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AGRIVOLTAIC SYSTEMS IN ITALY: Technical and economic evaluations in the current regulatory context.

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“Luck is what happens when preparation meets opportunity.”

Seneca

Picture 1 Photo by Martha Bergmann

ABSTRACT

Agrivoltaic systems could be one possible multi-target solution for energy transition, climate adaptation and farmers' low incomes. In fact, they combine food and energy production on the same land in a synergistic way.

The actual Italian legislation is evolving a lot in the past few years following the main law, D.L. 77/2021 on agrivoltaic now called L. 108/2021. With this law it is possible to see who can install and benefit from these systems and how to access to possible NRRP funds. More specific guidelines on agrivoltaic definition and access to European funds were made from Mite (ministry of energy transition) together with CREA (Italian agricultural research center) and other associations.

There are different types of agrivoltaic: on open or closed fields, simple or advanced, on single or multi axes etc… All these systems are still under studying and each could be applied in a specific situation. Most of the experimentations come from the Fraunhofer Institute for Solar Energy Systems in Germany.

Agrivoltaics have multiple benefits beside the economic ones; they can help to create more resilient agricultural systems against climate change (lowering also some agricultural costs like for irrigation) and helping to innovate the agricultural sector but there are also some drawbacks starting from the investment costs to the management of a complex system during its lifetime.

An agronomic report is required at the beginning to explain the crop and landscape mitigation plan and each year to justify the maintenance of agricultural production. This is why advanced monitoring and precision farming are essential, not only for agricultural production but also to avoid damage to the panels and to preserve the electric production which is the most profitable source of this system. Economic investments are quite high, but the revenues are as well, both for the investor which is usually an electric company but also for farmers who can get revenues both from crops and the lease of the building rights. The funds from NRRP plan could make it possible for farmers to invest and own directly a small agrivoltaic system increasing a lot their income with a payback time of around 7 years on average.

There are already multiple examples of these systems in Italy and it seems there will be an increased amount of them in the next years because they are more socially accepted and for this have a simpler and faster authorization process.

ACKNOWLEDGEMENTS

It feels strange for me to write this thesis now, after the bachelor I started working and ever since I never thought I’d go back to university. Instead, here I am, writing the master thesis at 30 challenging myself once again.

Everything changed in university compared to when I finished it before Covid, I’ve never done any lesson online before and it’s all more developed in the use of technologies.

This helped me a lot to integrate and understand more the reality we are living in.

I want to thank my family, friends, classmates and professors who helped me get back on the study track.

I hope that with my example I can help people like me to understand going back to university is always a good investment for your knowledge and your future. I understood that University gives you curiosity and some basis to start working but it’s how you apply and delve into the topic that matters the most.

Finally, I thank myself for not giving up when I was close to doing so, for creating amazing new connections with people and for accepting to go out of the comfort zone to grow.

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1 NOMENCLATURE

APV Agrophotovoltaics

CAPEX capital expenditures

ct cents

€ euros

FM Financial Mechanism of the UNFCCC

GM ground-mounted

GWp gigawatt-peak

ha hectare

IFES Integrated Food-Energy Systems

kWh kilowatt hours

kWp kilowatt-peak

LCOE levelized cost of electricity

LER Land equivalent ratio

LUE land use efficiency

MWp megawatt-peak

OPEX operating expenses

p price

pb performance/performed benefit

ppr price-performance ratio

PV photovoltaics

RE renewable energy

$ United States dollars

(Schindele et al., 2020)

2 INTRODUCTION

This past year there was an increase of energy cost and climate change effects.

Many businesses didn't start or closed due to energy costs; it was realized how dependent we are on outside resources. Energy supply costs, on average, account for more than 20% of the variable costs of farms.(*Agrivoltaico, ok Ue al secondo bando da un miliardo. Meno vincoli sull'autoconsumo*, 2023)

Our society relies heavily on fossil fuels, which is not sustainable. Nuclear energy could be one solution, but as of today it is banned in Italy. Right now, we could use different renewable energy resources that are more decentralized and environmentally friendly like: biomass, hydropower, geothermal, wind, and solar. The main problems of these technologies are their intermittent nature, storage cost and especially land occupation (Balali et al., 2017).

The photovoltaic (PV) system, which exploit solar energy and semiconductor materials, is today the most economical efficient solution in Italy to produce renewable energy and for this reason it has grown the most among all.

According to the International Energy Agency (called "IEA"), the installed capacity of PV in major countries was approximately 402 GW in 2017, 70 times higher than in 2006. (Sekiyama T, 2019)

Roof-top PV systems can partially satisfy electricity demands, but it's not as easy as it seems especially in a country like Italy where there are a lot of historical and landscape constraints, roofs that cannot sustain additional weight and companies that do not want to bind themselves to long contracts for energy production.

There has also been a tender to encourage photovoltaics on roofs called Parco Agrisolare (*DECRETO Mipaaf 25 Marzo 2022*), but it ended up not so used because it allowed farmers to put photovoltaic panels on top of their farms' roofs just for self-consumption and they were not interested or ready for a big use of electricity just for themselves (Redazione, 2022).

As a major renewable energy source, large (commercial scale) PV power stations are key for meeting the demands of the main production sectors, but these systems are facing a problem: competition in land use for food especially in densely populated regions.

Ground mounted photovoltaic systems are not subsidies anymore in Italy but the costs for unit production is quite efficient and quite convenient for big investors, this could bring the risk of farmland to be consumed.

Agriculture is an important sector in Italy which has been the most affected by climate change and increase costs of energy and raw material.

Farmers are facing a lot of issues due to lack of water and funds and increased energy costs.
Due to extremes events like drought and excessive solar radiation, farmers lost a lot of yield especially for some sensitive crops like corn (*Corn and Soybean Production down in 2022, USDA Reports Corn Stocks down, Soybean Stocks down from Year Earlier Winter Wheat Seedings up for 2023*).

This trend seems to persist and even increase in the next years, weather experts say that the climate latitude and vegetation biomes shifted 400 km south compared to less than 100 years ago and that's concerning (Gonzalez et al., 2010).

Lot of land is going to face abandonment and desertification. Water has become a major issue, here in Italy many rivers became too shallow and many crops have become unsustainable to grow for lack of precipitation. Maybe in the next years we'll have to adapt and change the type of crops which can be more suitable for this changed environment. The desert in Africa is expanding and this is causing a lot of pression on local population that without fresh water must leave aggravating the immigration problems in other countries.

Farmers to stay competitive in the market will need to adapt quickly to these new conditions and find ways to create resilient systems that can provide different sources of income.

In the future there are predictions that countries which are densely populated, with limited flat areas, will face difficulty in trading off their agricultural estate to install purely solar farms or other renewable energy facilities such as wind turbines (Mamun et al., 2022).

Because of the constant development of our society (infrastructure, industrial estate, housing development etc…) and soil degradation and desertification, cropland is expected to decrease globally by between 50,000,000 ha (the size of Spain) and 650,000,000 ha (twice the size of India) by 2100. Because of this cropland is becoming a very scarce resource (IPCC, 2019).

Often the main complain of the application of photovoltaic is the consume of agricultural land but we tend to forget that the main contributor of land consumption is cementification through infrastructures, factories etc… Agrivoltaic in this sense could preserve land from excessive urbanization.

There are some predictions that say by 2050, we will need 40% more water, 50% more energy and 60% more food to satisfy the demands of our growing population (Ringler et al., 2016). This will cause a series of issues and challenges connected adding significant stress at the nexus between water, energy, and food.

Integrated Food-Energy System (IFES) could be one approach to face the challenge in terms of sustainable land use because it enables on the same land, the simultaneous production of food and energy.

Agrivoltaic, also called agro-photovoltaic (APV) systems can be one specific solution of this kind of approach to adapt to climate changes and land competition problems for primary resources (Schindele et al., 2020). This technology has different applications with many benefits but also constraints.

To make agrivoltaic a possible solution, is essential to have a panoramic view of the regulations starting from the European level down to national and regional level and to know the possibilities of fundings support from NRRP or PNRR in Italian

(*The National Recovery and Resilience Plan (NRRP)*, Italian Decree-Law No. 59 of 6 May 2021)

Moreover, we need to study which crops to cultivate under this system that could benefit from partial shading condition.

From the electric part we have to know the possible costs of initial investments, the price of selling the energy, the profit and the return on investment.

All this information has to be collected to make a dynamic business model to help support farmers' decision making.

Right now, the whole system is not standardized yet, so we have to get our data from real study cases, scientific articles, personal experiences, interviews and conferences.

3 METHODOLOGY

3.1 Introduction

This research is conducted with a scientific approach and has the objective of providing decision support to investors, particularly farmers, navigating the intricate Italian regulatory landscape. The research methodology combines qualitative data collection from various sources, including scientific articles, interviews, conferences, and real-world cases, with financial analysis utilizing Excel spreadsheets. This holistic approach was used because of the novelty of agrivoltaics in Italy, the lack of statistical data and the evolving regulatory framework.

3.2 Qualitative Approach and Data Collection

The qualitative approach was chosen to address the following challenges inherent to the agrivoltaic context in Italy:

1. Limited Statistical Data: Agrivoltaics is a relatively new phenomenon in Italy, resulting in insufficient historical data for robust quantitative analysis.

2. Diverse Applications: The variety of applications for agrivoltaic systems in Italy makes it challenging to establish standardized utility-scale frameworks.

3. Evolving Regulations: Many laws are still in draft form and notices have not yet come out. Numerous agrivoltaic projects haven’t started yet and are in various stages of administrative approval.

3.3 Data Sources

To overcome these challenges, the research used a non-probability sampling method to collect data from the following sources:

a. Scientific Articles

Relevant information was extracted from scientific articles found online in website like Google scholar, enabling a comprehensive understanding of agrivoltaic technology, benefits, challenges and future researches on the interaction between plants and solar panels.

b. Interviews

Structured interviews were conducted with experts and practitioners actively engaged in agrivoltaic projects. These interviews provided firsthand insights into practical challenges, real-world case studies, and current industry trends.

c. Conferences and Seminars

Participation in agrivoltaic-related conferences and seminars facilitated access to up-to-date insights and emerging trends within the field.

d. Real-World Cases

Already existing case studies were considered, such as research conducted by Prof. Amaducci at Università Cattolica del Sacro Cuore - campus di Piacenza, and Le Greenhouse company in Calabria. They were analyzed to gain insights into existing systems and their performance to get data for the Excel elaboration.

3.4 Financial Analysis

3.4.1 Data Processing

After collecting data, Microsoft Excel was used as the primary tool for data organization and analysis. All information regarding financial parameters was used and put into a dataset.

3.4.2 Scenario Simulation

The research simulated various investment scenarios to support decision-making processes. These scenarios considered an average agrivoltaic system with specific parameters, including a system height of 2.1 meters and 7 meters between rows. The agricultural aspect of the analysis was based on a standard crop rotation of five years, including soybean, wheat, and alfalfa. The aspect of revenue generated from electricity was made considering the scenario with NRRP funds or without them and with different prices of the energy sold into the market or to GSE (gestore servizi energetici).

3.3.3 Financial Indicators

Multiple financial indicators were used to evaluate the feasibility and attractiveness of agrivoltaic investments:

a. Payback Time

The payback time indicator was used to determine the number of years required for an investor to recover their initial investment. It is used as a fundamental assessment of short-term financial viability.

b. Net Present Value (NPV)

NPV analysis was utilized to assess the long-term profitability of agrivoltaic investments. NPV calculates the value of an investment throughout its lifetime by discounting future cash flows to present value using the Weighted Average Cost of Capital (WACC). A higher NPV suggests greater long-term profitability.

c. Internal Rate of Return (IRR)

The IRR, derived from the NPV analysis, indicates the hypothetical rate at which the NPV of the investment equals zero. If the IRR exceeds the actual cost of capital, the investment is not favorable.

d. Return on Investment (ROI)

ROI measures the efficiency or profitability of an investment by calculating the ratio between net income over and the initial investment. It is used in a way to have a parameter to compare with other similar investments.

3.4.3 Accounting for Uncertainties

To account for uncertainties and dynamic economic conditions, scenarios considered a 3% annual inflation rate for 20 years or more and potential cost increases.

3.5 Summary

This research is an integrated analysis that combines regulatory insights and economic findings to provide a comprehensive overview for potential investors interested in the agrivoltaic sector. This includes an exploration of the benefits of plant/solar panel interactions, the direction of research in terms of technologies and materials, and an assessment of the potential returns from agrivoltaic investments under different economic scenarios. Since a qualitative method was mostly used all this information might be subjected to personal interpretation.

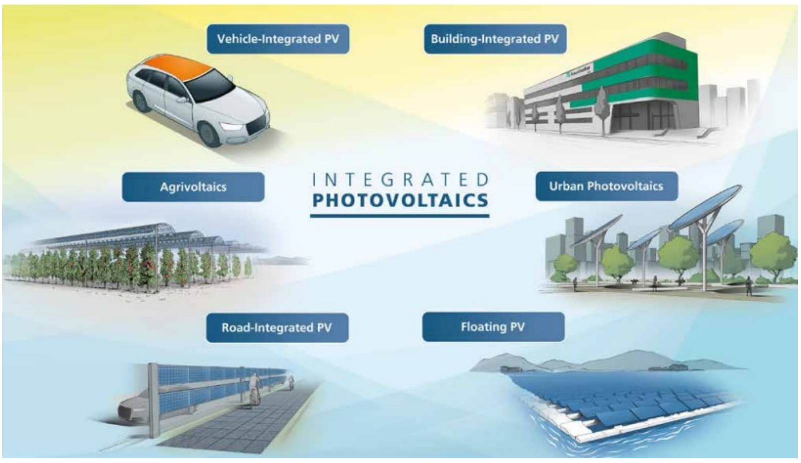
The final goal is assisting investors, particularly farming companies, in navigating the complex Italian agrivoltaic landscape and making informed investment decisions.

4 DEFINITION & DIFFERENT SYSTEMS

The Archetype of the agrivoltaic system is the agroforestry system, which involved intercropping between crops and trees. Trees could grow fruits while protecting the crops underneath from excessive radiation. This system mimic Nature where in a forest there are different layers of vegetation. Then, at the end of 1800’s the solar panel was invented.

The first application of combining photovoltaic and agriculture was in 1975 when the first photovoltaic water pump was launched. With time, photovoltaics innovations have been used to supply the needed power for different agricultural applications such as crop drying, cultivation in a greenhouse, irrigation and more. Now there’s also a growing interest in combining photovoltaic for energy production used in desalination farms that could be very helpful in countries with a lack of fresh water.

Photovoltaic systems (PV) can be applied not only in agriculture but in many other fields. They can be applied on parking lots to shade cars, on the side of roads to protect also from view and noise, on water bodies like lakes to lower excessive evaporation. New studies made it possible to create semitransparent or transparent modules that can be applied also on vehicles or on buildings instead of windows or pavements. There’s a lot of research on this topic, especially to make panels more efficient and sustainable with alternative materials.



Picture 2 Photovoltaic applications (© Fraunhofer ISE)

Agrivoltaic combines food production with energy production from the Sun. This concept was first proposed in 1982 by Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems ISE (Trommsdorff et al., 2022).

The first reported stilt-mounted agrivoltaic farm experiment was performed in Montpellier, France in 2010.

Nowadays more than 2200 APV systems have been installed with a capacity of about 2.8 GWp as of January 2020 (Schindele et al., 2020).

There are different types of agrivoltaics, the main distinction is made between independent systems on open fields and integrated systems in closed buildings.

In open fields panels can be mounted near ground practicing permanent grassland and animal grazing, or they can be placed high enough (over 2,1 meters) for machines to pass and cultivate crops underneath (these last ones are called advanced agrivoltaics). The photovoltaic panels can be mounted on single or double axis with a tracking system to better follow the sun, the electricity production could increase of 15% for trackers following the sun compared to traditional fixed angle photovoltaic systems.

It's important to design the system in collaboration with engineers and agronomists to be sure of maximizing panels density creating enough space between and at the end of rows so tractors can move and turn for agricultural operations.

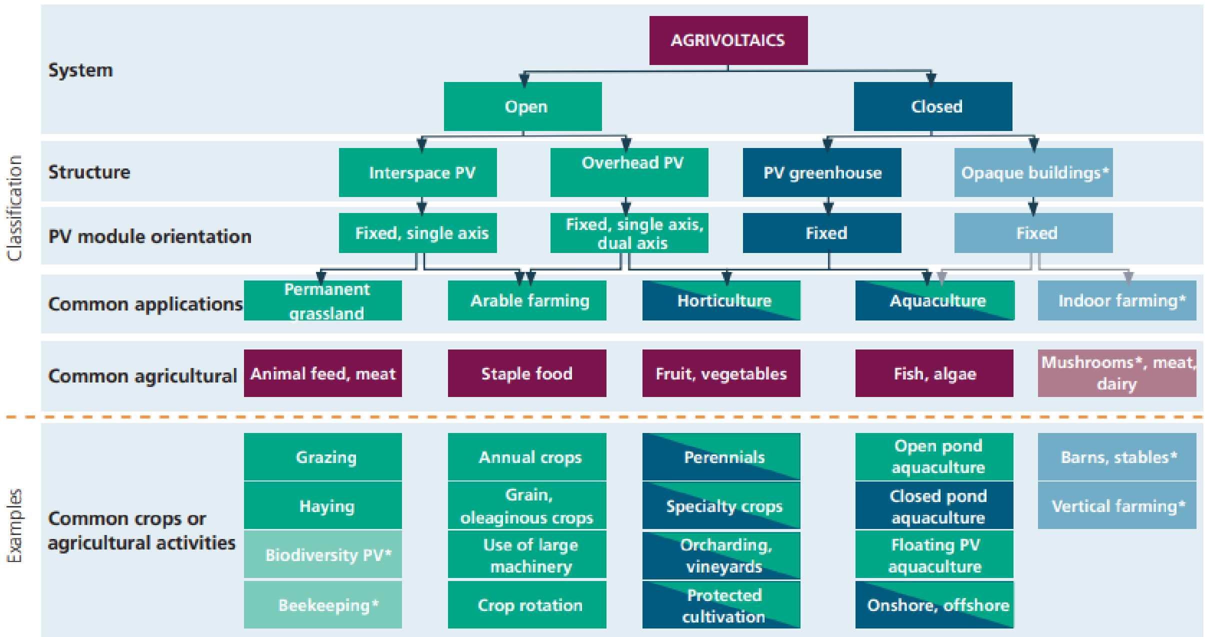
Panels can also be mounted between rows vertically instead of horizontally above them. This system can be applied in areas where there are height and visual impact restrictions or where space is limited on the rows of the crop.

In a vertical agrivoltaic system, the panels are typically mounted on vertical walls or poles erected in-between the crops. This allows for the efficient use of space and provides partial shade for the crops.

Vertical agrivoltaics can help to mitigate urban heat island effects, as the panels provide shading and can help to cool the surrounding environment. Additionally, they can function as wind breakers saving soil from erosion, used as barriers to prevent pesticides drifting between fields or even as fences for animals.

In closed environments photovoltaic (PV) panels can be used over buildings or green houses to produce special crops underneath.

PV for greenhouses is a promising solution for the competition of land resources between food and energy production because it allows continuous food production and electricity generation throughout the year.

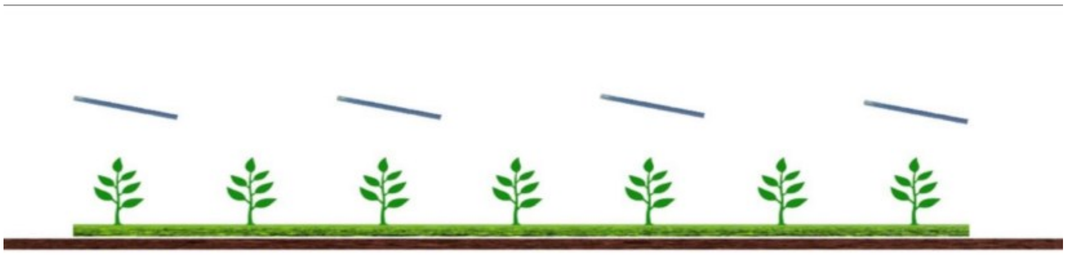


Picture 3 Different agrivoltaic systems (Trommsdorff et al., 2022, © Fraunhofer ISE)

The efficiency of the single panel has improved a lot in recent years and it's now around 600 W compared to 240 W of the first installations. This efficiency is increased in the agrivoltaic bifacial system where also the albedo (reflected light) can be absorbed (Cheo et al., 2022).

In the Italian guidelines of reference (Mase, 2022) there are described 3 main types of agrivoltaic:

1. Agrivoltaic where cultivation happens between and over the rows with a 100% cultivation ratio.



2. Agrivoltaic system where cultivation happens only between panels and not underneath them.

3. Agrivoltaic system with vertical panels between the rows of crops and with possible passage of animals underneath them.

Between these three systems the simplest and cheapest system is number 2 but only 1 and 3 are considered advanced and therefore fundable by NRRP.

The specific requirements and legislation will be presented in the next chapter.

Agrivoltaic's examples:

Picture 4 Integration of simple APV system and pasture (© enelgreenpower.com)

Picture 5 Overhead system for orchards (© BayWa r.e.)

Picture 6 Advance APV system with dual axis tracker (© https://remtec.energy/)

Picture 7 Overhead system enabling cultivation with a potato harvester (farm community Heggelbac, © Fraunhofer ISE).

Picture 8 The vertical solar system that combines bifacial modules (© Next2Sun GmbH) .

Picture 9 Agrivoltaic on top of greenhouses (© Legreenhouse.it)

Picture 10 Aquaculture+phoyovoltaics (© Fraunhofer ISE)

5 REGULATIONS

5.1 European overview

In the last years the UN, the European Union and the main international agencies focused their attention on the production of renewable energies(Colantoni et al., 2021).

UN 17 sustainable goals

In September 2015, the UN stipulated Agenda 2030 which includes 17 guidelines of action, among which there is also the development of agro-photovoltaic systems to produce renewable energy.

Picture 11 UN 17 sustainable development goals (United Nations, https://www.un.org/).

With **EU Directive/2018/2001** (*Renewable Energy Directive: EU Directive/2018/2001*), as part of the 'Clean energy for all Europeans' package, the European Union aimed to be the main leader in renewable energy sources.

The new directive sets a new target for renewable energies for 2030, which must be equal to at least 32% of final energy consumption. Moreover, to reduce CO_2 emissions, EU will ban all fossil fuel vehicles by 2035 with the aim to prevent temperatures to raise more than 2°C and reach carbon neutrality by 2050.

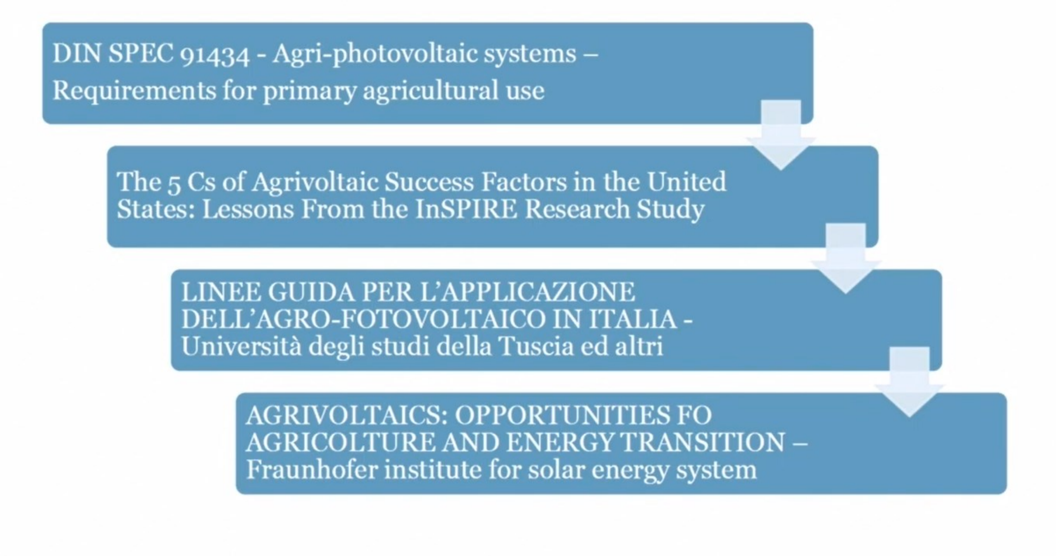
Member States will be able to propose their own targets energy sources in the ten-year national plans and progresses made towards national targets will be measured every two years when EU Member States publish their national progress reports on renewable energies.

The European Commission, to support agro-photovoltaic, intends to implement initiatives within the European Biodiversity Strategy, with the aim of accelerating the transition to a new sustainable food system. Furthermore, the Commission has already proposed to integrate agro-photovoltaics into Climate Change Adaptation Strategy.

With **REPowerEU** regulation, on the 18th of May 2022 (*REPowerEU*), EU has fixed more ambitious community goals to be independent from Russia's importation of oil and gas. There are three pillars: energy saving, diversification of supply and production of renewable energy. Some of the goals include increasing energy production from renewable recourses from the actual 40% to 45% of the total energy production by 2030 and by the same year to increase the photovoltaic production to 600 GW. Considering that now the production of energy from photovoltaic is less than 100 GW (Statista) we can predict a boom in this technology in the next years and countries of south Europe could have a big advantage in this.

Right now, Germany is the country leading the legislation on agrivoltaic and has made a specific regulation called *DIN SPEC 91434* which leads the example for other countries.

There have been made also agrivoltaic guidelines in US and in Germany by The Fraunhofer Institute for Solar Energy Systems ISE.



Picture 12 Other guidelines on agrivoltaic.
From personal video of Mauro Camilletti – Mcprogetti 10/11/2022 - Ecomondo 2022, Rimini Fiera (SGR Efficienza Energetica, 2022)

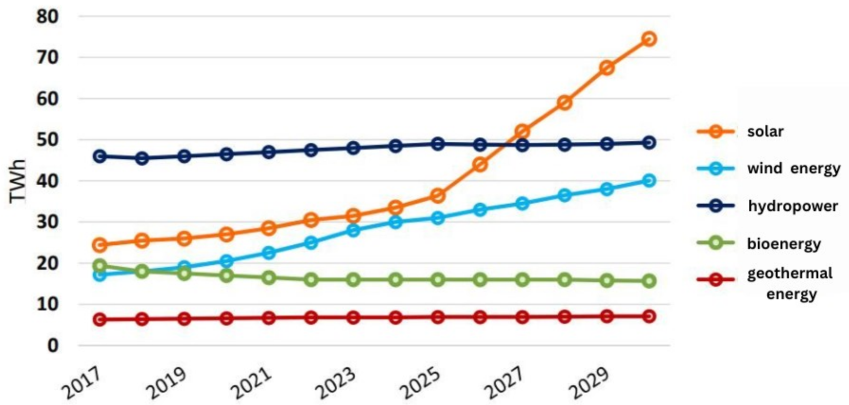
5.2 Italian overview

In Italy alone the annual electricity requirement is equal to 320 TWh (data Terna) and only 24 TWh derive from photovoltaic plants.

The electricity requirement in 2022 was met for 86.6% by national production destined for consumption, for a value of 277.1 TWh and for the remainder 13.4% by imports from abroad for an amount of 42.8 TWh, up by 32.9% compared to 2020.

In in Italy, it was founded SEN (*Strategia Energetica Nazionale 2017 | Ministero Dell'Ambiente e Della Sicurezza Energetica*,) that contains more ambitious targets than those of the UN 2030 agenda and at national level in 2020, MISE (Ministero dello Sviluppo Economico) adopted PNIEC 2030 (*Pubblicato Il Testo Definitivo Del Piano Energia e Clima (PNIEC) | Ministero Dell'Ambiente e Della Sicurezza Energetica*), which represents a fundamental tool for turning our country's energy and environmental policy towards decarbonization.

Based on research from ENEA (ente nazionale per le energie alternative) the nominal power of renewable plants in Italy is today around 25 GW. To achieve the established objectives from PNIEC, around 70 GW of renewable plants have to be installed by 2030, with an average of 6GW per year and, considering that the current annual installed power is less than 1 GW, it is necessary to find alternative solutions to accelerate this step especially considering that by 2050 to reach carbon neutrality we have to reach 350 GW power (*Rinnovabili, l'Energy Report*, 2022).



Graph 1 Expected trajectory of electricity generation (redazione regionieambiente.it, 2019)

The Polytechnic Institute of Milan estimates that to reach around 50 GW of electricity from photovoltaic, 15 GW will be derived from industrial and commercial roofs, 10 GW from energy communities and the other 25 GW from other surfaces like quarries and landfills but also agricultural land.

In Italy there are 16 million ha of agriculture surface, of these more than 2 mln are unutilized which could be used for photovoltaic plants. To reach 25 GW of production we would need just 0,23 % of the total agricultural surface (around 38.000 ha) but it's difficult to find big extensions of land all together.

From Mite (Ministero della Transizione Ecologica) to Mase (Ministero dell'Ambiente e della Sicurezza Energetica)

The ministry in Italy is responsible for defining and implementing environmental policy, protecting Nature and biodiversity, managing natural resources, and promoting sustainable development.

The ministry carries out various activities and initiatives, such as defining national environmental policies, promoting projects for ecological transition, managing environmental funds, and monitoring environmental quality. Examples of practical interventions promoted by the ministry include the creation of wind parks, the promotion of low-impact buildings, the establishment of protected areas for biodiversity conservation, the reduction of greenhouse gas emissions in the transportation sector, and sustainable water resource management.

As for prospects, the Ministry of Ecological Transition is focusing on promoting a low-impact society that can manage natural resources sustainably to protect biodiversity. The ministry's future objectives include reducing greenhouse gas emissions of 55% by 2030, increasing renewable energy sources use up to 33% and energy efficiency by 32.5% by 2030.

Energy communities

Energy communities are also promoted by the same ministry.

Their initiatives focus on producing, managing, and sharing energy resources. These projects aim to promote renewable energy and energy efficiency in local communities by enabling residents, businesses, and other stakeholders to work together and manage energy systems that meet their needs.

Energy communities can take many different forms, depending on the resources available in the community and the goals of the project. For example, a community might set up a solar panel installation on a community center and distribute the generated energy among the members of the community. Alternatively, a group of farmers might come together to develop a wind or agrivoltaic farm that supplies energy to their farms and surrounding areas (*Comunità energetiche rinnovabili alla vigilia della svolta - T24*).

Overall, energy communities are designed to promote energy independence, sustainability, and resilience, and can help communities to reduce their reliance on fossil fuels, reduce their carbon footprint, and create local economic opportunities.

The Italian government is favoring these communities to reach the ambitious goal of decarbonization and energy autonomy by 2050.

Energy communities will be a great opportunity for sustainable economic development and social cohesion.

The government will provide an incentive tariff on the share of energy produced by these communities, the power that can be financed is equal to a total of 5 gigawatts (GW), with a time limit set at the end of 2027.

Only in communities created in municipalities with fewer than 5,000 inhabitants, the measure will allow a non-refundable grant of up to 40% of the investment. The intervention may concern both the construction of new plants and the upgrading of existing plants.

The measure is financed with 2.2 billion euros from the Pnrr and aims to achieve a total power of at least two gigawatts.

The measure then clarifies which are the eligible expenses (from the supply and installation of the accumulation systems to the technical and/or technical-administrative tests). The maximum investment cost is 1,500 euros per kilowatt for plants up to 20 kW which has to be gradually lower for bigger plants.

As for the incentivized tariff for the energy produced, GSE could give three bands of incentives are indicated: for power plants up to 600 kilowatts, the tariff consists of a fixed rate of 60 euros per MWh increasing to 80 euros for plants below or equal to 200 kilowatts. There is also a correction factor depending on the geographical area: 4 euros per megawatt hour more for the central regions and 10 euros more per MWh for those in the north.

Whoever obtains the grant can ask to combine it with the incentives in the tariff, in cases in which the capital grant is all given, the due tariff will be reduced.

Energy communities can be done by groups of citizens, condominiums, small and medium-sized enterprises, but also local authorities, cooperatives, associations and religious bodies: whoever chooses to join a community, must first identify an area where to build the plant with renewable technologies, then a contract of incorporation of the association will be required which has environmental, economic and social benefits as its main corporate purpose.

The manager of this measure is the GSE (Gestore dei Servizi Energetici GSE S.p.A.) which will be able to verify the eligibility of the interested parties to guarantee the concrete possibility of accessing the benefits of the measure.

5.2.1 Italian agrivoltaic laws

In Italy laws on agrivoltaic are quite new and still developing together with the industry and universities experimentations.

In this research there will be explained 4 significative legislations regulating the agrivoltaic systems in Italy but there are more evolving especially after the war in Ukraine and the energy crisis

4 main regulations:

- D.M. July 5, 2012
- FER1 c.d. “rinnovabili” D.M. 4 luglio 2019
- D.L. 8 novembre 2021, n. 199
- D.L. 77/2021,

D.M. July 5, 2012

One of the first regulations for agrivoltaics started in 2012 with photovoltaic greenhouses in the agricultural context. They have been viewed favorably and encouraged with the definitions of this law , as a "structure with a minimum height of 2 meters, in which the photovoltaic modules constitute the construction elements of the roof". (MINISTRO DELLO SVILUPPO ECONOMICO, 2012)

Indeed, the new agro-photovoltaic systems are compared to a "modern open greenhouse" or a mobile photovoltaic roof (without however involving the construction of closed volumes), with a minimum height from the ground equal to two meters, usually equal to about 3 meters with a maximum inclination of the module mounted on the tracker of about 2.4 meters. This height allows the cultivation of the entire surfaces affected by the system and the management of the field with the usual practices and agricultural machines.

FER1 c.d. “rinnovabili”, D.M. 4 luglio 2019

The legislative decree: FER1 o c.d. “rinnovabili”, D.M. 4 luglio 2019, introduced a new system of incentives for installation of new renewable energy production plants. (MINISTRO DELLO SVILUPPO ECONOMICO, 2019)

This law divides the renewable energy plants that can access the feed-in tariffs into two categories based on the technology (established or advanced technology), the renewable source and the type of investment. The incentives are paid from GSE for the electricity produced and injected into the grid.

It has established 6 priority criteria for access to incentives:

• PV systems built on landfills and contaminated land.

• systems with charging stations (15% of capacity of the power plant).

• aggregated systems.

• greater discounted offer on the incentive (max 30%).

• lower tariff

• date of the application form.

For plants with power greater than 1MW, a low auction is foreseen where the photovoltaics plants compete in the same group together with onshore wind farms. Smaller plants with power less than 250 kW can assess a higher all-inclusive tariff.

The feed in tariff is given to compensate the LCOE (levelized cost of electricity) which, for advanced agrivoltaic, may be higher than the average 50 €/MWh at national level. At the moment the highest possible incentive tariff for agrivoltaic is 85 €/MWh.

With the recent "simplification decree" of 2021, the legislator intervened by extending the regime of incentives promoting photovoltaic systems in the agricultural (or agro-photovoltaic) sector, provided that the simultaneous presence of the following 3 conditions:

• use of innovative solutions.

• raised off the ground

• have monitoring systems that make it possible to verify their environmental impact.

D.L. 8 novembre 2021, n. 199

This law defines the implementation of EU Directive 2018/2001 of the European Parliament of the Council on the promotion of the use of energy from renewable sources. Here it is defined how the incentives of the PNRR will be distributed. (PRESIDENTE DELLA REPUBBLICA, 2021a)

In section C of article 14 we find the term agrivoltaico, by defining it they give the prerequisites to get the non-refundable incentives from the recovery plan. Basically, they say that funds will be given only to advanced agrivoltaic plants able to preserve agricultural activity.

In Chapter II of this law, it’s said that payments will be made by the GSE (Gestore servizi energetici) for energy produced and sold or self-consumed for the entire duration of its useful lifespan defined for the type of plant.

These incentives are also issued according to the plant's size and capacity.

Distinction is made between large plants of 1 MW or greater capacity in which the incentives are established through downward auction systems referring to quotas of power. While for small plants with a capacity of less than 1 MW, incentives will be dispensed through calls for tenders in which prerequisites for access related mainly to cost efficiency and the maintenance of environmental and territorial protection.

In the same law the suitable areas for agrivoltaic are defined as:

- areas where there are already photovoltaic plants.
- areas subject to remediation identified by Legislative Decree 152 of 2006
- disused or abandoned quarries and mines that cannot be exploited in other contexts.
- disused sites of railway, highway and airport companies.

In addition to the previously mentioned areas, agricultural areas are also considered suitable if at 500 meters from industrial, commercial areas and highway. This area is called SOLAR BELT.

Contrastingly, there are prohibited areas in a one-kilometer strip from property subject to the protection of fine arts (belle arti). This makes a lot of confusion because in Italy there are a lot of historical landscape assets which are close to unrestricted and suitable areas.

D.L. 77/2021

In Italy the most important law that defines and differentiate agro-photovoltaic systems is D.L. 31st of May 77/2021 which is now converted to law L. 108/2021 defined governance of the National Recovery and Resilience Plan. (PRESIDENTE DELLA REPUBBLICA, 2021b)

Article n. 18 of DL. 77/2021 defines the typologies of projects to implement the production of sustainable energy that have been introduced by the NRRP (*The National Recovery and Resilience Plan (NRRP)*) and PNIEC (*Pubblicato Il Testo Definitivo Del Piano Energia e Clima (PNIEC) | Ministero Dell'Ambiente e Della Sicurezza Energetica*).

Articles 22 and 23 give indications to expedite the administrative procedures concerning such projects that will have to be carried out through VIA (valutazione impatto ambientale) in a short time frame.

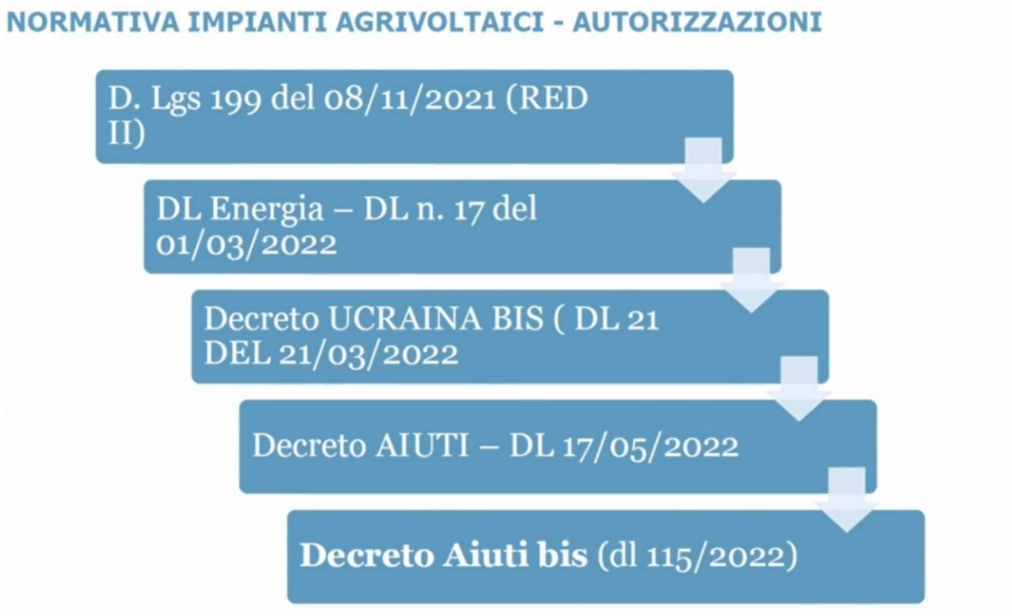
In Article 29 it is stated the need to submit projects to the superintendence (sovraintendenza) specifically established for the NRRP active until the end of 2026, and this has the task of protecting cultural assets and landscape. Currently in Law No. 108 of July 30, 2021, and in Chapter V, there are defined the provisions on landscaping.

Moreover, this law states that the agro-photovoltaic plant, due to its characteristics, useful for combining agricultural production with the production of green energy, is eligible for state fundings given through the NRRP (PNNR in Italian) while ground mounted photovoltaic plants are not eligible.

The plants must be equipped with monitoring systems that make it possible to verify the impact on crops, water savings, agricultural productivity for different types of crops and the continuity of the activities of the farms involved, also by enabling the application of digital and precision agriculture tools.

There is no precise reference of the standard suitable elevation height of the panels from the ground which wallow agricultural practices, but they have to be distinguished from ground mounted photovoltaic systems which have a minimum distance from soil lower than 2m which must not be founded by the government because they consume agricultural land.

Other legislations on agrivoltaic



Picture 13 Italian regulation development on agrivoltaics.

From personal video of Mauro Camilletti - Mcprogetti

10/11/2022 - Ecomondo 2022, Rimini Fiera (SGR Efficienza Energetica, 2022b)

The last legislations on this topic have been: Decreto aiuti DL 17/05/2022 and Decreto aiuti bis (dl 115/2022) which have helped to simplify and accelerate the bureaucratic processes to authorize agrivoltaics projects. With these legislations it has been made clearer that access to funds is possible for advance agrivoltaics while it's not for ground mounted photovoltaics which have been already cut from funding in 2012 with D.L. 24/01/2012 n. 27.

5.3 Veneto Region legislation

In Veneto region there's the law: **19 luglio 2022, n. 17** (Consiglio regionale del Veneto, 2022), that gives norms to regulate the construction of photovoltaic systems on top of the soil. It derives from European directives and from already existing laws like D.L. 8 novembre 2021, n. 199 with some more specific integration.

Below are the main points and articles of this regional law are presented.

Art.1: The purpose of this law is to aim to the de-carbonization by 2050 and promote the use of renewable energies defined by: PNIEC (Piano Nazionale Integrato per l'Energia ed il Clima) combined with the planning legislation of the European Union.

At the same time, it aims to preserve the agricultural soil and the valuable areas.

Art.2: Photovoltaic systems converts solar energy into electric energy, they are classified as:

- Ground mounted system with photovoltaic modules positioned on the ground where the whole surface is covered.
- Agro-voltaic modules: raised off the ground on land kept under cultivation qualified as Utilized Agricultural Area (UAA) according to the ISTAT definition, so as not to compromise the continuity of the activities of agricultural and pastoral cultivation.
- floating solar system.

It defines valuable agricultural areas where there's a presence of identity agricultural landscapes. It also states the need of an agronomic report and registration to the land registry office.

Art.3: unsuitable areas are: UNESCO sites, MaB areas (Man and the Biosphere), historical and touristic areas, wet areas, Rete Natura 2000 sites, SIC (siti importanza comunitaria), ZPS (zone protezione speciale), regional parks, nature reserves, traditional agricultural area like agricultural terracing, valuable agricultural areas like DOP, DOC, organic or protected by FAO and areas with potential risk of hydrogeological instability.

Art.4: Cases evaluation. Power plants equal to or greater than 1 MW (that respect the constraints above) can be made as agrivoltaic without surface limitations or as ground cover but the surface of agricultural land has to be 15 times more than the one occupied by the system. If it's less than 1MW this surface limitation doesn't matter. For floating systems or the one in an abandoned quarry it can be made after an examination of the site. For the agrivoltaic system, it's required an agronomic report and a monitoring of its crop production effectiveness during the next years.

In the other articles of this regional law, it is defined the power of the Regional Council which defines the operational guidelines and the distances that such facilities must have from the perimeter of unsuitable areas considering minimum distance of 1000m. It is required a VIA procedure to assess the environmental, economic and social sustainability of the project and its realization through PUAR (Piano Autorizzatorio Unico Regionale). There are defined the most suitable areas as in D.L. 8 novembre 2021, n. 199: brownfields, quarries and disused mines, agricultural land abandoned for more than 5 years or in a state of disrepair, parking lots and buildings. Finally, it's stated the importance of the monitoring of the agricultural production and soil condition throughout the years.

The most discussed and controversial topics of this law are the definition of suitable land and monitoring. Especially for organic certification, farmers must get out of the contract and return to conventional to be able to get the permissions even if organic agriculture could be perfectly integrated in an agrivoltaic system also in areas of non-agricultural and scenic value. For monitoring instead, specific guidelines are not presented and explained because of lack of practical examples.

5.4 NRRP (PNRR)

Now, in Italy, executive technicians are working to create the call for tenders to access the funds and unlock 1.1 billion from the NRRP (*The National Recovery and Resilience Plan (NRRP)*). The main technical tool of reference for definitions, size and classification is: "linee guida impianti agrivoltaici mite – enea, gse, crea, rse" (Mase, 2022) which provides:

• Characteristics of agrivoltaic systems

• Arrangement of PV modules: pattern and performance

• Requirements for agri-voltaic systems

Picture 14 Linee guida CREA-GSE

Agrivoltaic could access double EU fundings: from NRRP and FER 1 or 2 for the feed-in tariffs but they have to respect some requirements.

5.4.1 Agrivoltaic requirements

A:

The minimum surface for cultivation must be 70% of the total surface and the max ratio between surface occupied by the modules and the cultivated surface (LAOR) equal to 40%.

The system has to be designed and built to adopt a spatial configuration and appropriate technological choices to allow the integration between agricultural activity and electricity production and enhance the production potential of both subsystems.

B:

Continuity of agricultural activity and electric productivity of at least 60% of the reference ground mounted photovoltaic systems. Minimum power of 300 kW, which means only big agrivoltaic systems could be made.

The agri-voltaic, during all its technical life, has to guarantee the synergistic production of electricity without compromising the continuity of agricultural and pastoral activity.

C:

The height of the modules height has to be at least 1,3 m for basic APV system with grazing animals but at least 2,1m on the median axis for advanced APV systems to cultivate crops with tractors underneath. These last systems are subject to more fundings.

The agri-voltaic system adopts innovative integrated solutions with high modules on land, aimed at optimizing the performance of the agri-voltaic system both in energy and agricultural terms.

D:

Base Agronomic monitoring

The agri-voltaic system has to be equipped with a monitoring system that allows for verification of the impact on crops, water savings, agricultural productivity for the different types of crops and the continuity of the activities of the farms concerned.

E:

Climate change monitoring

The agrivoltaic plant is equipped with a monitoring system which, in addition to respecting the requirement D, allows to verify the recovery of soil fertility, the microclimate and the resilience to climate changes.

To receive fundings from the PNRR all these requirements must be respected.

Stakeholders must include at least an agricultural business or a temporary association of enterprises (ATI, associazioni temporanee d'impresa) which include at least one agricultural enterprise.

5.4.2 Incentives features

Incentives will be assigned by GSE (gestore servizi energetici) that will distribute funds for 1.1 billion euros from NRRP through competitive procedures (tender notice or "bando di gara"), consisting of:

a) a capital grant of up to 40% of eligible costs.

b) an incentive tariff on the production of net electricity fed into the grid.

The tariff is assigned through low auction procedures starting from 85 €/MWh (investors have to offer a discount of at least 2% of the tariff) and incentives are recognized for 20 years. If the power of the agrivoltaic system is less than 300 kw, the incentive tariff could be of 93 €/MW . The incentive tariff can change depending on the location and size of the system reaching up to 103 €/MWh (93+10 €/MW of correction) maximum in northern regions. In this way the price of 85 €/MW is guaranteed to the producer. In agrivoltaic system with a power over 300 kw, the investor can independently take care of the sale of energy which in case the market provides less than the 85 €/MW, the GSE provides the difference, in the case the energy is sold for a higher price then a balancing payment must be given to GSE.

Power kw	**Incentive tariff €/MWh**	**Maximum cost €/kW**	
1 < P ≤ 300	95	1.700	
P>300	85	1.500	
Geographical area			**Correction factor**
Central regions (Lazio, Marche, Tuscany, Umbria, Abruzzo)			4 €/MWh
Northern regions (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piedmont, Trentino-Alto Adige, Valle d'Aosta, Veneto)			10 €/MWh

Table 1 Incentivized tariff based on size and location of the system (GSE).

Picture 15 Distribution of correction price factor in Italy (GSE)

Maximum eligible investment cost for the agrivoltaic system is **1.500 €/kW** which includes the following items:

1. construction of advanced agri-voltaic systems (photovoltaic modules, inverters, mechanical structures for rising the modules, electromechanical modules orientation systems, electrical components)

2. supply and installation of storage batteries systems

3. equipment for the monitoring system expected by the CREA/GSE Guidelines

4. connection to the national electricity grid

5. auxiliary constructions, machinery, hardware and software equipment

6. pre-feasibility studies

7. planning, geological and geotechnical surveys, safety management, daily assistance and work accounting

8. technical tests and administrative support

Expenses from 6) to 8) can be financed up to 10% of the amount eligible for financing. Operations have to start within 12 months of the communication of the outcome of the competitive procedure.

In Italy the legislations for agrivoltaics are evolving quite fast every year, we are still waiting to have more clearance about:

- the suitable areas for these systems
- guidelines on monitoring
- call for access to PNRR funds for agrivoltaic.
- call for access to funds for mature renewable energies FER1 and for innovative renewable energies FER 2 (agrivoltaic could collocate in this last one)

5.5 Authorizations

The authorization process of an agrivoltaic plant is quite complex and could require multiple years and great costs. On the other hand, the authorization for ground mounted systems is becoming almost impossible to obtain in Italy.

Before starting an agrivoltaic construction, it is needed the permit from the region for the construction and operation of the plant, the possession of the finally accepted grid connection quote, the demonstration of continuity of agricultural and pastoral farming activity underlying the plant and the use of new construction components, the compliance with national and EU environmental protection standards (article 17 of EU Regulation 2020/852) and the possession of a statement from a banking institution (surety bond) attesting the financial and economic capacity of the investor, taking into account the expected profitability of the system itself.

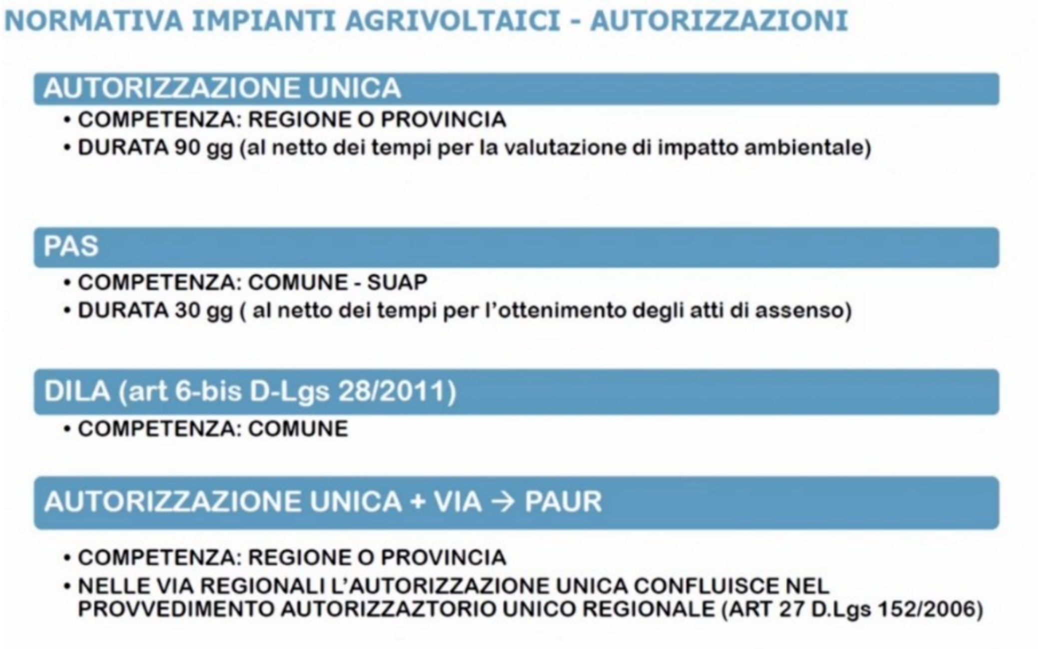
In Italy the administrations require agronomic and engineer reports and many feasibility and environmental impact studies.

The main authorization procedures could be:

- “Autorizzazione unica”, which is the most used procedure within regional and provincial jurisdiction for ground mounted photovoltaic plant. This procedure is long (it can require years) and complex with service conferences with many agencies and stakeholders.

- “Autorizzazione unica + VIA”, which can be merged into a PAUR (Piano Autorizzatorio Unico Regionale), regional procedure that speeds up and simplifies the authorization process.

- the other simplified procedures are called PAS (Procedura Abilitativa Semplificata) and DILA (dichiarazione inizio lavori, art. 6-bis D-Lgs 28/2011) which are authorization procedures only with the municipality and are becoming more used for their speed of acceptance and simplicity.



Picture 16 Different authorization processes for agrivoltaic in Italy.
From personal video of Mauro Camilletti - Mcprogetti

10/11/2022 - Ecomondo 2022, Rimini Fiera (SGR Efficienza Energetica, 2022b)

5.6 Contracts

5.6.1 Building rights or “diritto di superficie”

Ground mounted plants will be less socially accepted and will require more time and authorization costs. With agrivoltaic lots of bureaucratic procedures could be simplified to produce energy on good agricultural land.

Because of high costs, agrivoltaic plants are usually built by energy companies or by big funds that either buy the land or rent it from owners for long period of time signing a contract of building rights called “diritto di superficie” in Italian.

It is also known as air rights or development rights, it’s a legal right where the owner of the land gives the right to build on or above their property to another person or entity.

In this way the person that gets this right can build a new building entirely or modify an existing one having the ownership of the structure for the future.

Usually, the land remains with its owner who gets compensation for its use and occupation and the costs of permits and approvals stay on the builder.

Building rights can be an asset for property owners, as they can generate additional income and increase the value of their property. For developers and builders, building rights can provide opportunities for new construction projects and expansion of existing properties.

A farmer or landowner, who rents the land with building rights to an energy company that builds an agrivoltaic system on it, could gain 3000/3500 €/ha for 30 years which is much more compared to an average agricultural rent of around 900 €/ha.

BUILDING RIGHTS CONTRACT EXAMPLE

This Building Rights Contract ("Contract") is entered into on [date] by and between [Owner's Name] ("Owner") and [Developer's Name] ("Developer").

WHEREAS Owner is the owner of the property located at [property address] ("Property").

WHEREAS Developer desires to acquire the right to construct a building on the Property, subject to the terms and conditions set forth in this Contract.

NOW, THEREFORE, the parties agree as follows:

Building Rights: Owner grants to Developer the exclusive right to construct a building on the Property (the "Building") in accordance with the plans and specifications attached.

Consideration. In consideration for the grant of the Building Rights, Developer shall pay Owner the sum of [amount] dollars within [number] days of the execution of this Contract.

Timeframe. Developer shall commence construction of the building within [number] days of the execution of this Contract and shall complete construction within [number] months thereafter.

Building Specifications. The developer shall construct the building in accordance with the plans and specifications attached.

Permits and Approvals: Developer shall be responsible for obtaining all necessary permits and approvals for the construction of the building, at its own cost and expense.

Inspection and Testing: Owner shall have the right to inspect the construction of the building at any time during the construction process. Developer shall allow Owner to conduct any necessary testing to ensure that the construction follows the plans and specifications.

In the event that Developer fails to commence construction of the building within [number] days of the execution of this Contract or fails to complete construction within [number] months thereafter or fails to comply with any other provision of this Contract, Owner may terminate this Contract and retain all payments made by Developer.

The grantor undertakes to work to maintain the energy efficiency of the panels. By way of example, it undertakes to work the soil with techniques and at times that avoid raising a lot of dust that may be deposited on the surface of the panels.

The parties are both obliged to provide insurance policies to protect the investment and the contract

Indemnification: Developer shall indemnify and hold harmless Owner from any claims, damages, or expenses arising out of or related to the construction of the building, including but not limited to any claims related to construction defects or violations of applicable laws or regulations.

Governing Law: This Contract shall be governed by and construed in accordance with the laws of the state of [state].

Entire Agreement: This Contract constitutes the entire agreement between the parties with respect to the Building Rights and supersedes all prior negotiations, understandings, and agreements between the parties.

IN WITNESS WHEREOF, the parties have executed this Contract as of the date first above written.

[Owner's Signature] [Developer's Signature]

(Building rights are subject to different regulations that can vary between regions and cities, that’s why it’s important to have a professional legal consultation before applying them).

Contract example taken from the agronomic studio: https://www.studiogdtagro.it/.

5.6.2 Agricultural proposal form

To justify an investment in agrivoltaic there is the need to stipulate an agronomic report and an agricultural cultivation proposal to present to local administrations.

Below there's an example of a form taken from the German regulation (*DIN SPEC 91434*, 2021).

1. General operating information:

Name and address of the company ……………….

Name and address of the contact person…………………………..

□owner □ tenant

Farm type:

□vegetable farm □arable farm □forage farm

□permanent cultivation □grafting farm □mixed farm

□other……

Farm size…………..

2. Information on the agrivoltaic system

Name and address of the owner (if not owner of the agricultural holding)

……………………………………….

Name and address of the operator of the agrivoltaic system

………………………………………..

Category of agrivoltaic system (installation and use)

…………………………………………

Clear height of the agrivoltaic system

………………………………………….

Specific PV power (in kwp)

…………………………….

3. Information on the total project area

Size of the total project area (size, field number, location)

…………………………….

Expected land loss due to agrivoltaic infrastructure.

……………………………..

Size of arable land

………………………………

4. Use plan for the agricultural land under agrivoltaic system (for three years or one crop rotation cycle)

List of planned crops on rotation cycle or permanent crop with sowing and harvest dates

………………………………………………………………………………

List of measures to protect crops.

………………………………………………………………………………

Planned machine and working widths.

…………………………………………………………………………………

Is tillage with the required machines ensured in relation to the system design?

…………………………………………………………………………………

Light requirements of crops

…………………………………………………………………………………

Is the light requirement of crops ensured by the agrivoltaic system design?

…………………………………………………………………………………

Water requirement of crops

……………………………………………………………………………………

Is water supply ensured by the design of the system?

……………………………………………………………………………………

For animal farms:

Animal species and use

……………………………………………………………..

Area and period of pasture

…………………………………………………………

Specific requirements for animal husbandry

………………………………………………………………………………………

5. Soil erosion and silting of the topsoil.

Measures to reduce soil erosion and topsoil siltation.

………………………………………………………………………………………
……

6. Residue-free assembly and disassembly

Measures to reduce permanent damages to agricultural land.

………………………………………………………………………………………

7. Calculation of economic efficiency

Reference yield (t/ha)……………………………………………………..

Forecast of crop yield (t/ha)…………………………………………

Forecast of electric yield (Kwh/ha)………………………………….

Explanations of the forecasts (quality reduction/increase)

……………………………………………………………………………………

Profitability from the farmer's point of view

……………………………………………………………………………………

8. Land use efficiency

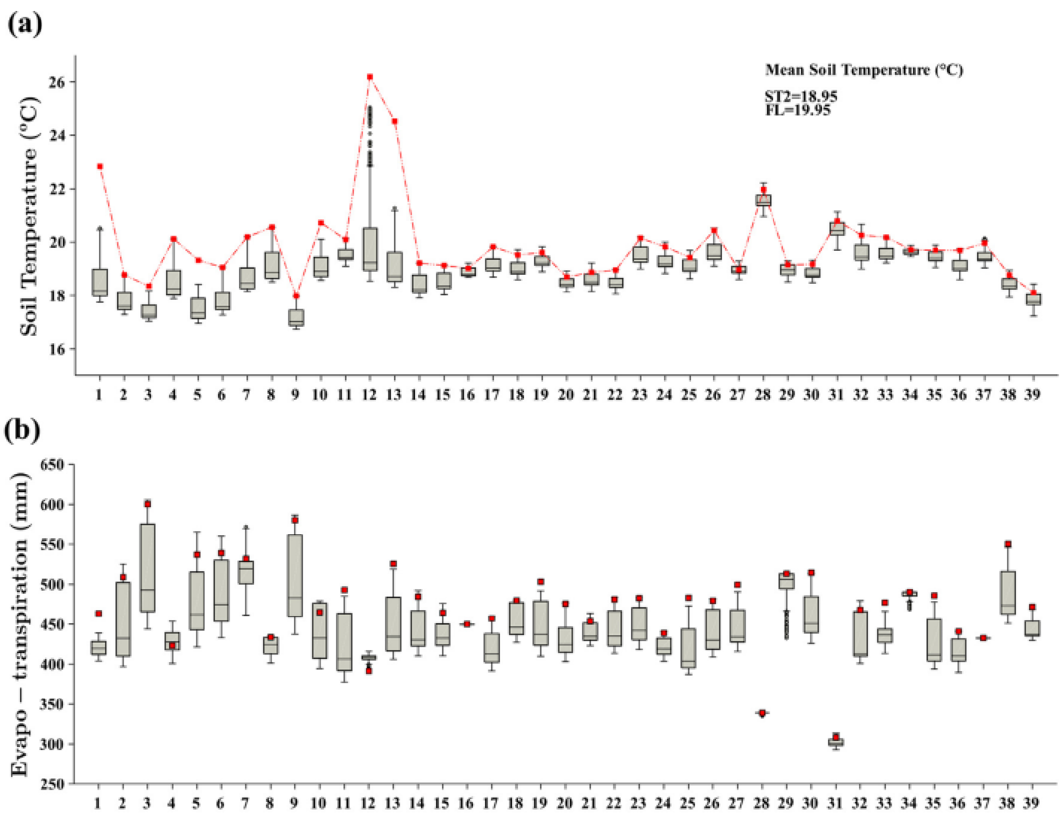
……………………………………………………………………………………

6 PROS AND CONS

6.1 Benefits

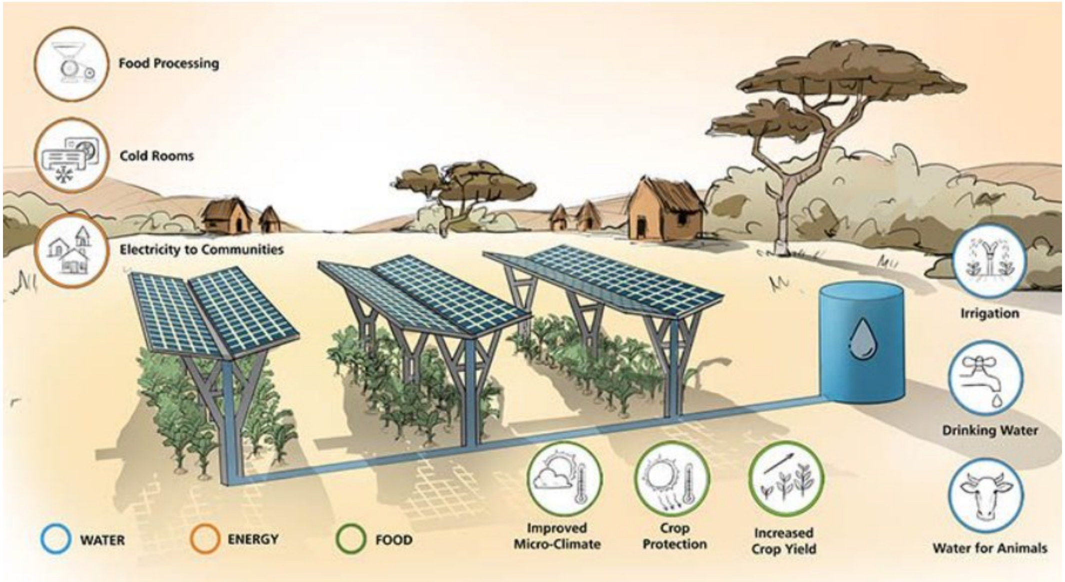
Agrivoltaic system could help farmers to create a more resilient system to climate change.

Indeed, solar panels can help to reduce soil temperature and increase soil moisture. In this way evapotranspiration by crops underneath is reduced (Amaducci et al., 2018).



Graph 2 Reported effects for 39 years of agrivoltaic on soil temperature (a) and evapo-transpiration (b). They are both lower under agrivoltaic, represented with the box plot, than under full light condition, represented by the red squares (Amaducci et al., 2018).

Water can also be collected and water use efficiency can increase, saving a lot of money on irrigation (Cheo et al., 2022).



Picture 17 Schematic diagram of a triple land use through agrivoltaics. APV-MaGa (© Fraunhofer ISE)

For these reasons they can be very effective in increasing yield of crops especially in dry areas or in drought years, also leaf area, fruit size and quality can improve increasing farmers income.

In some months of the year the radiation can be too strong causing photosynthesis inefficiency or sunburn which can be prevented with agrivoltaic systems.

Some shade-intolerant crops like corn and tomato can be adapted to this system if there's a qualified agronomist able to know in which phase the crop requires more sun.

Land use efficiency (LUE) increase because in the same field it can be produced both electricity and food, to produce the same amount of food and energy produced by a 100-ha agrivoltaic farm we would need 170-ha farm where food and electricity crops are used independently (Chalgynbayeva et al., 2023).

Landowners can get high profits from selling the building rights to the companies that install these systems on their land, in this way they can have a stable income compensating for the loss of agricultural production due to climate change. The value of solar energy production coupled with shade-tolerant crop production has led to an economic value increase of more than 30% on farms using agrivoltaic systems instead of conventional agriculture. All of this will contribute to lowering the risks for farmers.

The energy companies who built the system could sell more energy because the crops underneath the panels help reduce the temperatures in hotter months increasing the energy conversion efficiency. Moreover, since the land underneath will be cultivated mowing and surveillance costs for the energy company will be reduced.

Agricultural land can be preserved as well as the incentives from CAP policies and more incentives could be gathered from the new PNRR plan.

Farmers could decrease their bill costs if they directly use the electricity and they could share the surplus with others creating energy communities.

Monitoring of agricultural activity will be required developing a more sustainable and technological farming that considers efficient use of inputs and soil fertility adopting minimum tillage and carbon farming techniques.

The presence of the agrivoltaic system does not cause permanent damage to the ground, at the end of the life cycle of the photovoltaic panels the whole system for the support and movement (poles, motors, wiring) could be completely removed.

Abandoned or arid land could be used and made productive again attracting new investors in agriculture in Italy or more arid countries.

Since the visual impact has to be reduced and an agronomist report has to be presented, edges with trees and bushes will be made around the system increasing biodiversity and ornamental aesthetic value.

To engage more the local population where these systems are made, crowdfunding could be proposed from electric companies to finance the systems in exchange of a good rate of remuneration creating an investment opportunity for local residents.

New jobs opportunities will be created not only for farmers and energy companies but also for agronomists, lawyers, electricians and manufacturers.

Some agrivoltaic plants could be transformed into educational farms for kids to see the union between traditional and new technology farms.

Finally, this is still a very recent topic and more university research could be done especially on new cultivars adapted for these systems, monitoring software, robotic machines and new material for solar panels and storage systems.

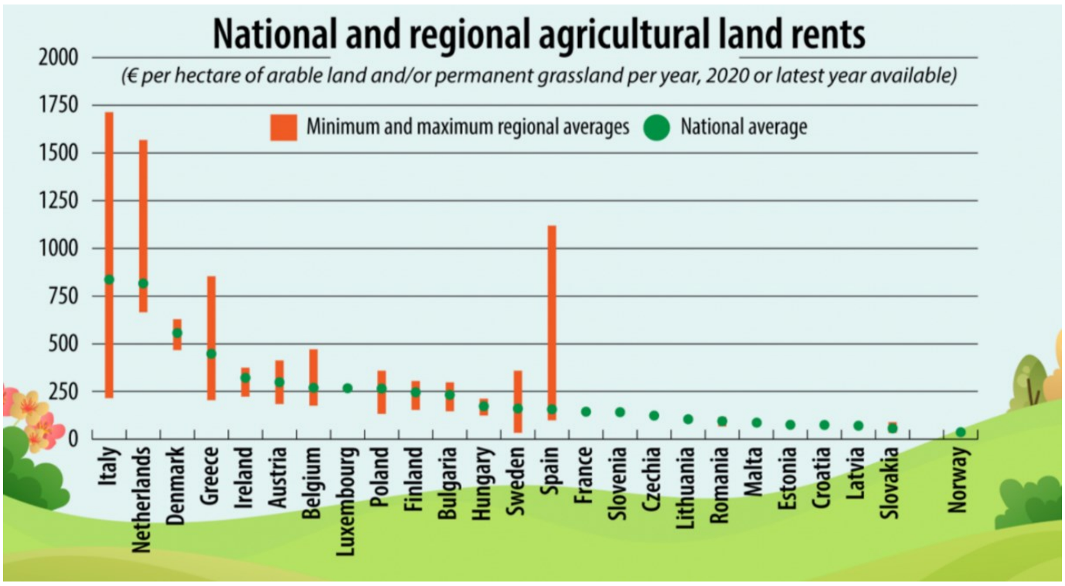
6.2 Constraints

There are many benefits for agrivoltaic systems but there are as many constraints that emerged during this research.

The first thing to know is where to build these systems, because where there's a lot of unproductive or desert land available, it's still more efficient and economically convenient to build big ground mounted systems.

In areas where land is scarce and in competition with urban areas it might be a great solution to increase land use efficiency.

There are consequences to the increased interest in farming lands close to urban areas, the installments of agrivoltaic systems might attract more investments and so increase the value of that land that could become too expensive for other farmers to rent it and making it profitable raising normal crops. In Italy this is already a trend since rental price for agricultural land is already 800 €/ha on average, one of the highest in Europe, with these systems it could reach up to 4000 €/ha (Legambiente, 2023).



Picture 18 Land rent price per ha in Europe (Legambiente, 2023)

Farming under these systems requires specific knowledge and machinery. For example, since dust could lower panels efficiency, it's required by the farmer that he works the soil when it's not too dry using minimum or no tillage techniques to prevent dust formation (soiling of the panels).

In this farm system it could be promoted carbon sequestration but there's the need of advanced monitoring tools that could be expensive or too complicated for farmers to use (in this case it's fundamental the support of an agronomist).

Not all crops perform well under these systems, especially if they are non-shade tolerant crops and in cold or humid areas where there might be not enough light or excessive humidity that create diseases problems to plants.

The yield of most crops under AV may be reduced due to an expected reduction in solar radiation by about one-third (Chalgynbayeva et al., 2023).

Land occupied by the steel pylons and auxiliary infrastructures is consumed and taken from agriculture use up to 30% of the total surface. Moreover, there's a risk that land used for this system and around it might lose interest for agricultural production in general since the economic value is already given by the energy production which make the systems designed to maximize energy profit with the risk that the rows of panels could be too narrow to allow tractors to move and turn to cultivate the land.

This is why the installation of PV panels must be carried out as a priority on already artificialized land, close to highways, in polluted land, roofs and car park covers.

The impact of these systems on landscape is relevant and people could protest against their construction, especially in areas close to touristic activities.

This makes it harder to obtain permission to build them requiring experts in law, agronomists and time to make the procedures like VIA (valutazione impatto ambientale) to get the permissions. They can require more than three years to obtain all the permissions before starting construction.

Moreover, the permissions in Italy are quite slow also because there are not enough government officials with appropriate expertise to solve the problem.

Since in Italy there are many valuable areas, it’s difficult to individuate large enough land which is free from landscape constraints. In addition, steep land is not very suitable for these systems or require specific adaptations that are quite expensive.

Connection to the electrical network has to be made and it might be expensive if it is far from it. If the plants are built in remote areas far from the energy consumer, it can create an overproduction difficult to handle which requires expensive batteries to store the energy to sell it when it’s more profitable.

Selling energy is not so easy, there’s the need to make a contract with an energy distribution company like GSE or with a private consumer because the price might be extremely volatile every year.

Investments to make agriphotovoltaic plants are high, above 1 mln €, and are not affordable for small farmers but for a pool of investors. There are also other costs of maintenance which require skilled and specialistic labour like electricians that might not be so available. Farmers that will cultivate underneath the panels will have to be formed to a new precision farming system because agricultural operations made with the wrong machines could damage the structures of the panels.

Loss of panel efficiency has to be considered (about 0.5% less every year) and dismantling costs after 20 years. This also causes the need to develop companies and effective methods for recycling large volumes of PV panels at the end of their cycle.

More research has to be done to make these systems more efficient both in electric production, since the panels required for agrivoltaic are different from the ones of domestic use, and for crop production in association. The whole production chain has to be implemented and we have to create new clear and favorable policies to move fast and stay competitive in Europe.

7 LEGREENHOUSE CASE STUDY

To present a practical example of agrivoltaic business working in Italy, in this study it has been reported the case of Legreenhouse. On the 27th of February 2023 Antonio Lancellotta was interviewed, he’s the co-founder of Legreenhouse which is a consortium born in Calabria that advises companies operating in the agri-energetic sector by providing a design package for land improvement plans and coordination of the construction of new agro-photovoltaic plants, with the supply of monitoring systems aimed at optimizing production factors and possible subsequent management.

Legreenhouse built the first agro-photovoltaic plants in 2009/2010 and they were one of the first in Italy. It was born as collaboration between the photovoltaic company controlled by F2i SGR, the largest independent Italian manager of infrastructure funds, local developer and farmers.

At that time ground mounted photovoltaics were subsidized as well as agro-photovoltaic. They decided to design and build special greenhouses with south-facing roof pitch equipped with solar panels.

They did preliminary study phase analyzing:

1. availability of good land both for cultivation and energy production which preferably has to be flat.
2. Water access.
3. Possibility of connection to electrical and distribution grid.
4. Absence of landscape constraints or other bureaucratic impediments.

After that, they passed to another phase of designing of the agrivoltaic systems associated with the cultivation one.

They studied the market and opted to specialize in growing the typical valuable crops of the area: citrus fruits. Traditionally farmers were already covering the lemon or cedar trees with shade cloths to improve fruit set, sunburn resistance and the aesthetic value of the fruits.

The choice of cultivar was especially important, they used the cedar variety Diamante as it was more demanded from the market also for religious purposes, but also different lemon varieties with dwarfing rootstocks and particular fructification.

Picture 19 Lemons under agrivoltaic greenhouse in Calabria (© Legreenhouse.it)

Over the years they made different trials implanting and explanting several times to find the cultivar that best adapts to these systems and they also did some research on horticultural crops. By doing so they collected the data and made some cultivation protocols replicated in other Italian areas.

They replicated this system in Sardegna where the greenhouses were covered with more panels and the shading effect was higher, so they had to choose different varieties and cultivars like finger lime.

In general yield is lower: it’s about 50 kg per plant compared to 80 kg on open field and canopy management is higher especially for the green pruning but, on the other side, the fruit’s quality (almost all 1st choice) and price are higher and there are less diseases problem because of the controlled environment.

Production is constant throughout the years because of protection from wind and extreme events and in this way insurance companies are also more favorable to lower their price.

Pollination is either made by autochthonous insects entering the greenhouse through the windows open at specific time of the day or by raising bees directly inside.

They have signed specific contracts with the distribution companies to provide the best products and to gain higher prices compared to the mass lemon production, for example they harvest lemons with leaves and bigger sizes.

The whole agrivoltaic system is complex and composed of different operators:

1. The owners of the land (not only farmers).
2. The energy company, in this case EF solare Italia, gets the building rights from the landowner and builds the electric infrastructures.
3. An agricultural company, in this case Legreenhouse, which chooses the right crops and agricultural operations that don’t damage the electric structure.
4. A maintenance company, in this case SET energie, which makes sure the photovoltaic system performs well during the following years.

In the new contracts, Legreenhouse, which is the agricultural consortium, usually directly buys the land instead of buying building rights. It can also happen that the electricity company, in this case EF solare Italia, makes a promise to buy the land from the owner if it gets permission to build on top of it.

It starts a period of analysis and project design during which, if the owner accepts this risk, he/she can get a periodic payment in exchange which will be summed and detracted from the redemption of land purchase and final payment.

Legreenhouse makes sure that the land which is cultivated under agriphotovoltaic system is managed in a way that preserves the good functioning of panels, for instance preventing too much dust or drifts from treatments with atomizers to cover their surface.

Legreenhouse is also developing an agriphotovoltaic system in an open field with bifacial modules. They have the intention to cultivate underneath: almonds, olive trees varieties like Arbequina, adapted to intensive and mechanized systems or other crops that are both profitable and adapted to produce under these shading conditions.

The costs of this kind of plant can vary a lot between the different systems but on average for a plant of 1MW the cost is more than 1 million euro all included and the return of investment is about 6 or 7 years. This period is volatile because it can vary from the energy price that changes every year since an incentive tariff on the production of net electricity fed into the grid is not given yet.

For these reasons, even if there are many limitations, ground mounted photovoltaic systems are still favored so it’s important to have new stronger policies and incentives that promote real agrivoltaic systems with synergic interactions between electric and agricultural production.

In agrivoltaic farms besides the environmental and production benefits there are also the monitoring benefits and interaction between farmers and maintenance electricians, in this way there’s always someone checking if everything is working correctly.

Electricity is consumed in a small part by agricultural activity but most of it is sold directly into the grid.

New plants are supposed to be designed with storage batteries, in this way the over production of energy during the day can be sold at night for a higher price.

Water use efficiency has increased a lot both from the partial covering of the panels that prevents excessive evapotranspiration but also from the use of efficient subirrigation, advance monitoring and software management (made by TalGil).

Legreenhouse has recorded a saving of more than 70% of water use compared to the same crop on open field.

Since it's a protected environment they also have less diseases problems that can be controlled efficiently quite fast. One of the most problematic pests they have is cottony mealybug that they control with natural soap washings. Another pest is red spider mites that are controlled with biological control by using other predatory mites.

Legreenhouse has found and tested a system that works and can be replicated in other areas and hopes to lead, with its example, this new opening sector. It works together with other associations and pool of professionals to analyze the feasibility of each project and many times has to refuse proposals because of different impediments (often related to the impossibility to make good agriculture in one land) and excess demands.

Finally, Legreenhouse is also promoting exchanges and cultural activities with other associations like Legambiente to spread this knowledge and create collaborations to improve the agricultural sector making it more sustainable for the environment, energy production and for the economy of the farmers of the future.

8 AGRONOMIC EVALUATION

8.1 Light spectra absorption

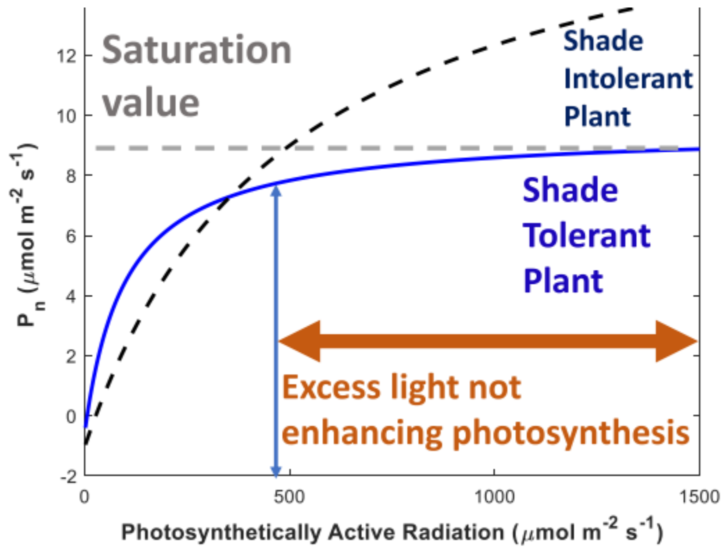
Plants can achieve their maximum rate of photosynthesis with only a small portion of the incoming sunlight. Like how a sponge reaches its saturation with water, as the intensity of light rises, there comes a point where the rate of photosynthesis is no longer restricted by the availability of light (saturation point), beyond this point, an increase in light does not result in a further enhancement of photosynthesis(Sekiyama & Nagashima, 2019).

Excessive sunlight can also impede the growth of crops. When plants are exposed to intense ultraviolet radiation on a regular basis, it can lead to significant harm to their DNA. To defend against sun damage, plants have developed protective mechanisms, including the synthesis of specialized molecules that are dispatched to the surface of their leaves. These molecules, known as sinapate esters, serve as a barrier against ultraviolet-B radiation and help prevent it from reaching deeper into the leaves.(Sekiyama & Nagashima, 2019)

Table 10. Light saturation points of selected crops [14].

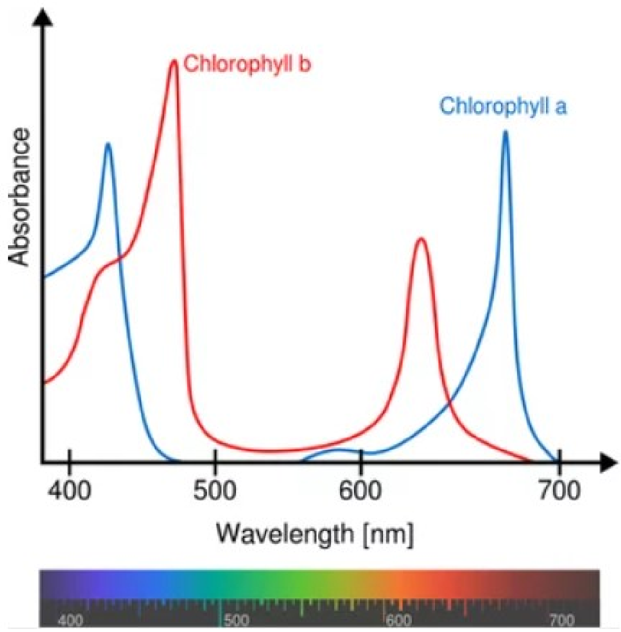
Crops	Light Saturation Points (KLX)	Crops	Light Saturation Points (KLX)
Corn	80–90	Rice	40–45
Watermelon	80–90	Carrot	40
Tomato	80	Turnip	40
Taro	80	Sweet potato	30
Cucumber	55	Lettuce	25
Pumpkin	45	Green pepper	20–30
Blueberry	45	Spring onion	25
Cabbage	45	Mushroom	>20

Table 2 Light saturation for different crops (Sekiyama & Nagashima, 2019)



Graph 3 Photosynthesis (Pn) per unit leaf area as a function of PAR (photosynthetically active radiation). As we can see shade tolerant plants reach a lower light saturation point over which, with more light, they don't photosynthesize more but they transpire more (Katul, 2023) .

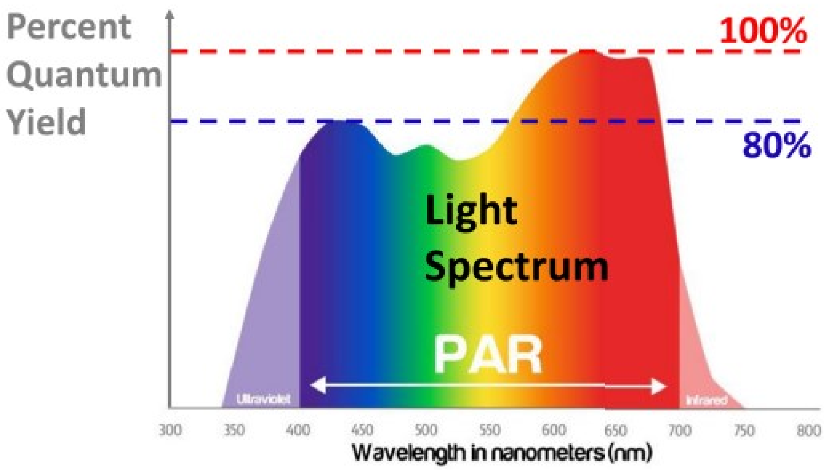
Plants cells have organelles called chloroplasts which have the function of converting light into sugar used as fuel for living. The molecules that allow photosynthesis are called chlorophyll b and chlorophyll a. Both capture light with two picks at blue (~450 nm) and red (~650 nm) color, while green is almost completely reflected as we can see in the graph below.



Graph 4 Absorption spectra of the chlorophyll a and b pigments in the visible light range, measured in a solvent. Both types barely absorb green light (Milne et al., 2015).

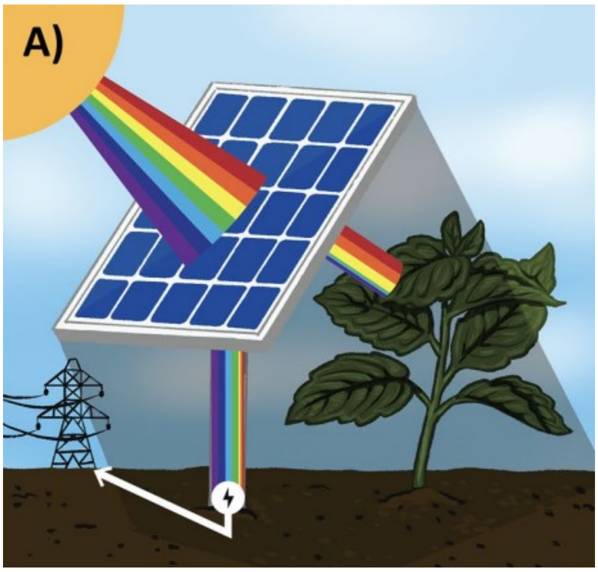
Since light spectra is not completely used by plants, it can be optimized in terms of utilization leading to sustainable and more efficient food and energy systems. In indoor farming for instance (Milne et al., 2015) producers use artificial led lights with more red emittance because the red part of the spectrum is more efficient in terms of carbon assimilation and water use by plants while the green and violet part is not used so much.

In an agrivoltaic system green ultra-violet and infrared light could be caught and used to produce solar energy(Camporese & Abou Najm, 2022). In fact, studies suggest that the bluest part of the light spectrum is the least efficient in terms of carbon assimilation and water use and could be effectively filtered out to produce solar energy.



Graph 5 Photosynthetic efficiency (ordinate) as a function of wavelength (abscissa) for photosynthetically active radiation (PAR). In the picture we can see that red light is more efficiently absorbed and used to store CO_2 as biomass by plants (Katul, 2023) .

Research is being made to produce more efficient semi-transparent photo-selective PV panels that can collect the excessive radiation to produce electricity while transmitting only the parts of the light spectrum most useful for plant photosynthesis saving water for crops.

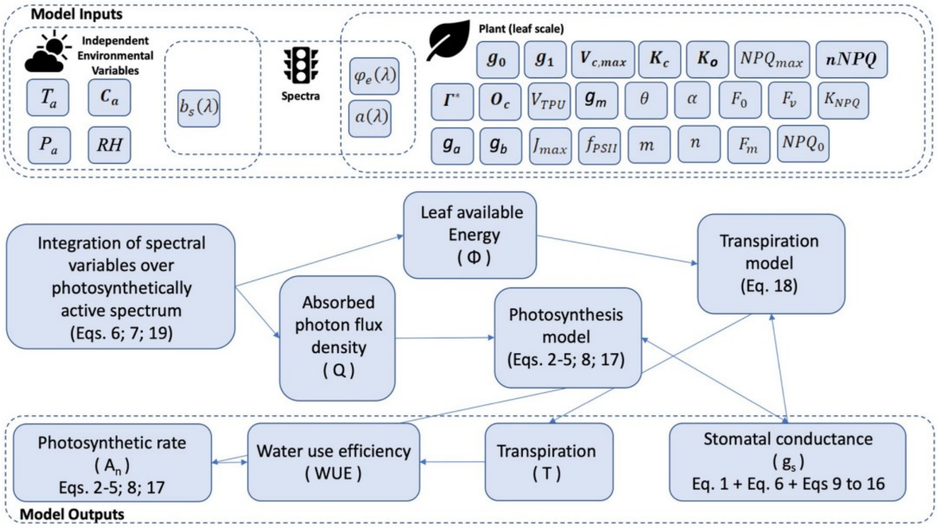


Picture 20 Picture 16 light spectra absorbed by panels and by plants (Camporese & Abou Najm, 2022)

Picture 21 A conducted study by Camporese & Abou Najm for UC Davis on different spectrum of light (red and blue), filtered to plants. (Picture by Andre Daccache/UC Davis)

Producing and using these panels requires knowledge both for engineering of materials and for plant response to different light spectra. It's fundamental to collect experimental data and compute photosynthesis and transpiration rates as a function of incident light spectral quality.

Camporese & Abou Najm developed a numerical model that reproduce the response of various C3 plants treated with different light wavelengths to predict photosynthesis, stomatal conductance, and transpiration which are all linked together as we see below in Picture 22.



Picture 22 Inputs and flowchart created for the model of plant's response to light (Camporese & Abou Najm, 2022) .

These models and experimentation tests showed that, using different lights treatments (blue, red and other wavelengths), when the fraction of blue light is given the results are less CO2 assimilation and more water consumption. It resulted also that increasing CO2 concentration enhances the differences between different light treatments.

It's important to underline that the plant response to different light treatments is most likely species-specific. This is why we must create and use accurate and updated PAR (photosynthetic active radiation) curves of each crop to see which is the most suited to be grown in controlled agricultural systems. The use of this model could be useful to foresee the suitability of different plant species to use in agrivoltaics.

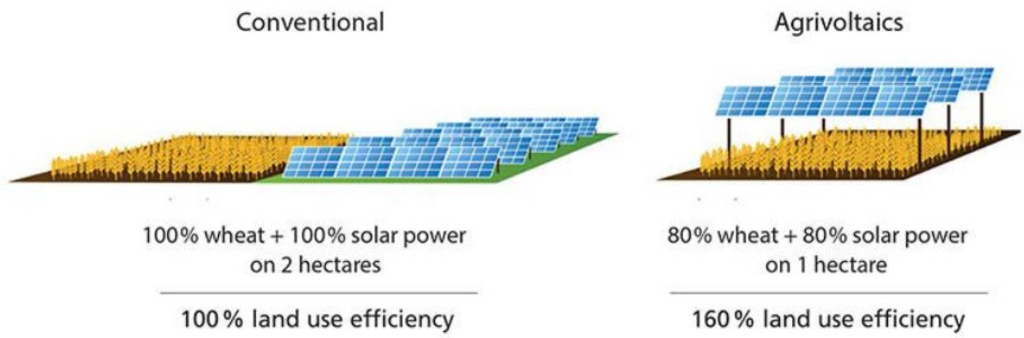
8.2 LER (Land equivalent ratio) & LUE (land use efficiency)

LER (land equivalent ratio) is “the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. It is the sum of the fractions of the intercropped yields divided by the sole-crop yields” (FAO).

ex. LER = crop yield in APV/monocrop yield + electricity yield in APV/ only PV yield

Agrivoltaic has a LER of 1,3/1,7 which means that to produce the same amount of electricity and crops of agrivoltaic it’s required 30-70% more land of separate surfaces (this data fluctuates based on the type of crop and the APV configuration)

So we can optimize the use of agricultural land compared to the two separate uses of photovoltaic and agriculture alone. Indeed, on the same surface of 1 ha we can have 80% of energy production and 80% of agricultural production which sum up to 160% Land use efficiency as a final input.



Picture 23 Increased land use efficiency with agrivoltaic (© Fraunhofer ISE)

8.3 Crops' yield calculation examples

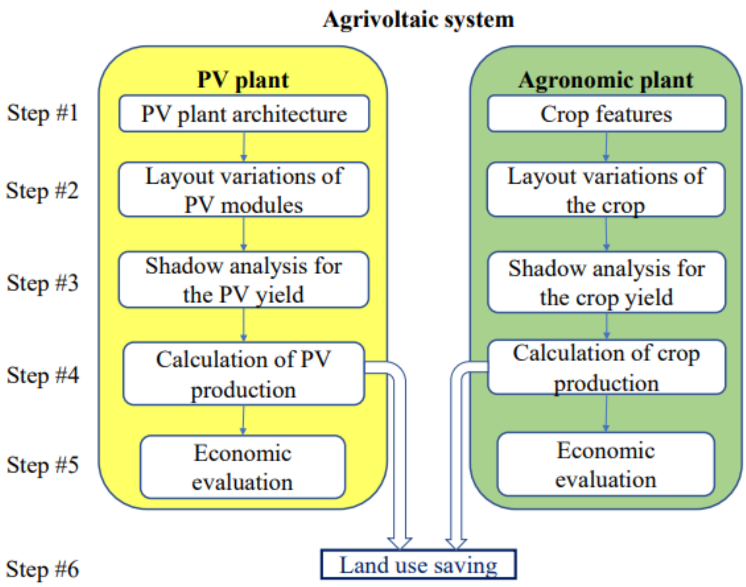
Climate change has given farmers many problems like drought and sunburn. Some crops are more shade resistant than others for example most of the leafy vegetables like spinach, arugula and lettuce but also potato can benefit under shade conditions while other like corn and wheat need high number of light hours. In any case all of them suffer when light and drought intensity are too high.

Sometimes farmers have to use frequent irrigation or mist irrigation to drop surface temperature of vegetables but in this way the water consumption and bill can increase a lot and water is becoming a scarce resource to preserve.

Agrivoltaic could be a solution to reduce water and sun stress on crops improving their quality and yield while reducing costs.

Together with genetic research to make crops more adaptable to climate change or to more shade conditions, we have to do more research on the interaction between agrivoltaic and other crops.

Since agrivoltaic is a complex system we need experts like agronomists, engineers, economists, lawyers and politicians to cooperate and design it.



Graph 6 Procedure for the design of an agrivoltaic plant (Ciocia et al., 2022).

With the new agrivoltaic systems with bifacial panels and dual axis we can modulate the amount of shade given to crops in different stages.

It’s important in this sense to have an agronomist support who can understand the different crops’ stages and specific light requirements for each of them. For instance, during germination plants may require more light and the panels can be turned diagonally to the sun in a way that less shade is produced.

Monitoring is also very important to understand how soil and crops respond to the shade and by reading it we can have a better understanding of the interaction between panels, crops and environment so we can have better yields.

In general, the value of solar generated electricity coupled to shade tolerant crop production created an over 30% increase in economic value from farms deploying agrivoltaic systems instead of conventional agriculture (Dinesh & Pearce, 2016).

Different software can be used to produce a model for the crop yield for instance STICS is a time step model which provides crop yields for various environmental conditions (Brisson et al., 2003).

The crop production is proportional to the solar ratio Rgr, the ratio between the irradiance in the agrivoltaic plant and the irradiance on the crops without PV modules (Ciocia et al., 2022):

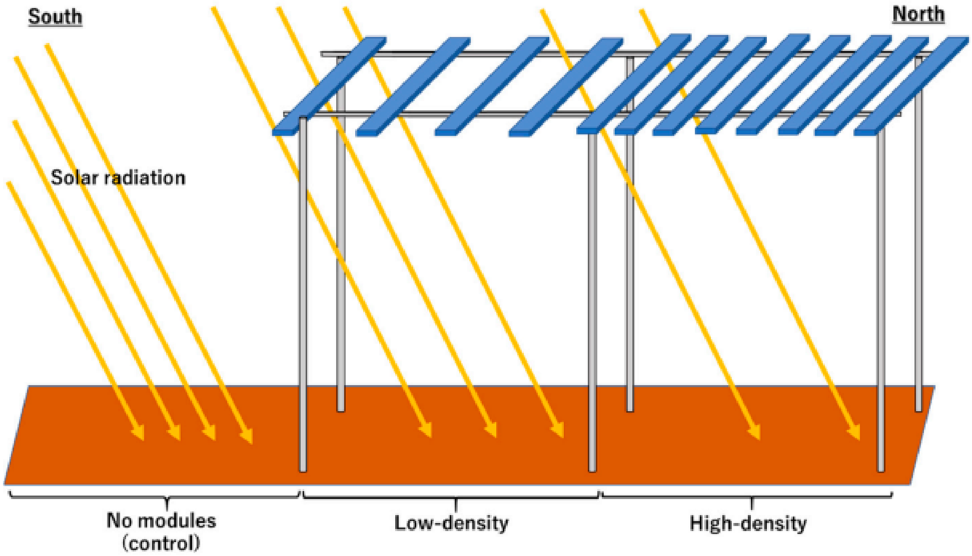
$$\frac{Yc(AV)}{Yc(OF)} = m \times Rgr + (1 - m)$$

Where $Yc(AV)$ is the crop yield under agrivoltaic, $Yc(OF)$ is the standard yield and m is the sensitivity of the crop to shadow.

In general, there’s still a lot of research to improve crops’ production under these systems and little information available on the shade-tolerant plant species’ performance (Chalgynbayeva et al., 2023).

8.3.1 Corn

Below it is reported a case study of a farm of CHO Institute of Technology in Ichihara City, Japan which analyze the relationship between agrivoltaic and corn (a less shade tolerant crop) production (Sekiyama & Nagashima, 2019).



Picture 24 Three PV module configurations at the agrivoltaic experimental farm (Sekiyama & Nagashima, 2019).

Corn was cultivated in a 100 m^2 field with 9 plants per m^2 following organic practices. It was evaluated the sensitivity of the corn yield per square meter with respect to changes in the level of shading.

If the corn biomass under shading is more than 90% of the one in standard condition, then it means that corn can be adapted under agrivoltaics too.

The corn's yield of the different systems was measured both for fresh and dry biomass.

Surprisingly, the corn yield of the low-density configuration was larger not only than that of the high-density configuration, but also than that of the no-module control configuration.

Table 1. Average fresh weight of corn crops grown in different configurations.

	Configurations		
	Control	**Low-Density**	**High-Density**
Average fresh weight (g)	372.2	393.0	358.8
Comparison with control	1	1.056	0.964

Table 2. Average biomass (dry basis) of corn stover grown in different configurations.

	Configurations		
	Control	**Low-Density**	**High-Density**
Average biomass (kg/m^2)	1.63	1.71	1.58
Comparison with control	1	1.049	0.969

Table 3 Average corn weight grown under different systems of agrivoltaic compared to control (Sekiyama & Nagashima, 2019)

The revenue was also calculated with the formula:

Vc [yen/m^2] = Y × P (where Y is the yield and P is the average price per kg of corn in 5 years period)

Table 7. Annual revenue per square meter from corn crops grown in different configurations.

	Configurations		
	Control	**Low-Density**	**High-Density**
Crop revenue (yen/m^2)	783.90	828.36	755.82

Table 4 Revenue (yen) of corn under agrivoltaic system (Sekiyama & Nagashima, 2019)

After that, it was calculated the total revenue from the different systems including the energy sold.

Table 8. Annual total revenue per square meter from corn crops and PV in different configurations.

	Configurations		
	Control	**Low-Density**	**High-Density**
Total revenue (yen/m^2)	783.90	3683.36	6465.82

Table 5 Total revenue (yen) of corn + electricity under agrivoltaic system (Sekiyama & Nagashima, 2019)

Agrivoltaic resulted with an increase of value of at least 3 times more compared to the standard field.

8.3.2 Lettuce

Lettuce together with other green leaves crops could be an optimal solution for agrivoltaic as they are more shade tolerant than other common crops especially the C4 one that need more light.

Here it is presented the results of an experiment of lettuce grown under agrivoltaic system.

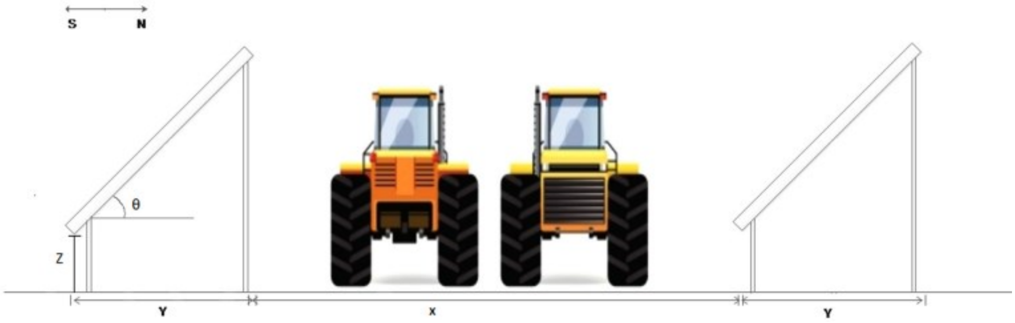
“Three different systems were used: ground mounted with cultivated interrow, half density (HD) and full density (FD). In both the configurations, the PV modules are mounted at a height of 4 m above the ground. In the HD configuration, there are two PV module arrays of 20 m x 1 m spaced 6.4 m apart while in the FD configuration, there are four PV module arrays spaced 3.2 m apart”(Dinesh & Pearce, 2016)

They used the simulator software STICS to see the interaction between growth of lettuce and the PV modules density. This provided the number of lettuce plants per m^2 and weight of an individual plant for a lettuce crop grown under standard temperature and soil conditions.

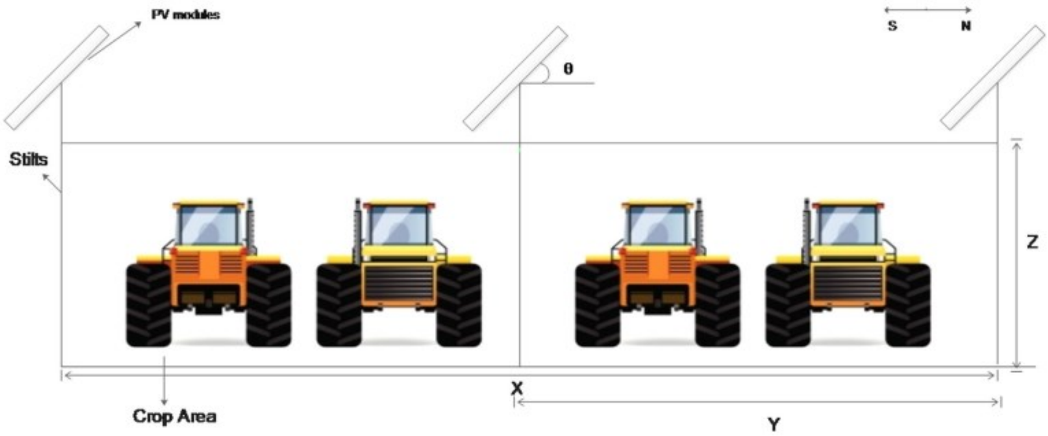
The crop yields (Y) in tons per hectare are calculated by: Y (Tons)=W x d where W is the fresh weight of lettuce plant (g) and d is the plant density per square meter. Resulted in a plant density of 9 per m2 and the individual weight of each lettuce plant is 557 g.

With this setup it was observed that for lettuce grown in the summer there was a 42% reduction in yields in FD and 19% at HD with respect to the weight of lettuce grown under clear sky conditions.

It was also observed that for lettuce grown in the spring there was no significant effect on the lettuce yields in HD and a 21% reduction in yields for FD. This was due to the moderate shading conditions during the spring planting. The moderate shading conditions during spring combined with the adaptive ability of lettuce and the HD configuration resulted in yields remaining significantly unaffected ”(Dinesh & Pearce, 2016).



Picture 25 . Agrivoltaic farm scheme having ground mounted PV modules with the area between the panels being used for farming. The spacing between the PV modules has been kept wide enough to allow standard sized farming equipment to pass between the rows (Dinesh & Pearce, 2016).



Picture 26 Agrivoltaic farm having PV modules mounted on stilts (Dinesh & Pearce, 2016).

Growing conditions	Season	Fresh Weight (g)	% Weight Reduction	Yield (tons/Ha)
Full Sun	Summer	561	N/A	50.49
	Spring	312	N/A	28.08
Ground	Summer	557	~0	50.13
Full Density	Summer	325	42	29.28
	Spring	246	21	22.18
Half Density	Summer	454	19	40.90
	Spring	309	1	27.80

Table 6 Lettuce yields when grown in different configurations and seasons (Dinesh & Pearce, 2016).

This research shows that agrivoltaic in certain conditions could be favorable for shade tolerant crops like lettuce but the system is not likely to produce enough food and clean energy to meet the increasing global demand if there isn't more research also on the effects on main food commodities which might be less shade tolerant.

8.3.3 Production alternation

Results from recent studies show that the agrivoltaic system has a quite big impact on the crops' yield underneath but varying every year.

It was evaluated that an average reduction of photosynthetic active radiation was about 30% under AV.

Results show also that soil temperature was decreased under AV every year, this creates more favorable condition for higher yields during hot and drier years compared to standard fields. Also plant height and leaf area of all crops is increased under AV.

In the study made by (Weselek et al., 2021) two years were studied: 2017 and 2018. The first year resulted in more humidity and colder temperatures while the second registered higher temperatures and more drought conditions.

In this study it resulted that in 2017 yield of winter wheat was -19%, then for potato -20% and -8% for grass-clover. Instead in the hot and dry 2018 the yield increased respectively by +3% for wheat and +11% for potato while still decreased for grass-clover by -3%. These findings show that yield reductions under AV are likely, but under hot and dry weather conditions, growing conditions can become favorable.

8.4 Costs and revenues of a typical crop rotation in the plains of northern Italy

In northern Italy the typical crops in the plain are corn, wheat, soybean, forage and vineyards.

Not all of them are easily suitable for agrivoltaic, especially if they need wide and big tractors.

That’s why for most of the new agrivoltaic plants the crop systems will be simplified as much as possible.

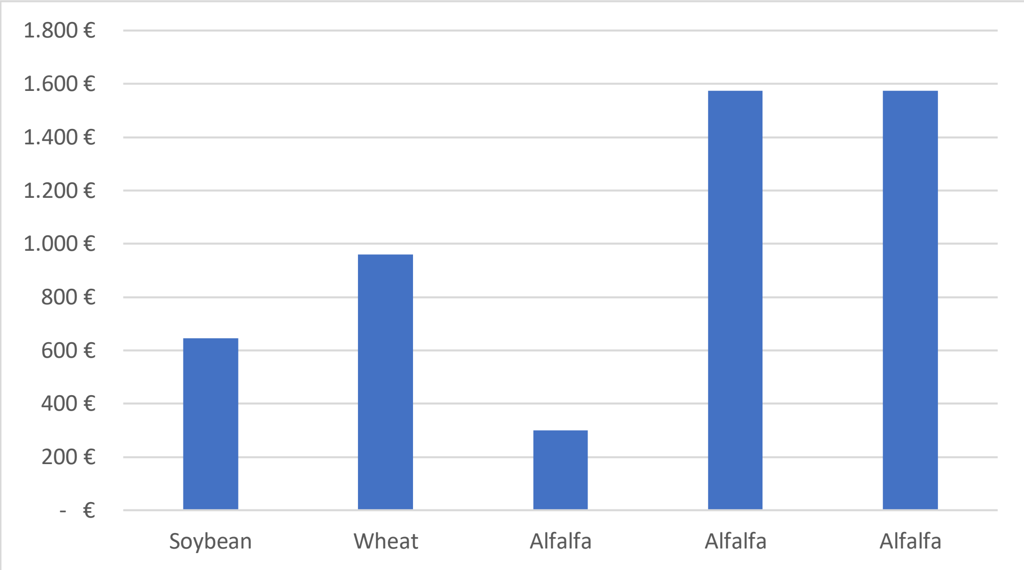
The table below (Table 7) shows the results of costs and revenues of a typical north Italian crop rotation that could fit an agrivoltaic system.

Under agrivoltaic system the yield and the profit from the crop is supposed to be reduced of about 25% on average compared to open field conditions (Weselek et al., 2021).

This is because of the shading conditions but also because of the space consumed by the supporting system of the agrivoltaic (own evaluation based on data from professional agronomic reports) .

	Soybean	Wheat	Alfalfa	Alfalfa	Alfalfa
seedbed preparation	200 €	70 €	200 €	- €	- €
sowing+ seed	290 €	245 €	230 €	- €	- €
fertilization + crop protection	620 €	640 €	405 €	150 €	150 €
irrigation	380 €	- €	200 €	- €	- €
harvesting (threshing + transport)	300 €	300 €	220 €	470 €	470 €
adversity insurance	45 €	45 €	45 €	45 €	45 €
total costs	1.835 €	1.300 €	1.300 €	665 €	665 €
avg. yield (tons/ha)	5	7	5	9	9
price (€/ton)	480 €	270 €	200 €	200 €	200 €
total revenues	2.160 €	1.890 €	1.000 €	1.800 €	1.800 €
gross margin	325 €	590 €	-300 €	1.135 €	1.135 €
gross margin + CAP funds	575 €	840 €	-50 €	1.385 €	1.385 €
agrivoltaic gross margin + CAP	431 €	630 €	-38 €	1.039 €	1.039 €

Table 7 Costs, revenues and gross profit with CAP funds of a typical Italian crop rotation system: soybean, wheat and alfalfa comparing standard and agrivoltaic conditions (data from interviews and tables with prices indexed by trade journals like https://www.informatoreagrario.it/)



Graph 7 Profit/ha/year obtainable from typical crops under agrivoltaic conditions in the north plain of Italy.

From this analysis it was concluded that the most profitable crop to produce under agrivoltaic today is forage (alfalfa) which even though the first year may go at a loss, in the next years could almost double the income from soybean or wheat. This is because in recent years, with drought problems and the rising costs of irrigation, production has decreased a lot creating a lack of supply of forage in the market. Agrivoltaic, in this case, not only could create an alternative income but could also reduce the costs, increasing water use efficiency for forage.

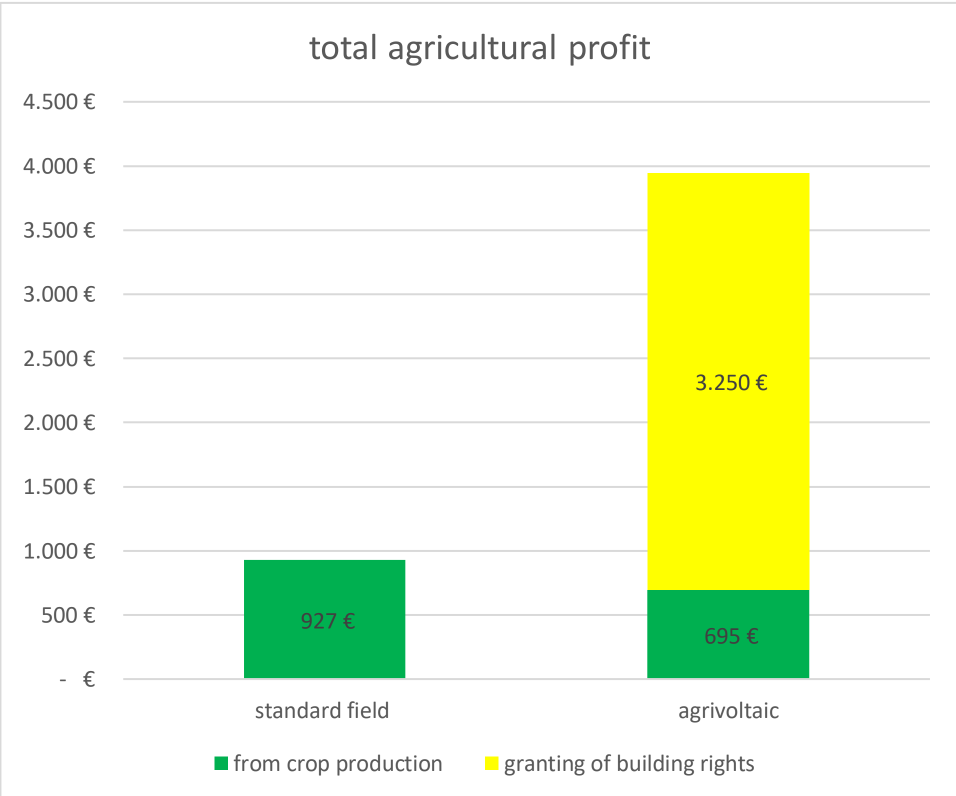
The average profit from this typical crop rotation in standard conditions, with the help of CAP funds, is less than 1000 €/ha/year which is quite low considering that a farmer could also have bad years of harvest.

Under an agrivoltaic system, crop production could decrease on average by 25% and so the profit, even though some cost voices could reduce a lot (as an example irrigation).

On average the gross profit from agricultural production under agrivoltaic could be around 700 €/ha/year with PAC funds. This is why it's important that it is counterbalanced from energy production or with a grant of a surface right to the electric company that builds the system.

This grant, in the case where the farmer is not the owner of the agrivoltaic system, could be quite substantial and reach up to 3500 €/ha/year compensating the agricultural loss.

In this case, as we see in the Graph 8, the average income of a farmer under agrivoltaic could be 4 times than that of a farmer in standard open field conditions. In the end, the economic benefit from granting the building rights for the agrivoltaic construction, could provide a higher and more stable income compared to a field in standard conditions.



Graph 8 Profit of the farmer in standard condition and with agrivoltaic (own data elaboration)

8.5 Monitoring

One fundamental aspect of agrivoltaic systems is to demonstrate they are working both for the agronomic part and for the electric one.

In Italy we still need more precise and practical guidelines on this aspect but there's something already said during the NRRP public consultation (Mase, 2022).

There are 5 aspects to monitor:

1) Continuity of agricultural activity
2) Microclimate
3) Resilience to climate change
4) Water saving
5) Soil fertility recovery

It must be demonstrated through an agronomic report that the land will be cultivated with a suitable crop even after the agrivoltaic system is planted so the land will produce food in the future. The microclimate has to be measured through a weather station and in particular the temperature outside and below the panels has to be measured through a PT100 sensor, the humidity has to be measured with a hygrometer and the wind speed with an anemometer.

Other sensors that can be used are:

- VP-4 sensor and 5TM sensor for air and soil humidity.
- PAR; QSO-S sensor for photosynthetic active radiation.

The resilience to climate change will be demonstrated with the agronomic support to individuate all the risks for the environment of the location. The water saving must be demonstrated through the effects of the panels on the soil moisture and through the demonstration of self-supply or purchase of water for the crops underneath.

Finally, soil fertility recovery has to be demonstrated through the recovery of abandoned land and the measure of organic matter and nutrient accumulation in the soil through the years with an agronomic study.

Picture 27 Sensors for monitoring in agrivoltaic systems (© Netsens-RemTec)

8.6 Reduction of landscape impact

To reduce the visual and environmental impact of the agrivoltaic system, it is needed to have an agronomic report with a project for a buffer zone with trees and other suitable bushes.

The masking and protection structure of the plant area have different functions.

First, the tree belt, must guarantee shielding from the most exposed viewpoints; on the other hand, it could incorporate an ecological system, ensuring transit and permanence of wild animals of various sizes, contributing to the connection of the elements of the ecological network promoted by the town planning instruments (PTCP and PAT).

This perimeter strip is an area restored to natural and semi-natural surface defined by law (example LR 14/2017, art. 2) compensating for the areas removed from agricultural use for the construction of subsystems of the planting under consideration.

In any case, at the end of its life cycle, the agrivoltaic system could be dismantled restoring the agricultural functionality of the land concerned.

Before choosing the tree species to plant, it’s important to analyze the climatic zone condition, the type of soil and the drainage system.

The most common solution in northern Italy for this buffer zone is a double row of poplars, with a possible enlargement in specific areas. The poplar trees fit well especially in north Italian landscape and can provide adequate shielding from elevated points of view with respect to the ground level.

The relative homogeneity of the single-species linear structure could then be compensated with a more complex articulation of the perimeter strip with different arrangement of the plants and variety of species used.

To promote wildlife, corridors could be implemented with a series of saplings and shrubs. This guarantees the continuity of the structure and the production of flowers and fruit that can support natural populations, from bees and other insects to mammals.

The core areas with wooded structures could provide areas for bigger wild animals to settle and rest.

The areas surrounding the arboreal elements should be grassed, to protect and stabilize the plant's perimeter ditches and to ensure the mobility of both the wild animals and for the maintenance of the wooded structure.

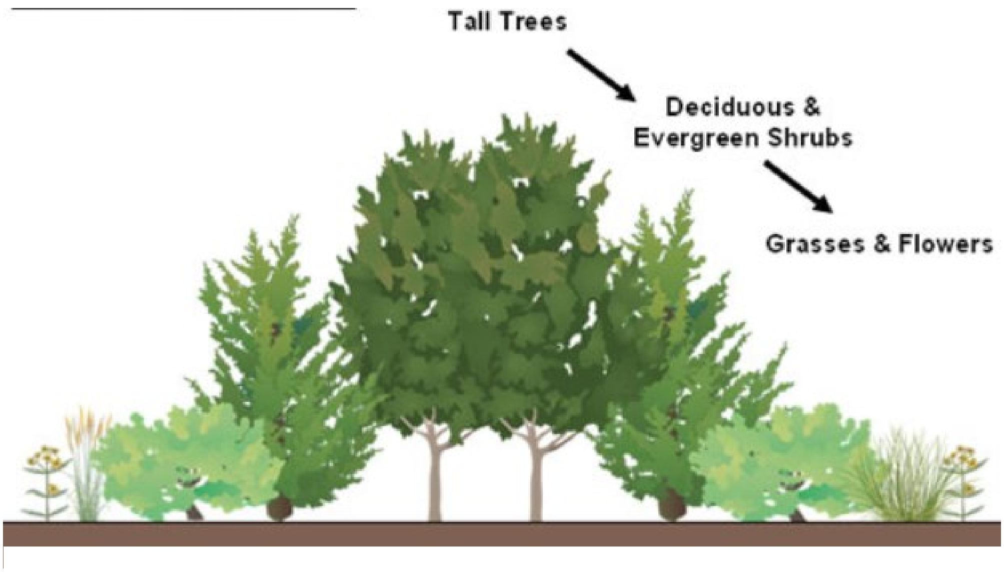
Picture 28 poplars that could shield an agri-voltaic plant (lafalda.it)

Picture 29 A common hedgerow flower bush: Viburnum opulus (©Leuven Botanical Garden, Belgium)

The most suitable species, besides poplar, for North Italy areas, are those listed in Table 8 (from professional agronomic report of prof. Berti, Unipd).

Tipologia	Nome scientifico	Nome comune	Tipologia	Nome scientifico	Nome comune
Alberi di II grandezza (altezza tra 12 e 25 m):	*Carpinus betulus* L.	Carpino bianco	Arbusti (altezza < 5m)	*Euonymus europaeus* L.	Fusaggine
	Carpinus orientalis L. Miller	Carpino orientale		*Hippophae rhamnoides* L.	Olivello spinoso
	Alnus cordata (Loisel.) Desf.	Ontano napoletano		*Ligustrum vulgare* L.	Ligustro
	Ulmus laevis Pallas	Olmo bianco		*Rhamnus catharticus* L.	Spincervino
Alberelli (altezza tra 5 e 12 m)	*Crataegus monogyna* Jacq.	Biancospino		*Rhamnus frangula* L.	Frangola
	Crataegus oxyacantha L.	Biancospino		*Sambucus nigra* L.	Sambuco
	Prunus cerasifera Ebrh.	Amolo		*Viburnum opulus* L.	Pallon di maggio

Table 8 Plant species that can be used for the buffer and confinement area of the plant (Berti, unipd)



Picture 30 Hedgerow scheme (maryland.gov/wildlife)

9 AGRIVOLTAIC ECONOMIC ANALYSIS

9.1 Initial investment

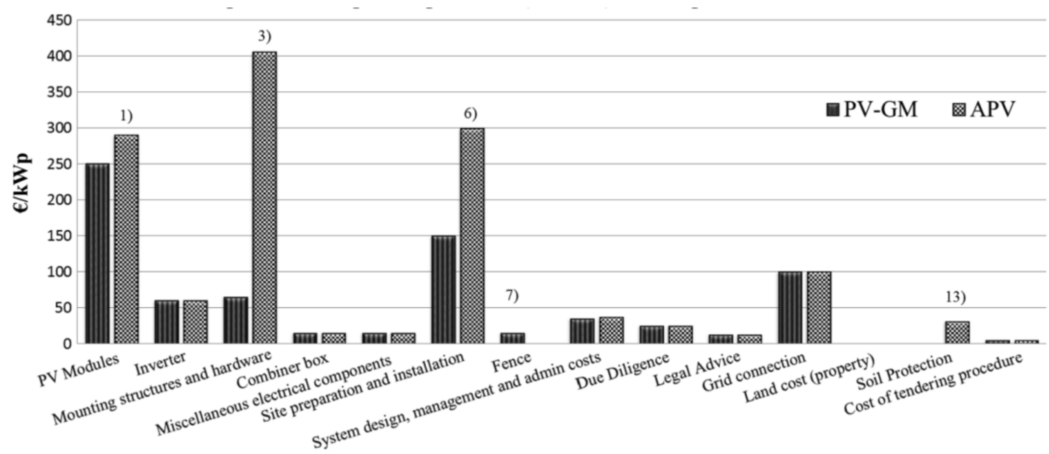
The cost of agrivoltaic plants can vary widely depending on a range of factors such as the size and complexity of the system, the type and efficiency of the solar panels used, and the cost of labor and materials in the region where the system is being installed.

Some researchers have estimated an initial investment of around 600.000 €/MW for agrivoltaic considering the costs of bifacial panels with monocrystalline silicon technology (≈22% efficiency), inverters, installation, tracking system and maintenance work (Ciocia et al., 2022) .

PV modules	200÷300	k€/MW
AC/DC converter	30÷50	
Installation of the plant	10÷15	
Tracking systems	130÷150	
Masonry work	80÷100	
Total cost	450÷615	

Table 9 Investment cost of the APV tracking system (Ciocia et al., 2022)

This figure is very optimistic and undersized especially in Italy. In fact, since there are not many agrivoltaic plants yet, there's a lot of variation in costs; in the public consultation of the NRRP there have been given some cost indications. The lowest estimated cost value is for traditional ground mounted photovoltaic plants of 750 €/kw (meaning 750.000 €/MW), we have then 800 €/kw for single axis tracking traditional PV plants, then 950 €/kw (with a variability of 270 €/kw) for agrivoltaic adapted for permanent crops and finally 1200€/kw (with a variability of +/- 375 €/kw) for agrivoltaic suitable for arable crops (Schindele et al., 2020). Thus, on average, we have an increase in price compared to traditional PV plants of 60% for agrivoltaics on arable crops and 25% for agrivoltaics on permanent crops.



Graph 9 Comparison of capital expenditure (CAPEX) associated with APV and PV-GM in € kWp−1 (© Fraunhofer ISE).

It's worth noticing that while the initial cost of installation may be higher than for a conventional solar power system, agrivoltaic systems have the potential to generate multiple sources of revenue, which can help to offset the initial investment over time. Farmers may be able to directly use the cheaper energy which is distributed by the energy company that builds the system in addition to selling crops that are grown in the shaded areas beneath the solar panels.

As with any investment, it's important to carefully consider the costs and potential benefits of agrivoltaic systems before deciding. Factors such as the location, climate, available land, and local regulations should all be considered when evaluating the feasibility of an agrivoltaic project.

In Fieragricola Tech congress of Verona (February 2023), there were some representatives of the REM Tec company which has some agrivoltaic patents and has produced the first agriphotovoltaic plants in Italy and now are expanding abroad.

They said that the initial investment for an APV plant is about 1.2 mln € per MW made on 1.5/2 ha and usually joint ventures invest in plants of at least 5 ha so they need to have some big funds behind. If the investment costs for 1 MW of agrivoltaic is 1.2 mln € the subsidies can cover 40% of that and the final cost could be 720.000€ which is still pretty high for an average farmer.

Picture 31 Different rendering models presented at Fiera Agricola tech congress (© REM Tec).

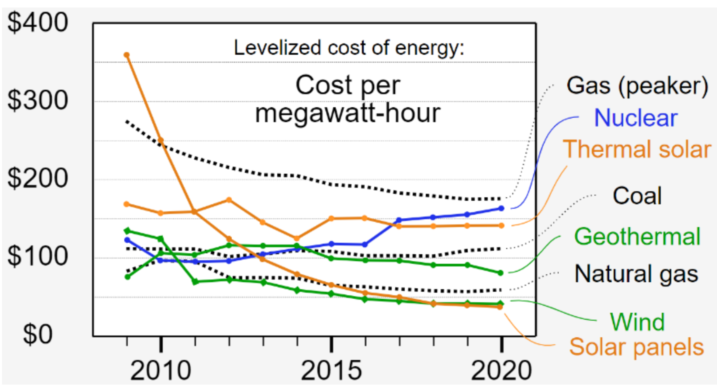
9.2 Electric yield

The electric yield is the one giving the greatest revenue from the land in the agrivoltaic system. It's important to find a balance between the light absorbed and the one left for crops to grow underneath.

It's also important to follow the requirement from CREA guidelines (Mase, 2022) that states an agrivoltaic plant should have an electricity production of at least 60% of a traditional ground mounted plant on the same surface.

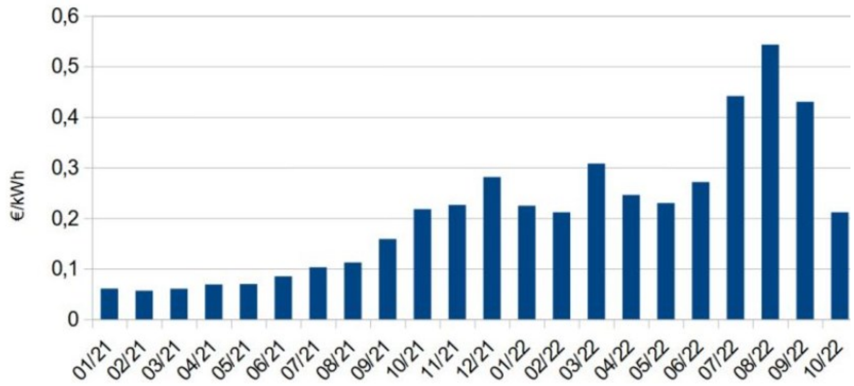
To maximize the efficiency of the panels there can be adopted different technologies as automated tilting to allow panels to follow perpendicularly the sun and always absorb the maximum capacity or bifacial panels that are able to absorb also the albedo increasing the efficiency per square meter. Also, semitransparent panels are developing, especially for greenhouses to let more light penetrate for plants.

In general electricity produced by solar panel is becoming more efficient and decreasing in price and right now it's the most convenient renewable energy resource as we can see from the graph below (Chrobak & Chodosh, 2021).

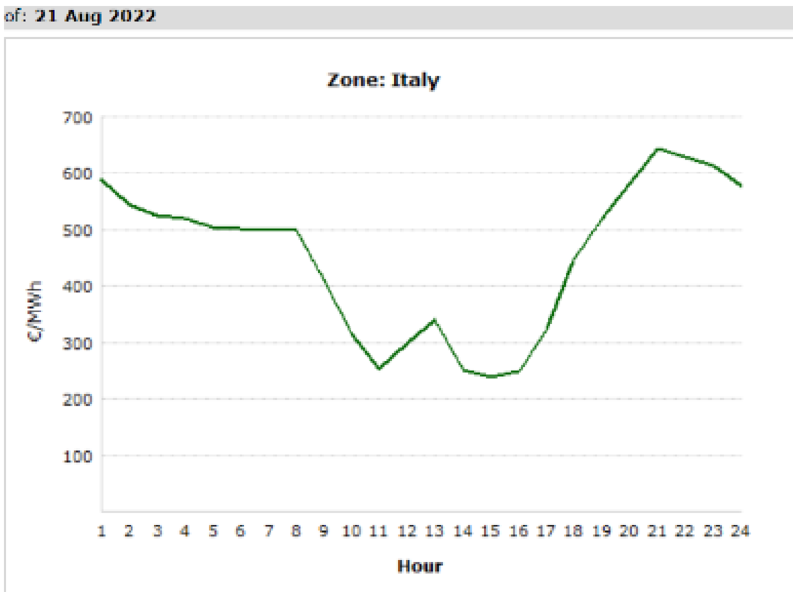


Graph 10 Levelized cost of energy (Chrobak & Chodosh, 29 January 2021)

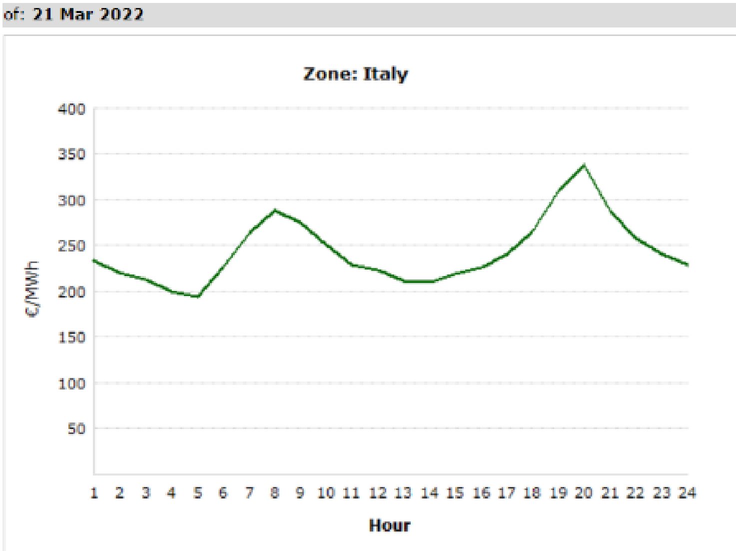
The cost of electricity in Italy is one of the highest in Europe and in the last years it has increased a lot as we can see from the graphs below from GME (gestore mercati energetici).



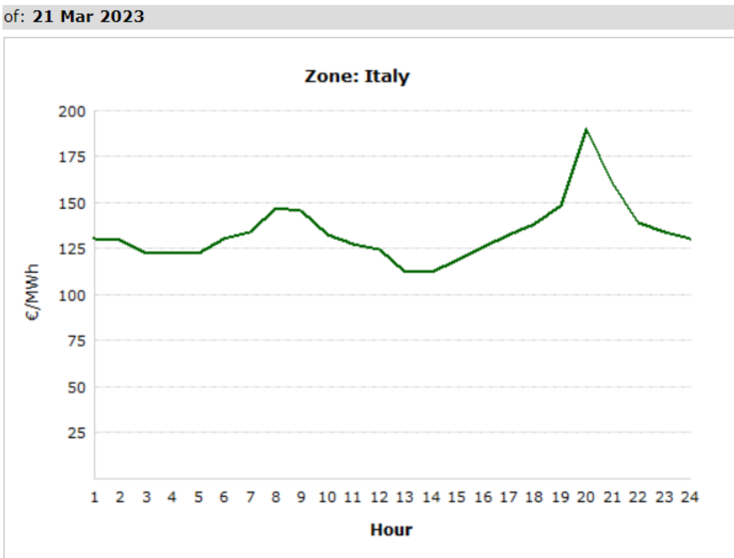
Graph 11 Energy costs for final consumer in 2021-2022 (https://www.newsauto.it/)



Graph 12 Electric energy price(€/MWh) reaching the highest for consumer on august 2022 (https://mercatoelettrico.org/it/).



Graph 13 Electric energy price(€/MWh) on March 2022 (https://mercatoelettrico.org/it/).



Graph 14 Electric energy price(€/MWh) on March 2023 (https://mercatoelettrico.org/it/).

From the previous graphs we can see that in August 2022 the energy cost for the final consumer has been the highest due also to the gas crisis.

Now the price has been stabilized also by government measures but it’s still high.

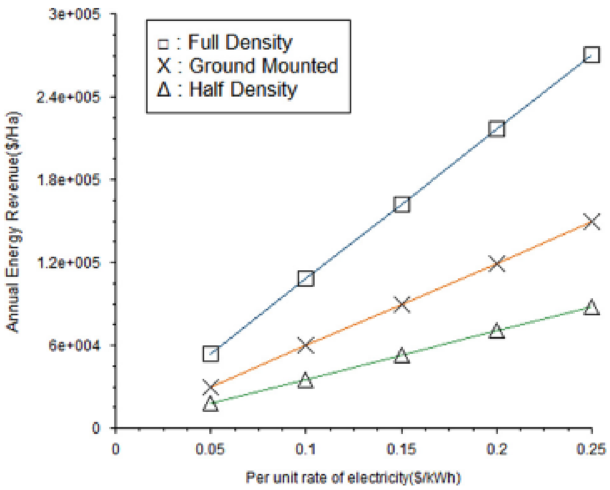
We can also see that the price fluctuates during the hours of the day due to the solar energy production that concentrates during the middle hours.

This is why the agrivoltaic systems should be coupled with a storage system that allow to catch the overproduction of energy during the day and sell it at night when the price is higher, but the storage systems consist in batteries that are still quite expensive to produce and we still need make them more efficient for large scale production.

As we see there are many factors that make electricity prices quite volatile so it’s important for companies that build the agrivoltaic systems to stipulate good contracts to sell the solar energy produced.

Usually, energy companies sell the production to GSE (gestore servizi energetici) but to be sure to have a stable income during the years they can also make direct contracts with the final consumer with a PPA (power purchase agreement). In this way they could get a higher fixed price for several years and at the same time, the consumers can get a stable and lower energy price for several years. In the case of agrivoltaic the price could be fixed at 85 € for MWh produced.

In this last case the government must act as guarantor in case the company cannot afford anymore to pay for that stable energy price.



Graph 15 Electricity revenue with respect to change in the per unit cost of electricity for various agrivoltaic farm configurations (Dinesh & Pearce, 2016).

To calculate the solar profit (S) per hectare per year we could use this formula:

$S = V_e - V_{LCOE}$

Where Ve is the value of the solar generated electricity per hectare per year and V_{LCOE} is the cost of the electricity, which is given by:

$V_{LCOE} = LCOE \times E_{av}$

Where **LCOE** is the levelized cost of electricity ($/kW h) and Eav is the solar electricity generated per hectare per year on the agrivoltaic farm.

LCOE can be thought of as "the average minimum price at which the electricity generated by the asset is required to be sold in order to offset the total costs of production over its lifetime" (*Levelized Cost of Energy (LCOE)*).

With agrivoltaic plants we can save land for agriculture and this preserved value is calculated by comparing agrivoltaic LCOE with ground mounted LCOE with the formula:

$p = LCOE_{APV} * M_{APV} - LCOE_{PVGM} * M_{PVGM}$

where:

p = price of APV implementation and preservation of cropland [€/ha/a]

$LCOE_{APV}$ = levelized cost of electricity for agrophotovoltaics [€/kWh]

$LCOE_{PVGM}$ = levelized cost of electricity for ground-mounted PV [€/kWh]

M_{APV} = annual electrical yield per ha APV [kWh/ha/a]

M_{PVGM} = annual electrical yield per ha PV-GM [kWh/ha/a]

(Schindele et al., 2020)

LCOE to produce 1 MW of electricity is higher for an agrivoltaic plant compared to a standard PV plant, this is reflected also on the land use efficiency with a current average of 1.45 ha/MWp for PV-GM implementation and almost 2 ha for agriphotovoltaic.

There's a big difference when we consider the region of collocation, in southern regions the productivity of electricity is higher and so the LCOE for agrivoltaic could get close to a standard PV plant with 60 €/MW. Instead in the north, where less electricity could be produced, an advance agrivoltaic system for arable crops, which has the highest and most expensive structure, could reach a levelized cost of electricity of 93 €/MW which is higher than the basic incentive tariff of 85 €/MW offered from GSE through NRRP funds. In any case even the last case, with the initial non-refundable incentive from NRRP, could be profitable in the end.

The highest value of earnings per year comes from conventional ground mounted optimized solar farm which could yield up to $274,000/Ha/year.

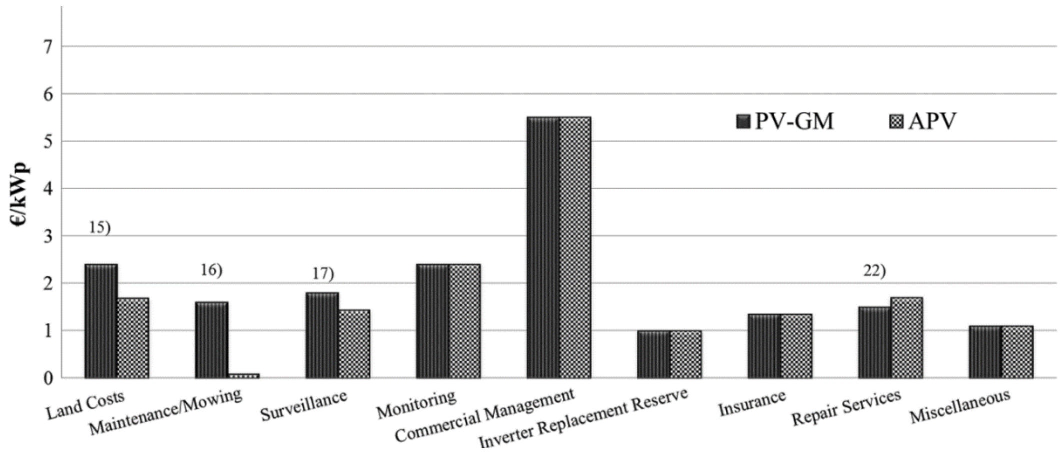
In the previous study case of lettuce (Dinesh & Pearce, 2016) in the full density case the full profit potential of the solar electricity S was $63,138/ha or more and for the half density case was $17,706/ha or more.

9.3 Operation and maintenance (OPEX)

Operating expenses, OPEX, are the expenses that a business incurs through its normal business operations (*Operating Expense Definition and How It Compares to Capital Expenses*, n.d.)

These costs for agrivoltaics plants shouldn't be underestimated especially because we still need more experimental cases to see the interaction between agricultural activities and electric components that are quite fragile.

For an agrivoltaic system OPEX are composed mainly of: land cost, maintenance/mowing, surveillance, monitoring, commercial or asset management, inverters replacement, insurance, repair service and miscellaneous (Graph 16). In general, the range of OPEX is between 1-3% of the initial investment and it depends on the dimensions of the plant.



Graph 16 Comparison of the OPEX (€/kWp) between agrivoltaic APV and ground-mounted PV-GM (Schindele et al., 2020 © Fraunhofer ISE)

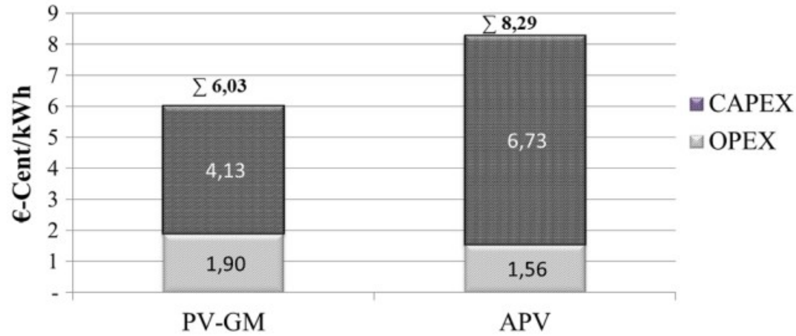
In a good system that works well between the agricultural and electric part, APV could have lower maintenance costs than normal ground mounted systems. Indeed, for a 1 MW standard ground mounted PV plant the annual cost of maintenance is around 18.000€ while for an agrivoltaic plant it is estimated to be around 16.000€ (Schindele et al., 2020).

The main reason for the lower maintenance costs in agrivoltaic is because the maintenance and mowing of the grass is already included by the farmer activities who could also help with surveillance lowering this cost. In addition, since the farmer could keep having an income from this land, the owner of the APV plant doesn't have to give a full substitute income to the farmer as in ground mounted systems but only a supplementary income through the lease of the building right decreasing the land costs. On the other side, it's very important that the farmer cultivate the land without causing damage or efficiency loss to the panels and having a program for the washing of the system especially after agricultural operation in the driest months that could cause soiling of the panels.

The costs of maintenance however are higher for agrivoltaics if there is damage because it requires skilled labor and more expensive machines to get higher off the ground.

In normal conditions the highest cost is the commercial management, as it's shown in Graph 16. Indeed, the commercial management of an agri-voltaic plant is responsible for marketing the electricity produced, managing contractual and financial relations, and managing the risks associated with the commercial activity of the project. This aspect is crucial to ensure the economic and financial success of the agri-voltaic plant in the long term. The other cost items like repair service (inverter substitution etc…), insurance and other smaller costs could be similar for both agrivoltaic and ground mounted systems.

In conclusion, the OPEX could be similar between ground mounted PV and agrivoltaic while there's still a big difference in CAPEX and so in the initial investment which is much higher for agrivoltaic.



Graph 17 Comparison of the LCOE in euro cents per kWh of APV and PV-GM split into CAPEX and OPEX (Schindele et al., 2020)

10 RESULTS

To understand how much the opportunity to invest money in the sector of agrivoltaic can make profits, an economic analysis has to be done. To do so, some data was extrapolated from companies in the sector and from personal interviews.

photovoltaic system power	1	MW
surface of agrivoltaic system	1,8	ha
hours of electricity production	1300	hours/year
photovoltaic investment cost	1.200.000	€
capital cost contribution NRRP	40	%
net investment cost with 40% funds	720000	€
maintenance costs	10.000	€/MW/year
plant insurance	6.000	€/MW/year
total OPEX	16.000	€/MW/year
efficiency loss	0,5	%/anno
energy price	85	€/MWh
yearly electric yield	1300	MWh/year

Table 10 Parameters of an agrivoltaic system of 2.1 m height. Sources from personal interviews with different energy companies.

As it's shown in the table above (Table 10), it was considered a standard agrivoltaic system of 1 MW and 2.1m high. The surface occupied by this plant is a little less than 2 ha (in this case it was estimated around 1,8 ha). The hours of energy production in Italy were estimated on average around 1300 h/year (*Impianto Fotovoltaico: Quanto Produce in Un Anno? | E.ON Energia*, n.d.). The initial investment for this system is around 1.2 million of € (Schindele et al., 2020), in this analysis there were made two cases: case 1 where no funds are given and case 2 where funds of 40% of the initial investment are given at the beginning from NRRP, thus reducing the investment to 7.200.000 €. The total annual costs of maintenance and insurance (OPEX) are considered of 16.000 € (Schindele et al., 2020) but it was assumed an increase by an average 3% every year due to inflation. Energy price sold to GSE instead is considered to be fixed for 20 years at 85 €/MWh as it is stipulated with NRRP to get funds (Il Ministro dell'Ambiente e della Sicurezza Energetica, 2023). The electric yield that could be made from this system is derived by the power of the system times the hours of work resulting of 1300 MWh/year. This yield will decrease every year by 0.5% due to the loss of efficiency of the solar panels ("Solar Panel Efficiency Over Time. Plus Tips to Improve It" 2022) also decreasing the profit.

To see if the investment is worth it, in this research it was used Excel to calculate the profit over a period of 20 years as reported in the table below.

	CASE 1 (zero contribution)				
years	**plant depreciation rate (i=5%)**	**OPEX (3% inflation)**	**total annual cost**	**Electricity revenue (€/year)**	**profit**
1	96.291 €	16.000 €	112.291 €	110.500 €	- 1.791 €
2	96.291 €	16.480 €	112.771 €	109.948 €	- 2.824 €
3	96.291 €	16.974 €	113.266 €	109.398 €	- 3.868 €
4	96.291 €	17.484 €	113.775 €	108.851 €	- 4.924 €
5	96.291 €	18.008 €	114.299 €	108.307 €	- 5.993 €
6	96.291 €	18.548 €	114.839 €	107.765 €	- 7.075 €
7	96.291 €	19.105 €	115.396 €	107.226 €	- 8.170 €
8	96.291 €	19.678 €	115.969 €	106.690 €	- 9.279 €
9	96.291 €	20.268 €	116.559 €	106.157 €	- 10.403 €
10	96.291 €	20.876 €	117.167 €	105.626 €	- 11.542 €
11	96.291 €	21.503 €	117.794 €	105.098 €	- 12.696 €
12	96.291 €	22.148 €	118.439 €	104.572 €	- 13.867 €
13	96.291 €	22.812 €	119.103 €	104.049 €	- 15.054 €
14	96.291 €	23.497 €	119.788 €	103.529 €	- 16.259 €
15	96.291 €	24.201 €	120.493 €	103.011 €	- 17.481 €
16	96.291 €	24.927 €	121.219 €	102.496 €	- 18.722 €
17	96.291 €	25.675 €	121.966 €	101.984 €	- 19.983 €
18	96.291 €	26.446 €	122.737 €	101.474 €	- 21.263 €
19	96.291 €	27.239 €	123.530 €	100.967 €	- 22.563 €
20	96.291 €	28.056 €	124.347 €	100.462 €	- 23.885 €
TOT	**1.925.822 €**			**2.108.108 €**	**-247.640 €**

Table 11 Calculation of costs and gross profit for an average agrivoltaic system of 1MW without any subsidies selling energy at 85 €/MWh for 20 years.

First of all, it was calculated the plant depreciation rate (96.291 €) to pay every year for 20 years to the bank for a hypothetical loan of 1.2 million €. It was calculated through the -PMT function of Excel using a fixed interest rate of 5%. Then it was calculated the total annual costs by adding the depreciation rate to the OPEX costs, which are supposedly increasing by an average 3% every year due to inflation. The yearly electric revenue was calculated by multiplying the yearly electric yield by the energy price of 85 €/MWh sold to GSE and reducing it by 0.5% every year due to panel efficiency loss. To calculate the profit then it was subtracted from the yearly electric revenue the total annual cost.

As we can see in Table 11, the profit from this system is negative since the first year resulting in a bad investment without any further analysis.

So, it might seem that without any funds it's not convenient to make agrivoltaic systems but still companies have made them in the last years. This is because either the systems were built on larger utility scale or with less expensive material (for example lowering the height) to decrease the costs.

Another option for companies would be selling the energy directly to other companies at a higher price than 85 €/MWh.

As we can see in the table below it's sufficient to increase the energy price to 116 €/MWh to see positive profits for the same system.

	CASE 1 (zero contribution)				
years	**plant depreciation rate (i=5%)**	**OPEX (3% inflation)**	**total annual cost**	**Electricity revenue (€/year)**	**profit**
1	96.291 €	16.000 €	112.291 €	143.000 €	30.709 €
2	96.291 €	16.480 €	112.771 €	142.285 €	29.514 €
3	96.291 €	16.974 €	113.266 €	141.574 €	28.308 €
4	96.291 €	17.484 €	113.775 €	140.866 €	27.091 €
5	96.291 €	18.008 €	114.299 €	140.161 €	25.862 €
6	96.291 €	18.548 €	114.839 €	139.461 €	24.621 €
7	96.291 €	19.105 €	115.396 €	138.763 €	23.367 €
8	96.291 €	19.678 €	115.969 €	138.069 €	22.100 €
9	96.291 €	20.268 €	116.559 €	137.379 €	20.820 €
10	96.291 €	20.876 €	117.167 €	136.692 €	19.525 €
11	96.291 €	21.503 €	117.794 €	136.009 €	18.215 €
12	96.291 €	22.148 €	118.439 €	135.329 €	16.890 €
13	96.291 €	22.812 €	119.103 €	134.652 €	15.549 €
14	96.291 €	23.497 €	119.788 €	133.979 €	14.191 €
15	96.291 €	24.201 €	120.493 €	133.309 €	12.816 €
16	96.291 €	24.927 €	121.219 €	132.642 €	11.424 €
17	96.291 €	25.675 €	121.966 €	131.979 €	10.013 €
18	96.291 €	26.446 €	122.737 €	131.319 €	8.583 €
19	96.291 €	27.239 €	123.530 €	130.663 €	7.133 €
20	96.291 €	28.056 €	124.347 €	130.009 €	5.662 €
TOT	**1.925.822 €**			**2.728.140 €**	**372.392 €**

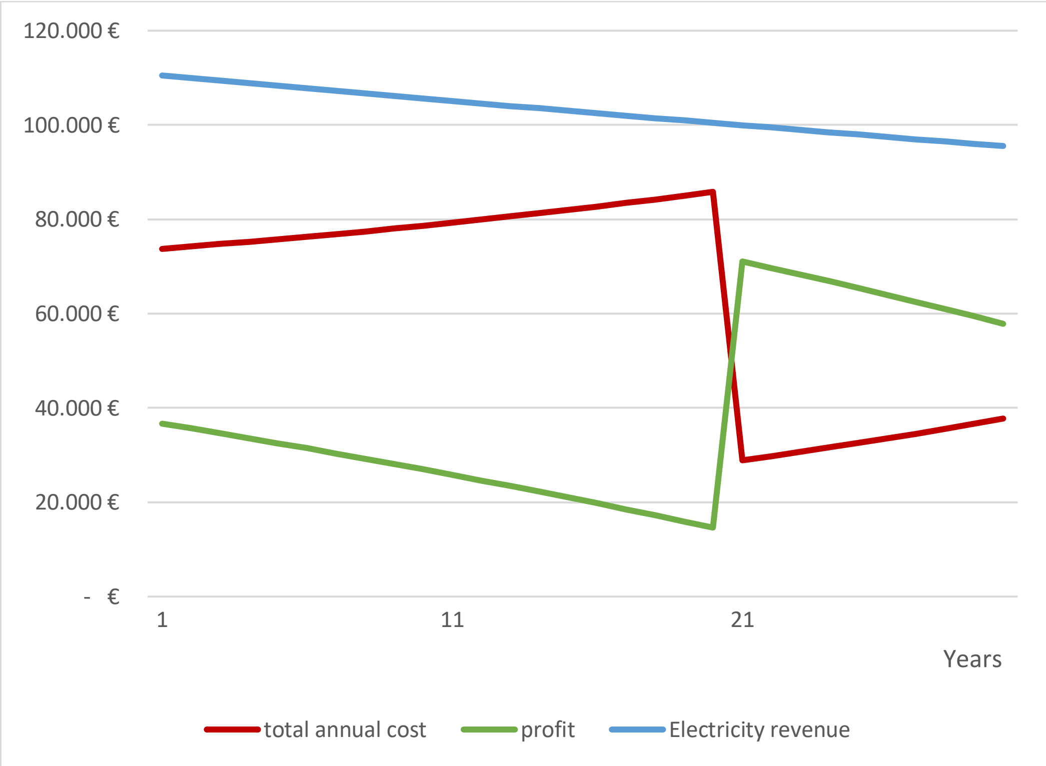
Table 12 Calculation of costs and profit for an average agrivoltaic system of 1MW without any subsidies selling energy at 116 €/MWh for 20 years.

In CASE 2, it was supposed that the investor (which has to be a company with at least one farmer) gets the funds of 40% of the total investment from NRRP at the beginning and he took out a bank loan, with a 5% interest rate for 20 years, to cover the 720.000€ remaining for a 1MW plant. He then has to sell the energy to GSE at 85 €/MWh for 20 years and by doing so he could get a profit of an average 26.134 € per year on a 2 ha field as we can see in Table 13.

	CASE 2 (40% contribution)				
years	**plant depreciation rate (i=5%)**	**OPEX (3% inflation)**	**total annual cost**	**Electricity revenue (€/year)**	**profit**
1	57.775 €	16.000 €	73.775 €	110.500 €	36.725 €
2	57.775 €	16.480 €	74.255 €	109.948 €	35.693 €
3	57.775 €	16.974 €	74.749 €	109.398 €	34.649 €
4	57.775 €	17.484 €	75.258 €	108.851 €	33.592 €
5	57.775 €	18.008 €	75.783 €	108.307 €	32.524 €
6	57.775 €	18.548 €	76.323 €	107.765 €	31.442 €
7	57.775 €	19.105 €	76.879 €	107.226 €	30.347 €
8	57.775 €	19.678 €	77.453 €	106.690 €	29.237 €
9	57.775 €	20.268 €	78.043 €	106.157 €	28.114 €
10	57.775 €	20.876 €	78.651 €	105.626 €	26.975 €
11	57.775 €	21.503 €	79.277 €	105.098 €	25.820 €
12	57.775 €	22.148 €	79.922 €	104.572 €	24.650 €
13	57.775 €	22.812 €	80.587 €	104.049 €	23.462 €
14	57.775 €	23.497 €	81.271 €	103.529 €	22.258 €
15	57.775 €	24.201 €	81.976 €	103.011 €	21.035 €
16	57.775 €	24.927 €	82.702 €	102.496 €	19.794 €
17	57.775 €	25.675 €	83.450 €	101.984 €	18.534 €
18	57.775 €	26.446 €	84.220 €	101.474 €	17.254 €
19	57.775 €	27.239 €	85.014 €	100.967 €	15.953 €
20	57.775 €	28.056 €	85.831 €	100.462 €	14.631 €
TOT	**1.155.493 €**			**2.108.108 €**	**522.689 €**
				AVERAGE	26.134 €

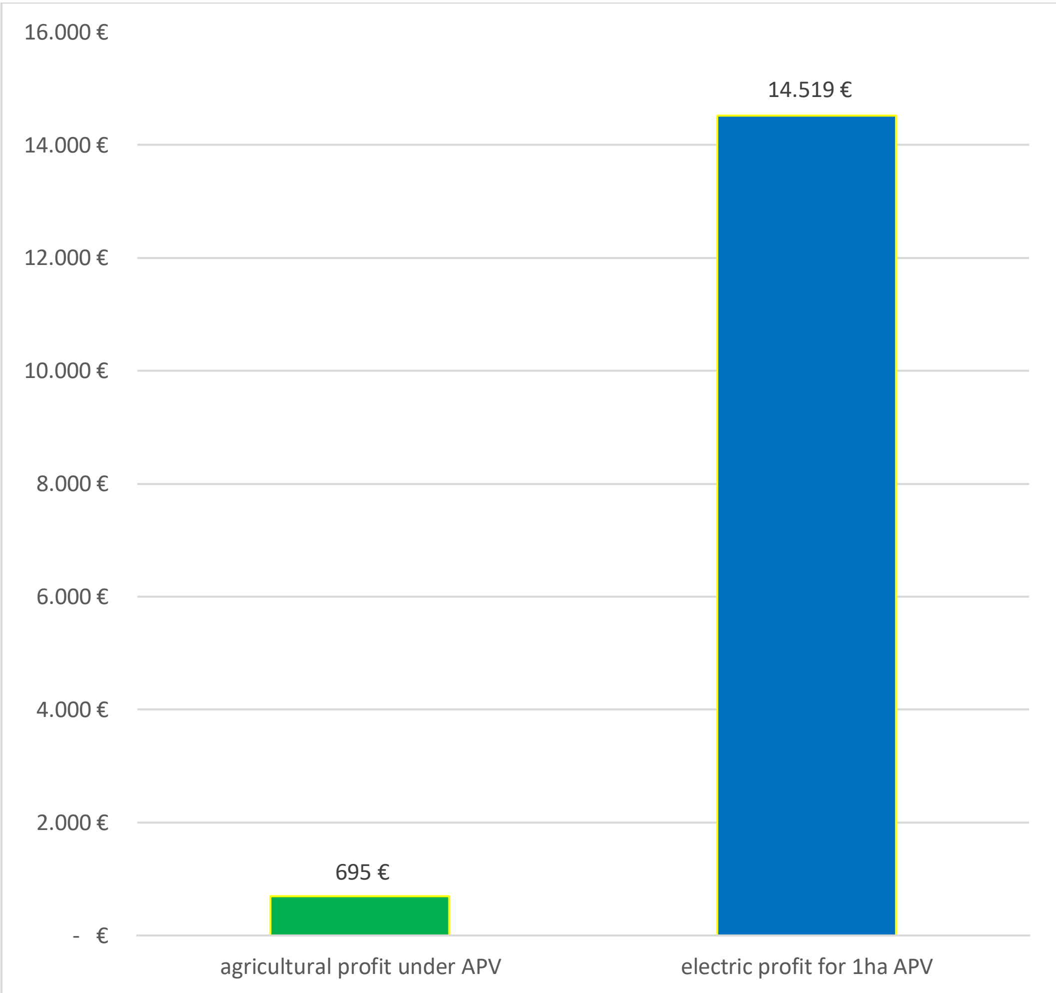
Table 13 Costs and profit for the hypothetical agrivoltaic system of 1MW with 40 % funds on the total investment and selling energy at a fixed price of 85 €/MWh for 20 years.

It’s important to consider that when the mortgage is paid off, after 20 years, the total costs drop down while the profit increases instantly to reach its peak (70.000€ for 2 ha) even if the electric revenue continues to decrease due to the loss of efficiency of the panels (around 0,5% every year) as we can see in Graph 18. This means that the investment could be good for more than 20 years and even better after this period but it depends a lot on the energy price of the market at which the energy will be sold which might be higher or lower than the 85 €/MWh granted from the NRRP.



Graph 18 Trend lines of an agrivoltaic investment for a period of around 30 years. Red line represents the total annual costs of an agrivoltaic system, the blue line is the electricity revenue made by selling energy at 85 €/MWh and the green line is the profit resulting from the two lines.

In an agrivoltaic system, it’s important to notice that the profit from agricultural production of 1 ha is only around 5% (695€/ha / 14.519€/ha x 100) of the profit from energy production as we can see in the Graph 19. This is why, when the farmer is not the owner of the system, he is well compensated for the loss of profit by granting the surface rights to the energy company. In exchange the farmer has to adapt his agricultural system to the agrivoltaic system in a way to prevent damage or other profit loss (like soiling of the panels).



Graph 19 Comparison of agricultural and electric profit on a 1ha field of APV.

Since the agrivoltaic profits in CASE 2 are positive, it makes more interesting to go deeper in the financial analysis, calculating the NPV of the investment that is a precious data to understand if there are alternative similar investments with equal range of risk that are more remunerable.

The Net Present Value (NPV) is the sum of all the present values of the operating cash flow minus the initial investment. The cash flow values are brought to present using an interest rate value (i) took from the weighted average cost of capital (WACC) of similar companies in the energy sector and was supposed to be 4.5%.

$$NPV = \sum_{i=1}^{n} \frac{Cash\ Flow_i}{(1+r)^i} - Initial\ Investment$$

NPV, being a data that measures the goodness of an investment compared to another, does not consider depreciation expense because it does not represent an actual cash flow and interest expense because it represents a financing expense. Also, taxes are excluded from operating expenses and are considered separately in the net profit calculation.

To evaluate the goodness of the investment and compare it to other investments, the ROI (return of investment) was also calculated. This is a ratio expressed in % between the average net income or margin (not considering the bank interest in this case) and the investment cost which is 1,2 million € for CASE 1 and 720.000 € for CASE 2. It measures the rate of return of money invested in order to decide whether or not to undertake this investment compared to other similar investments.

To calculate the NPV, the payback time and ROI of the investment of CASE 2, an excel table was made as shown below Table 14.

payback time case 2 (WACC= 4,5%)		
years	cash flows	cumulative cash flows
0	-720000	-720000
1	94.500	-625.500
2	93.468	-532.033
3	92.423	-439.609
4	91.367	-348.242
5	90.298	-257.944
6	89.217	-168.727
7	88.121	-80.606
8	87.012	6.406
9	85.888	92.295
10	84.749	177.044
11	83.595	260.639
12	82.424	343.063
13	81.237	424.301
14	80.033	504.333
15	78.810	583.143
16	77.569	660.712
17	76.309	737.021
18	75.028	812.049
19	73.728	885.777
20	72.406	958.182
TOT.	**1.678.182**	

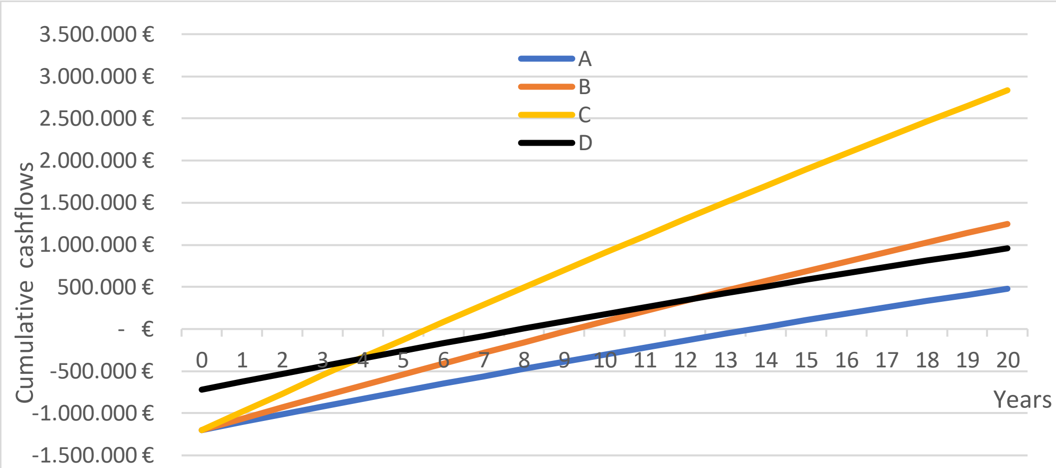
Table 14 Operating cash flows of an agrivoltaic system with 40% incentive from the NRRP selling energy at 85 €/MWh.

NPV	393.201 €
IRR	10,50%
PB years	7,9
average margin	83.909 €
ROI	11,65%

Table 15 NPV, IRR, payback time and ROI of CASE 2 (40% incentive) selling energy at 85 €/MWh.

NPV resulted positive for CASE 2, this means that the investment that we are considering is creating value and worth pursuing it.

To see after how many years the investment could be recovered, the payback time has been calculated by adding cash flows generated by the system to the initial investment. With this calculation it is formed the cumulative cash flows that start from a value of -720.000 € in CASE 2 until it reaches a breakeven point, the payback time, and start to become positive.



Graph 20 Payback time of different investments on agrivoltaic: A is CASE 1 (no incentives) selling energy at 85 €/MWh, B is CASE 1 (no incentives) selling energy at 116 €/MWh, C is CASE 1 (no incentives) selling energy at 180 €/MWh, D is CASE 2 (with 40% incentives on the initial investment) selling energy at 85 €/MWh.

This payback time could be reduced only lowering the initial investment or by selling the energy produced at higher price but in this last case the NRRP funds could not be given.

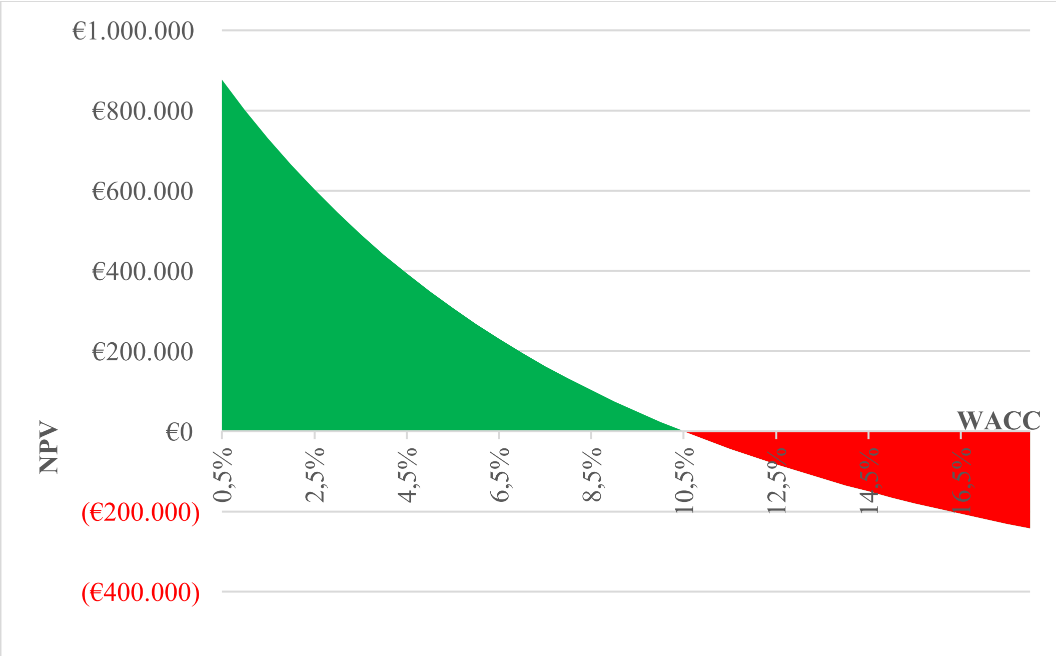
As we can see in the graph above (Graph 20), the investment of CASE 2 (D) , with the NRRP funds, has a payback time of around 7 years but even if no funds are given, CASE 1, if the energy is sold independently, it could be a good investment.

In fact, if energy is sold at 116 €/MWh (today average market value) CASE 1 (B), the payback time could be a little more than 7 years but if it is sold in time slots where energy is more expensive, for example at 180 €/MWh, through the use of storage batteries, the payback time could be less than 7 years.

In both cases of CASE 1 (B & C), even if no funds are given from the NRRP, the investments could generate more income in the long run than CASE 2 with the incentives, but with a higher risk to fail if the energy market price drops.

Since the cost of capital could vary every year, we have to see until which rate it is convenient to invest in this system. For this reason, it was calculated the internal rate of return (IRR) which is the rate at which the net present value reaches zero. The IRR is the threshold where our business plan makes sense, if this rate is higher than the cost of capital rate WACC, then the investment is favorable, otherwise not.

To show the link between the changing rates (representing the cost of capital) and the NPV, a graph has been made and is shown below.



Graph 21 NPV changing at different capital cost rates for the investment CASE 2 (where 40% of initial investment is given). This shows an IRR of 10.5%.

This graph shows that the internal rate of return, IRR, of this investment is 10.5% which is actually quite good because it's much higher than the actual WACC (4.5%). If it happens that in the future the WACC increases more than 10.5%, the investment won't be profitable but it is quite unlikely.

So, considering that this research is speculative and with margin of errors, it seems that from this study investing in an agrivoltaic system with support from NRRP funds will give good revenues and could be one of the best investment options in the sector for farming companies.

To see more in detail graphs and economic values on an excel spreadsheet, see the link below.

https://docs.google.com/spreadsheets/d/1CtvLZ9PreLWswyF9wwMhjhQ1CWzVE3R5/edit?usp=sharing&ouid=114162737619833560513&rtpof=true&sd=true

11 CONCLUSION

The agrivoltaic system could be a solution for managing the intense competition between land resources, food and energy production.

If shade tolerant crops are utilized, crop yield losses could be minimized and, with further researches, also the performance of shade-intolerant crops, which are expected to grow poorly in low-light environments, it is expected to become more attractive.

Rather than boundary separated infrastructure between food and energy productions, agrivoltaic system models represent a potential solution able to optimize food-energy co-generation systems.

A lot of scientific research needs to be done both to genetically improve the crops able to adapt to agrivoltaic conditions as well as engineering solutions to improve the efficiency of the energy production system and finding new material like opaque organic panels to enhance the synergy between crops and energy production.

This can bring collaborations between different stakeholders and benefits beyond food and energy economic revenue, including water conservation, soil health, ecological restoration and climate change mitigation.

The installations of PV panels must be prioritized on already artificialized land, polluted or desert land, roofs and car park cover but the installation of agrivoltaic plants in marginal or abandoned land or in area where agricultural crops are losing economic interest or suffering a lot from climate change (e.g. excessive solar radiation), could be a useful solution to be promoted.

The figure of an agronomist in this case is of fundamental importance to make an agronomic report justifying the investment of the APV system by an electricity company on a selected land. Moreover, an agronomist could be the mediator between electric companies and farmers to find suitable land for these systems and help farmers to have better income.

Farmers need to be able to evaluate incomes advantages generated by APV solutions from the whole investment or from the building rights granted to electric companies. Together with the income from the building rights or electricity production, they could still earn from crops underneath keeping CAP subsidies. Moreover, they could take advantage of the situation by implementing useful precision farming and monitoring technologies to be more efficient and resilient to climate changes.

Now, with the coming incentives from the European NRRP, farming companies could finance a small agrivoltaic system themselves with the support of a 40% capital grant and an incentivized tariff of 85 €/MWh for 20 years that prevents the risk of the drop of energy price in the market.

The economic and financial analysis performed in the thesis highlights that the access to the capital grant guarantee the sustainability of the investment, because it wouldn’t be economically sustainable without funds if the energy price would be 85 €/MWh for a small-scale system.

Under a subsidized scenario, the investment in APV guarantee its sustainability even in the case of a financial loan supplied by a bank, given that the current cost of capital is below than the IRR as we calculated in the case where NRRP subsidies were given.

Looking at the global financial and economic analysis, the biggest part of profit is coming from energy sold and not from crops cultivated underneath. This causes investors to prefer simplified agrivoltaic systems with lower costs that maximize energy profit at the expense of agricultural production.

For this reason, it’s important to subsidize advanced agrivoltaic systems that enhance agricultural production underneath. To do so, clearer policies have to be made especially for crops and soil monitoring under the panels and the support of an agronomist is needed to navigate the complex regulatory system and to find adaptable crops’ varieties to provide a good profit reducing climate change impact and incentivizing farmers’ activity.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

12 BIBLIOGRAPHY

Agrivoltaico, ok Ue al secondo bando da un miliardo. Meno vincoli sull'autoconsumo. (2023, June 22). Il Sole 24 ORE. https://www.ilsole24ore.com/art/agrivoltaico-ok-ue-secondo-bando-un-miliardo-meno-vincoli-sull-autoconsumo-AEJe37nD

Amaducci, S., Yin, X., & Colauzzi, M. (2018). Agrivoltaic systems to optimise land use for electric energy production. *Applied Energy*, *220*, 545–561. https://doi.org/10.1016/j.apenergy.2018.03.081

Balali, M. H., Nouri, N., Omrani, E., Nasiri, A., & Otieno, W. (2017). An overview of the environmental, economic, and material developments of the solar and wind sources coupled with the energy storage systems. *International Journal of Energy Research*, *41*(14), 1948–1962. https://doi.org/10.1002/er.3755

Brisson, N., Gary, C., Justes, E., Roche, R., Mary, B., Ripoche, D., Zimmer, D., Sierra, J., Bertuzzi, P., Burger, P., Bussière, F., Cabidoche, Y. M., Cellier, P., Debaeke, P., Gaudillère, J. P., & Hénault, C. (2003). Overview of the crop model STICS. *European Journal of Agronomy*. https://doi.org/10.1016/S1161-0301(02)00110-7

Camporese, M., & Abou Najm, M. (2022). Not all light spectra were created equal: Can we harvest light for optimum food-energy co-generation? *Earth's Future*, *10*(12). https://doi.org/10.1029/2022EF002900

Chalgynbayeva, A., Gabnai, Z., Lengyel, P., Pestisha, A., & Bai, A. (2023). Worldwide Research Trends in Agrivoltaic Systems—A Bibliometric Review. *Energies*, *16*(2), Article 2. https://doi.org/10.3390/en16020611

Cheo, A. E., Adelhardt, N., Krieger, T., Berneiser, J., Santillano, F., Bingwa, B., Suleiman, N., Thiele, P., Royes, A., Gudopp, D., Sidibé, A., Fahmy, K., Tambo, E., Diallo, Y., & Sogoba, B. (2022). *Agrivoltaics across the Water-Energy-Food-Nexus in Africa: Opportunities and Challenges for Rural Communities in Mali*. https://doi.org/10.21203/rs.3.rs-1503422/v1

Chrobak, U., & Chodosh, S. (2021). Solar power got cheap. So why aren't we using it more. *Popular Science*, *2*, 21.

Ciocia, A., Enescu, D., Amato, A., Malgaroli, G., Polacco, R., Amico, F., & Spertino, F. (2022). Agrivoltaic System: A Case Study of PV Production and Olive Cultivation in Southern Italy. *2022 57th International Universities Power Engineering Conference (UPEC)*, 1–6. https://doi.org/10.1109/UPEC55022.2022.9917595

Colantoni, A., Cecchini, M., Monarca, D., Ruggeri, R., Rossini, F., Bernabucci, U., Primi, R., Stefano, V. D., Bianchini, L., Alemanno, R., Speranza, S., & Da, P. P. (2021). *Linee guida per l'applicazione dell'agro-fotovoltaico in italia*.

Comunità energetiche rinnovabili alla vigilia della svolta—T24. (n.d.). Retrieved July 2, 2023, from https://t24.ilsole24ore.com/art/comunita-energetiche-rinnovabili-alla-vigilia-della-svolta

Consiglio regionale del Veneto. (2022). *LEGGE REGIONALE n. 17 del 19 luglio 2022 Norme per la disciplina per la realizzazione di impianti fotovoltaici con moduli ubicati a terra.* https://bur.regione.veneto.it/BurvServices/Pubblica/DettaglioLegge.aspx?id=481082

Corn and soybean production down in 2022, USDA reports Corn stocks down, soybean stocks down from year earlier Winter Wheat Seedings up for 2023. (n.d.). Retrieved June 25, 2023, from https://www.nass.usda.gov/Newsroom/2023/01-12-2023.php

DECRETO Mipaaf 25 marzo 2022—«Parco Agrisolare». (n.d.). https://www.gazzettaufficiale.it/eli/id/2022/06/28/22A03720/sg

DIN SPEC 91434:2021-05, Agri-Photovoltaik-Anlagen_- Anforderungen an die landwirtschaftliche Hauptnutzung. (2021). Beuth Verlag GmbH. https://doi.org/10.31030/3257526

Dinesh, H., & Pearce, J. M. (2016). The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *54*, 299–308. https://doi.org/10.1016/j.rser.2015.10.024

Gonzalez, P., Neilson, R. P., Lenihan, J. M., & Drapek, R. J. (2010). Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography*, *19*(6), 755–768. https://doi.org/10.1111/j.1466-8238.2010.00558.x

Il Ministro dell’Ambiente e della Sicurezza Energetica. (2023). *Decreto-Agrivoltaico_03.04.2023*. https://confagricolturaveneto.it/wp-content/uploads/2023/04/Decreto-Agrivoltaico_03.04.2023_def.pdf

Impianto fotovoltaico: Quanto produce in un anno? | E.ON Energia. (n.d.). Retrieved August 5, 2023, from https://www.eon-energia.com/informazioni-utili/impianto-fotovoltaico-quanto-produce-anno.html

IPCC. (2019). *Special Report on Climate Change and Land—IPCC site*. https://www.ipcc.ch/srccl/

Legambiente. (2023, February 3). *Boom dell'agrivoltaico: Fino a 4mila euro all'anno per affittare un ettaro di terreno*. Greenreport: economia ecologica e sviluppo sostenibile. https://greenreport.it/news/energia/boom-dellagrivoltaico-fino-a-4mila-euro-allanno-per-affittare-un-ettaro-di-terreno/

Levelized Cost of Energy (LCOE). (n.d.). Corporate Finance Institute. Retrieved July 7, 2023, from https://corporatefinanceinstitute.com/resources/valuation/levelized-cost-of-energy-lcoe/

Mamun, M. A. A., Dargusch, P., Wadley, D., Zulkarnain, N. A., & Aziz, A. A. (2022). A review of research on agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *161*(C). https://ideas.repec.org//a/eee/rensus/v161y2022ics1364032122002635.html

Mase. (2022). *Linee Guida in materia di Impianti Agrivoltaici*. https://www.mase.gov.it/sites/default/files/archivio/allegati/PNRR/linee_guida_impianti_agrivoltaici.pdf

MINISTRO DELLO SVILUPPO ECONOMICO. (2012). *DM 5 luglio 2012 Attuazione dell'art. 25 del decreto legislativo 3 marzo 2011, n. 28, recante incentivazione della produzione di energia elettrica da impianti solari fotovoltaici (c.d. Quinto Conto Energia).* https://www.gazzettaufficiale.it/eli/id/2012/07/10/12A07629/sg

MINISTRO DELLO SVILUPPO ECONOMICO. (2019). *DECRETO 4 luglio 2019 Incentivazione dell'energia elettrica prodotta dagli impianti eolici on shore, solari fotovoltaici, idroelettrici e a gas residuati dei processi di depurazione*. https://www.gazzettaufficiale.it/eli/id/2019/08/09/19A05099/sg

Operating Expense Definition and How It Compares to Capital Expenses. (n.d.). Investopedia. Retrieved August 5, 2023, from https://www.investopedia.com/terms/o/operating_expense.asp

PRESIDENTE DELLA REPUBBLICA. (2021a). *D.L. 8 novembre 2021, n. 199: Attuazione della direttiva (UE) 2018/2001 del Parlamento europeo e del Consiglio, dell'11 dicembre 2018, sulla promozione dell'uso dell'energia da fonti rinnovabili.* https://www.gazzettaufficiale.it/eli/id/2021/11/30/21G00214/sg

PRESIDENTE DELLA REPUBBLICA. (2021b). *D.L. 77/2021 Governance del Piano nazionale di ripresa e resilienza e prime misure di rafforzamento delle strutture amministrative e di accelerazione e snellimento delle procedure.* https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legge:2021-05-31;77

Pubblicato il testo definitivo del Piano Energia e Clima (PNIEC) | Ministero dell'Ambiente e della Sicurezza Energetica. (n.d.). Retrieved June 29, 2023, from https://www.mase.gov.it/comunicati/pubblicato-il-testo-definitivo-del-piano-energia-e-clima-pniec

Redazione. (2022, September 14). Parco agrisolare, aiuti solo per l'autoconsumo freno all'energia rinnovabile. *Sicilia Verde Magazine*.

https://www.siciliaverdemagazine.it/2022/09/14/parco-agrisolare-aiuti-solo-per-lautoconsumo-freno-allenergia-rinnovabile/

Renewable Energy Directive: EU Directive/2018/2001. (n.d.).

REPowerEU. (n.d.). [Text]. European Commission - European Commission. Retrieved June 25, 2023, from https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

Ringler, C., Willenbockel, D., Perez, N., Rosegrant, M., Zhu, T., & Matthews, N. (2016). Global linkages among energy, food and water: An economic assessment. *Journal of Environmental Studies and Sciences*, *6*(1), 161–171.

Rinnovabili, l'Energy Report: 65GW da installare al 2030. (2022, May 17). https://www.infobuildenergia.it/approfondimenti/rinnovabili-italia-130-gw-installato-2030/

Schindele, S., Trommsdorff, M., Schlaak, A., Obergfell, T., Bopp, G., Reise, C., Braun, C., Weselek, A., Bauerle, A., Högy, P., Goetzberger, A., & Weber, E. (2020). Implementation of agrophotovoltaics: Techno-economic analysis of the price-performance ratio and its policy implications. *Applied Energy*, *265*, 114737. https://doi.org/10.1016/j.apenergy.2020.114737

Sekiyama, T., & Nagashima, A. (2019). Solar Sharing for Both Food and Clean Energy Production: Performance of Agrivoltaic Systems for Corn, A Typical Shade-Intolerant Crop. *Environments*, *6*(6), 65-. https://doi.org/10.3390/environments6060065

SGR Efficienza Energetica (Director). (2022, November 24). *L'agrivoltaico, i bandi PNRR: Il quadro normativo*. https://www.youtube.com/watch?v=ucwQdo-nltk

Solar Panel Efficiency Over Time (Plus Tips to Improve It). (2022, October 2). *EcoWatch*. https://www.ecowatch.com/solar/solar-panel-efficiency-over-time

Strategia Energetica Nazionale 2017 | Ministero dell'Ambiente e della Sicurezza Energetica. (n.d.). Retrieved June 29, 2023, from https://www.mase.gov.it/comunicati/strategia-energetica-nazionale-2017

The National Recovery and Resilience Plan (NRRP). (n.d.). MEF. Retrieved June 19, 2023, from https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/

Trommsdorff, M., Dhal, I. S., Özdemir, Ö. E., Ketzer, D., Weinberger, N., & Rösch, C. (2022). Agrivoltaics: Solar power generation and food production. In *Solar Energy Advancements in Agriculture and Food Production Systems* (pp. 159–210). Elsevier. https://doi.org/10.1016/B978-0-323-89866-9.00012-2

Weselek, A., Bauerle, A., Hartung, J., Zikeli, S., Lewandowski, I., & Högy, P. (2021). Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate. *Agronomy for Sustainable Development*, *41*(5), 59. https://doi.org/10.1007/s13593-021-00714-y

13 SITOGRAPHY

- Agronotizie https://agronotizie.imagelinenetwork.com/agricoltura-economia-politica/2022/04/08/prezzi-d-affitto-dei-terreni-agricoli-nel-2020-l-italia-segna-il%20primato/74659#:~:text=Seguono%20il%20Veneto%20con%201.243,il%20Piemonte%20(1.040%20euro).
- Azocleantech https://www.azocleantech.com/
- Corporate finance institute https://corporatefinanceinstitute.com/
- EF Solare Italia https://www.efsolareitalia.com/
- Enel https://www.enelgreenpower.com/
- FAO https://www.fao.org/
- Fieragricola TECH https://www.fieragricola.it/category/fieragricola-tech/
- Fondo F2i SGR S.p.A. https://www.f2isgr.it/it/index.html
- Greenreport.it https://greenreport.it/news/energia/boom-dellagrivoltaico-fino-a-4mila-euro-allanno-per-affittare-un-ettaro-di-terreno/https://solarimpulse.com/
- Grist https://grist.org/
- GSE https://www.gse.it/
- Investopedia https://www.investopedia.com/terms/w/wacc.asp
- Ise Fraunhofer https://www.ise.fraunhofer.de/en.html
- Key energy https://en.keyenergy.it/
- Legambiente https://www.legambiente.it/
- Legreenhouse https://www.legreenhouse.it/
- L’informatore agrario https://www.informatoreagrario.it/
- Mcprogetti https://www.mcprogetti.com/
- Netsens https://www.netsens.it/en/meteo/solar-and-agrivoltaic-farms/
- Normattiva https://www.normattiva.it/
- Pivot Energy https://www.pivotenergy.net/
- Polimi https://www.polimi.it/

- RegioneVeneto https://bur.regione.veneto.it/BurvServices/Pubblica/DettaglioLegge.aspx?id=481082
- RemTec https://www.remtec.energy/
- Set Energie https://www.setenergie.com
- Statista https://www.statista.com/
- Studio agronomico gdtagro: https://www.studiogdtagro.it/
- TalGil https://talgil.com/Software
- Terna https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche