affairs, by changing the use of the land the farmer would end up losing the incentives deriving from the EU.

MATERIALS AND METHODS

The present technical note describes an experimental photovoltaic system of extremely small size at the service of powering the experimental projects of the agricultural company of the University of Tuscia. In particular, this plant (Figure 1), in addition to feeding the adjacent greenhouse for the energy needs of the experimental crops, will be tested for suitable crops to be planted under the modules and between the rows of modules. This project allows the Experimental Farm of the University of Tuscia to take advantage of private funding for research in the agricultural sector.

FIGURE 1
PLANT INSTALLATION AREA

The modules (Figure 2) are in monocrystalline silicon and distributed inverters. The photovoltaic modules will be placed on the ground through suitable galvanized steel structures with mono-axial tracking arranged in parallel rows suitably spaced to avoid mutual shading phenomena and limited maximum heights.

FIGURE 2
MODULES OF PLANT

The impacts on the landscape component were estimated as well as the mitigation measures to be implemented to assess the sustainability of the work in the environment and is practically invisible from abroad from the same farm (as shown later in this report). Furthermore, it is emphasized that the work is temporary and will be removed at the end of the financed experimental project. The area in question falls within the municipal area of Viterbo, province of Viterbo, but is located outside the town in production areas and adjacent to industrialists, in the locality of Riello.

The project involves the construction of a photovoltaic system on the ground of about 15 kWp of power; the modules are in monocrystalline silicon and distributed inverter. The photovoltaic modules will be placed on the ground by means of suitable galvanized steel structures with mono-axial tracking arranged in parallel rows suitably spaced to avoid mutual shading phenomena. Photovoltaic systems consist of modules, frames to support the panels and electrical infrastructures. The panels are mounted on structural steel or aluminium frames in such a way as to allow them to assume the right angle and orientation with respect to the sun. The panels are connected with electrical cables and above ground wiring to carry the generated Direct Current (DC) electricity. DC is converted to alternating current through an inverter and the current then passes through a transformer to increase the voltage to match the voltage of the connecting line. The frames on which the solar panels are attached are typically anchored below the surface to protect the panels and structures from wind stress. The planned crops include medicinal plants that will be selected based on their best performance in relation to the climatic characteristics of the site.

SITE CHARACTERIZATION

An evaluation of the site was carried out from the point of view of temperature (°C), solar radiation (W/m^2), rainy days (days), to assess the potential of the site from the energy point of view, and cumulative rainfall (mm) and temperature (°C) were compared for the evaluation of the agronomic species. All data (both monthly and annual) are for a 10-year period (2010-2020). Data were taken from the database of ARSIAL (Regional Agency for the Development and Innovation of Agriculture in Lazio) from the Integrated Agrometeorological Service. The trend of solar ration (W/m^2) versus temperature shows, as expected, a similar trend with a temporal shift in temperature. Obviously, the trends are increasing for the summer period with a maximum average of 37.4 °C and a minimum average of 2.7 °C for the temperature and a maximum average of 8439 W/m^2 and a minimum average of 1050 W/m^2 for the solar radiation (Figure 3). Monthly data are derived from daily averages over a 10-year period.

It is interesting to observe how the average temperature over 10 years has an increasing trend (Figure 4).

Solar radiation over the 10 years analysed has an oscillating trend with an average range of 4435 W/m^2, which opposes the rainy-day trend with a maximum average of 10 days per month for each year (Figure 5).

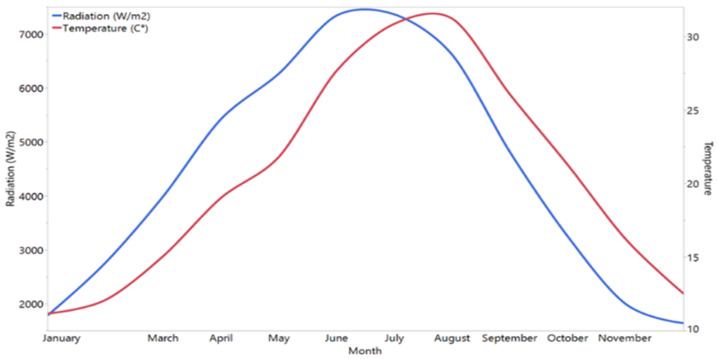

FIGURE 3
AVERAGE MONTHLY TREND CURVES OVER A 10-YEAR PERIOD (2010-2020) FOR TEMPERATURE (°C) (RED) AND SOLAR RADIATION (W/M²) (BLUE)

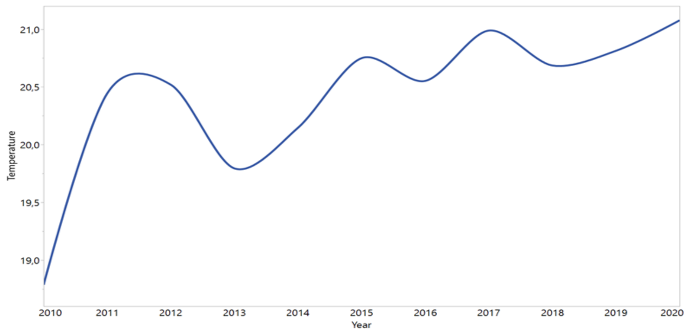

FIGURE 4
AVERAGE TEMPERATURE TRENDS BETWEEN 2010 AND 2020

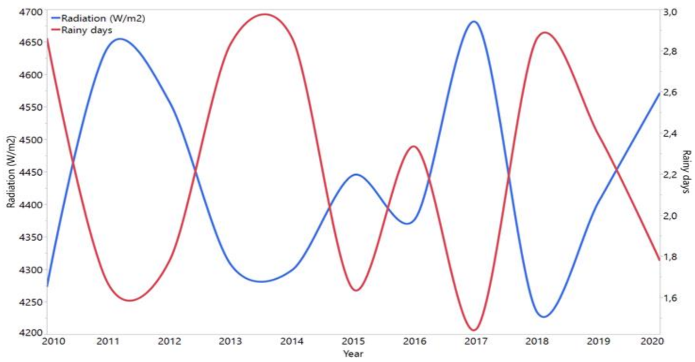

FIGURE 5

AVERAGE TREND OF SOLAR RADIATION AND RAINY DAYS IN THE PERIOD 2010-2020

For the calculation of the annual thermopluviometric balance, the Bagnouls-Gaussen elaboration has been adopted, which relates the amount of monthly mean precipitation with the values of monthly mean temperatures, always referring to time series analysis.

This relationship can then be summarized by the formula (1):

$$T(°C) = 2 \times P(mm) \quad (1)$$

Where,
T=mean value of monthly temperature obtained by processing the mean monthly values of each year of the period considered.
P=average value of monthly precipitation obtained by processing the monthly precipitation of each year of the period considered.
This relationship is used to evaluate the "dry period" or "water deficit" of the year, which begins when the precipitation curve falls below the temperature curve and ends when the trend is reversed, thus identifying the periods of so-called "water surplus".
In the considered area there is a dry period starting from the end of May to the beginning of September (Figure 6).

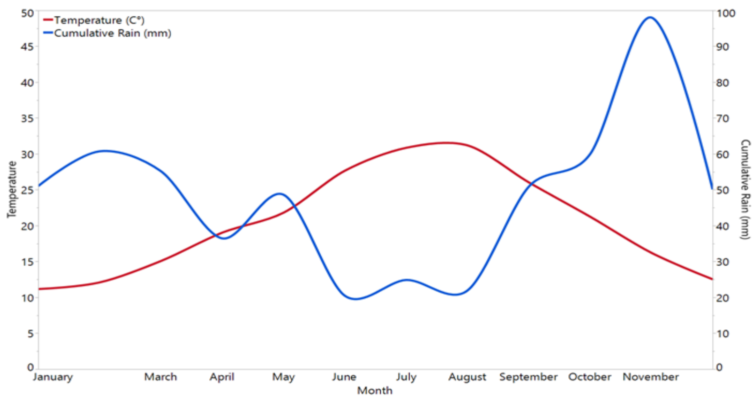

FIGURE 6
THERMOPLUVIOMETRIC DIAGRAM OF BAGNOULS-GAUSSEN THAT SHOWS IN ABSCISSA THE VARIOUS MONTHS AND ON THE ORDINATES, ON THE LEFT THE TEMPERATURE SCALE AND ON THE RIGHT THE PRECIPITATION SCALE IN DOUBLE SCALE

LAND EQUIVALENT RATIO (LER)

The LER is a concept developed in the agronomic field that describes the relative fraction of the agricultural area required by monoculture crops (Dupraz et al., 2011) to provide the same production of the same crops but made in intercropping (Khanal et al., 2021). In the simplest case of only two cultivated species, the LER is the result of the following formula (2):

$$LER = Y_a cons/Y_a mono + Y_b cons/Y_b mono \quad (2)$$

Where the subscripts a and b indicate two hypothetical agricultural crops, the terms “mono” and “cons” indicate, respectively, the monoculture or the associated condition (Figure 7).

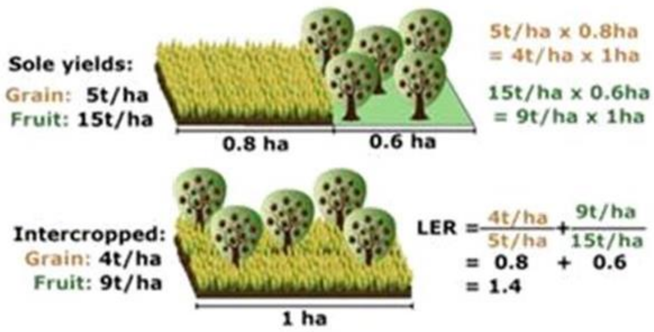

FIGURE 7
HYPOTHETICAL AGRICULTURAL CROPS

The design methodology applicable for an agrivoltaic system is shown below trying to collect the main characteristics.

MONITORING OF EXPERIMENTAL TESTS

Here are some monitoring techniques of the experimental tests to be carried out on Agrivoltaic sites. The in situ measurements to be carried out are:

- The consumption of water;
- Energy consumption per unit of product (application of the LCA, Life-Cycle Assessment);
- The measurement of albedo;
- The evaluation of shading;
- Animal welfare;
- The assessment of bee deaths through monitoring 4.0.

KEY PERFORMANCE INDICATORS

The KPIs, Key Performance Indicators, are key performance indicators that represent the index of the progress and feasibility of the process.

The main KPIs that must be considered are listed (Schindele et al., 2020):

- Consumer preference for national products;
- The possible application of the organic certification of productions;
- The tradition of some local productions;
- The protection of autochthonous and/or endemic floristic crops and resources, with particular attention to the identification of local ecotypes that can constitute a resource of great agronomic, nursery and nutraceutical interest in terms of morpho-functional adaptations and the presence of active ingredients;
- The conservation of a cultural heritage including history, customs, traditions that constitute a set of resources;
- Cost reduction management and maintenance;
- The economic enhancement of the free surface;
- Greater integration into the territory;
- The increase in jobs;
- The integration of agricultural income;
- The diversification of agricultural products;
- The modernization of methodologies and technologies;
- Sustainable development;
- Low environmental impact;
- The economic opportunity in the area.

ENVIRONMENTAL AND ECONOMICS RESULTS EXPECTED

The main objective of the experiment is to demonstrate that the Agrivoltaic system has the same impacts on the environment compared to classic ground or roof photovoltaic systems (Weselek et al., 2019). On this point it will be necessary that unlike the primordial Agrivoltaic plants, modern plants do not have a greater environmental impact than other renewable energy production systems present in Italy. In terms of issuance it will prove that the acidification from AV systems is about one sixth that of the Italian electricity mix and one twentieth or thirtieth that of biogas systems (Agostini et al., 2021).

At the same time, however, Agrivoltaic allows us not to consume the soil and to cultivate the same thanks to the combination of energy and agriculture (Marrou et al., 2013). From an economic point of view, it will be shown that despite a high initial expense, the Agrivoltaic plant is able to offer greater revenues deriving from the production of electricity compared to traditional ground-based PV. Costs and revenues vary depending on the area where the system is to be installed, but are generally similar if not better than traditional ground photovoltaics, improved precisely by the combination with the cultivation of specific plantations (Horváth et al., 2010). Even from a working point of view, the Agrivoltaic would lead to a greater employment of workers, as on the one hand there is the need for technicians to install the systems and take care of their maintenance; on the other hand, there are the crop workers who take care of the agricultural part with a daily commitment. A further objective is to demonstrate that the economic and environmental costs of Agrivoltaic plants are comparable to those of other photovoltaic plants, although the reduced impact on land occupation and the stabilization of agricultural production are significant added values that should be adequately exploited in a future energy system dominated by increased human ownership of land and climate change (Aroca-Delgado et al., 2020).

CONCLUSIONS

In conclusion, the use of agriculture technology offers important advantages such as, for example, the possibility of selling food and renewable energy production. This aspect is fundamental in the new industrial cities where the production of renewable energy is increasing but at the same time cultivation and agricultural land must also be protected. If on the one hand there will be an increase in the production of renewable energy, therefore, on the other hand there will necessarily be an alteration of the microclimate. This does not mean that in some cases, for particular categories of crops, it is possible to obtain a saving of water for irrigation, as under the panels there are shaded areas capable of allowing the cultivation characteristics of those plantations. Currently, however, the relative effects of the panels on crops should be investigated with more detailed studies. In this regard, this experiment aims to shed light on the effect that agrivoltaic systems can have on the productivity of certain types of crops. Surely, Agrivoltaic can be an important component of agricultural systems, addressing some of the main current and future social and environmental challenges, such as climate change, global energy demand, food security and land use.

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