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Techno-economic assessment of two Agrovoltaics case studies

TESI DI LAUREA MAGISTRALE IN MANAGEMENT ENGINEERING - INGEGNERIA GESTIONALE

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List of abbreviations

APV: Agrivoltaic

PV: Photovoltaic

PNRR: Piano Nazionale di Ripresa e Resilienza

LCOE: Levelized Cost of Electricity

NPV: Net Present Value

PBT: Pay Back Time

IRR: Internal Rate of Return

RES: Renewable Energy Source

PUN: Prezzo Unico Nazionale

PZ: Prezzo Zonale

FiP tariff: Feed in Premium tariff

ROI: Return on Investment

OCT: Order Cycle Time

POD: Point of Delivery

Abstract in lingua italiana

Il seguente documento si concentra sull'analisi della tecnologia Agrivoltaica nel quadro normativo italiano del 2023. Il tentativo è quello di valutare la fattibilità di un investimento nel segmento di mercato Agrivoltaico, dove per Agrivoltaico viene intesa l'unione sullo stesso terreno di produzione elettrica e agricola, considerando gli attuali incentivi disponibili. Regimi di incentivi sviluppati dal governo italiano per affrontare gli obiettivi stabiliti nell'ambito del Piano Nazionale di Ripresa e Resilienza in materia di elettricità prodotta da impianti utilizzanti fonti rinnovabili come il fotovoltaico o l'eolico. Per fare questo, è stata data una definizione di Agrivoltaico, tenendo conto di tutti gli aspetti positivi e negativi introdotti dall'implementazione di impianti fotovoltaici su un'area di suolo, con la volontà di sfruttare l'area anche per attività agricole. Una revisione della letteratura è stata effettuata alla ricerca delle migliori tecnologie e pratiche disponibili sul mercato mondiale. È stato dettagliato come e perché la configurazione di Agrivoltaico potrebbe essere la soluzione per i problemi attuali nel campo agricolo come la siccità e gli eventi meteorologici estremi. Il progetto è stato sviluppato grazie a un contributo di due imprenditori agricoli e di Erreci, azienda che opera nel mercato delle installazioni fotovoltaiche. L'area di interesse per lo studio è stata quella di Piacenza, Emilia-Romagna, dove l'agricoltura è uno dei settori di business più importanti della provincia. Sono state condotte due analisi, da un lato un piccolo progetto di APV, con una potenza massima di circa 60 kWp. D'altra parte, una più grande, con una potenza media installata di circa 900/1000 kWp in base alle diverse impostazioni tecnologiche proposte. Le due analisi sono state condotte congiuntamente, sfruttando le conoscenze pregresse sia degli imprenditori agricoli che di Erreci dal punto di vista agricolo e tecnico. In primo luogo, un design tecnico è stato sviluppato in base ai vincoli spaziali. Poi, partendo dal layout disponibile, è stata effettuata una valutazione economica per verificare che le condizioni degli investimenti potessero risultare profittevoli per gli imprenditori. Infine, è stata sviluppata un'analisi di sensitività, cercando di valutare le ipotesi più importanti fatte e cercando di capire se le conclusioni finali avessero potuto essere modificate a causa delle variazioni di alcuni parametri. Le analisi sono state eseguite su località specifiche, ma l'idea dietro l'analisi proposta in questo elaborato è stata quella di produrre un modello di valutazione di modelli di business simili, indipendentemente dalla localizzazione geografica specifica all'interno del territorio italiano.

Parole chiave: Agrivoltaico; Schema incentivante italiano; Tecnologia fotovoltaica; Tracker fotovoltaici; Energia auto consumata; Energia immessa in rete.

Abstract

The following paper focuses on the analysis of Agrivoltaic technology in the Italian regulatory framework of 2023. The attempt is the one of evaluating the feasibility of an investment in the Agrivoltaic market segment accounting available incentive schemes. Incentive schemes developed by the Italian government to tackle different objectives posed within the 'Piano Nazionale di Ripresa e Resilienza' concerning electricity produced by RES plants. To do that, a definition of Agrivoltaic was given, considering all the positive and negative aspects introduced by the implementation of PV plants over a soil area, with the willingness of yet exploiting the area for agricultural activities. A literature review was carried out searching for the best available technologies and practices on the worldwide market. It was detailed how and why the Agrivoltaic configuration could be the solution for nowadays problems in the agricultural field like droughts and drastic meteorological events. The project was developed thanks to an input given by two agricultural entrepreneurs and by Erreci, a company operating in the photovoltaic installations market. The area of interest for the study was the one around Piacenza, Emilia-Romagna, where agriculture is one of the most important business sectors of the province.

Two analyses were conducted, on the one hand a small APV plant, with a peak power around 60 kWp. On the other hand, a bigger one, were the reference scale changed around a peak power installed of 900/1000 kWp according to the different proposed layouts. The two analyses were conducted jointly, exploiting know-how of both agricultural entrepreneurs and Erreci from the agricultural and technical perspectives. First, a technical design was developed according to space constraints. Then, starting from the available design, an economic evaluation was performed checking whether investments conditions could have been fruitful of not for the entrepreneurs. Finally, a sensitivity analysis was developed, trying to evaluate the most important assumptions made and trying to understand whether final conclusions could have been modified due to some parameter's variations. The analyses were performed over specific locations but the idea laying behind the paper was the one of resulting a precursor of similar business models evaluation regardless of the specific geographic localisation around the Italian territory.

Keywords: Agrivoltaic; Italian incentive schemes framework, Photovoltaic technology; PV trackers; Energy self-consumed; Energy fed into the grid.

1. Introduction

The following paper was developed within the attempt of offering a techno-economic analysis and assessment of two case studies regarding the potential implementation of two different Agrivoltaic plants. Objectives of the paper, and therefore of the underpinned analysis, were the ones of first, tackling which are the current technologies available in the Agrovoltaic market, with a detailed review of the literature. Second, sizing and designing the best solutions possible with available situations. Indeed, land areas were predetermined and could not being changed, thus strong physical constraints were present. Third, one the technology would have been dealt with and the design phase completed, an economic evaluation was thought being necessary to understand if, how and when the investments could have been suitable for entrepreneurs. Finally, a sensitivity analysis was conducted to judge the robustness of the proposed ideas.

The entire work was conducted within an internship program in a private company. The company is called Erreci Impianti S.r.l. and it was the host for a time horizon which started in January 2023 and ended in July 2023. The company has its headquarter in Busto Arsizio (VA), but the majority of activities related to the thesis work were conducted in the local office of Fiorenzuola d'Arda (PC). Together with Erreci Impianti, it was possible to collaborate with the startup Renewable Community and Repower Italia, both enterprises correlated with Erreci. Renewable Communnities could be considered as a spin-off of Erreci, or as a subsidiary, while Repower Italia has owned equity capital of Erreci since 2022. Within the seven months' period, the main activities performed were:

- Precautionary activities related to the design and sizing of a PV plant.
- Data analysis related to the supply chain of the company as well as inbound and outbound logistics.
- Technical design of plant, using GstarCAD software.
- Research within company's databases as well as Google Scholar's ones to highlights all solutions related to Agrovoltaics projects in Italy.
- Inspections in PV plant, both already working ones to monitor their performances and future prospected ones, collecting data.
- Networking activities within the association BNI, widespread in Italy as well as in Europe and USA, referral networking.

Nowadays the European Union is facing one of the worse energy crises of its history [1]. In 2022 electricity and gas prices reached unprecedented peaks all around Europe. Electricity reached the maximum of 870 €/MWh in Italy, gas went up to 275 €/MWh. Italy was not a solitary case, indeed, apart from some exceptions like the Iberian Peninsula [2], similar prices were experienced by all European citizens. The outbreak of the Ukraine war in 2022 followed two years of the Covid-19 pandemic, worsening even more an already complex landscape for what concerns energy management and security. The entire European Union is fossil fuel resources dependent on foreign countries and the thin equilibrium which used to regulate the market suddenly fell. In addition, figure 1 reports how it happens that not only European countries are net importers of fossil fuel energies, but they also are dependent on few suppliers as shown in the supplier concentration index (SCI), which is defined as the concentration of main energy carriers imports from suppliers outside the European Economic Area (EEA). The overall SCI is computed as a weighted average of the singular SCI of each energy sector (oil, natural gas, coal).

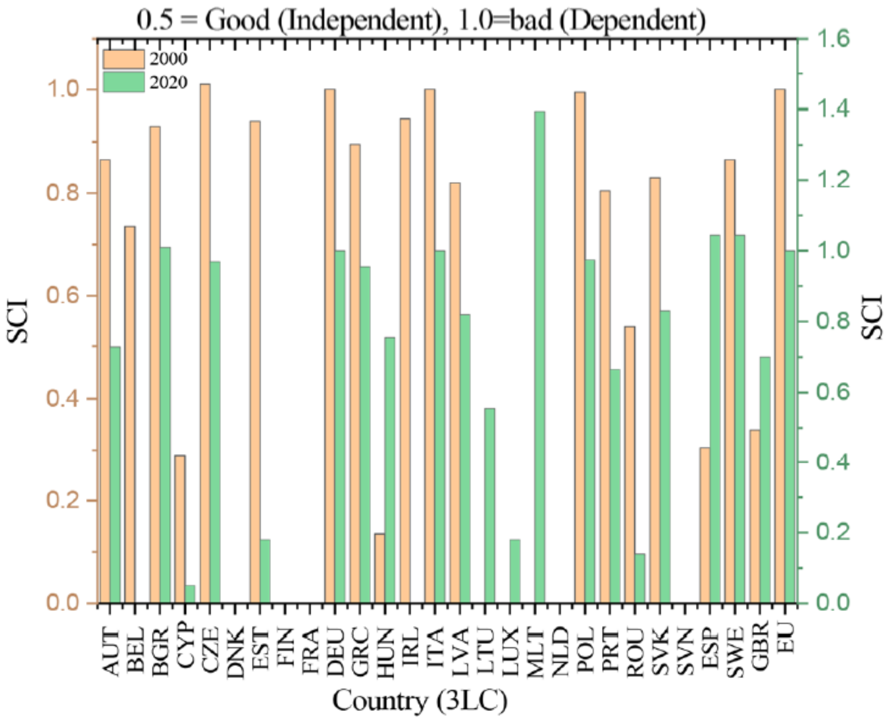


Figure 1: Energy security index of EU member states, based on the supplier concentration between 2000 and 2020 [1].

As shown by [1], if SCI is high enough, close to 1, it may happen that a situation in which stopping the furniture from one supplier, like the Russian Federation, affects in disruptive consequences the market. These events pointed out a new theme in the energy landscape: the security of supply which was put in danger by the overreliance of the European Union on carbon energy import [1]. Security of the energy supply around Europe which comes together with the need to decarbonize the economy. Climate change is causing problems more and more with time flowing. Droughts followed by floods, unforeseen hailstorm which destroy agricultural yield, higher temperatures affecting the wellbeing of raised animals are just a tiny part of situations experienced due to the climate change which have negative impacts over humanity. The green energy transition is perceived as the only solution by many and, according to that, it was decided to speed up the process increasing the targets for the coming years in basically all sectors and segments [3]. Electricity production by photovoltaic technology is one of the two biggest sources in the renewable energy landscape together with eolic one. In Italy, it accounts the 36% of the overall renewable energy production [4]. Indeed, together with Eolic, in the last twenty years, its technology was improved and further developed to lower the LCOE thanks to economies of scale. Nowadays they offer the lowest LCOEs among all the possible renewable solutions and the case will remain constant for the medium/long term according to many studies [5], [6]. Thus, since the business' attractiveness of photovoltaics was countless times proven and demonstrated, companies both at the national and multinational levels have undertaken the market pathway [1].

The European Union, as well as most of the world's regulators, have started a transition process towards green energies in the last two/three decades. Transition which has been forced by the catastrophic events that climate change is causing more and more frequently. Electricity production thanks to photovoltaic technology is a forerunner of the transition. Indeed, due to technological advancements huge economies of scale have been achieved and nowadays costs are comparable to the ones of electricity generation with traditional fossil fuel sources. As it was firstly thought, PV were designed to be built on rooftops, the easiest solution at the dawn of its life. Despite the number of rooftops available being far from expired, the outlook for the incoming future is the installation of photovoltaic plants more and more directly on fields. Indeed, grounded-mounted photovoltaic plants are easier to install and maintain, nonetheless, bigger modules could be installed which can offer higher Energy Efficiency Coefficients and, concurrently, even lower Temperature Coefficients for P_{MAX} as shown in figure 2 [7], [8].

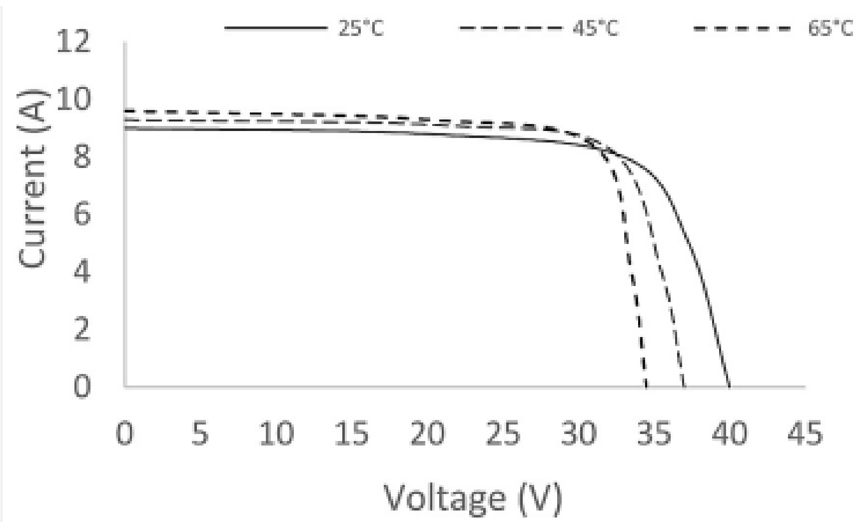


Figure 2: Effect of Temperature on Solar Cell I-V Curve [8].

It is not the objective here to doubt the effectiveness of rooftop installations, on the contrary, the solution was and remains a real good opportunity worldwide. Nonetheless, the development flow is here under analysis. Indeed, according to a recent study provided by [9], going ahead with the current paradigm will not allow Italy, as well as many European countries, to reach the "Green Deal" targets in terms of installed capacity. Moreover, the recent "Fit for 55" has raised these targets to 70 GW of new installations. It is more and more clear how utility-scale plants are required and necessary to speed the transition up.

On the one hand, the situation could be harmless if the fields mentioned are related to areas where agriculture or raising activities are not implemented for one reason or another. On the other hand, if the photovoltaic plant is realized on an agricultural field that was previously dedicated to food production, the situation here comes to an annoying one. The trade-off accounts for energy, electricity, in this case, production, and food. Unfortunately, both are required, and no one can overtake the other. The global population is constantly increasing and so are food requirements, yet a big share of the world population lives in undernutrition conditions, therefore, every single square meter of agricultural soil should be reserved to tackle the hurdle [10]. Thus, in the very last years, a concept has started gaining momentum little by little: Agrivoltaic. The theoretical framework is rooted in the 1980s, but it was not until the early year 2010s that the first concrete experiment was performed. Agrivoltaic could be the solution to the beforehand explained trade-off and paradox. It enhances the two activities, energy production and food to stand on the same ground area achieving a combined gain that is higher than the sum of the two theoretically separated ones [10].

Supporting the very recent development and spreading of the concept of Agrivoltaic, in winter 2022-2023 the company Erreci Impianti Srl was contacted by two entrepreneurs from the area of Piacenza, Emilia-Romagna – Italy. The company has a 25 years' experience in the installation of photovoltaic plants, offering turnkey products including all the part of project management. It has always installed rooftop plants, as well as ground ones. The two entrepreneurs own an agricultural firm with businesses including the cultivation of tomatoes, the most diffused in the area, and breeding activities of milk-cows and chicken. In this paper it will be explained how the company developed two precautionary offers for the entrepreneurs, both leveraging over the new concepts of Agrivoltaic, called Agrovoltaco or Agrivoltaico in Italy. On the one hand, in the project named APV1, the need will be the one of having a RES plant to produce green energy which will be used as first goal for self-consumption meanings. Then, the rest will be fed into the grid and sold. The company has studied all the technological implications of the new business models, since it has never experienced such an opportunity before, and then it proposed all the solutions studied to the entrepreneurs. Benchmarking all the hypotheses, the decision was undertaken accounting technical positive and negative aspects highlighted by Erreci and, on the other side, pros and cons posed from the agricultural point of view by the entrepreneurs. On the other hand, a second plant has been precautioned. In this second situation, there was not accounted a self-consumption part since it was thought to exploit differently a soil area which is currently exploited by entrepreneurs for their usual business. The site dimension of APV2 is different from the one of APV1, being APV1 an area of almost 0,3 ha while APV2 may count over an area of approximately 4,2 ha. It is worth noticing how, instead of deep diving immediately over the Agrivoltaic projects, Erreci decided to study firstly the theory and the state of the art in literature for what concerns the Agrivoltaic hemisphere. Indeed, this concept is relatively new, it has been 'founded' almost 40 years ago, in 1982, by it is still nowadays quite an unexplored market segment. The reason why of the mistrust laying around the APV concept is due to huge costs on the one hand, both CAPEX and OPEX of an APV plant are higher than a traditional PV, and on the other hand by the complexity of management embedded. Indeed, to correctly run an APV plant, the owner must possess knowledge on both technical and agricultural side, as it will be explained within this paper's reasonings.

In addition, this paper tried to establish some economic analyses, having as reference guidelines some documents released by the Italian government between the second half of 2022 and the beginning of 2023. Unfortunately, the reality is that, even though the APV technology has gained a consistent amount of funds within the Piano Nazionale di Ripresa e Resilienza (PNRR), it has not been clarified yet how practically the RES plants implementation will work. There are some hypotheses for both the prerequisites required for the plant to be named as APV technology and for the incentive schemes aspect. Over than all the noble reasoning around the climate change impacts and how the APV will enhance a further development of RES plant, indeed the reality is that solutions like APV will break into the market if and only if they will be made convenient and fruitful from an economic point of view. As happened for photovoltaic twenty years ago, a new technology requires incentive schemes to break the market. Suppositions have been made since it has not yet been released a final and authoritative document. The hope of this paper is the one that the European Union, together with the Italian government will be able to speed the process up allowing the start of this new breed of change.

Table 1: Schematized summary of Agrivoltaic 1 and Agricoltaic 2.

	Agrivoltaic 1	**Agrivoltaic 2**
Surface area [m²]	2.800	42.00
Revenue stream	Self-consumption and Energy fed into the grid	Energy fed into the grid
Opportunity cost	**NO**: land area currently unutilised	**YES**: agricultural activities going on
Coordinates	45.004318646708775, 9.529816203507655	44.95591847344866, 9.57989915453145

2. Literature review

2.1 Defining Agrivoltaic

Even though within the concept of APV, which is bounded by the German field of research and studies, both greenhouses and open-field agricultural activities are considered PV installations, the focus of this work is deep diving the open-field branch of APV. In this sector, years of research have developed countless innovative solutions for both what concerns the technology and the design point of view. It is almost certain worldwide how exploiting the food-energy nexus offered by this type of system may be a keystone to enhance the so hardly needed sustainable development [10].

An Agrivoltaic system (APV) could be defined as: "A photovoltaic plant adopting solutions which aim to preserve the continuity of agricultural and livestock activities on the installation site" [13].

Furthermore, [14] defines more practically Agrivoltaic as: "A framework to exploit agricultural areas for food and electricity production both at the same time".

Either way, it is undoubtedly true how two systems must communicate together cooperating for a better future worldwide. Teamwork should be achieved within the two systems. Energy production and agriculture have been nothing but distant in history for what concerns targets, business models, and procedures. Nevertheless, their multidisciplinary natures should be thought of and developed concurrently without any speculative attempt from one or another to take advantage of the other's expense [14]. The goal of both the regulator and all the players involved, as highlighted in figure 3, should be obtaining a sum, agricultural yield, and energy produced, higher than the divided values of the two.

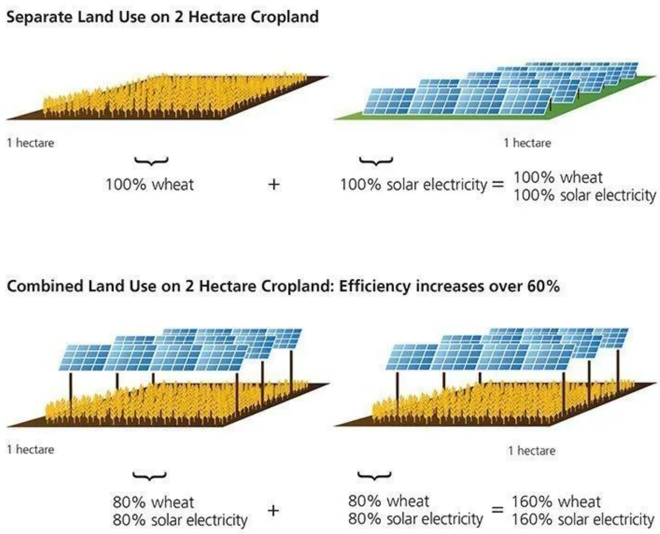


Figure 3: The concept of solar agriculture's resurgence [24].

A milestone of the Agrivoltaic as intended today is understanding how each plant stands alone and could not be replicated in a standardized way, at least not yet. Many case studies should be developed, moving from a theoretic-only paradigm towards a more practical one, learning by doing should be the statement of the next stage in the Agrivoltaic history [14]. [15] state how human beings are currently facing an interrelated issue that may be unpacked in three subsystems: preserving ecosystems through sustainable development, assuring a certain level of food security, and tackling the climate change challenge before Earth will cross a point of no return. Moreover, [6] synthesize all the agreements made by United Nations (UN) Member States in the last 10 years. Sustainable Development Goals (SDGs) have been set as well as many other reference thresholds to be caught up with. At the current state of the art, Europe should reach 45% of renewable energy in its energy mix by 2030 with more than 600 GW of capacity which should be installed again by 2030 [3]. Unluckily, in the last years, the growth rate of installed capacity in Italy as in continental Europe has not been high enough to forecast such achievements in 7 years, not even close.

It is doubtless that renewable energy is the correct pathway to be followed to enhance human beings living in a condition like what they are used to. Average global temperature is arising everywhere, and it must be kept under control and conditions, indeed it is almost hopeless nowadays thinking about avoiding its rise at all. Nevertheless, even renewables are not somehow immune from criticisms and scepticism as explained by [16]. Indeed, it is worth stopping to reflect on at which expenses renewable plants are created. Photovoltaic plants have been historically related to the rooftop installation paradigm, so a wide majority of the installations used to refer to modules installed on rooftops without affecting the environment at all. For seek of completeness, the electricity generation is green for what concerns the pure generation phase. Indeed, if we open the view to the entire value chain it should be detailed how building PV modules requires silicious, which is the main component. Therefore, it is quite straightforward how extracting silicious and moreover its disposal are two phases far from being net zero emissions. To get a complete and exhaustive perspective an LCA analysis should be performed even in this case of green energy production. Nevertheless, [10] agree with [16] when reflecting on large-scale photovoltaic plants. That business model has been spreading around since the second half of the 2000s and it is quite established nowadays with Power Purchase Agreements and Merchant Plants as new ways to generate value for utility companies. Always [16] while reflecting with a long-term perspective analyse how the either-or paradigm could not be sustained. Indeed, installing photovoltaic plants on agricultural lands means acting at the expense of food production, a very sensitive issue. Producing energy in place of food is a procedure that must be interrupted, and with the logic the sooner the better. Nevertheless, the ongoing installation activity of photovoltaic plants on the field should not be aborted but simply rescheduled towards abandoned areas that are not suitable, and neither could become so for agriculture. Another point of interest is how local communities could be reluctant to accept renewable power plants. Indeed, huge photovoltaic plants, as well as Eolic turbines or geothermal power plants, impact the landscape at the expense of local communities' economy and well-being. So far to avoid that kind of problem and collective dissatisfaction, governments have always strictly regulated the use of agricultural land for the installation of photovoltaic energy production. Soil consumption, landscape impact, and competition with food production have always been placed in opposition. Figure 4 graphically represents the Agrivoltaic concept and idea.

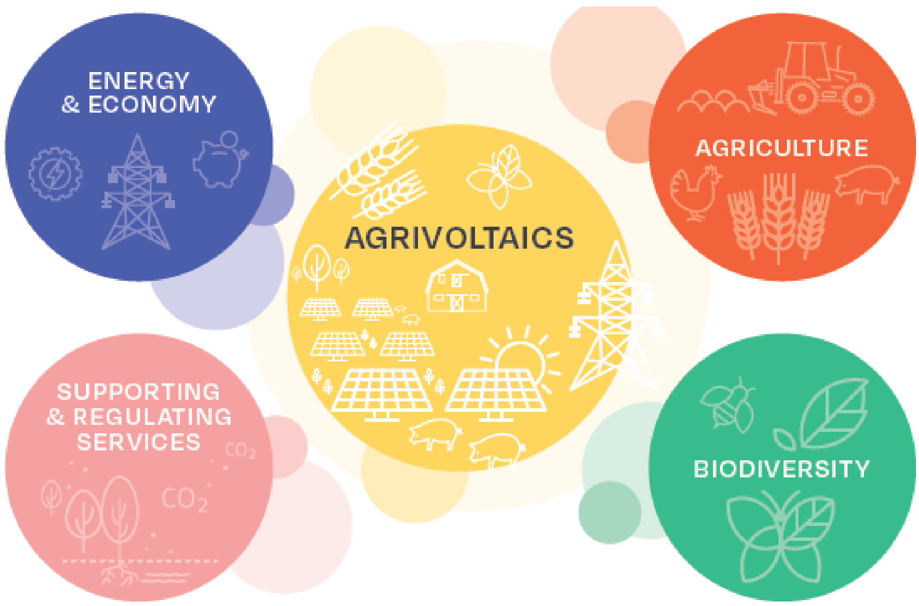


Figure 4: Agrivoltaic conception as SolarPower Europe [45].

Agrivoltaic could be the keystone to merge all needs together. Combining electricity production with agricultural yield may be a one size fits all solution. Green energy will be produced in such a configuration but not in the food production expenses. The underpinning idea was introduced by [17], the two scholars grounded their work on the conviction that a partial shading could be tolerated by crops and in some cases become even beneficial. In addition, the combination of the two could be better accepted by local communities which will have two outputs granted, decarbonised electricity and crop production, within the same input, one field. Bounding together agricultural activities and photovoltaic production is a win-win solution with many potential positive aspects and declinations [16]. As stated once again by [16] the reduction of solar radiation impacting plants and cultures affect the average soil temperature, which has a chain effect as a drop in evapotranspiration and water required. Furthermore, it has been proved that thanks to the presence of photovoltaic modules shading the soil, average grain yield not only was not affected negatively, but it benefited from the new situation with significant growth. So, despite the collective consciousness, the farm yield could be maintained at the previous level even by adding the energy production component. Finally, the higher economic profitability carried by photovoltaic production might help on the agricultural side as well. Indeed, fields and lands in rural areas which are not exploited nowadays due to bad conditions as low output and performance grated may be reclaimed thanks to money brought by the electricity production side. In other words, the Agrivoltaic configuration helped the culture handles climate change's negative effects like the more and more frequent situation of drought happening. As briefly mentioned before, while explaining how energy and food production may coexist properly in the same field it should not be forgotten the economic advantages that the solution carries. Both [18] and [15] delineate the economic perspective of the landowner who is the most interested in new benefits. Introducing energy production on the farmer's side, as Agrivoltaic does, could be a way to diversify their income sources. Although the new CAP 2023-2027 will be crucial to tackle recurrent issues in the farming industry such as the massive exposition to market demand fluctuations, a farmer who will attempt a diversification strategy towards green energy production will enhance himself by collecting more stable earnings.

To go back to the first time that the concept of Agrivoltaic broke into the scene it is required to refer to 1982. Indeed, [17] have been the first scholars to reflect on the opportunity for solar energy conversion and agriculture to coexist. Before the two activities were not considered complementary ones, with photovoltaic modules arranged at the ground level replacing any kind of plant cultivation. [17]'s initial idea was installing photovoltaic modules in rows at a certain height from the soil, approximately 2 meters, then keeping three times the height of the modules as a pitch from one row to another. The interlinear distance was thought high enough to allow solar radiation to reach the ground in an almost uniform way, keeping the shadow's level under predetermined thresholds. Two-thirds of the solar radiation without modules was the compromise obtained. Therefore, it was possible for the crop to grow within an almost traditional process and for the modules to produce energy exploiting the direct, reflected, and diffuse part of the solar radiation [17].

Despite their pioneering idea, Goetzberger and Zastrow couldn't implement a concrete experiment on the field. Thus, for almost thirty years Agrivoltaic remained just an abstract concept without real applications. Only thanks to [19]'s work it was possible to develop the first pilot project about APV in Europe in Montpellier. Many attempts were made to allow sufficient sun radiation to reach the ground. The work started focusing on the tilt angle and the slope of the PV modules, which have been positioned at around 4 meters of height since the beginning, to allow tool machines to freely act below the PV structures. The project was finally developed with a twofold structure. On the one hand, a "full density (FD)" PV modules structure was implemented. The term "full density" it was meant optimal electricity production despite suffering from the agricultural perspective. On the other hand, a "half density (HD)" PV modules structure was developed. In this case, priority was given to crop yield, with an attempt of avoiding losses in this perspective. Both the configurations were investigated with a tilt angle of 25°, which could even be manually modified in the range of 20°-35°. In addition, 1,64 meters were left from the bottom of one PV panel and the top of the subsequent one. In figure 5 is showed a graphical representation of the configuration described.

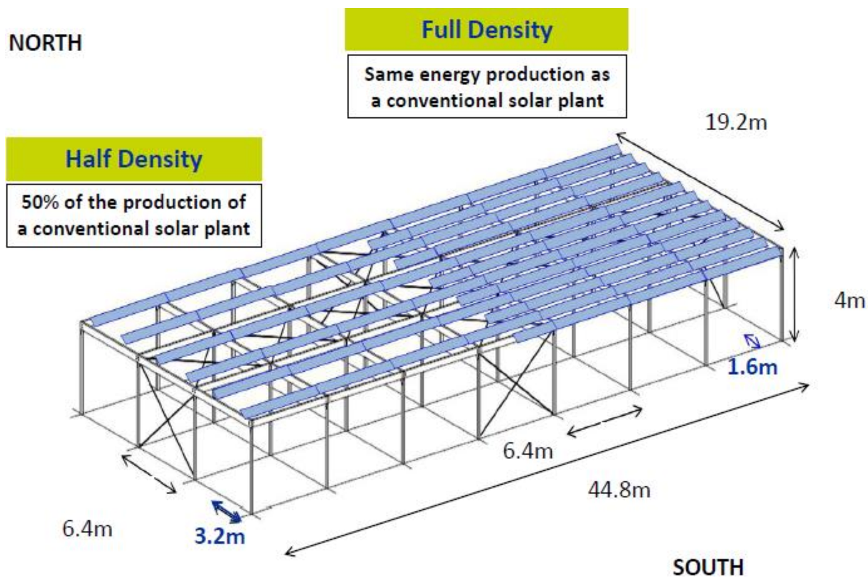


Figure 5: APV system under study [42].

Finally, the big difference between the HD and FD configurations which was analysed is the incident radiation that was able to reach the soil. Indeed, with software called: R-Free Software Foundation Inc., fsf.org, it was possible to simulate the average incidence of radiation hitting the soil in each of the two configurations. Results showed how under FD APV 43% of sun radiation reached the soil. The parameter grows to 71% under HD APV. It is worth specifying how these values are not constant over the year. Indeed, in the winter season slightly lower values are experienced while the opposite, with higher values happen during the last part of spring and all of summertime along. Moreover, differences were experienced in irradiation levels within the adoption of different gradient: the East/West gradient showed more constant values while the North/South showed higher peaks in favourable moments but even lower downsides in unfavourable one during the year. In figures 6 and 7 a graphic representation of these results is highlighted [19].

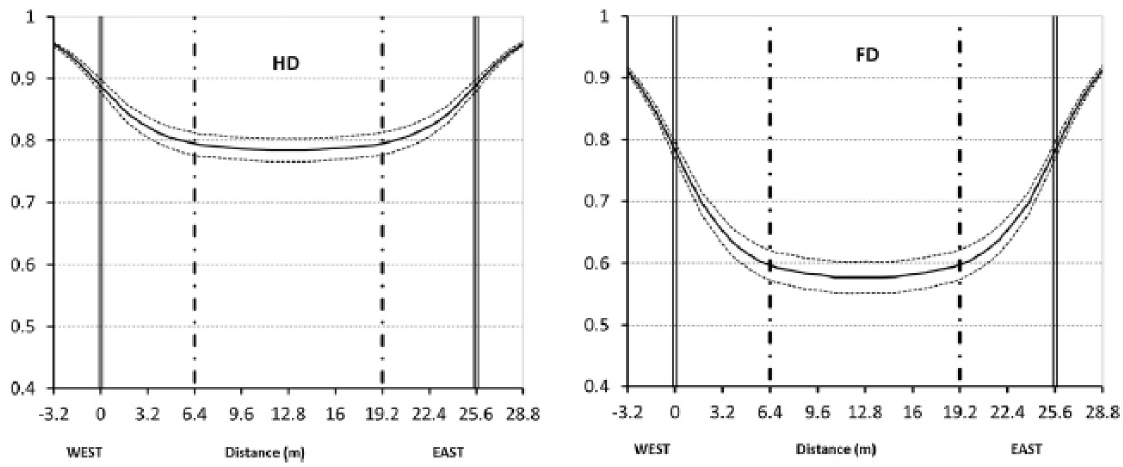


Figure 6: HD's and FD's percentages of irradiation in the East/West gradient. The black line is the average value, while the dotted ones are a 95% confidence interval. Vertical lines are the array's limits (black ones) and measurement area's limits (dotted ones) [19].

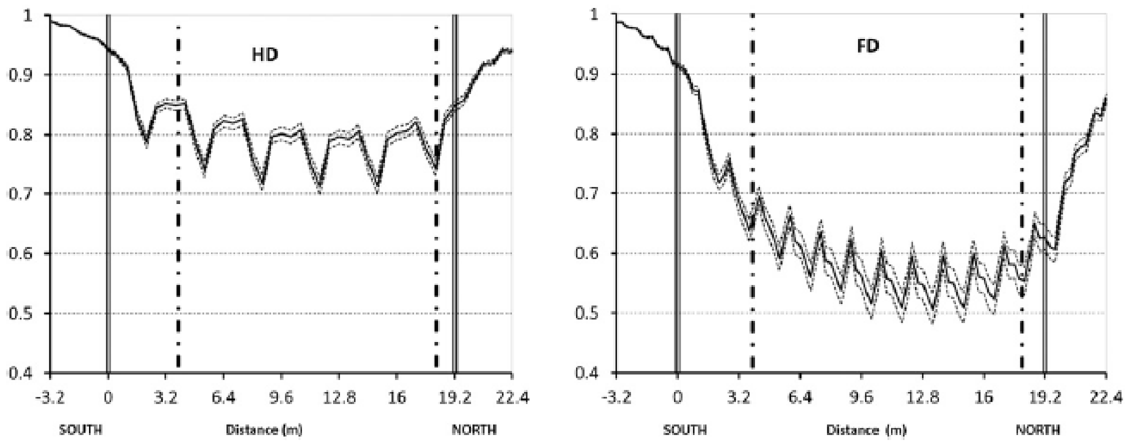


Figure 7: HD's and FD's percentages of irradiation in the North/South gradient. The black line is the average value, while the dotted ones are a 95% confidence interval. Vertical lines are the array's limits (black ones) and measurement area's limits (dotted ones) [19].

Since the beginning pilot projects in the early years 2010s, APV has experienced a skyrocketing path worldwide. Projects were carried out in South America and Asia as described by [20] and [21]. The former described how successful were projects in all India thanks to the water savings which were experienced both with winter and summer crops yield. The latter depicted instead many technological advancements due to APV installations in Chile where the presence of the structure was useful to shelter crops from extreme weather events like strong windstorms, quite common in Chile. Installations in Chile have been under the control of the Fraunhofer Institute for Solar Energy Systems, which is the frontrunner of European research, and it has even tried to test its technology in different climate areas worldwide [10]. Even though APV case studies have been present all around the world since the early 2000s and physical installations started their diffusion a decade after once again in many different countries worldwide, it is possible to point out a leader in the market: Japan. Indeed, between 2014 and 2020, out of the 2200 APV farms which were built worldwide, 1992 were specifically developed there. The overall installed capacity dealing with APV only reached, at the end of 2020, the massive value of 2,8 GWp [22]. Moving towards a more local perspective, within the European Union and within the Italian landscape, Università Cattolica del Sacro Cuore in Piacenza and the company Rem Tec were the two pioneers in the market segment. Indeed, starting from 2011 they joined their knowledge to [23] first APV systems in Italy. Three are the projects developed in those years, across 2011 and 2012, which are installed in Castelvetro Piacentino (PC), Monticelli d'Ongina (PC) and Borgo Virgilio (MN). All the projects were developed using a patented system called Agrovoltaico®, accounting an elevated structure (4-5 meters as reference height) and a biaxial solar tracking system. In table 2 a recap of the main features of all the three APV systems is performed. In the following chapters, the economic aspect will be analysed as well as a deeper and more detailed analysis will be performed on the technology which lays behind the concept.

Table 2: Rem Tec's datasheets over already existing plants [30], [6].

Main features/characteristics	Castelvetro Piacentino (PC)	Monticelli d'Ongina (PC)	Borgo Virgilio (MN)
Height available below the system [m]	4,5	4,5	4,5
Nominal Power [kWp]	1.293,6	3.229,8	2.150,4
Tracker technology	Biaxial	Biaxial	Biaxial
# Of PV modules installed	4.620	11.535	7.680
# Of trackers installed	462	1.154	768
PV modules' typology	280 Wp Polycrystalline	280 Wp Polycrystalline	280 Wp Polycrystalline
Expected production [kWh/year]	1.890.000	4.842.000	3.325.000
Plant surface [ha]	6,83	17,11	11,42
Power installed/Plant surface [kWp/ha]	189	189	188
Total surface of PV modules (S_{pv}) [m²]	8.963	22.378	14.899
S_{pv}/Total surface of the plant (S_{tot}) [%]	13	13	13
Date of the connection to the national grid	28/04/2011	29/08/2011	27/04/2011
Pitch distance [m]	12	12	12
LCOE [€/MWh]	93	84	87

LER [#]	1,38	1,50	1,46

Although elevated APV systems are the first-born sons in the literature and research streams, they are not the only existing solution from both a technological and layout point of view. It has been mentioned at the beginning of this chapter how open field APV only would have been the focus of the analysis. Well, it must be mentioned how much research are currently being performed for greenhouses APV. Indeed, as sustained by [10] the market value of greenhouses crops is on average higher than the open field's crops, so that many are trying to break into the possible market niche. APV applied in greenhouses configurations end up being a closed systems where impacts of the presence of PV modules is way lower than the open field type. Indeed, the shading effect caused by the APV does not affect the humidity parameter and neither the air temperature one, since both are already artificially regulated. As previously described, many different configurations have been studied and still are for what concerns the elevated APV framework, due to that, it is not possible to summarise the concept in one model only. In addition, other opportunities have broken into the scene in the more recent years as the vertical mounted bifacial APV. As stated by [23], much more is yet to come in the field since commercialization in still well undersized, regulators are nowadays starting to feed into the market attractive incentive schemes which will attract many greedy players and investors which have been just monitoring the system until now without intervening. The [24] provided a detailed classification of APV systems which is reported in figure 8.

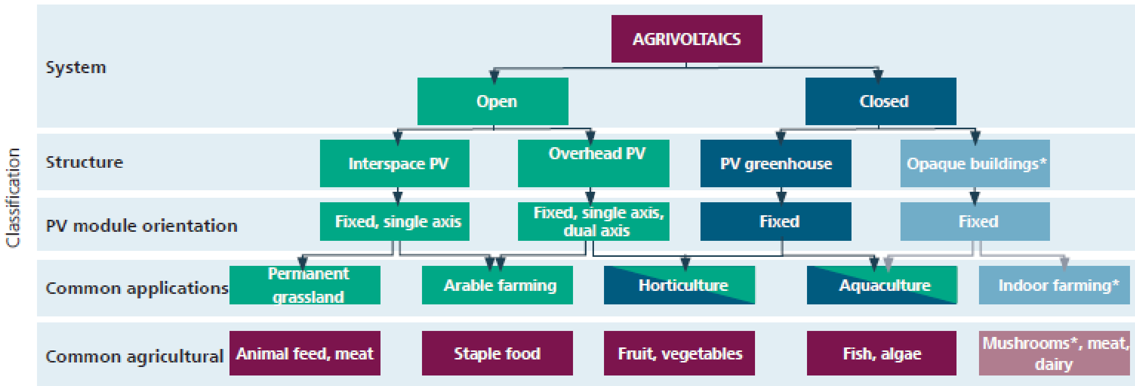


Figure 8: Classification of APV systems [24].

2.2 Suitable crops

Although the concept of APV has embedded a wide range of positive aspects, it must be said how it is not a one size fits all solution. As almost all technology, it does not exist a universal framework which could be standardized and therefore be applied over whatsoever type of problem. So, discussing about APV solutions, it must be highlighted how not all the crops are suitable to be cultivated within an APV solution. Indeed, the presence of PV modules, regardless the configuration, the orientation and all other technical parameters affects the ASR parameter hitting the soil surface on that specific field. Therefore, studied have been carried out to understand whether some plants' species could have been more suitable than others. The [24] reported studies affirming how extremely shade-tolerant plants, such as leafy vegetable species (such as lettuce), field forage species (such as grass/clover mixtures), different pomaceous and stone fruit and berry species, and other specialized plants (such as wild garlic, asparagus, and hops) seem to be particularly well suited. In figure 9 a scheme regarding vegetable types is depicted.

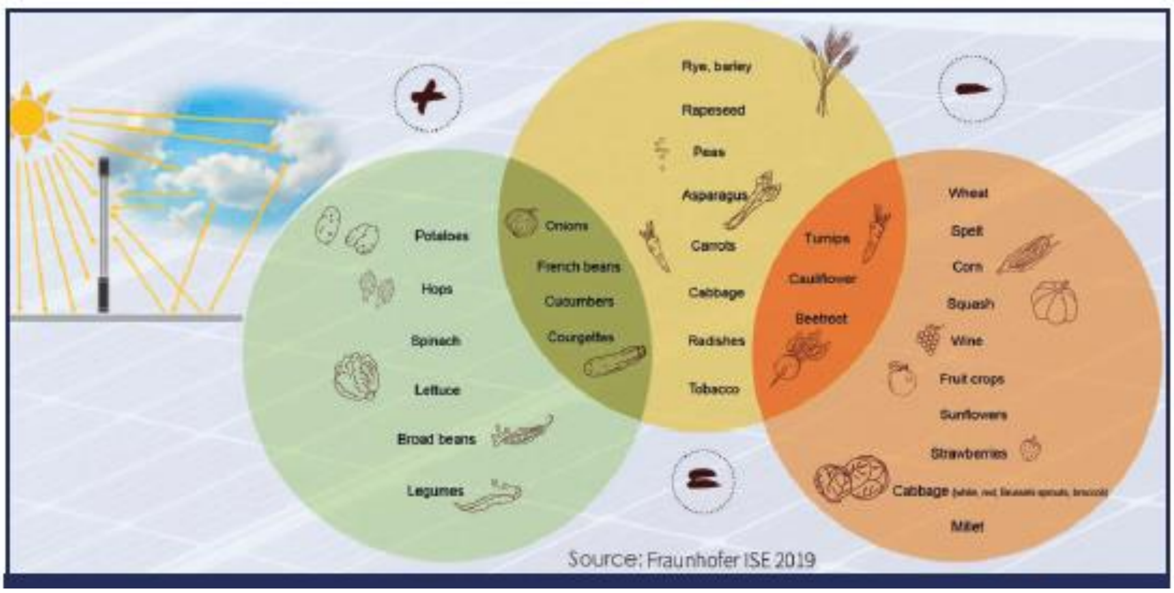


Figure 9: Crop's types of subdivision, according to their suitability for APV implementations [24].

Deep diving the topic, APV results being an optimal solution which offers the maximum potential in fields where specialized crops are cultivated. Indeed, often permanent fruits offer the highest ratio in terms of space occupied and economic value produced. Again, the value added gained with a lower direct irradiance of viticulture or all the fruits related to a high-water need is the highest possible. In the fruit business, a higher shading effect offered by the APV plant could be able to increase the sugar content of the final product, raising its quality once hitting the market. On the other hand, vegetables such as spinach or lettuce, presenting large leaves are too taking advance of the shading granted by PV modules. Studied again by the [24] affirmed how a 30% higher productivity could be reached with this latter type of products. Moreover, fruits three might experience costs decrement up to the 60% with the correct APV plant studied. Lastly, the seasonality of the crop matters. Indeed, all this theoretic aspect of shading effect brought by the APV plant will not affect winter crops like all the kind of cabbages with a sensible effect. Indeed, those cultivations are often cultivated with low to no sun irradiation days and sometimes even in greenhouses. Consequently, effects will not be as high as crops which are usually cultivated in the spring/summer seasons.

A concept might be introduced here to better clarify the border between plants favoured by a lower ASR, neutral ones and even plants which are negatively affected. The concept of the Light Saturation Point, which is an explanation of how all plants need light for the photosynthesis but, it is also true how the very same photosynthesis process stagnates after a certain ceiling. If it stagnates, it means that higher quantity of radiations will not make the plant grow further but instead it will damage the crop. Each plant has a specific LSP. It is straightforward how the lower LSP of the plant, the more suited the plant is for an APV configuration. A graphic representation of the LSP is represented in figure 10.

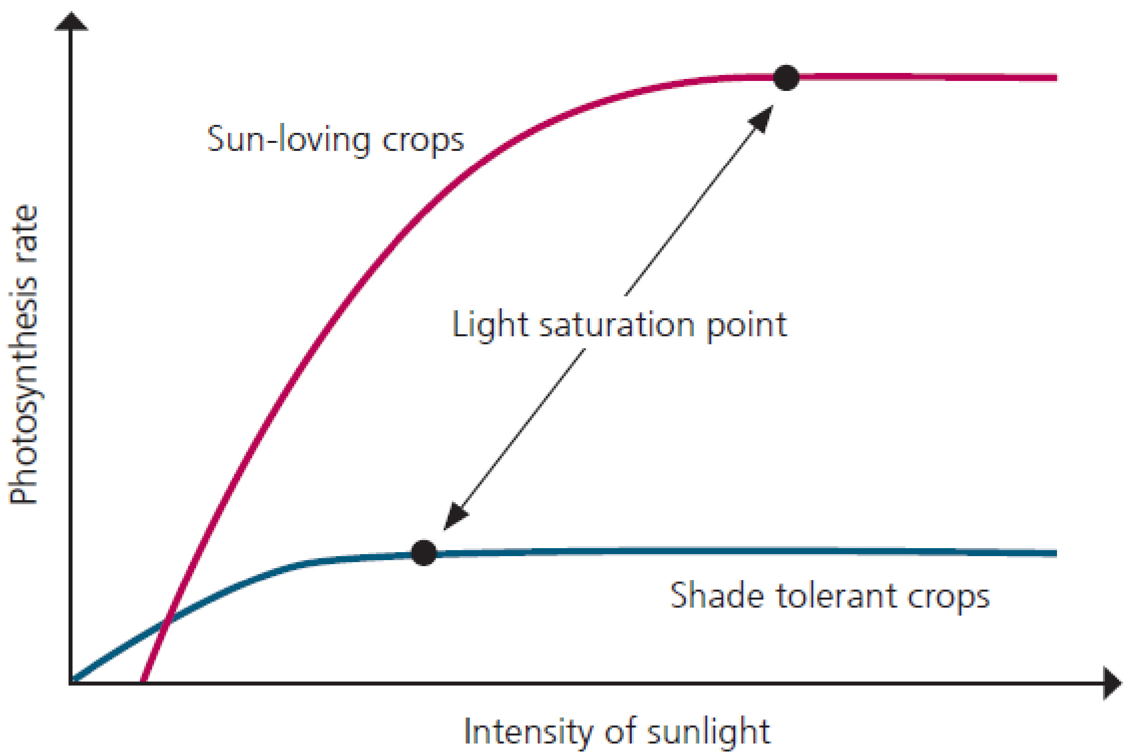


Figure 10: Graph of the photosynthesis rate plotted with the intensity of sunlight. Two examples: shade-tolerant and sun-loving crops [24].

2.3 Benefits of Agrivoltaic

Looking through history, scanning many of the existing technologies and solution, in this paper it has grown the idea that the APV concept has often been slowed down by the theoretical conception that the solution would have been a bad mixture of agriculture and PV production. That the coexistence of the two would have damaged since it would have been too complicated to cultivate crops through PV modules, which are nothing but not the most resistant material worldwide. Agricultural yields would have diminished if compared to a full field cultivated and electricity produced would not have been as high as the one coming from a traditional ground-mounted PV. All these concerns are somehow rightfully made but, many are also the benefits introduced by a APV implementation. Persuading the public opinion about these benefits and moreover spread their awareness is the first steppingstone to allow a real APV development and break out into the market scene. Then, which are these stressed benefits?

1. ***Water saving***

Lower amount of ASR hitting the solid and therefore any kind of plant cultivated due to the presence of PV modules cause a decrease in the amount of water needed by crops. Of course, since in the last years Italy as all the world are facing more and more homogeneous rainfalls and it is no more a rare event that a long drought period may happen, the lower water is required in agriculture the better. One of the main agricultural related APV indicators, the WUE, was thought exactly to monitor and evaluate this aspect.

2. ***Higher agricultural yield***

In this point it must be specified how this is not a universal statement. Indeed, it is true that for certain crops types a lower ASR coefficient is beneficial for the final production but this fact it is not true for all agricultural products. Indeed, keeping as example one of the simplest products worldwide as tomatoes, it requires a high irradiation and therefore it is not suitable for APV solutions. On the other hand, there are products which thanks to a higher shaded time have benefits over their final output.

3. ***Protection from extreme weather conditions***

Having as example the Pianura Padana, an area of Italy where in times it has always been quite rare to experience extreme climatic events, it is important to underline how APV plant may also offer a shelter function for crop growing beneath them. Indeed, as said, Pianura Padana used to be quite rarely affected by events like storms, hail, and intense wind. Unfortunately, in the last 10 to 15 years these kinds of situations have started becoming less and less rare and nowadays it may happen than in one summer season two/three occasions happen where these events impact the territory destroying an important share of agricultural yields. Well, PV infrastructure may help in this situation as well as in the case of extreme ASR incidence on the crops. ASR may be harmful if too excessive or too concentrated, APV plants may also contribute with this issue if the ASR's incidence reduction is studied before the implementation and is kept under monitoring.

4. ***Second source of income for fields' owners***

This point is quite explainable using the LER parameter. Indeed, the traditional income or source of it for a farmer is equal to 1. Regardless of the economic amount that 1 means, since in the agriculture and breeding market there are many and many different solutions, 1 is supposed being the end of the year net income for a farmer who cultivates the field. Then, let's supposed that 1 is also the overall income if the very same field would been used for PV production, ground mounted. If the APV coefficient is higher than 1, as demonstrated in literature by many real cases examples, it means that the farmer would benefits from an economic point of view by the solution, therefore, APV should be seen as not only a way to safeguard the environment and the climate but even a business opportunity. Finally, since agricultural or breeding activities are quite unstable and influenced by the summer weather, it has become common that due to an unforeseen weather event all the yield was destroyed. Well, in this paper it has been reflected how electricity produced by APV could also be as a more stable and certain economic gain.

5. ***Higher PV production***

PV modules are known for their need of light and sun to perform at their maximum levels. Nevertheless, it is also true that, even though it is not such a widespread knowledge, PV performances start decreasing after a certain temperature is reached. Usually, this temperature is set equal to 25°. This is the point after that there is an incremental decrease in the PV performance, specifically in the maximum reachable power coefficient which start losing some decimal percentage points after that threshold. In other words, it must be depicted how after 25° there is an inverse proportional relationship between the PV production and the temperature. The proximity with living beings and with the ground may alleviate this issue keeping the temperature slightly more under control.

6. ***Protection from soil erosion and degradation***

The presence of PV modules and moreover of APV structures has a shading effect on the soil which is less exposed to high temperatures and sun radiations. Moreover, it is more difficult to perform intensive agricultural activities on a field where an APV plant is built and consequently the human impact is limited by the solution.

7. ***Positive impact on the environment***

Finally, APV can be seen as a one size fits all solution in terms of solving the trade-off energy production versus agriculture. It has become in the last years a debate even more than a trade-off, with many and many experts debating upon which one of the two would have been the best. APV can be the keystone to turn the problem upside down and enhance a greener period for both the topics.

2.4 Technologies, configurations, costs, and sizing

According to the contemporary literature, the food-energy (FE) nexus is dealt by the APV in many different technological configurations. The different layouts which were developed in the last 20 years are due to the complex nature of the embedded issue. As a matter of fact, PV modules disposition should be adapted to agriculture requirements and performance objectives in terms of yearly production. Unfortunately, electricity and food necessities are nothing but far from being complementary. As a starting point, the previously detailed parameters should be tackled and once a value will be found for them, a suitable configuration will follow. Geometry and density of PV modules are the two leverages on which players involved may act to enhance the positive ending for the APV plant. Recently all governments worldwide have started to create incentive schemes regarding APV installations. Indeed, as all emerging technologies, it is more expensive than the existing and established ones and, as so, it requires to be sustained by an artificial structure in its first phase of development. Italian government have release in 2022, embedded in its 'Piano Nazionale di Ripresa e Resilienza' a guidelines' scheme which account 1,1 billion€ which will be distributed in APV plant with a framework of 40% non-repayable incentive of the overall initial investment for the plant. In this document, 5 macro parameters were established, and it was declared that an APV plant must respect some or all of them to grant itself the access to the funds. Later, a detailed analysis of these 'Linee guida in materia di Impianti Agrivoltaici' will be performed. Unfortunately, it has been noticed while structuring this paper how no money was assigned to the R&D phase of the technology. Indeed, the Italian regulator structured a financing scheme quite attractive from the point of view of plant installers and investors. Nevertheless, it did not consider any laboratory, university of research institute. This is perceived in this paper as a mainstream weakness. Indeed, as it had often happened in Italy, R&D business are left apart and then, after years, there is the epiphany that technological progresses should have been required to grant to the technology the opportunity to self-sustain and expand itself even after the incentive period has ended. With PV technology the same had already happened, indeed the technology was left apart in Italy as in all Europe and nowadays all the know-how on this topic is kept by the Asian countries which make the rules of the game in the market. The risk is the one of committing the same mistake with APV, overfocusing on installations and forgetting the technological advancements. Leaving apart the debated reflection, before deep diving the technology it must be mentioned as in this paper the focus will be the on-field installation of APV, sector which is affected by incentive schemes and by this new wave of interest. Indeed, for seek of completeness, APV accounts also the greenhouse part of the installations and of the technology. Nevertheless, in this paper it will just be mentioned but no detailed analysis will be performed. Both in [13] and [10] a summary of all the available opportunities is present. Figure 11 presents configurations and lists some concrete examples realised in the world. Also, companies responsible for the plant's construction are listed.

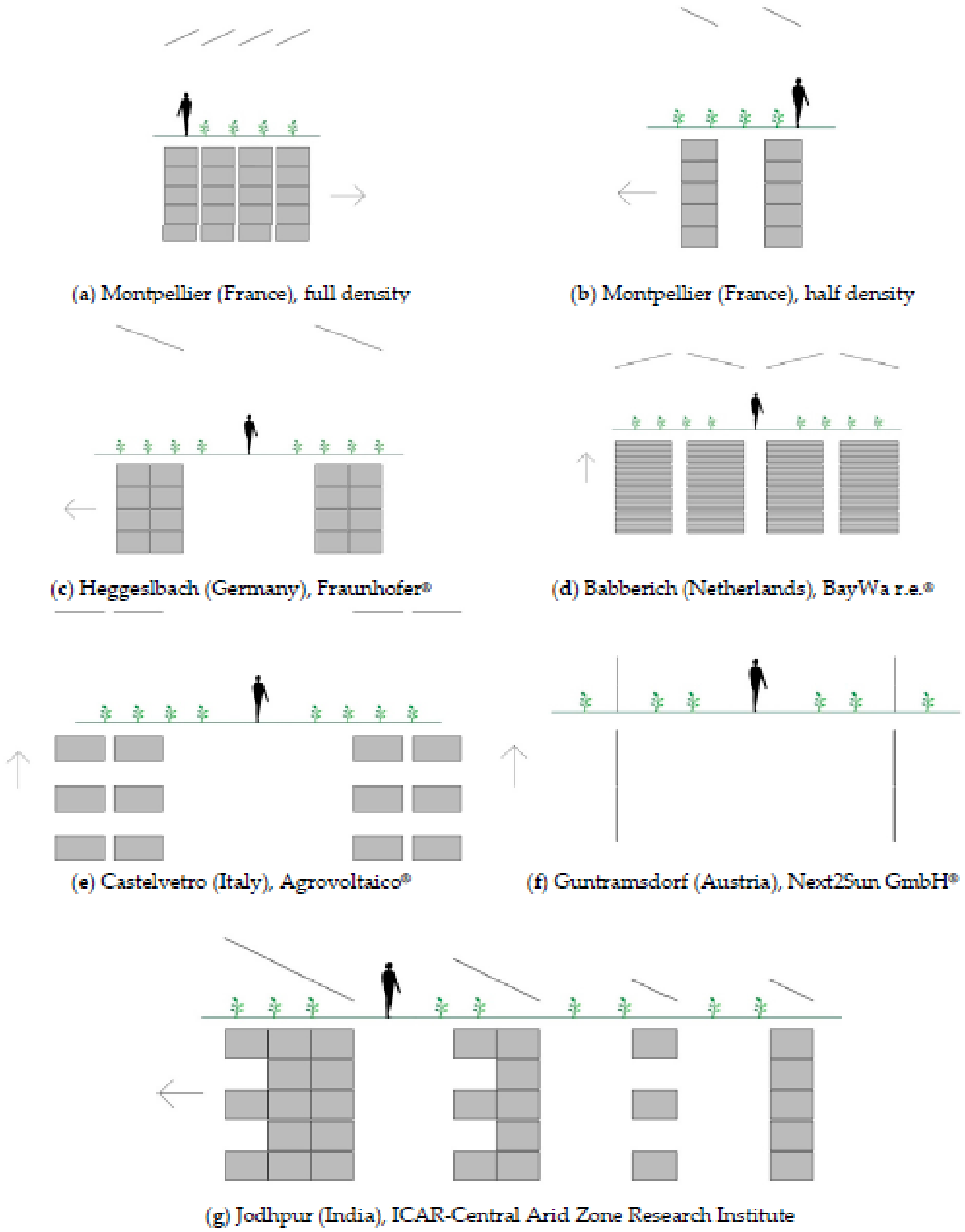


Figure 11: Patterns' opportunities at the current state of the art worldwide, all examples are already operating, and historical data can be collected [10].

This stream of research and studies is formally addressed as "On ground PV + Open-field crops" by [10]. Within the stream, two sub-categories concerning the design approach are identified and represented in figure 12:

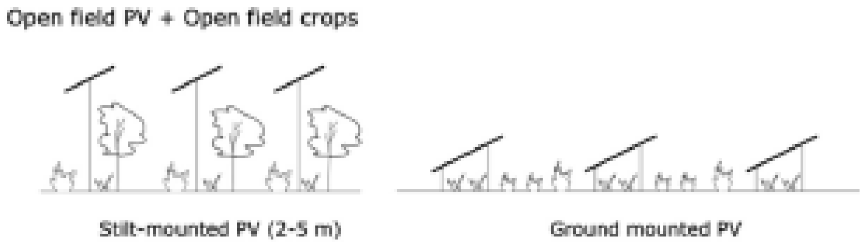


Figure 12: APV typologies, macro-systems [10].

- ***Ground-mounted PV***.
- ***Stilt-mounted PV***, with the PV infrastructure elevated from 2 to 5 meters from the ground level.

Considerations and analyses will be carried out accounting all the technical and technological principles of the PV ecosystem. In addition, all the aspects related to [25] agriculture will be included in the moment of evaluating trade-offs. Again, the combination of the two will be studied. How are them correlated and how changing one aspect of the word will have consequences, either positive or negative, over the other.

2.4.1 Ground-mounted PV

Dealing with Ground-mounted layouts, the oldest solutions are the ones where PV modules are oriented South with a tilt angle between 20° and 35°. PV modules can be fixed with 2 or 4 poles usually according to studies about the wind and snow loads. As far as the modules will be stable, the traditional reasoning is the less the better both from an environmental impact and economic point of views. On the agricultural perspective, activities may be performed between PV modules and in some cases even below them if the height of the lowest margin is higher than 0,7/0,8 m. Grazing is often the most common solution adopted here. Indeed, it solves problems related to the utilisation of agricultural machines as tractors which are complex to manoeuvre in tight situations. One more consideration should be done: as highlighted in the study [26] of [25], not all animals can be grazed in an APV plant. Indeed, mid to low height ones represent the best solution (sheep, chicken, and goats), regardless of their nutritional habits since on the soil grass will grow regardless. Therefore, cows and horses are not a suitable opportunity unless it is decided to erase the height of the PV modules from the soil area.

If agriculture is the activity selected to be performed within and/or below the modules, on average are crops like watermelon or melon are cultivated, thus crops which require low to zero mechanic interventions and are still carried out physically by farmers and workers. Finally, heterogeneous patterns and solution may be implemented. It means cultivating many crop's types in the same field allowing to differentiate crops according to the available height. Of course, this solution exploits at the maximum level the height available in the system whereas it rises the complexity level. A graphical example of a study performed by [26] presents this very last point figure 13. In the study, the minimum height available under the PV structure is set equal to 0,8 m.

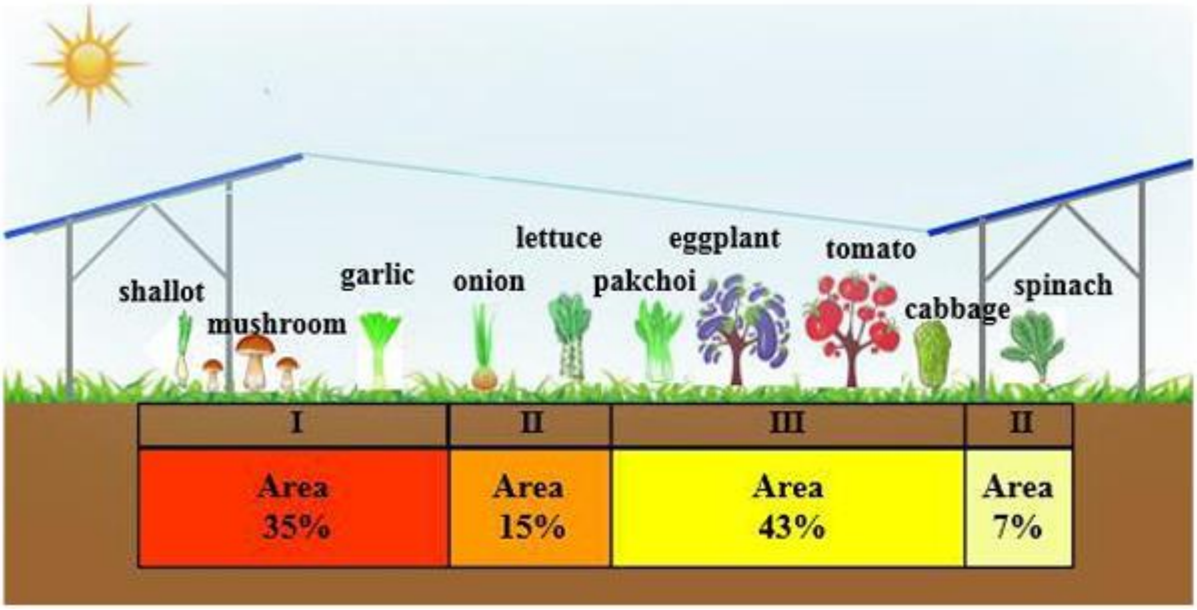


Figure 13: Suitable cultures [26].

Within the Ground-mounted APV options, the vertical mounted bifacial PV one has gained momentum in the last years. While dealing with the Agrivoltaic's configuration which accounts vertical installations of bifacial photovoltaic modules oriented towards the east/west direction with a certain row distance, Next2Sun is the leading company both at European and global level, as affirmed by [10]. The German startup experienced a massive growth in less than a decade. It was founded in 2015 and since than it developed countless innovative solutions regarding Agrivoltaic and specifically the vertical mounted installations. Its first pilot system is the Eppelborn-Dirmingen solar park, Saarland (GE) and was developed in 2015, it is the first project dealing with vertical installed bifacial Agrivoltaic in Europe and it covers an area of 7 ha with a total power of 28 kWp [27]. Since then, Next2Sun's R&D laboratories have never stopped working and they have reached the capacity of projecting, developing, and installing a project as big as the Donaueschingen-Aasen solar park, Baden-

Württemberg (GE) which covers an area of 14 ha, with a nominal power of 4,1 MWp, completed in the second half of 2022. If these two plants, as well as all other projects developed by the company, are structured on the electricity self-consumption business model plus a grid connection to absorb the excess of generation, the last project which was launched in 2022 in Neißeaue in the district of Görlitz (GE) will be combined with other system combinations as a set of battery storage. The project will be completed in different steps, the first sector was completed in the third quarter of 2022. The site stands over almost 69 ha and once it will reach its peak it will account for a nominal power of 20 MWp. Next2Sun usually works with an interrow space between 8 and 12 meters, numbers which have been confirmed even by more recent studies by [28] and [23]. This specific kind of solution (vertical-mounted bifacial photovoltaic modules) is a patented frame system by the company itself. Following a summary of the current state of the art has been performed for what concerns the overall concept, electricity yield, installation hurdles, and landscape impacts. The core idea behind Next2Sun's APV concept lies around a vertical mounted system accounting from 1 to 3 photovoltaic modules positioned horizontally, sustained by a steel structure. Modules are bifacial, meaning electricity production on each side and are therefore oriented east/west to optimize production. Figure 14 shows some examples of vertical mounted APV developed by Next2Sun.

Figure 14: Agrivoltaic existing plants [27].

Furthermore, the portion of the soil available for agriculture after the plant construction is 90% respect to the original area. The east/west configuration allows the plant to get a technical yield, in terms of kWh/kWp higher than the traditional south-oriented one. In [29] analysed the irradiance received by the vertical-mounted PV modules, East/West and a traditional South facing configuration. They end up with results presented in figure 15. Row's height usually stands between 1,8 (1 module) and 2,80 meters (2 modules), in few cases where wind and soil conditions are favourable a third module can be added reaching almost a height of 4 meters overall. Each row will be between 0,2 and 0,3 meters wide. Row's distance could stand between 8 and 20 meters for an optimal combination of crop and electricity yield. Apart from the drilling process of the steel poles, no extra foundations are required, no concrete or other pollution materials will be added to the soil traditional ecosystem. Moreover, poles are stuck from 1,6 to 2,6 meters deep. To work within rows, 0,5 meters should be left freely available each side. To conclude, the presence of the module rows will cause an average of 15% losses of sunshine to the soil.

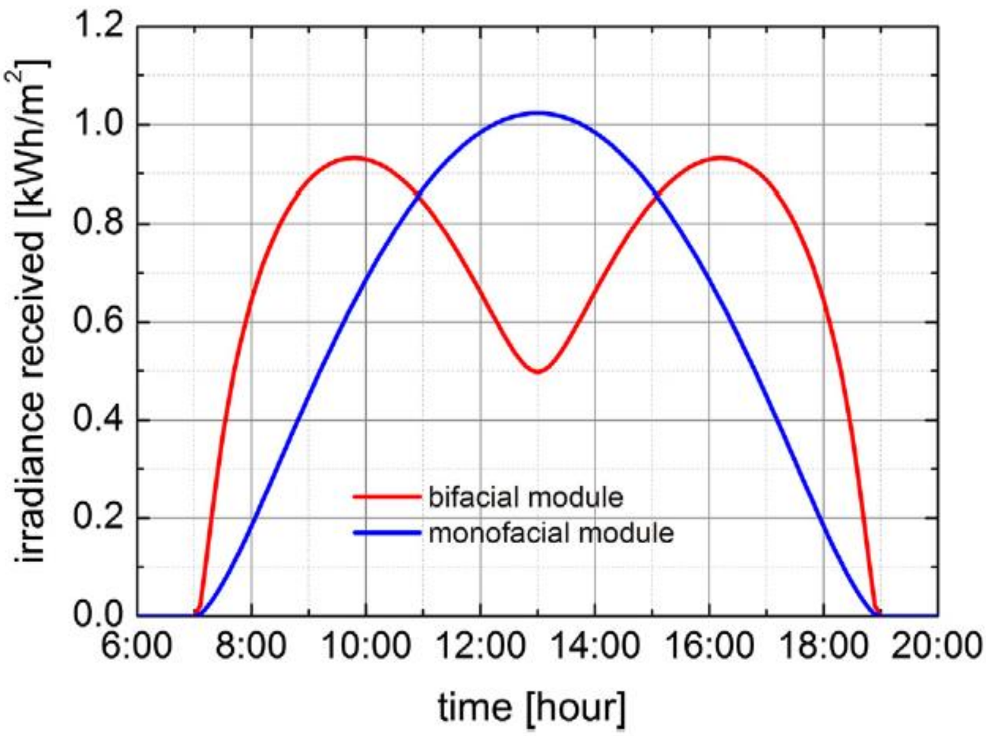


Figure 15: Bifacial vs Monofacial solar yields [29].

Electricity yield:

If compared with a conventional south-facing PV system, Next2Sun east/west solution has 5% to 15% higher electricity yields per kWp. Keeping as a references parameter a row spacing of 10 meters, a nominal power of approximately 0,4 MWp/ha can be gained in a traditional configuration. In addition, almost 98% of the original space will remain available for agricultural activities. The specific frame structure system will generate 2 peaks of electricity production, in the morning and in the evening matching the daily peaks of demand from the market. Consequently, the excess production will be fed into the grid in the day hours where prices are at their highest levels. On the contrary, a traditional south oriented installation will produce its peak in the central part of the day where traditionally the market demand is not at its maximum. Once again, figure 15 represents a concrete example of possible electricity yield per unit of surface which can be gained thanks to the specific layout.

According to [28] and [29], as well as according to data founded in [40], bi-facial PV modules grant to the plant owner a higher electricity yield which can be positioned between +12% and +25% if compared to a traditional mono-facial PV module. Indeed, the variability is caused by factors as the surface beneath the plant. For example, if the bi-facial plant is positioned over a white surface as a membrane, the ones used to avoid water infiltration, results are higher since white is, by far, the natural colour with the biggest capability of reflecting the sun light. On the other hand, it makes no sense offering a bi-facial PV solution when the surface around modules is characterised by dark colours since they will capture most sun radiations once these latter would hit them. Grass, as the Agrivoltaic situation, is a sort of hybrid situation. Indeed, results gained by bi-facial PV modules are settled in the between of plus value array. Traditionally, values from +15% to +18% are considered as gains obtained with such installation types. [28] highlighted how, within the first 5 meters from the grass level, no considerable differences are present in the higher efficiency obtained by PV modules. On the other hand, if modules are positioned further from the grass, positive reflection effects start decrease. Dealing with bi-facial PV modules, the core concept which must be dealt by is the albedo coefficient. The albedo coefficient is a parameter, which differs according to the type of surface considered, which account the bigger electricity produced by bi-facial PV modules rather than mono-facial ones. Considering its crucial importance, further on in the document, a specific chapter will be reserved to deep dive the albedo coefficient.

Finally, the economic aspect must be considered in the PV modules framework. Indeed, as extracted from [40] costs are different from traditional PV modules and bi-facial ones. As extracted from the company's database, mono-facial PV modules usually commercialised and installed present a cost which varies form 25 €-cent/Wp to 29 €-cent/Wp. On the other hand, bi-facial ones are generally sold in a price range from 30 €-cent/Wp to 33 €-cent/Wp. These prices are constant, regardless the peak power of the modules. Indeed, in the PV market, the specific cost €-cent/Wp is not influenced by the module's size. Therefore, the delta in terms of price, considering average values, is set between 14% and 20% more for bi-facial rather than mono-facial ones [40].

Efficiency:

Investment costs for the frame are around 700 €/kWp considering a turnkey installation. Compared to traditional grounded mounted photovoltaics plants costs are 15-20% higher. A recent study carried out by [28] on vertical mounted APV systems divides the concept in three sub-models which are tackled in parallel: the solar radiation and shading part, the PV one and the crop yield one. On many occasions the three of them are in trade-off's situations each other and, according to that, it must be paid attention to find the best solution to the interrelated topic. The final takeaways of the study suggest how row distance between bifacial PV modules vertical mounted affects the solar radiation hitting the soil and as a chain reaction the overall agricultural yield. Tests were performed in a range from 5 to 20 meters of distance with two different crops as oats and potato. In addition, the LER was computed being bigger than 1,2. This value shows how the combined utilisation of the soil for the two different activities gives a productivity output higher than the two singular ones with the soil used as a mono production plant. Afterwards, an optimisation model taken again from [28] will be explained.

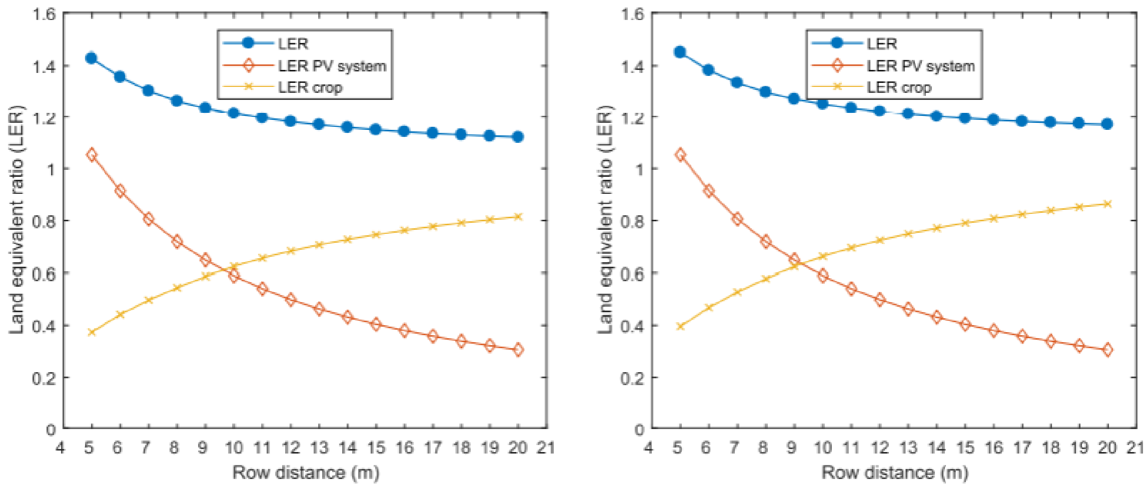


Figure 16: LER representation (Electricity, crop yield and overall). Potato (left) and oats (right) [28].

It is worth highlighting how for both oats and potato the optimal row distance in between 9 and 10 meters, and, as expressed before, in both cases the APV LER is higher than the two resulting ones in the mono use case. In addition, results state how the PV's contribution share in the overall LER is way bigger than the agricultural one and how the PV's LER decreases when incrementing the row distance. Due to this situation, as expressed by figure 16, it exists a negative correlation coefficient between the row distance and the global LER due to the PV's impact. The optimal row distance is therefore picked as the interception between the PV's and the agricultural LER.

First, some reflections must be done dealing with solar irradiation and shading. [28] refers to PAR data with the direct, reflected, and diffuse radiations. Azimuth and tilt angles are defined here to define a solar position algorithm: $\alpha_s(°)$ as the tilt angle, also called solar altitude and $\gamma_s(°)$ as the azimuth angle considered. As well, [16] utilise $\gamma_s(°)$ and $\alpha_s(°)$ but the second is called elevation and not tilt angle. Both papers define the solar vector in a coordinate framework which can be adjusted to each location on Earth as:

$$\vec{\boldsymbol{S}} = \boldsymbol{S_S\hat{\imath}} + \boldsymbol{S_E\hat{\jmath}} + \boldsymbol{S_Z\hat{k}} \qquad (1)$$

Where $\hat{\imath}, \hat{\jmath}, \hat{k}$ are defined as vectors identifying axes, respectively the south, east and zenith axes directions. Afterwards S_S, S_E and S_Z are defined with respect to tilt and azimuth angles:

$$\vec{\boldsymbol{S}} = \begin{cases} \boldsymbol{\cos\alpha_s \cos\gamma_s} \\ \boldsymbol{\cos\alpha_s \sin\gamma_s} \\ \boldsymbol{\sin\alpha_s} \end{cases} \qquad (2)$$

[29] define a more accurate model to compute solar radiations reaching the soil. Statistical approaches are used with a detailed use of the DGSRD models, already present in literature, which was further studied in the paper. Even though more variables are considered by [29], in the paper is not considered the PV presence and so it will be used to confirm [28] and [16] results. Having defined a structure for the solar vector it is possible to compute all shadings caused by PV modules on the ground and the ones caused each other by PV modules' rows. This step is possible thanks to the projections of all elements on the horizontal ground axe. It is worth computing the shading coefficient (S_F) for any element/axe:

$$\boldsymbol{S_F} = \frac{\boldsymbol{S_{F,b}\times I_b + S_{F,d}\times I_d + I_r}}{\boldsymbol{I_b + I_d + I_r}} \qquad (3)$$

Where, I_b, I_d and I_r represent the direct, diffuse and reflected irradiances over the soil/ground surface in the optimal condition, without any shadings. Yet, $S_{F,b}$ is the shading factor for the direct beam irradiance while $S_{F,d}$ is the dual one for the diffuse one. In addition, it is required to introduce two more parameter as $A_{shading}$ which is the shaded area [m^2] and can be compute using geometrical frameworks and once again by orthogonal projections. Yet, A_{tot} [m^2] is introduced for seek of clarity as the total area available between two PV rows. One of the most complicated steps is the computation of $S_{F,b}$ and $S_{F,d}$. The former can be computed as:

$$\mathbf{S_{F,b}} = \frac{A_{shading}}{A_{tot}} \qquad (4)$$

A hypothesis must be underlined: indeed, the area between the soil (horizontal axe) and the bottom of the vertical mounted PV structures is considered as a shading one. Indeed, for most of the time grass grow down there and it is quite complicate for the farmer of the PV player to keep it clean to allow the sun passing through. In [28] case study the height is considered being 0,7 m, in figure 17 the distance is called R1. Whereas, as it will be detailed afterwards, in the newest Italian guidelines that height is required to be at least equal to 1,3 m. this issue will require a detailed analysis to avoid risking to oversimply calculations. In figure 17 $A_{shading}$ is clearly highlighted. The latter as:

$$\mathbf{S_{F,d}} = \frac{\int_{\alpha_s=0}^{\pi/2}\int_{\gamma_s=0}^{2\times\pi} \mathbf{S_{F,b}} \times \mathbf{R}_{\alpha_s\times\gamma_s} \times \cos\vartheta \times \mathbf{d} \times \boldsymbol{\Omega}}{\int_{\alpha_s=0}^{\pi/2}\int_{\gamma_s=0}^{2\times\pi} \mathbf{R}_{\alpha_s\times\gamma_s} \times \cos\vartheta \times \mathbf{d} \times \boldsymbol{\Omega}} \qquad (5)$$

Having Ω as the solid angle [sr], ϑ as the incidence angle [°], d as the row distance and $R_{\alpha_s\times\gamma_s}$ as the radiance [W/m²/sr].

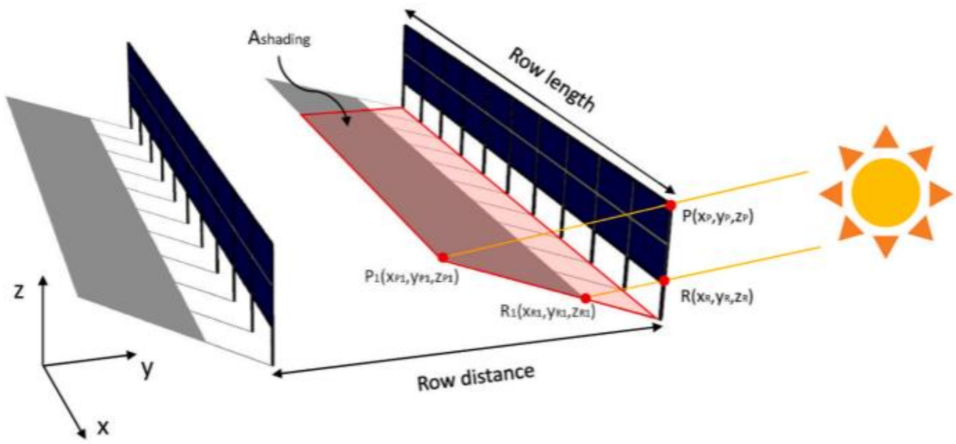


Figure 17: Shading scheme APV system [28].

To sum up, the model implemented by both [16] and [28], which is almost the same apart from few differences in the nomenclature and in the fact that [16] focus more on Stilt-mounted PV, give us a way to compute the global impact from a shading point of view that an implementation of an APV plant may have. Figure 18 depicts the electricity production (EL) in relation with pitch distance between each PV row.

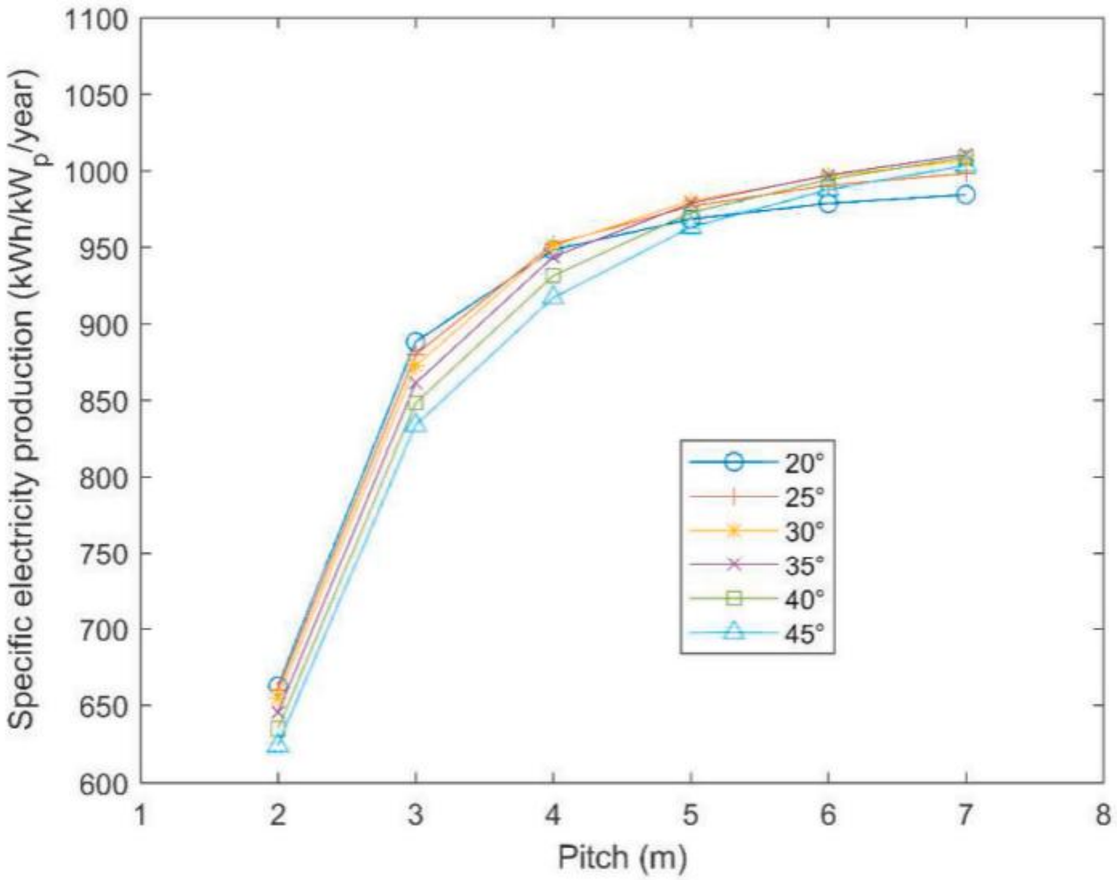


Figure 18: Specific electricity production as a function of the tilt angle [°] and the pitch [m][28].

2.4.2 Stilt-mounted PV

Elevated structures with solar tracking systems, Stilt-mounted PV, are the second family type of Agrivoltaic installations' configuration. As Next2Sun is the company leader in the vertical mounted bifacial Agrivoltaic systems, the Italian startup Rem Tec plays the very same role when moving towards the elevated modules' configuration. The company has developed many patents from its foundation and nowadays it operates worldwide exploiting soil ground and optimizing solar energy production from renewable sources and agricultural one. The technology is called Agrovoltaico®. As affirmed by [30], they technology does not damage the agricultural yield, despite it may even enhance a higher yield, in some conditions, thanks to the shadows it generates. Rem Tec has been carrying out studies on the technology since 2011 with Università Cattolica del Sacro Cuore in Piacenza. Studies performed in the last decade showed how the agricultural yield for maize, one of the most common crops in the area, could increase up to 4,3 % [16], [30]. Agrovoltaico® accounts 4 main configurations shown in figure 19, and their main characteristics are summarized in table 3.

Table 3: Summary of existing patented technologies [30].

Agrovoltaico® Solar Tracking System		
	Tracker 1.0	Tracker 2.1
Tracker power	$2{,}5 \leq X \leq 4{,}35$ [kWp/tracker]	$X \leq 16{,}8$ [kWp/tracker]
Tracker # of modules	10 PV [modules/tracker]; mono- or bi-facial	24 PV [modules/tracker]; mono- or bi-facial
Tracker height	4-5 [m]	4-5 [m]
Tracker length	12 [m]	14 [m]
Agrovoltaico® Suspended AGV		
	AGV Linear	AGV Chessboard
Tracker power	$X \leq 830$ [kWp/ha]	$X \leq 830$ [kWp/ha]
Structure's overall spans	15-25 [m] each; ground projection; they can be repeatable	15-25 [m] each; ground projection; they can be repeatable
Tracker height	4-5 [m]	4-5 [m]
Rows' distance	6 [m]	6 [m]

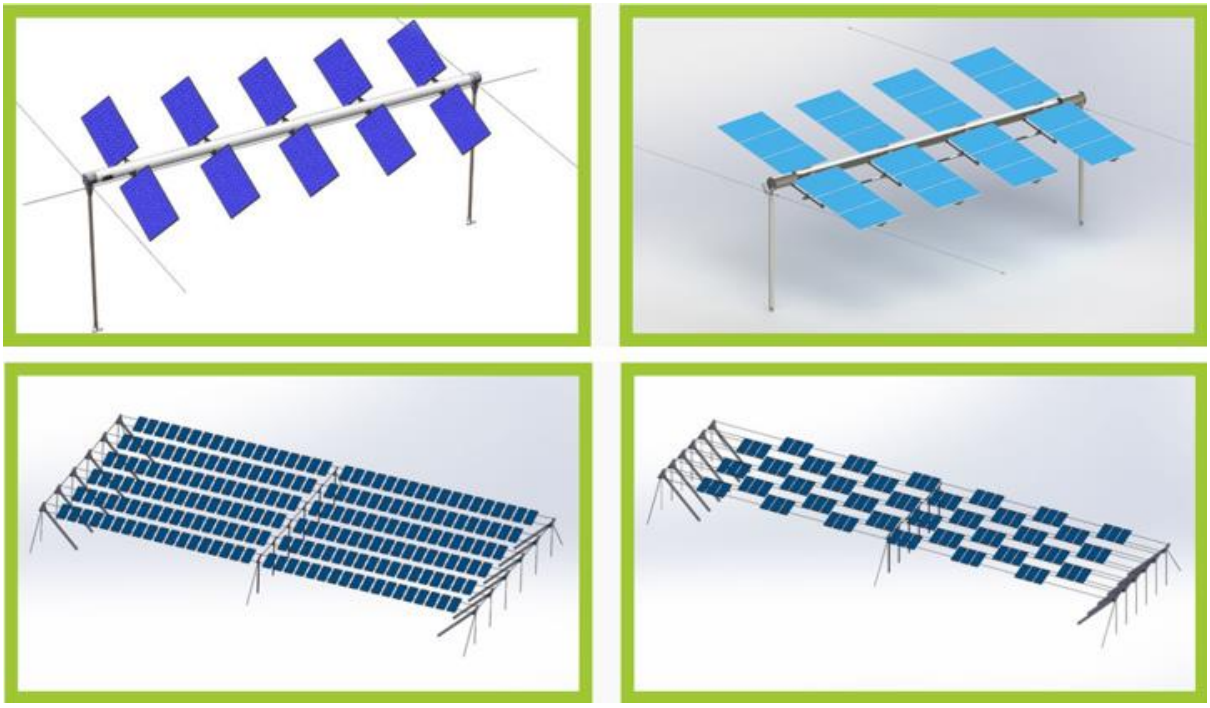


Figure 19: Tracker 1.0 (Top-left); Tracker 2.1 (Top-right); AGV Linear (Bottom-left); AGV Chessboard (Bottom-right) [30].

One last peculiar characteristic for all the Agrovoltaico® configurations is that they are adaptable even to soil with a slope up to 15%, so a territory which could be compared to a rolling one, going out from the original location area of flat and vast fields.

The study developed by [16] is universally considered as a milestone of the APV literature. Deep diving the paper, the authors analyse the Stilt-mounted branch of APV systems. In the paper, Italian examples implemented by RemTec are used to gather data in other to fill in an algorithm to evaluate the appropriability of possible areas in the future. [31] is another cornerstone of the literature contributing to the shading effects' computation. On the one hand, both end up with the same results as [28] for the shading overall vector, expressed in equation 6. On the other hand, [31] and [16] defines different equations for the computation of the singular vectors given the very different layout affecting the plant in analysis. The equation 6 is though for being able to account any kind of solar radiation hitting the soil.

$$\begin{cases} \tan\vartheta' \\ \cos\varphi = \alpha \times \cos[\cos\alpha_s \times \sin(\gamma_s + \tau)] - \frac{\pi}{2} \\ \vartheta = \begin{cases} \pi + \vartheta' & if\ \vartheta' < 0 \\ \vartheta' & if\ \vartheta' > 0 \end{cases} \end{cases} \tag{6}$$

Where ϑ *and* φ are respectively the rotation angle of the first axe tracker and the second one, day-light follower and season-light follower. the orientation angle of the field is indicated by τ, having east/west as main reference direction. In his paper, [28] agree with [16] stating how analysis on APV should not be performed on a specific year. Indeed, as [22] did, considering shading effects of an APV plant in a very dry and hot year will overestimate positive effects due to water saving and lower temperatures. Consequently, LER from [22] reached values up to 1,5; way bigger than the already high 1,2 of [16] and [28]. Moreover, analyses should try to account as much crop type as possible due to the traditional business model in agriculture which accounts a predetermined rotation over the years to preserve the biological values of the soil.

2.5 Key performance indicators (KPI) and technical parameters

In the previous section a brief recap of the chronological path which has seen the development of APV concept has been presented. As highlighted before, it does not exist a singular stream of research and development but many slightly different ones worldwide. As well, technologies are different according to the companies which install the solution, the objectives which the entrepreneurs want to achieve, and the rules imposed by the regulator in the local national market. In this section a recap of the main design parameters, coefficients and indicators guiding the adoption of APV systems will be performed. The objective here is offering on overview of decision-making leverages from both an operational and strategic point of view.

2.5.1 Land Equivalent Ration (LER)

As briefly described by figure 3, the Land Equivalent Ratio is an indicator used to assess APV system's performance thanks to a comparison between the traditional approach, a photovoltaic plant one the one hand and a farm set up on the other, with a consumption of two fields contemporary and the integrated solution of the two activities on the same field. As explained by [28], LER measures whether the combination of the two, crop yield and electricity production, produces a value higher, equal, or lower than the one given by the singular utilization of the same soil area for one activity only. In literature, LER is generally computed as:

$$\boldsymbol{LER} = \frac{Y_{c,apv} \times \alpha}{Y_{c,ref}} + \frac{E_{PV,apv}}{E_{PV,ref}} \qquad (7)$$

Where:

- $Y_{c,apv}$ represents the agricultural yield in the specific case of APV configuration [t/ha].
- $Y_{c,ref}$ represents the agricultural yield in a traditional case without PV plant in the same area accounted before [t/ha].
- α is a reduction coefficient which accounts the area around the APV mounting structures and consequently cannot be cultivated neither harvested [#].
  It may be computed with the following relation:

$$\boldsymbol{\alpha} = \mathbf{1} - \frac{\textit{Unused Area}}{\textit{Total Area}} \qquad (8)$$

- $E_{PV,apv}$ represents the energy (electricity) produced by the APV system [kWh/m²/year].
- $E_{PV,ref}$ represents the energy (electricity) produced by a conventional grounded mounted PV plant system [kWh/m²/year].

The relations above are the ones specifically presented by [28]. Dealing with LER it is worth clarifying how values higher than 1 indicate how the integrated approach gives an overall output which is more effective than the two on them separated. The model given by [28] presents a LER equal to 1,3 on a pilot project developed in the middle of Sweden. Whereas [16] affirmed how the LER may vary in a range from 1,23 up to 2,05 according to different layouts of the APV plant. Although LER is probably the first indicator which is looked at while talking upon APV technologies and concepts, it is also true that LER does not account for how the two sides of the computation participate in the result. Indeed, whether electricity production has a similar impact of agricultural yield in the final value of LER, or it has twice, three times the impact is a matter impossible to be extracted from the parameter. As affirmed by [10] LER above 1 may be obtained even if the final agricultural yield accounts for the 10% of the system. That is why other parameters must be analysed and benchmarked to express a final judgment on the APV concept.

2.5.2 Land Area Occupation Ratio (LAOR)

The LAOR coefficient comes into place when talking about the system's design and technical feasibility. Indeed, the technical feasibility of the APV is heavily affected by the final configuration which is decided. The Land Area Occupation Ratio can be defined as follows:

$$\boldsymbol{LAOR} = \frac{S_{PV}}{S_{TOT}} \qquad (9)$$

Where S_{PV} is the total area of photovoltaic modules of the APV system and S_{TOT} is the total area of soil occupied by the APV system. The value is usually found expressed in percentage terms [%]. The definition reported here is given by [13]. As a matter of fact, it all comes to a trade-off decision between energy production or agriculture. The best compromise should be found to settle PV modules in a way such that a satisfying energy production efficiency will be achieved and at the same time agriculture will not be penalized due to an excessive shading situation. High LAOR values, the closer to 1 the better, if considering electricity production only [10]. Clearly, the higher the LAOR, the worse the situation will be from a food production point of view. In table 4 some real examples of APV plants and their relative LAOR are listed to have an idea on some real values of the parameter presented in real case.

Table 4: State of the art examples of LAOR's values [13].

APV plant	***LAOR***
APV Jinzhai 2016 Nominal Power: 545 kWp	**20%**
APV Borgo Virgilio 2011 Nominal Power: 2,1 MWp	**13%**
APV Castelvetro 2011 Nominal Power: 1,3 MWp	**13%**
APV Heggelbach 2016 Nominal Power: 194 kWp	**35%**
APV Nidoleres 2018 Nominal Power: 2,2 MWp	**29%**

2.5.3 Water Usage Efficiency (WUE)

Both [16] and [10] state how another useful indicator to evaluate the effectiveness of APV plants is the WUE index. Yet, the indicator asks for measures of water's consumption after the implementation of the plant on the field and at the same time it requires data taken in a traditional year without the APV but always referred to a field in the same geographic area. It represents a both effective and rather simple way to assess benefits of the food-energy-water triple bottom line nexus. As mentioned before, APV systems were firstly implemented in some areas of the world like South America or Asia with the attempt of reducing water consumption thanks to shading effects, both areas characterised by issues of water scarcity. Nonetheless, in the very last year's climate change is causing water scarcity problems even in the inland Europe. In some cases, consistent droughts happened in the middle of summer in southern European countries. Having said so, it seems clearer why water resources management is no more a problem limited in some part of the planisphere only. On the contrary, regulators of all the world should be worried about it. Literature offers a straightforward relation to compute the parameter as:

$$\boldsymbol{WUE} = \frac{\boldsymbol{WUE_{PV}} - \boldsymbol{WUE_{control}}}{\boldsymbol{WUE_{control}}} \quad (10)$$

On average, WUE is computed as a unit of biomass per unit of water used $[kg/m^3]$. WUE_{PV} indicates the water efficiency level under APV system while $WUE_{control}$ represents the same value but in a condition without APV.

2.5.4 Annual Solar Radiation (ASR), Photosynthetically Active Radiation (PAR), Global Horizontal Irradiance (GHI)

The global irradiation reaching the Earth's surface is a milestone in the scientific literature of human being. Indeed, life on Earth is influenced by that parameter and as well is the food-energy nexus. Both the components are affected in different ways by the radiation. Many ways of describing the concept are available. In this paper three of them will be presented. The ASR parameter is considered being one of the most important one which should be evaluated while considering an APV system's construction hypothesis. It accounts both the direct solar and the diffuse radiations hitting the ground. It is though being a crucial determinant for both the energy player and the farmer. As unit of measure, as reported by [15], is commonly used $[\frac{kWh}{m^2 \times year}]$. An equivalent option used by [16] is $[\frac{kJ}{m^2 \times year}]$.

The implementation of an APV system will always decrease the ASR, thus the turning point from a strategic point of view is understanding whether the effective ASR will be enough to satisfy the needs of the hypothesised crops which will be cultivated on the specific field. As [15] have done, in this paper will also be used the EU PVGIS database. The database accounts specific data concerning weather forecasts and historical values, all divided in regions to enhance a more accurate analysis. It is worth underlying how this parameter is strongly affected by the geographical location. Indeed, if APV technology and layouts are usually implementable everywhere worldwide, while computing ASR data the plant location must be considered at the discussion's beginning. According to the location, ASR will affect even economics analysis related to the plant. Indeed, evaluating the economic profitability of a plant in the South Europe, where ASR's levels will be massive is rather different than evaluating the very same APV plant in the Nord Europe where the same shading effects could be deadly harmful for crops given the already limited ASR reaching the ground.

For a seek of completeness, it must be said how both [18] and [28] prefer to describe the sun radiation hitting the ground with the term PAR: Photosynthetically Active Radiation. The very same lines of reasoning of ASR are applicable with this parameter. Once again, as ASR before and as GHI will be later, PAR accounts in its definition the direct, reflected, and diffuse radiations. Late in this paper, it will be introduced a decomposition framework exploiting a vector analysis to better understand the parameter. Finally, the most well-known definition of the topic is the Global

Horizontal Irradiance as reported by [32]. Many research and forecasts institutions work daily on the topic. Figure 20 represents the state-of-the-art situation worldwide while figure 21 is given a more concrete idea of the direct, reflected, and diffuse radiations are [31].

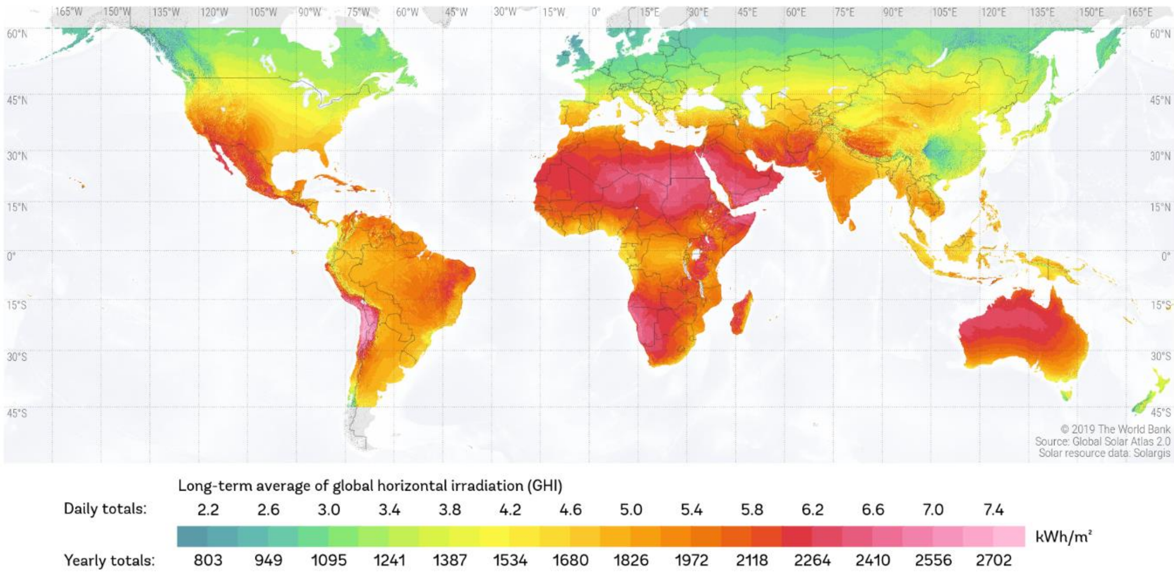


Figure 20: Solar resource map – Global horizontal irradiance [33].

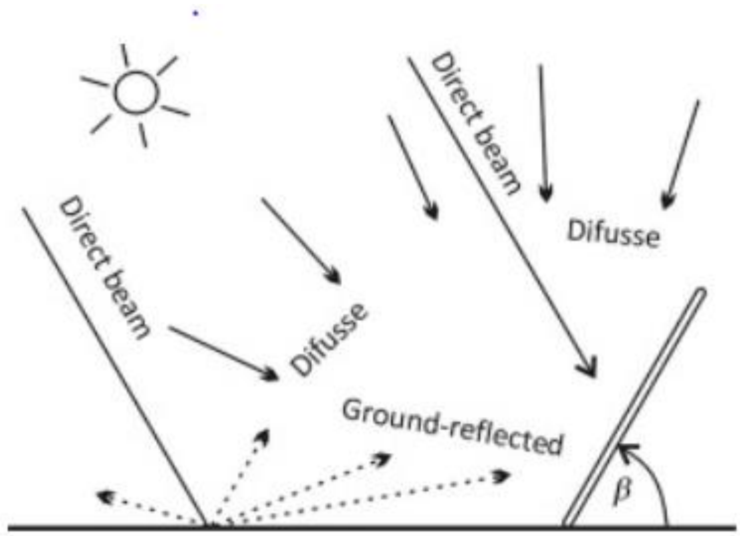


Figure 21: Direct, reflected and diffuse radiations' representation [34].

2.5.5 Pore

Landscape impacts are a matter of primary importance while analysing the APV framework. Indeed, the percentage of space occupied by the APV plant on the overall space available is kept under particular attention during the design phase. [31] defines a parameter which account exactly the dual concept. Indeed, the "Pore space" is defined as the space left for any kind of activities on the same field once the APV has been completely implemented. In other words, the Pore can be identified as the plant density level. Ideally, the Pore is the space which should be destined to enhance an adequate level of exosystemic activities. To represent the space Pore, it is wise to structure the field and the related APV within a tridimensionality matrix. In figure 22, a representation of the concept is provided. In addition, figure 23 shows a three-dimensional pattern and provides two relations to compute an algebraic output of area and volume of the space Pore:

$$\boldsymbol{PORE\ SPACE\ AREA} = TOTAL\ SOIL\ AREA \times AREA\ PROJECTED\ BY\ THE\ PV\ MODULES\ ON\ THE\ GROUND \quad (11)$$

$$\boldsymbol{PORE\ VOLUME} = PORE\ AREA \times H \quad (12)$$

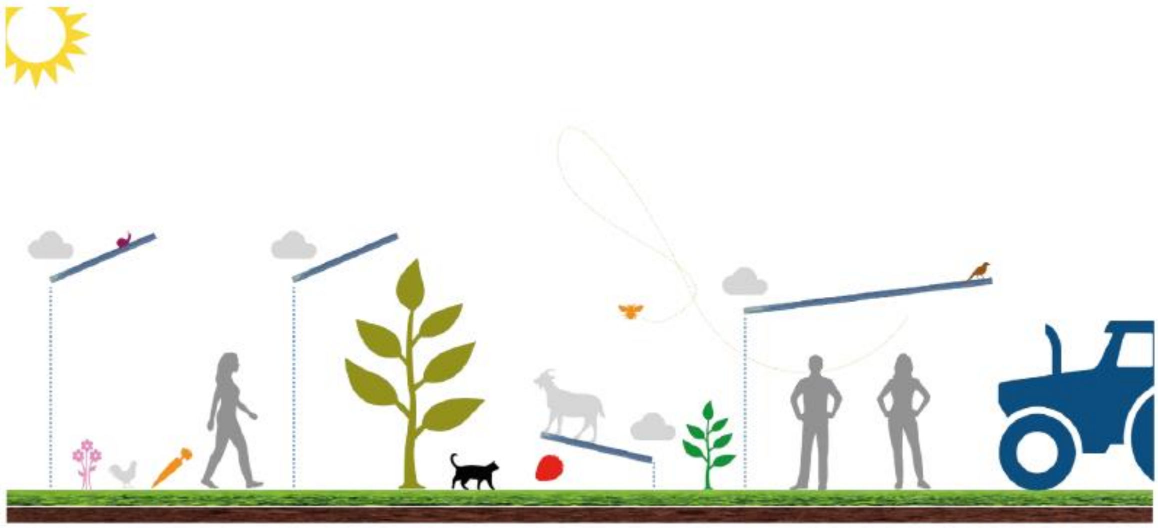


Figure 22: Graphical schematization of an APV system [31].

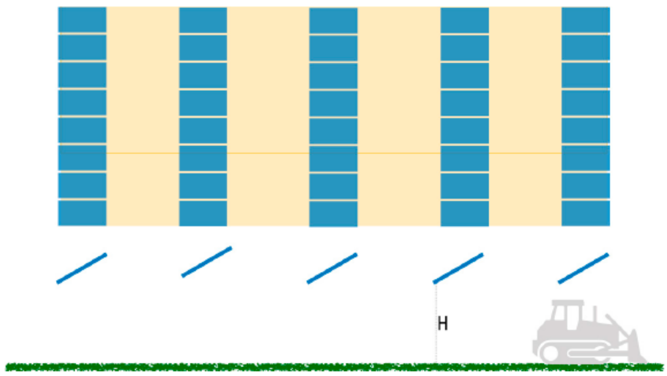


Figure 23: Three-dimensional pattern scheme of APV [10].

2.5.6 Tilt and Azimuth angles (°)

These are the two milestones when it comes to talk about PV installations. Indeed, acting on these two values an investor can modify the electricity yield of the PV modules in terms of specific electricity production [kWh/kWp]. The tilt angle is explained as the inclination given to the installed PV module. In traditional applications like rooftop PV, the tilt angle is often the one already affecting the rooftop since modules are simply attached to the existing rooftop. In other occasions, like the grounded PV the aim is the one of optimising the electricity yield and on average the best solution in literature is the one of having a tilt angle comprised from 20° to 30°. In the situation of APV, the tilt angle also affects the shading effect of the modules and consequently the changes which happen on the agricultural crop. Therefore, it is twice important.

On the other hand, the Azimuth angle is the orientation of the PV structures and modules in respect to the horizon. In most cases, an East/West orientation is given by a -90°/+90° configuration. The South orientation, which is the noblest orientation since it grants the maximum solar irradiation (ASR) and straightforwardly the maximum energy production, is usually associated to an Azimuth angle equal to 0°.

2.5.7 Levelized cost of electricity (LCOE)

LCOE is the most diffuse parameter to compare electricity sources. Indeed, it provides a value usually expressed in [€-cent/kWh] or [€/MWh] which results being quite straightforward as a ratio to benchmark different sources as fossil fuel ones versus renewables or more in detail for example photovoltaic versus gas methane. [22] provide the same equation to compute the LCOE as the one given by [32] whether [18] do not provide any analytical formula. LCOE is computed as:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} A_t \times (1+i)^{-t} - R_n}{\sum_{t=1}^{n} M_{t,el} \times (1+i)^{-t}} \quad (13)$$

Where: I_0 represents the initial investment (CAPEX), A_t all operating expenses (OPEX) apart from the residual value at the end of asset's life R_n. The expected life is represented by n. To conclude, all values are actualized with the interest rate i. Until now, all the financial aspects have been tackled. Afterwards, the electricity produced over the entire year is summed up in the reference $M_{t,el}$; computed as:

$$M_{t,el} = \sum_{t=1}^{n} S \times \delta \times (1-d)^t \quad (14)$$

Where S is the overall annual solar irradiation, δ is the system efficiency and 'd' indicates the efficiency losses.

2.5.8 Albedo coefficient

The albedo coefficient is defined as the portion of the sun light, specifically the incident sun radiation, which is reflected in all directions once it has impacted the physical surface, whatsoever material made of. In other words, the albedo is the capability of a surface to reflect the sun light. Technically speaking, the albedo coefficient is unique for each material, and it is usually indicated by the symbol ϱ.

Borderline values are 1, which indicates the maximum albedo possible, in this case all the light which impacts the material is reflected, and 0 which on the other hand is the minimum albedo, indicating that no light is reflected as explained in figure 24. In the PV market, the albedo is a matter of primary importance when it comes to bifacial PV modules. Bifacial modules are PV products which have the capability to produce electricity towards the PV effect on both sides of the module. Of course, there will always be a front side and a back one, with the former having a way bigger productivity than the latter. White surfaces and snow are two situations where the albedo is as close to1 as it is possible finding it in nature. On the other hand, dark surfaces are characterized by low coefficients of albedo and therefore they tend to absorb most of the incident solar radiation. Since in this paper a discussion will be undertaken tackling the topic of bifacial PV modules installed on green grass surfaces, agricultural fields, as explained by [35], a discrete value for the albedo coefficient tin the case of green grass will be a value equal to 20%. It means that the 20% of the sun radiation hitting the will be reflected towards the bifacial side of the PV modules. Although in literature it is possible finding values up to 35% indicating the same green grass, in this paper the value found by [35] will be kept offering a cautious analysis.

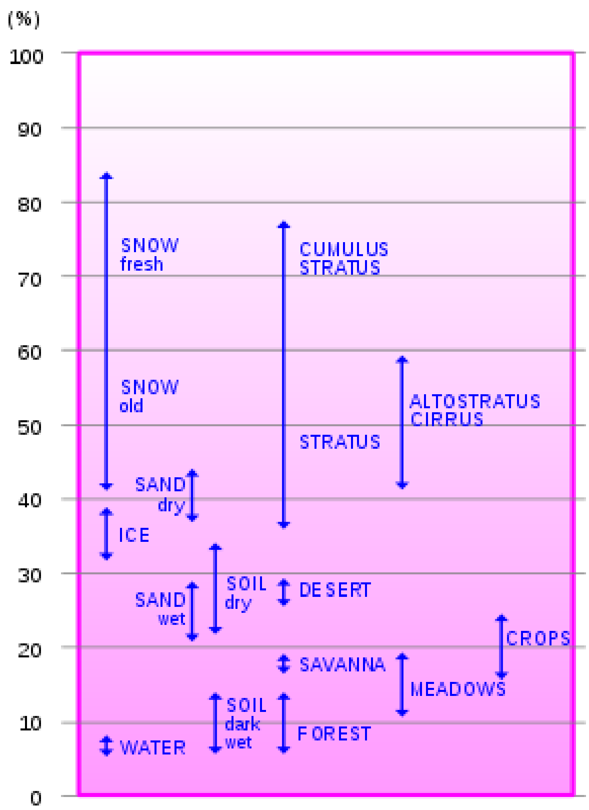


Figure 24: Albedo coefficients [36].

2.6 Economic Evaluation of Agrivoltaic

Previously in this paper a definition of APV has been given and the main technologies available at the current state of the art have been explained. Although knowledge of definitions and technologies are a milestone to study the APV concept, the economic aspect is the one that makes the rules of the game at the end of the day. Indeed, a technology may be as green as possible, as efficient, or noble as possible but all it matters for its real development on a large scale is whether it is able to grant a certain return on investments (ROI). Philanthropy is quite rare nowadays, and entrepreneurs are much more interested in making money than safeguarding the planet's ecosystems. Having said so, for seek of completeness, it must be stated that almost all the technologies which are trying to break into the market need to be sustained from an economic point of view. Twenty years ago, traditional photovoltaic plants needed incentives to be feasible, while nowadays thanks to further R&D performed and new economies of scale, incentives are vanishing on that type of plants. A study published by [15] declares how APV requires government incentives schemes to become cost competitive with other energy sources. Moreover, since considering the same field the nominal power which can be installed is much bigger with a traditional photovoltaic plant than an APV, even economies of scale are standing against the implementation of APV currently. [18] agree with Feuerbacher about the policy-support requirements. The former paper presents the Italian situation with a detailed analysis on PNRR, which has dedicated 1,1 billion€ to sustain the implementation APV plants, even though an operative decree has not been published yet. The latter, explain the very same situation but from the German perspective. [15] went even more in detail stating how solar radiation and investments costs are two key determinants together with economies of scale to judge the profitability of an APV plant. Moreover, agricultural yield as well as agronomic costs do not impact significatively on the full budget prospect of the plant. [18] analyse a case study plant in the north of Italy (Bozzolo, MN) where a Stilt-mounted configuration of APV is implemented with 4 m height from the ground level and a total power of 720kWp. CAPEX is estimated being 60% higher than a traditional ground-mounted PV plant for the same power, on yearly base. Both plants are south oriented (Azimuth angle 0°) and inclined with a tilt angle of 35°. Instead, OPEX are computed being 8% lower than the same PV plant as before. Finally, the LCOE of APV is computed equal to 0,0815 €/kWh while taking once again the traditional PV, its LCOE is equal to 0,0603 €/kWh. It must be clarified how agricultural economic gain are not reported and neither inserted in the computation of APV's LCOE. The addition of this factor will reduce the delta between the two even though it is clear how Italian government must intervene to close the gap with economic subsidies or incentives. Without any form of subsidy, APV will remain confined to a market niche for many years to come.

Another study performed by [22] provides similar values for traditional PV plant and APV for what concerns LCOE. Data are extracted from a case study in Germany. LCOE of APV is computed equal to 0,0828 €/kWh, with a delta in comparison to the traditional LCOE of a ground-mounted PV equal to +38%. In addition, [22] first differentiated CAPEX and OPEX of the two plant typologies and then they compared each of them, as shown in figure 25.

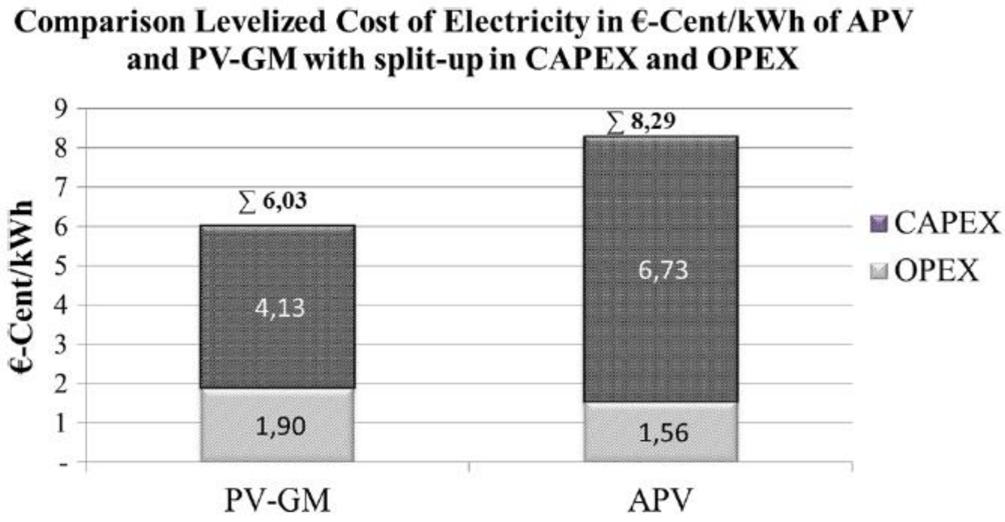


Figure 25: LCOE's comparation [€-cent/kWh], splitting up CAPEX & OPEX [16].

Nowadays everyone talks about the sustainable development paradigm. From politicians, to economists, entrepreneurs, and legislators. All the events that have affected and are currently affecting the planet have contributed to sensibilize the public opinion on the immediate necessity of a paradigm shift. Energy production is one of the most impactful causes of CO_2 emissions worldwide and, talking truthfully, something in the energy production value chain has started changing in the last years. Nevertheless, as pointed out by [32] and [16] at the end of the day all choices end up being concentrated in an either-or statement. Indeed, whether the investment in producing energy towards green vectors is profitable in the mid-long term or the choice will remain a fossil fuel oriented one. Due to this situation, many opportunities have been built to sustain renewable energy and much has been done in terms of R&D. Business models like Power Purchase Agreement (PPA), ESco were implemented and in many cases, there is still room for improvement both concerning the market diffusion, number of projects, and dimension, size of projects. Agrivoltaic belongs to the family of renewable energy's concepts and, as so, needs economic feasibility and moreover profitability to be able to definitively break into the market, leaving the actual market niche where it is settled and where in most cases it is related to the 'pilot project' phase.

[15] to clarify the deadlock in APV's adoption created by the economic point of view declare how, to fully adopt APV, a farmer needs to have the following inequality satisfied:

$$\boldsymbol{E_{AV}^{AGRI} + E_{AV}^{PV} - E_{BASE}^{AGRI} > 0} \qquad (15)$$

The inequality represents the fact that, even the most sustainability-oriented farmer will find the willingness to invest if and only if the contribution margin of agricultural and photovoltaic productions combined ($E_{AV}^{AGRI}; E_{AV}^{PV}$) will be higher than the contribution margin of the same field in the BASE case without any APV system implemented. The very same reasoning can be done from the point of view of a general entrepreneur, having in this case the necessity of:

$$\boldsymbol{E_{AV}^{AGRI} + E_{AV}^{PV} - E_{BASE}^{PV} > 0} \qquad (16)$$

In other words, the same field configured for APV should provide a ROI higher than the field configured for a traditional ground mounted PV. Otherwise, the choice will again fall on the traditional investment type. In addition, thanks to studies performed in Germany, [15] declare an LCOE for APV systems of 0,03 e-cent/kWh. LCOE is fascinating compared to the electricity tariff by [15]. It is highlighted how the electricity tariff, so the price at which the electricity produced by the APV is sold, can be compared to the market LCOE. Both can be considered as the break-even point, in other words, the point at which the investment shifts from unsustainable to sustainable at the entrepreneur's eyes. An outlook of the expected evolution path of APV's LCOE are presented in figure 26, where different prospectives are accounted from a cost reduction point of view. Expenditures in R&D will make the difference in this direction. The more private and public institutions will invest in R&D the faster will the APV's development be.

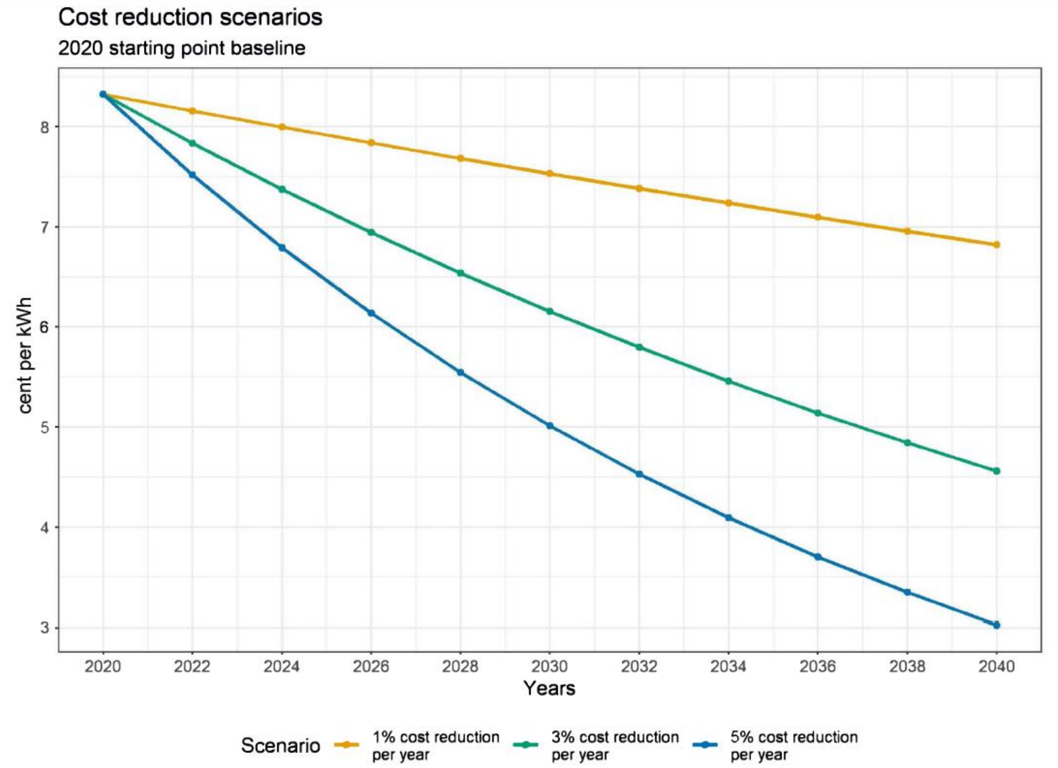


Figure 26: APV's break-even points (LCOE/electricity tariff) assuming 1%; 3% and 5% of cost reduction [15].

2.7 Existing APV business cases

As [45] reported in the mid of 2023, the idea and the concept of Agrivoltaic could be summed up as a sort of evolution, or even step ahead of the technology from the traditional utility scale PV. Indeed, APV considers something more and provides more opportunities to the plant owner. Nonetheless, it enhances the sustainable energy transition in correlation with the nutrition issue. In other words, Agrivoltaic has started gaining momentum as a powerful alternative to traditional business models which have worked in the last fifteen years but are nowadays starting to foresee some cracks at the horizon. Figure 27 gives to the paper some examples of the alternatives introduced by APV.

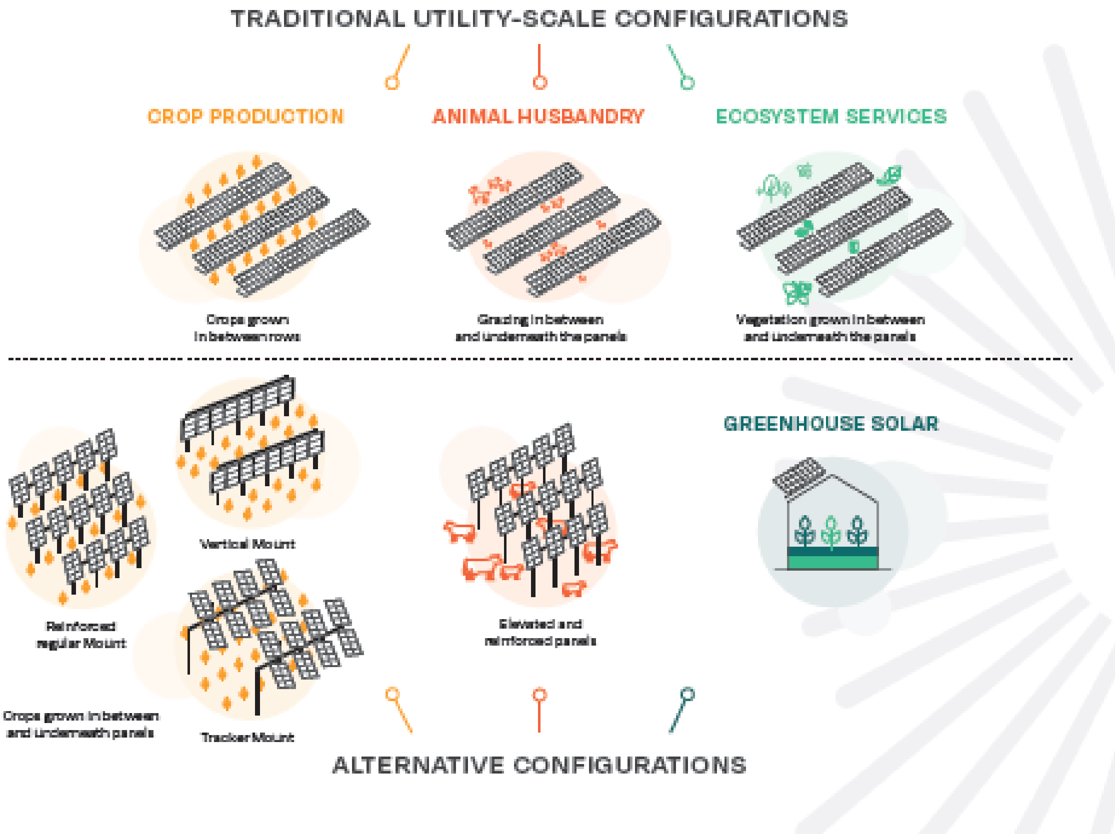


Figure 27: Benchmark between traditional ground PV and APV [45].

As summed up by the LER parameter, values higher than 1 are the starting point for any evaluation over APV.

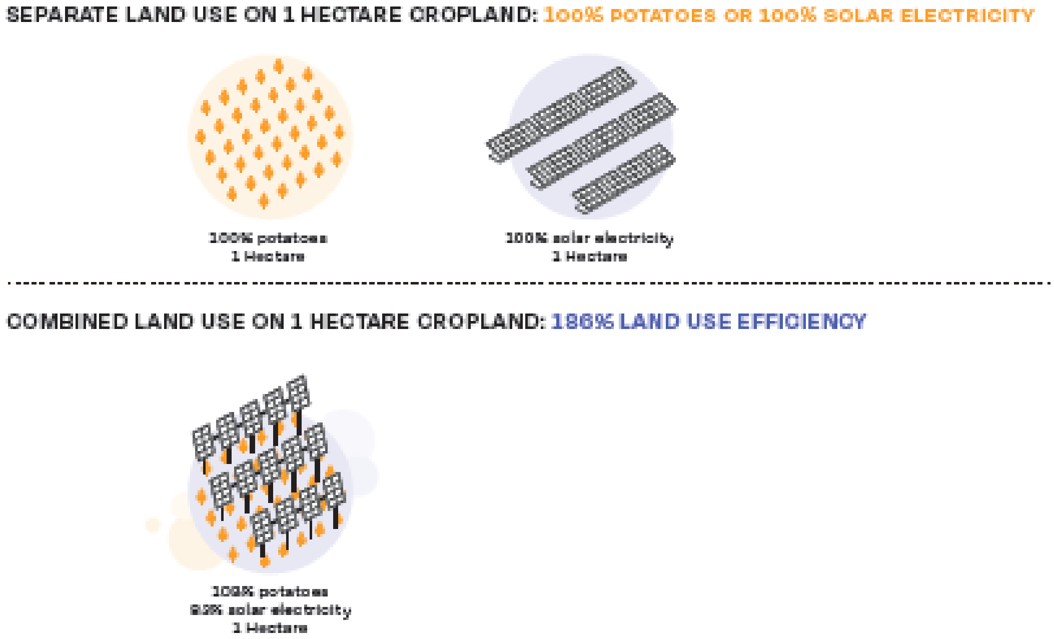


Figure 28: LER parameter > 1 enhances APV models [45].

In the last years, as reported by [10], [16], [22], [28] and [45] many business cases were developed with the Agrivoltaic technology. Japan, France, and Germany are three of the biggest leaders of the field. Indeed, [10] reported how the approach to innovation in Japan has always been faster than European or American ones. Moreover, having Japan one of the highest population densities of the world, in terms of [# people/km^2], enhancing a technology which could produce on the same soil energy and food, solving the nexus, has always been seen as a win-win approach in the country. On the other hand, Germany and France are the leader countries in Europe, two of the biggest European food producers and well positioned for investments in new energy sources. Many are the examples of already working cases presented in the previous part of the paper, as well, many are yet to be analysed. In table 5 are reported APV cases installed over greenhouses, being this type of solution quite attractive for entrepreneurs for two reasons: first, fruits have on average higher value added rather than field cultivation and second, fruits have bigger benefits gained from a lower solar radiation hitting them rather than field crops.

Table 5: Sum up of existing business cases [16], [22] and [45].

Position	Akuo, France	Toulouges, France	Bavaria, Germany	Graz, Austria	Oedheim, Germany
Peak power installed [kWp]	175	250	1.850	340	115
Connected to the national grid	2015	2017	2019	2022	2022
PV modules	Monofacial - Fixed mounted - Monocrystalline	Monofacial - Fixed mounted - Monocrystalline	Bifacial – Tracker equipped - Monocrystalline	Bifacial – Tracker equipped - Monocrystalline	Bifacial – Tracker equipped - Monocrystalline
Crop type	Apricots	Winter vegetables	Grain – Crop rotation	Pome fruit	Raspberry
Biggest benefits	Water saving	Water saving – Protection from heavy hailstorm	Lower PV modules' temperature	Water saving – Higher agricultural yields	Higher agricultural yields
LCOE [€/MWh]	112	105	82	85	90
LER [#]	1,64	1,56	1,98	1,84	1,93

The former ones are just a part of the over 550 APV project currently in place in Europe [45]. Some are projects accounting low peaks power installed, in the range of 15 to 50 kWp. The attempt in this case is experimenting and it is exactly the direction that the technology must undertake to lower its LCOE. Unfortunately, Italy, as it will be detailed subsequently, is not putting much attention over the research phase. Field crops as well as fruits are two streams of development which will be undertaken by the APV technology in the next years. No one of the two much be avoided since opportunities are countless in both [10].

2.8 Italy: State of the art, Policies and Business Models

In June 2022 a document intitled "Linee Guida in materia di Impianti Agrivoltaici" was published by the Italian's Agriculture and Ecological Transition ministry (MITE). The MITE was the project's coordinator, nevertheless it included the presence of:

- GSE S.p.A., which is accounted for the management of all the energy services in the country.
- RSE S.p.A., a player acting in the research and development world.
- ENEA, which is the national agency dealing with new technologies and sustainable development.
- CREA, a council for research and analysis on agricultural economies.

The document is a first draft of the framework which will guide the future development of Agrivoltaic plants in Italy in the years to come. Its scope is the one of designing a clear picture of which should be the minimum requisites that an Agrivoltaic plant should possess in order to be defined so. The first cornerstone which has been posed is the differentiation between an Advanced Agrivoltaic plant and a Traditional one. Indeed, as it is written in the "DL 24 gennaio 2012; Articolo 65, 1-quarter e 1-quinquies" an Agrivoltaic plant can be defined Advanced if and only if:

- Even though it enhances photovoltaic green energy production, it does not harm the agricultural or breeding activities. In addition, it may allow the implementation of digital technologies and precision instrument in the two activities.
- It accounts monitoring systems to obtain a real time impact analysis of the new photovoltaic plant.

Being defined Advanced is a crucial point in the business since in the Italian government has recently decide to assign 1,1 Billion€ within the recovery plan after the Covid-19 pandemic (PNRR). Since parameters like Return on Investment (ROI) and Pay Back Time (PBT) are still in the research phase, being able to get access to government funding is a matter of primary importance for the development of APV solutions.

In addition, the paper gives another definition of Agrivoltaic system which defines the system as: "A three-dimensional space composed by the photovoltaic modules, by the free space between and below them, by all the required structures to sustain the modules and all the features required for the agricultural activities". Altogether, the overall space occupied is called the Agrivoltaic Volume. To avoid that one activity overwhelms the other, and in the very specific case it will be the photovoltaic production overwhelming the agriculture, parameters have been set together with 5 requisites (A, B, C, D, E) to enhance the optimization of the overall system's performances. In table 6 it is summarised which requisites must be respected to distinguish Advanced Agrivoltaic from Traditional one, as detailed once again by the [13].

Finally, between June and July 2022 a public consultation went on within all the Italian institutions which matter in the business. The released document is called 'Consultazione pubblica PNRR M2C21_agrivoltaico'. Once again, the amount of 1,1 billion € was highlighted as available in the incoming future for the APV solution. Furthermore, the objective was et equal to 1,04 GWp of new installed capacity ideally by 2026. In the document all the requisites for an APV implementation to be defined as so are listed, as well, the incentive scheme is explained here. In this paper, differently than the previous one, it is identified a specific amount of money which will be granted as incentive over the energy fed into the grid by the APV plant for a time span of 20 years. The amount will be defined through an auction procedure where the baseline will be 85 €/MWh in the first year. In the subsequent years, this tariff will be decreased by 2% yearly.

Table 6: Incentive schemes required prerequisites [13].

<table>
<tr><td rowspan="3">Traditional Agrivoltaic</td><td>A</td><td rowspan="3">If compliant to all, the plant is still considered APV but no access to PNRR incentives is granted.</td></tr>
<tr><td>B</td></tr>
<tr><td>D.2</td></tr>
<tr><td rowspan="5">Advanced Agrivoltaic</td><td>A</td><td rowspan="5">If compliant to all, access granted to the PNRR incentive schemes.</td></tr>
<tr><td>B</td></tr>
<tr><td>C</td></tr>
<tr><td>D</td></tr>
<tr><td>E</td></tr>
</table>

2.8.1 Requisite A

It requires the plant to be projected and configured so that it will allow the integration between electricity production and agricultural one, adding value to both the final products. Two requisites are identified to be satisfied:

- **A.1: A minimum amount of surface being preserved for agricultural activities.**

This condition recalls the "DL 77/2021" saying that at least the 70% of original surface must be preserved untouched for agricultural purposes. In other words, the continuity of the preexisting agricultural activities must be granted. This threshold has been set to remain complaint to the so called "Buone Pratiche Agricole", an Italian document which states thresholds and parameters to shelter farmers and agricultural activities from other business with higher values added. The concept can be synthetized in the inequality below.

$$S_{agricultural} \geq 0,7 \times S_{tot} \qquad (17)$$

Where $\mathbf{S_{agricultural}}$ can be defined as: "The area remaining available for agricultural activities at the end of the plant's installation" and the $\mathbf{S_{tot}}$ as: "The total area on which the plant insists".

- **A.2: A maximum amount of surface being covered by photovoltaic modules.**

Keeping once again in mind the attempt of preserving wither agriculture or livestock, a limit is introduced. On the other hand, the aim of the regulator is also the one of not obstruct the implementation of more and more ambitious and innovative solutions. Having said so, it is necessary to define the concept of LAOR, a parameter which represent the ration between $\mathbf{S_{pv}}$ defined as: "The total surface encumbered by the photovoltaic modules" and, $\mathbf{S_{tot}}$. The following inequality should be respected.

$$LAOR \leq 40\% \qquad (18)$$

2.8.2 Requisite B

It requires the system during all its lifecycle to grant the continuity of agricultural/breeding activity. A synergy must be implemented between the two encountering worlds. Again, two sub-requisites are required to be satisfied:

- **B.1: Continuity of the agricultural activity, which accounts for 2 elements:**
    - **B.1.a: The existence and the output of the crop.**

To be compliant with the B.1.a requirement, in the years following the plant installation a monitoring system should be implemented for what concerns the final output of the agricultural yield. As a unit of measure, it may be used [€/ha]. Values obtained in the following years will be benchmarked either with average yield values of the geographical area if the surface was not cultivated before the installation, or if agricultural activities were present those output will be picked up as benchmarking standards. The process here described requires a quite detailed monitoring system, a topic which matches the sub-requirement D.2 which will be subsequently analyzed.

- **B.1.b: Minimum electric production.**

In this case, the regulator decided to set a minimum value for what concerns electricity production by comparing existing Agrivoltaic plants with traditional photovoltaic ones. Here is defined the concept of Specific Electricity Productivity as "The amount of GWh produced in each hectare per year [GWh/ha/year]".

The specific electricity productivity of an Agrivoltaic plant, $\mathbf{FV_{agri}}$, should be compared with the one of a traditional photovoltaic plant, $\mathbf{FV_{standard}}$, and the following inequality should be satisfied:

$$FV_{agri} \geq 0,6 \times FV_{standard} \tag{19}$$

With the term 'standard' it is intended a ground PV with a tilt angle equal to 20° and perfectly South-oriented. It's reference productivity, in term of kWh/kWp/year will be computed using the PVGIS database.

2.8.3 Requisite C

It specifies the height of the Agrivoltaic installation with respect to the soil. Indeed, photovoltaic modules should be elevated from the ground to allow agricultural and livestock activities. To better understand the requisite C, it is necessary to recall the distinction made in literature between Stilt-mounted APV and Ground-mounted APV. In the document released by the Italian government:

- Type 1 APV is identified as the Stilt-mounted family, regardless the type of technology used, where the minimum height is computed to grant the continuity of agricultural activities within and below the PV modules. A double utilization of the soil is depicted in this case with a maximum level of integration. Indeed, the land area available for agriculture is the same area available for the PV plant, apart from the land occupied by the sustaining structures.
- Type 2 of APV is the one defined as a combination of PV modules and agriculture on the same field, but no activities are thought to be performed below the PV modules. The reason why is that height available below the modules is not sufficient to allow any king of operations.
- Type 3 APV is the code used to identify the Ground-mounted one, specifically in this case the vertical mounted technology. Here the percentage of ground available for agriculture after PV modules' installation is not as high as in the type 1, at least not always, but is certainly higher than type 2.

Height available is a matter of primary importance since it is related to the usability of the soil itself for agriculture. Indeed, whether PV modules are sufficiently elevated from the ground a crop rather than another can be cultivated. So, the height of the PV plant influences the type of crop cultivated and moreover the type of PV plant determines factors as the shading level, protection from intense windstorm or even the level of protection from extreme weather like hailstorm. In addition, the height of the modules influenced the easiness of movements within the field. Indeed, in the type 1 it will be easier to move around for worker, machines, or animals than in types 2 and 3. Animals have been mentioned since, all the reasoning made for agriculture are applicable even to breeding activities. It has been investigated all the categories of APV presented in the document and it has been expressed how the requisite C deals with the relative height from the ground level. To sum up, types 1 and 3 foresee an advanced APV configuration, meaning a combined production of both electricity and crop. These two are accountable for the biggest share of incentive schemes which have been thought by the regulator. On the other hand, type 2 is not accountable as advanced APV and, as straightforward as that, it will not be recognized a significant share of the incentive schemes. As stated by the Italian government, fixing a minimum height to be respected any kind on installation related to APV, is an insurance policy for agriculture and to protect its development which otherwise could be threatened by the higher economic profits related to energy production. That is why, limits are fixed at:

- Height at least equal to 1,3 meters in the case of breeding activity, to allow the movement of animals.
- Height at least equal to 2,1 meters in case of agricultural activity, to safeguard the movement of agricultural machinery.

2.8.4 Requisite D

With requisite D the monitoring and feedback parts of the APV plant come into the scene. Indeed, to be funded by the regulator the APV installation must maintain some specific parameters' values in the long run. To do that, requisite D requires the owner of the plant to install a detailed monitoring system. Within the D requisite, the two parameters under analysis are: water savings and the continuity of the agricultural activity on the soil.

1. **D1: Water saving's monitoring.**

On of the biggest benefit introduced thank to an APV implementation is the reduction of water needed for agriculture on the field. Indeed, the shading effect of the PV modules reduces the average temperature at soil level and therefore whatever kind of crop will grow on the soil with a lower need of be irrigated. In addition, with some specific configurations, the APV plant may become an asset to collect the rainwater, store it and use whenever needed. Even though these advantages are present, they should not be left unattended and consequently the regulator requires the monitoring system to be able to quantify the advantages brought. The water usage by the plant can be measured thank to smart meters installed on the field or, with a simpler approach, counting the number of water tanks used during the year on the surface. It is straightforward as knowing only the water consumptions after the APV implementation does not satisfy the analysis required. Indeed, it is necessary to possess information about the base-case situation, meaning the field cultivated without any king of APV plant. SIGIRAN and RICA are two databases suggested by the Italian government to be kept as examples and sources to perform a comparative analysis and benchmarking the two situations. It is worth underling how many farms in Italy possess wells and private lakes which are exploited as self-supplying for water. In these specific cases, it must be known how even with private sources, farmers have a limited number of m^3 of water which they can extract from the soil yearly and usually these boundaries are monitored by appropriate meters. Furthermore, in the paper it is specified how as a regulatory framework should be taken by APV owner the 'Decreto Ministeriale 31/07/2015' which detailed how to monitor water consumption in all Italian farms.

2. **D2: Agricultural activity continuity's monitoring.**

Elements which should be accounted at this point are the existence and the yield of the crop plus the continuity of the specific products' codes. In other words, an agronomist should be contacted, and the person should perform a detailed analysis of the yield, comparing situations before and after the existence of the plant. The agronomist should afterwards sign a paper granting that nothing has change, or at least that changes are within preestablished boundaries. No products' codes should be changes, and agricultural companies should not give up any specificity for favoring the energy produced by the APV plant. Here, the 'Decreto Ministeriale 12/01/2015' is the reference containing the guidelines to proceed.

2.8.5 Requisite E

Requisite E focuses once again on the monitoring system of the plant. Specifically, it is structured in three subcategories as: restoring the soil fertility, preserving, and empowering the microclimate and at last ensuring to the environment a certain resilience to climate change and all events caused by it.

1. **E1: Restoring soil fertility.**

The point here is the one of monitoring how APV plants' constitutions could enhance a restoring of soil areas even in areas that nowadays are abandoned and considered impossible to utilize. The monitoring system here is bounded together with all the structure concerning requisite D and E, without any too specific constraints.

2. **E2: Microclimate.**

The presence of the APV structures on the field may modify its microclimate. Indeed, the group formed by plant, ground, insect and all the other living things are affected, and the same time affects the microclimate. In other words, the Space Pore is impacted by this situation. These alterations may positive or negative affect the agriculture and therefore it must be monitored. Smart sensors may be positioned in the bottom side of PV modules and parameters as humidity, temperature and air speed may be analyzed over time.

3. **E3: Resilience to climate change.**

A risk assessment analysis is required in this point by the regulator. Guidelines are provided in the Italian PNRR where it is required that in the designing phase of the APV plant, the possibility of significant events due to climate change may happen. Indeed, more and more in the last years, heavy meteorological events had happened and often it caused devastation in building and therefore PV plants as well hypothetical APV ones. The reference scheme contained in the PNRR is referred to the DNSH criteria (Do Not Significant Harm), meaning how the environment should be preserved and safeguarded when designing the plant to resist climatic events.

In conclusion, it must be noted how briefly, requisites D and E may look quite complex either that the task would be performed by the APV installer and even more with the hypothesis that farmers would be forced to do that. In this paper, it has been noted and reflected about how the Italian government has left to the APV plant's owner the opportunity to delegate this aspect to an external expert, who is supposed to be operating mainly in the agronomic market. This point is rather crucial to simplify the management process and to eliminate some degrees of complexities. A three-year time spanned relation is required to be provided to the authority. In table 7 all the prerequisites required by the regulator are summed up. In the following section it will be verified whether the projects precautioned in this paper will be compliant or not.

Table 7: Summary of incentive schemes' prerequisites [13].

Prerequisite	
Minimum agricultural surface left available after the APV implementation	$\boldsymbol{S_{Agricultural} \geq 0,7 * S_{Total}}$
Minimum LAOR = Overall surface of PV modules/Overall agricultural surface	$\boldsymbol{\frac{S_{PV}}{S_{AGR}} \leq 40\%}$
Minimum height required	**1,3 m – If breeding activities**
	2,1 m – If agricultural activities
Minimum electric production, having as reference a standard PV. Standard – South oriented, 20° as tilt angle, grounded PV	$\boldsymbol{FV_{Agri} \geq 0,6 * FV_{Standard}}$
Maximum CAPEX	**1.500€/kWp installed**

To conclude, looking to the incentive scheme from a practical point of view, as previously said the incentive related to the reimbursement of the CAPEX equal to a maximum of the 40% of the initial CAPEX will be provided by the government through a mechanism of capital account. It means that entrepreneurs will have to sustain the costs at year zero and always at year zero the government will reimburse the 40% of the expenses as soon as it will have the insurance that the entrepreneurs have truly sustained the costs. This scheme is forced within the attempt to avoid, or at least decrease, the corruption which is unfortunately still common in Italy and would have led the government toward the risk of frauds.

Within CAPEX for what concerns the RES plant projected with the Agrivoltaic technology, allowed expenses will be.

- Expenses to the physical construction of the APV plant: PV modules, inverters, sustaining structures, electric cables, and all other components.
- Storage systems.
- Monitoring instruments, smart meters and all sensors which could be used in the monitoring activity.
- Expenses for the connection procedure of the RES plant to the national electric grid.
- Expenses for the logistic activities related to the project.
- Field set up expenses.
- Expenses for machineries required to install the sustaining structures.

- Project development and consultancy costs (Maximum amount equal to 10% of the overall CAPEX).
- Geological analysis and technical tests plus trials (Maximum amount equal to 10% of the overall CAPEX).

Updated regulatory framework – April/May 2023

Furthermore, between April and May 2023 the Italian government released a new version of the law decree regarding the Agrivoltaic market. Indeed, incentive schemes and technical parameters were updated from the version available at the beginning of the thesis work. This new version was sent to the European Commission which will evaluate it, even though there are not any deadlines posed, and it will send back the regulatory framework to the Italian government. With or without modifications, the Italian government will afterwards officially kick off the business maneuver with the willingness of reaching objectives posed, with a time horizon of 2026 as first check point.

According to the new paper, GSE will remain the institution uncharged of monitoring the market, releasing incentives, and keeping relationships updated with APV owners. In addition, GSE will be appointed of verifying the compliance of APV plants with prerequisites set. The reference paper for what concerns technical prerequisites will remain the [13]. For seek of precision, the only difference between this new one and the old decree is embedded in the economic framework, which nonetheless, resulted being quite a significant modification. Indeed, in this new decree the 'Two Part tariff' was introduced. This new for is no more based on auction to set the tariff recognized to APV electric production. On the contrary, a tariff was set and the remuneration for the RES plant owner will always be the same. If the market price of electricity will be lower than the tariff, the government will pay the difference, while if the market price of electricity will skyrocket again as happened in the last two years, the RES plant owner will reimburse to the government the difference between the market price and the tariff. In other words, this new scheme grants a higher security to the government which will see its risks decrease, at least from an economic point of view. The incentive scheme will again be granted for a time horizon of 20 years.

Finally, the minimum peak power required in the previous version, which was equal to 300 kWp per plant, was removed and in the new configuration all APV plant will be allowed regardless their dimensions, if they will respect economic limitations summed up in table 8.

Table 8: Updated main economic and technical features of APV's law decree as declared by MASE in May 2023 in "Decreto Governativo Agrivoltaico".

Nominal peak power	Tariff [€/MWh]	Maximum allowed cost [€/kWp]
$1 < P \leq 300$	93	1.700
$P > 300$	85	1.500

In Emilia Romagna, where the plants studied will be built, the GSE recognizes an extra incentive equal to +10 €/MWh to account for the different level of ASR if compared to the South of Italy. Finally, the LAOR parameter is no more mentioned as constraint in the new law decree, differently from the previous one.

PUN - Market value

PUN value stands for Prezzo Unico Nazionale and it is the average price of electricity in Italy, average because the Italian peninsula is divided in seven market areas, each one has its PZ, Prezzo Zonale, but consumers pay within their energy bills the PUN, to consider the different cost of energy production experienced in different areas of the country. Every day the PUN is settled in the Day Ahead Market, meaning that the PUN value is defined one day in advance and then it is often adjusted in the Infra-day market to account instability of the national grid and unpredictable peak of consumptions. In the paper, as well in the entire energy investment assessments, PUN value is a matter of massive importance since it represents energy prices. Moreover, in this paper, it will affect all the self-consumption reflections. Indeed, when talking about energy self-consumed by an industry which has its own RES plant, to evaluate that energy the value used is the PUN. Then, in the self-consumption reasoning, other expenses as taxes and transmission and distribution charges are considered. The self-consumption quote represents a massive role in the economic evaluation since it is reflected in a direct saving in the monthly energy bill. Finally, even the energy fed into the grid, with some RES plant business models is evaluated and paid by the GSE to the RES plant owner at the current PUN value. On the other hand, in a business model as the two-part tariff, the PUN is no more a difference maker parameter since the energy tariff is predetermined by auctions and is kept fixed regardless the market fluctuations.

Of course, forecasting PUN fluctuation is nothing but complex, moreover if the time horizon analysed is twenty or more years. The last two and a half years are an example of how the PUN value could be volatile. In the following part of the paper, assumptions will be made to forecast, with reasonable assumptions, the PUN value required in the economic analyses. In table 9 are reported PUN values of the first half of 2023, while in table 10 the averages of PUN values of the last years have been reported.

Table 9: Summary of PUN market values – first half of 2023 [43].

Time period	**PUN [€/MWh]**		
	Average	**Minimum**	**Maximum**
January	174	48	295
February	161	62	272
March	136	3	245
April	134	10	260
May	105	9	197
June	103	20	191

Table 10: PUN's trend in the last years [43].

Reference year	**PUN [€/MWh]**		
	Average	**Minimum**	**Maximum**
2015	52	6	145
2016	43	11	150
2017	54	10	170
2018	61	7	159
2019	52	1	108
2020	39	0	163
2021	125	3	533
2022	304	10	870

LCOE - Trend analysis

As highlighted in the latest report carried out by IRENA [44], in the last ten to fifteen years the worldwide trend regarding photovoltaic costs has been the one of a reduction in the entire line. Indeed, due to the massive campaign towards sustainability and green energy production, huge number of capitals have been invested in research and development field, dealing with all RES technologies, including PV. From 2011 to 2021, Italy for example has experienced a reduction in the LCOE of utility scale PV equal to -88%. Obviously, these values are not completely reflected in small PV too, since economies of scale are more difficult to be achieved in domestic plant, from 3 to 20 kWp installed, rather than in utility scale ones, where peak power involved are few MWp. In figure 29 this aspect is summed up and numbers from all around the world are provided.

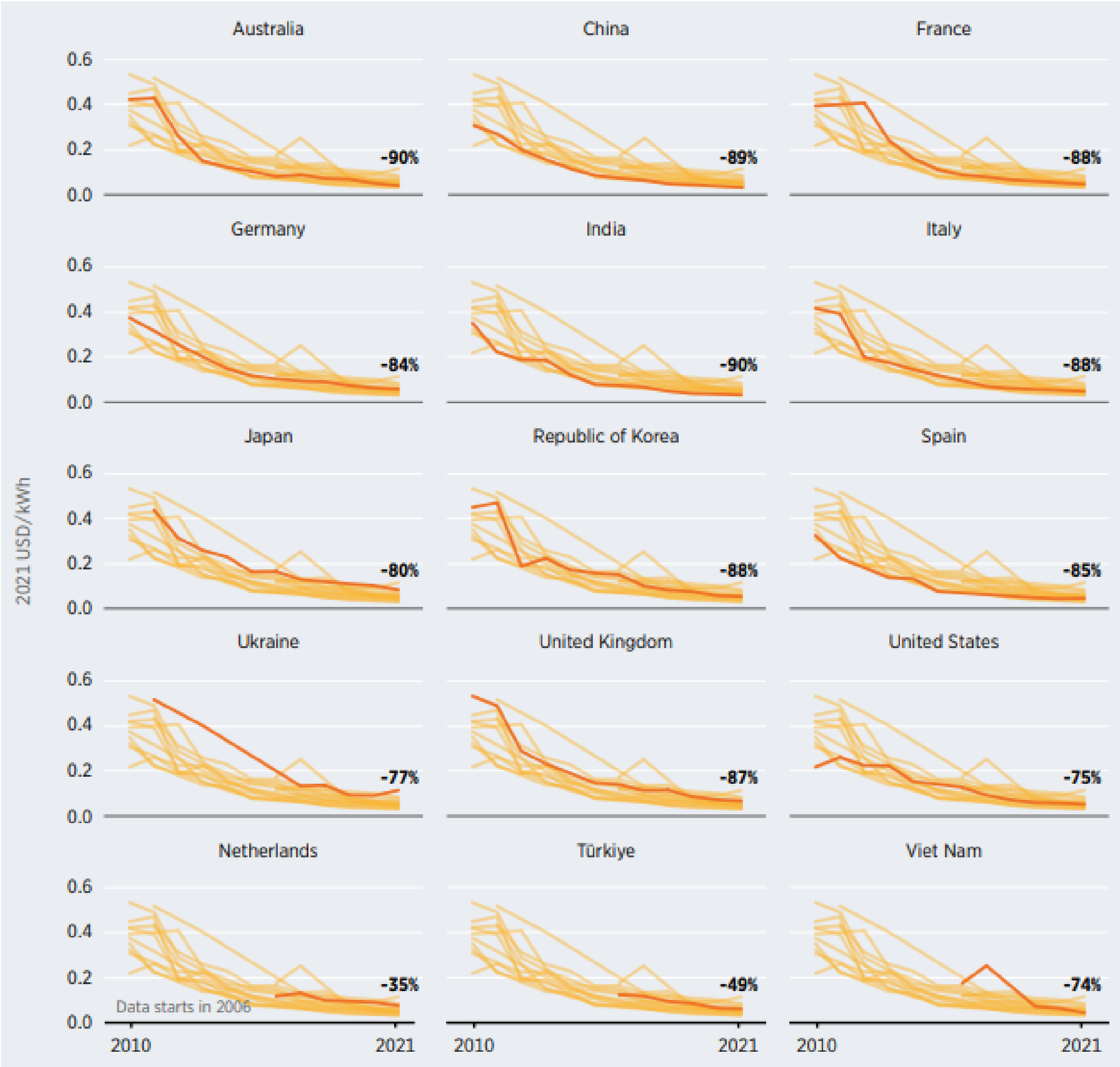


Figure 29: LCOEs' trends worldwide [44].

Unfortunately for Agrivoltaic technologies, since this new wave of innovation has just started spreading worldwide, research and developments have not jet reached such efficiency levels. Therefore, LCOEs regarding APV projects will be higher, regardless of the type of installation, if compared with traditional utility scale PV. Indeed, as it happened for PV fifteen years ago, in this initial phase, incentive schemes are required to turn the technology from inconvenient to a convenient one. The hope and the willingness of regulators worldwide, as well as environmental institutions, is the one of reaching levels of efficiency high enough to turn Agrivoltaic into a competitive technology as soon as possible, maybe with even a faster development process than the one experience by traditional PV. Always according to [44], at the current state of the art, the difference between an average LCOE of a utility scale PV and an Agrivoltaic one can be settled between 30% and 40% more. This gap considers both higher CAPEX and OPEX which are required to be sustained in the case of APV projects. Moreover, agricultural yields are considered in the LCOE computations. These latter are present in APV LCOEs while are missing in LCOEs of utility scale PV plants, regardless the specific configuration. In figure 30 it is reported how the decrement in the overall LCOEs values in PV sector was possible mostly due to the technological advancements in PV modules. Indeed, the cost of modules significantly affect the CAPEX of a RES plant, and it was one of the first research areas tackled to achieve economies of scale and productivity benefits. In the project here, a monocrystalline PV module will be considered, which is the technology enhancing the best available performances within all the products available in the market.

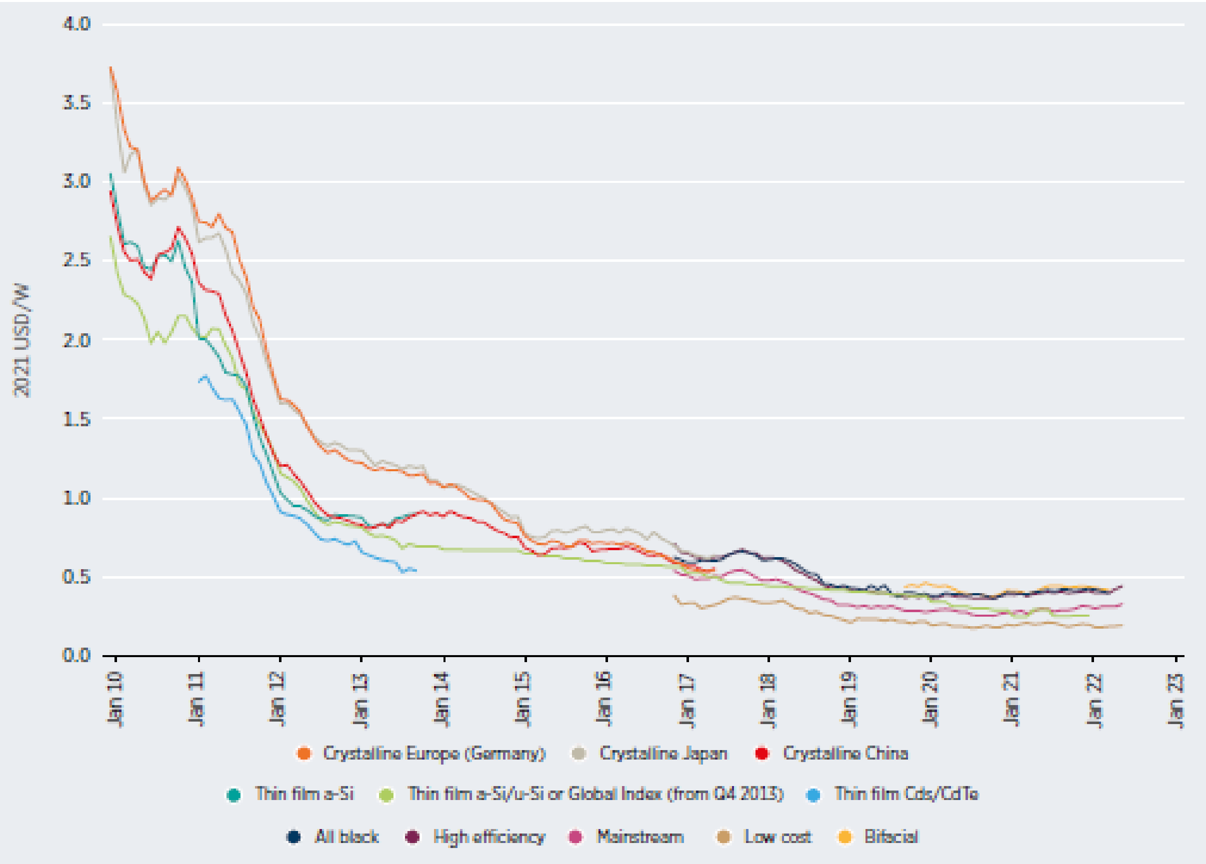


Figure 30: PV modules' costs – Trend analyses over the last thirteen years [44].

3. Agrivoltaic projects' results

3.1 The company

Starting from January 2023 a concrete project regarding APV's systems implementation has been carried out between the company Erreci Impianti S.r.l. and two entrepreneurs in the city of Piacenza, Emilia Romagna, Italy.

The company is a relatively young company, which was born in the April of 1990 in Busto Arsizio (VA) named as Erreci Impianti S.r.l. At the beginning of his experience, Roberto Rosanna, the founder, was mainly an electrician operating in both residential and commercial businesses. During the first years, the main activity was the one of realizing and maintaining electrical systems spacing over an operating field equal to the province of Varese with some excursion in the Milan area. Then, in 2002 the company had a massive turnaround with Roberto's brother, Alessandro, joining the business to help his brother handling the growing number of orders. Alessandro had a different background respect to his brother, bringing in the company a more economic and legislative, he graduated in law, oriented point of view. In the same years, a third figure joined the management team, Andrea Dieci. Andrea was a young engineer, who had studied electrical engineering both at bachelor and MSc levels. The three of them together raised the company business up to unexpected levels. Indeed, in 2007 to Erreci Impianti S.r.l. another branch was added with a business unit called Erreci S.r.l. the new business unit was dedicated to photovoltaic plants installation, a market which was skyrocketing as in Italy as in the rest of Europe in that period. Erreci S.r.l. since the beginning of its campaign has offered turnkey installation, covering all the steps of value and supply chain. In 2009 both the business units joined together reached 10 ml€ of sales. A second headquarter was opened in Fiorenzuola d'Arda. First, it was an opportunity to leave the regional boundary of Lombardia and exploit all the opportunities presented in an economically rich area as Emilia Romagna. After having surfed the wave caused by all the different 'Conto Energia' in Italy, massive incentive schemes which helped the diffusion of photovoltaic plants, even though the system was badly managed and it ended up running out of money from one day to another, the company experienced an economic crisis in the subsequent years. Moreover, all Italy went through economic crises between 2008 and 2014 which affected all the sectors of Italian economy. To reestablish a safe position in the market, it was decided to start the reselling business of utilities as gas methane and electricity itself. Once again, a successful move which led the company rising again both in terms of employees and sales. Erreci kept growing and in 2020 the company found a startup called 'Renewable Community', another strategic and wise move to tackle the business of Renewable Energy Communities, a business which three years ago was standing at the horizon and today is on the table of regulators and strategic businesses units of the most important companies worldwide. REC and APV plants are the two strategic directions that the board decided to undertake in the contemporary timeframe, being aware of the huge potentialities behind both. The range of customers will rise and at the same time incentive schemes are forecasted to be structured by the Italian government to sustain the development of these two markets.

Figure 31: Erreci, Renewable Community and Repower logos [40].

Nowadays, Erreci is a so defined PMI: Piccola-Media Impresa, which are the main type of business that characterize the Italian landscape. Finally, in 2022 Erreci was chosen by Repower as a photovoltaic partner to develop plants together. On the one hand, Repower is one of the most important players at European level as seller of utilities, with countless other business sectors as the e-mobility, charging points and others. It owns a capillary net of salesforce spread all over Italy. One the other hand, Erreci has a deep and consolidate know-how of photovoltaic plants. One of the ideas behind the joint venture is the attempt of the two of exploiting Repower's net to sell photovoltaic installations at a pace faster than ever and with a higher efficiency. What will come further is unforeseeable, there are no certainties, but Erreci will keep on growing in all directions, without precluding itself from any business opportunity which will show up at the horizon. During the second semester of 2022, Erreci was contacted by two entrepreneurs from the Piacenza area to talk about an Agrivoltaic project's development. Both come from the agriculture field, so they have a concrete know how about the agricultural side of the topic whereas they needed a partner from the photovoltaic side. The company was honored that the choice of the two entrepreneurs fell on it even though, at the beginning, few tensions arose. Indeed, since the company had never worked on a similar kind of project before, the threat of not being able to sustain such a new business was present. Nevertheless, after a study phase where research was conducted to better understand both the state of the art of the technology underpinning the topic and the regulatory framework, the project was settled.

3.2 The project

The Italian government, towards its PNRR (Piano Nazionale di Ripresa e Resilienza), allocated 1,1 billion€ for the development of APV projects. These projects should respect some or all the prerequisites and guidelines expressed in the previous paragraph. Clearly, such a massive amount of money attracted in the last year both private and public players trying to collect funds as much as possible. In most of the cases, a joint venture between a photovoltaic and an agricultural preexisting know how were thought being necessary and as so Erreci's project started. No opportunities concerning the APV layouts were excluded, and as so all the alternatives were studied to present to the customer/partner all the wide range of occasions. A predefined scheme was developed with some clarification of the differences about the definition of advanced and traditional APV. Since incentive schemes were different according to the category in which would have fell the plant after its realization, it was crucial knowing the concept in advance to perform economic evaluations. During February 2023 a first inspection was performed. First, it was the first time for company's managers to meet the clients in person, and second it was an opportunity to talk clearly about ideas and expectations both sides. The first meeting was held on the 21st of February 2023. Differently from what was originally expected, the two entrepreneurs showed two possible field on which they declared intentions to build two different APV plants. Indeed, the two of them resulted interested in investing on the one hand into a small APV plant, to be built on a land area of approximately 2800 m^2 and on the other hand on a way bigger area of almost 42000 m^2. The two solutions from now on will be called APV1 the smaller one and APV2 the bigger one. For seek of simplicity, the two of them will be analyzed in parallel, trying not to mix up information and concepts. Finally, after the two inspections on both the areas, there was a moment in which APV technologies were explained to the entrepreneurs. Indeed, the reasoning was the one of starting from them, explaining all the characteristics of the literature available solutions and checking some real and concrete examples already working worldwide. Since Erreci has the sufficient know-how to install either Stilt-mounted or Grounded-mounted solutions the crucial topic that mattered was understanding whether the APV plant would be coupled for example with the usage of tractors or with breeding activities. In addition, investments costs are different. Talking about averages, Stilt mounted solutions are more expensive than Grounded ones, with the counterpart on the production side. Once again discussion about average values, the electricity production capacity installed on 1 ha of soil is higher with Stilt than Grounded mounted. As previously mentioned, both the entrepreneurs were very prepared on the topic, and they had already done some research.

3.2.1 Scenarios Analysis

In the first part of the project four scenarios were considered, trying to create a perspective as wider as possible, the reasoning behind this initial work was the one off understanding which solution could have been feasible and why so, on the other hand the attempt of understanding which opportunities should have been abandoned and why was a necessity too. Because of limited resources, in the first phase of the work a scheme was created aiming at sharpening the paradigm into one only technological solution over the vast literature existing. Scenarios analyzed were:

1.0 Solution AS-IS: considering the current utilizations of the land areas remaining the same even in the future.
2.0 Solution TO-BE1: Grounded-mounted APV with vertical mounted PV bifacial modules oriented East/West.
3.0 Solution TO-BE2: Stilt-mounted APV with PV modules having 1 tracker (day-light follower).
4.0 Solution TO-BE3: Stilt-mounted APV with PV modules having 2 trackers (day- and year-light followers).

The first question which needed to be answered was the one of understanding whether an APV plant implementation could have been a more profitable solution than the current situation, in both the land areas. An economic analysis will be performed using data given from the customers about their current profits from the fields as a AS-IS solution, while concerning the energy side will be performed detailed analysis benchmarking the trade-off costs-benefits. The second question instead, regarded the technological aspect and specifically which type of APV technology would have been better for the situation. Indeed, as cited before, all the solutions have positives as well as negative aspects. While waiting for AS-IS scenario's data, the first reflection was the one that to look at the APV as an attractive solution from the economic perspective, the money coming from the Italian PNRR were needed. Indeed, the last released incentive scheme accounted for a 40% non-repayable incentive given to the investor of the overall investment amount. As it has always been, it was thought that an emerging technology requires strong incentive schemes to break into the market scene. Without, there would be no possibilities to self-sustain itself in the 'early-adopters' phase of the S-shape curve of the technology. Therefore, the first milestone was the one of structuring whatsoever plant in a way that the incentives would have been assured. According to that, as a first step to justify the scenarios 2;3;4 was the one of making them compliant with the guidelines given by the regulator.

According to this necessity, reflections were made searching for the easiest technological solution which could be implemented satisfying all the steps of the guidelines, to allow the APV plant falling in the advanced type. Since Erreci is a technician and installer company but, it is far from being a manufacturer and a producer, three suppliers were contacted. They have been operating in the PV sustaining structure market for years and they have the know-how to advise through precautionary approaches Erreci with some detailed parameters. Many of the following information are also gathered here are summarized from literature. Having collected many of the required knowledge, some reasoning, evaluations, and some considerations were performed trying to assess the reasons why one or another scenario could be better than others. It must be mentioned the fact that, non-differential expenses were not considered in the analysis because of their explicit nature. Indeed, the reasoning was the one of adopting the same PV modules type and inverters. All these expenses are non-differential ones, meaning that they should be undertaken in all the scenarios and do not affect final considerations.

In the following subchapters the two projects will be assessed and analyzed with a specular approach, for both the APV1 and APV2 a technical and economic evaluation will be given for all the three scenarios which do not include the AS-IS case. The reasoning and working process will always be the same, indeed, it will firstly be carried out a sizing process using GstarCAD and SolarEdge as reference software's, then the most important KPIs will be computed and the compliance with the regulator's prerequisites will be evaluated. Then, the economic evaluation will be performed trying to furnish to the reader of this paper an overview as wider and comprehensive as possible. As schematization of the working approach is given in figure 32.

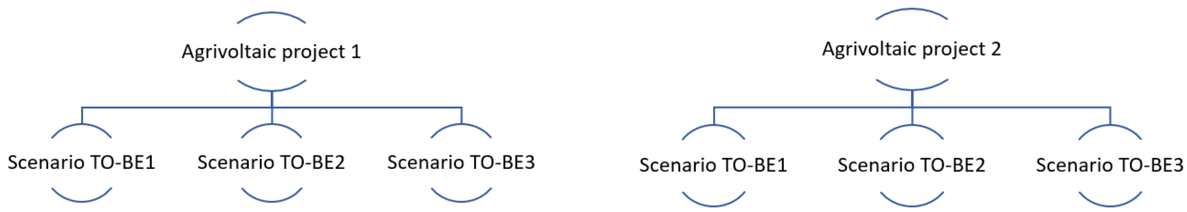


Figure 32: Scenarios analysis – Schematization of all the scenarios explored within the paper.

Finally, before deep diving the analysis part correlated with the two possible Agrivoltaic plants, in the table 11 below all the decision variables are listed from both the economic and technical perspectives.

Table 11: Technical and economic variables/coefficients considered.

Decision variables- Technical side	Economic side's KPIs
Agrivoltaic cofiguration	NPV
Modules distance	IRR
Pitch distance	PBT
PV module and inverter types	LCOE

3.3 Agrivoltaic plant 1

Dealing firstly with the APV1, the underpinning idea of the two were the one using the plant for self-consumption as a primary objective. Indeed, it is necessary to specify how next to the southern border of the field a well is present. It is 120 m deep, and it is used from April to late October to water the adjoining fields. Having experienced in the last two summers many drought and electricity costs as high as they have never been before, at the end of last summer the decision was taken to finance the development of a PV plant. The two business figures were well informed on all the opportunities available dealing with PV world at the current state of the art both in Italy and specifically in Emilia Romagna. According to that, they researched during wintertime on how difficult is nowadays obtaining allowances to build ground PV plants on agricultural soil. In addition, neither the Solar Belt rule was implementable in the condition. The concept of Solar Belt was introduced by the Italian government in 2022 in the law decree "17/2022 Energy Decree" with the attempt of favoring PV installations regardless the specific plant type. the concept is related to the new European Green Deal to speed up the implementations of renewable energy sources. The concept accounts for some simplifications from a regulatory point of view for PV plants. Specifically, it declares how even agricultural land areas are suitable for PV installations if:

- Areas are within a 500 meters' perimeter from an area with industrial, commercial of manufacture usages. The rule states for areas without any cultural bonds.
- Areas are within a 500 meters' perimeter from an active factory. The rule states for areas without any cultural bonds.
- Areas are within a 300 meters' distance from motorway [37].

Thus, after having understood the current industrial paradigm around the PV world, the two entrepreneurs understood that APV could have been their best chance to have the plant get up to full speed in a reasonable timespan. Moreover, as previously cited, a governmental document was released just few months before talking about an interesting incentive scheme. With this landscape behind and around them, they decided to contact Erreci Impianti and so the project started. The first meeting ended with an agreement between the parties agreeing upon the fact that enough information was collected to start the precautionary step of the business. The first step of the precautionary process was the one of collecting consumption data of the well. To do that, load curves were required. The two entrepreneurs downloaded the well's curves from the E-Distribuzione portal with their specific POD's credential and they sent all data to Erreci. Monthly data were downloaded referring to the last year. Since data of January 2023 were not present yet, the entire year 2022 was downloaded. The reason why load curves were so important is summed up in the attempt on performing a detailed energy analysis. Indeed, developing a precise analysis of which is the current consumption of the POD, and which would be the production of the plant, the energy self-consumed and the energy fed into the grind would have given a more comprehensive experience to the customer. Indeed, because customers are not always precisely informed about the energy world, trying to give them a specific perspective which could go beyond the simple economic analysis could have completed the scenario and clarified potential doubts to them.

As done with the Solar Belt concept, it is required to specify what a load curve is and why it is so important. Thus, a load curve can be defined as "A representation of the electricity demand over time, which depicts the evolution path of the electric power required by the consumer to the electric national grid over time." [38], [39]. Therefore, it can be summarized as a straightforward instrument to evaluate a customer's consumption, which may be done with a yearly perspective but even on a daily base. Plotting consumption, production, and insertion of a hypothetical industrial plant plus a PV plant can be useful to analyze requirements, pros and cons of a hypothetical implementation and its economic impacts. Moreover, in a hypothetical discussion with the customers, a graphical representation could turn to be helpful in appearing more prepared than competitors and describe why the investment could become a win-win situation from both the technological and economical sides. Load curves were downloaded as a column vector into an Excel datasheet. In addition, curves were in a quarter hour structure. The situation presented two hurdles which needed to be solved. Indeed, to be processed by the company software, the datasheet needs to be on an hour base and in a daily matrix. Step one of the data' elaboration required to sum up hour by hour the quarterly consumption data. Moving from a matrix [1x35040] into a one [1x8760]. Subsequently, as second step a transposition was required to shift the column vector into a matrix of dimensions [365x25], where 25 is due to the column reporting the specific day and then all the hours columns. While the first step was performed with a simple addition formula in Excel, in the second phase a short Excel's macro was implemented. The reason why all the work was required is twofold:

- On the one hand, a first analysis will be performed using Excel and some graphs will be discussed. This attempt is though being useful to get a first draft idea on the plant size. Indeed, before starting sizing a plant too big or too small for the customers' requirements, which will require extra work afterward, an overview may help in the understanding process. Precision of the first proposal will be increased and the risk fact in the precautionary document will be dropped.
- On the other hand, Erreci has developed and sharpened in the last 8 years a software, called Barbarasa, which is the brain behind the final step of the precautionary process. Indeed, after the design and sizing phases have ended, the proposed solutions are fed into the software together with the load curves. The software will then perform a comparison between the production/consumption profiles using the PVGIS database. The process gives as output a very detailed and precise analysis, straightforward and easy to

explain to customers. The only drawback is that the software asks in input a specific configuration of the load curves matrix, the [365x25].

Macro 1: ***Load curves Matrix***

```
1.0 Sub Vettore ()

  2.0 Sheets("MODEL"). Select
  3.0 For giorno = 1 To 365
      cella1 = "D" + Format ((giorno - 1) * 24 + 8, d) + ":D" + Format ((giorno - 1) * 24 + 31, d)
      Range(cella1). Select
      Selection.Copy
      cella2 = "J" + Format (giorno + 10, d)
      Range(cella2). Select
      Selection.PasteSpecial Paste: =xlAll, Operation: =xlNone, Skip Blanks: =False, Transpose: = True
  4.0 Next giorno
  5.0 Range ("J11:AG375"). Select
  6.0 Selection.Cut
  7.0 Sheets("RESULT"). Select
  8.0 Range("C3"). Select
  9.0 ActiveSheet.Paste
 10.0 For giorno = 1 To 31
      Range ("B" + Format (giorno + 2, d)). Select
      ActiveCell.FormulaR1C1 = "'" + Format(giorno) + "/01/2005"
 11.0 Next giorno
 12.0 For ora = 1 To 24
      Range (Chr (ora + 66) + "2"). Select
      ActiveCell.FormulaR1C1 = "'" + Format(ora) + ".00"
      Next ora
 13.0 Columns ("B: B"). Select
 14.0 Selection.ColumnWidth = 12
 15.0 Selection.HorizontalAlignment = xlCenter
 16.0 Rows ("2:2"). Select
 17.0 Selection.HorizontalAlignment = xlCenter
 18.0 Range("A1"). Select
 19.0 Sheets("MODEL"). Select
 20.0 Range("A1"). Select

21.0 End Sub
```

At the end of the elaboration process, a total consumption for the year 2022 was computed in 58.597 kWh. In addition, thanks to an invoice which the customer sent to Erreci, it was possible to better schematize the POD state of the art, with its characteristics better clarified as in table 12.

Table 12: Values extracted by the well's invoice.

Well's POD IT001E53286210	
Power available	100 kWp
Power reserved	100 kWp
Voltage	380V (Low Voltage)

Table 12 highlights how having the load curves and having an overview of the opportunities laying on the specific POD, the APV plant which will be dimensioned should not have a power higher than 100 kWp, since the current limit imposed by the POD. This fact is explainable because the Italian authority (ARERA) set up a limitation saying how a whatsoever type of PV technological plant must not overtake the maximum power committed by the POD. Another option fairly, could be the one of requiring, if needed by energy consumptions, a power increment to the energy supplier. Due to this topic, because the increment of the available power was not impossible as a matter of fact, before starting with the sizing process of the plant, a graphical analysis has been carried out by overlapping the production curve of a generic APV plant [40], the historical consumption curve of the well in 2022 and the hypothetical insertion curve given by the difference between the production and the consumption. As for this first phase, a generic Grounded-mounted PV plant was taken as reference parameter for the production curve since no historical concrete examples were present in the company know-how. Figures 33 and 34 show result with two hypothetical APV plants with a nominal installed power of 50 (hypothesis 1) and 100 kWp (hypothesis 2). Specifically, the blue curve represents the consumption of the POD. It is possible observe how the consumption is concentrated in the summer months, due to the presence of the well only bounded to the POD. During summer months the blue curve is way higher than the other two. On the other hand, the orange curve is the APV production over the entire year. It is possible noticing in this case how the curve respects the traditional PV productivity, with higher amount of energy produced in summer and lower ones at the end/at the beginning of the year, in winter times. Finally, the grey curve is the amount of energy fed into the grid, this value is equal to the amount of energy produced by the APV plant deducted by the amount of energy consumed, in other words, the self-consumed quote. It is interesting noticing how, during summer, the grey curve is almost always equal to zero, meaning that the entire amount of energy produced is self-consumed to satisfy well's requirements. On the other hand, in winter months, when the well is not used, the grey curve is equal to the orange one, stating how all the energy produced by the APV is fed into the grid. Clearly, during the summer, the energy produced is not enough to satisfy requirements, partially because the well is used even during night hours, when the

APV does not produce regardless the dimension, and partially because a bigger size of the APV plant would be necessary to fully match the amount of energy demanded. The flip side of the coin is the fact that, the bigger the plant, the better would the situation be in summer, until a certain peak power, but as well, the worse if considering winter period. Indeed, since the energy self-consumed is valorized with higher economic values than the one fed into the grid, the objective of a plant designer should always be the one of maximizing the self-consumed quote of energy. For the 50 kWp power APV plant, the self-consumption quoted, thus the share of energy self-consumed over the total amount of energy produced, having as a time frame a yearly valuation, is approximately the 29%. On the other hand, in the 100 kWp case, the self-consumed parameters drop util 21%. Between the two, it is therefore preferrable the first hypothesis.

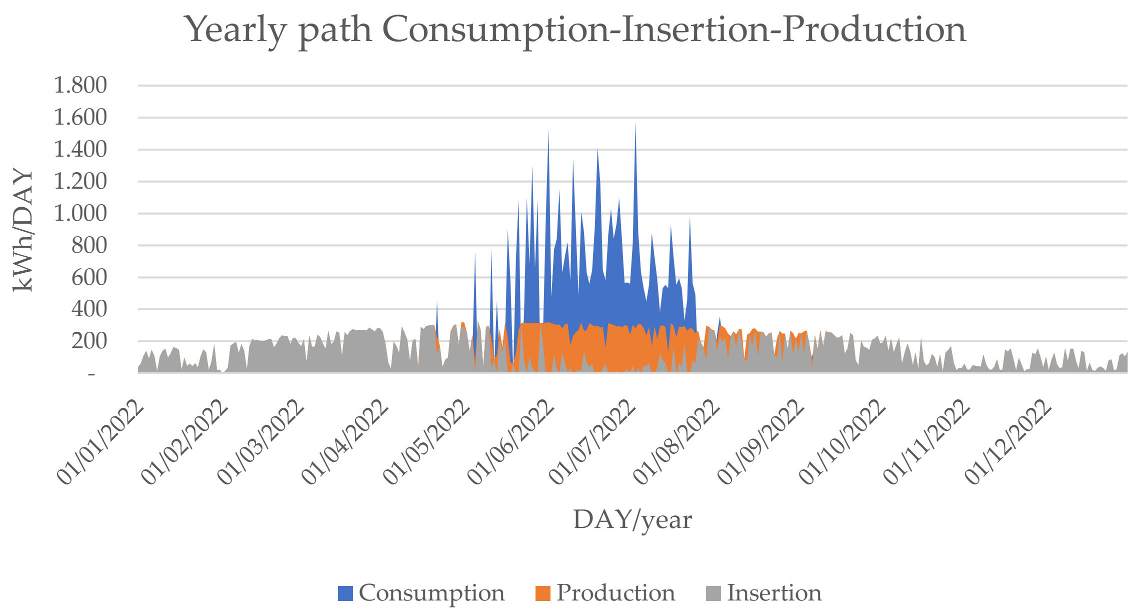


Figure 33: 50 kWp plant; Consumption curve=blue; Insertion curve=grey; Production curve=orange.

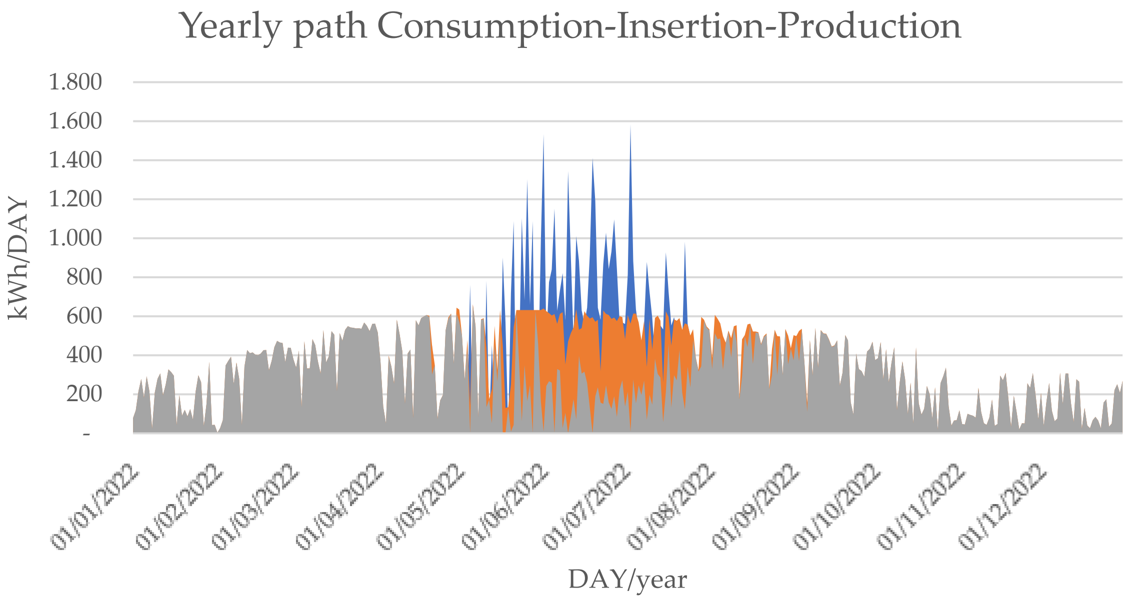


Figure 34: 100 kWp plant; Consumption curve=blue; Insertion curve=grey; Production curve=orange.

Together with the graphs, some parameters were computed to have a clear picture's overview of the opportunities handled. As reported in table 13, in both cases the self-consumption percentage is not extremely high. This fact is caused by the utilization path of the well. Indeed, in many months of the year, from the second half of October to the end of March/beginning of April the well is kept off completely and all the electricity produced by the plant will be fed into the grid. On the contrary, during summer's months, needs are way bigger than the production in both the configurations, saying how even a bigger dimension of the plant could be accepted considering only a limited sample time. In addition, during summer the watering process is often a 24/7 time based, meaning how during night the consumption still present whereas the production is zero. Although in this situation the option of storage systems may be considered, together with an oversizing of the plant to cover all the daily demand during summer and being even able to store energy for the night, three problems lead to interrupt the storage idea. First, the size of the field is not as big as should be to oversize a plant up to 250/300 kWp power which should be the minimum dimension to deep dive the solution. Second, in the Italian landscape, the Covid-19 pandemic, together with the Russia-Ukraine war and lately the incentive scheme 'SuperBonus 110%' lead to a shortage of products. Third, linking with the previous consideration, higher demand and low supply brought storage systems' prices to unprecedented peaks which will not necessarily allow the investment to be recovered in a reasonable amount of time. Since the economic Pay Back Time was on top of the list of the customers' requirements, the idea of storage systems was abandoned. Moreover, it was noticed how the percentage of self-consumption decreased from the 50 kWp size to the 100 kWp one while the percentage of withdrawal reduction increased. This inverse proportion caused a tradeoff which must be accounted in the sizing process. Indeed, the attempt of Erreci was the one of not sacrificing any of the two parameters to be able to present to the customers a datasheet with satisfying values both sides.

Table 13: Reference parameters for the benchmarking of the solutions.

	APV1_Hypothesis 1	APV1_Hypothesis 2
Power	50 kWp	100 kWp
Consumption	58.598 kWh	58.598 kWh
Production	66.367 kWh	132.733 kWh
Insertion	47.339 kWh	104.876 kWh
% Withdrawal reduction	32,5%	47,5%
Self-consumption	28,7%	21,0%

The idea behind this initial analysis was also the attempt of understanding how and how much the potential plant's installation would have affected the well's management system. To compute the withdrawal reduction, it was used the following equation:

$$\frac{\%\ of\ selfconsumption * Energy\ produced\ by\ the\ plant}{Energy\ consumed\ by\ the\ well's\ POD}$$

Again, the self-consumption percentage was computed as:

$$\frac{(Energy\ produced\ by\ the\ plant - Energy\ fed\ into\ the\ grid)}{Energy\ produced\ by\ the\ plant} * 100$$

3.3.1 Scenario TO-BE1

As a first attempt, all the computational criteria accounted in the precautionary approach were listed. The reason why is that collecting an outlook over all the possible strategic leverages could turn to be helpful in the decision-making process.

1. Cost perspective criteria:
   - PV modules
   - Inverter
   - Sustaining structures
   - Installation costs (infixion in the ground)
   - Other electric components (string cables)
2. Technological projecting criteria:
   - Tilt angle
   - Azimuth angle
   - Specific energy production expected [kWh/kWp/year] (PVGIS, 2023)
   - Power reserved in the POD
   - Height; width; length of the APV rows
   - Wind load [41]

It was decided that the APV system, vertical mounted would have accounted one level of modules. The aim of the ideas was twofold: on the one hand, one level would have limited the final height reached and therefore caused less problems in terms of wind load. Indeed, the higher the structure would have been, the bigger it would have been the sail effect. This situation is caused by the Italian framework which, as detailed in the previous chapter, requires a minimum height of 1,3 meters for breeding activities and 2,1 meters for agricultural. On the other hand, the second reasoning performed was the one of trying to exploit the space available as much as possible with one level, understanding if a sufficient power could be gained and limiting sustaining structures' costs and just in case increment to the second row. To do that, next step was defining a pitch distance between rows. Here it was decided to keep the worse scenario possible, to hypothesizing of being always on the 21st of December, when the shadow of objects, and consequently of PV rows, is maximum. On that date, Sun rays are at their minimum. During this task it was used GstarCAD 2022 software, and the drawing scheme is reported below in figure 35. As discussed, the Sun rays' line was inclined by 21°, it was considered the breeding limit of 1,3 meters height from the soil and the overall height of the PV module plus horizontal sustaining structures were considered equal to 1,5 meters. Last, an average depth of 0,3 meters concerning the APV vertical structure was considered. All these values were decided benchmarking both the existence Erreci's know-how and the literature review which was done on real implementations' parameters. Figure 35 shows the ideal distance to be kept.

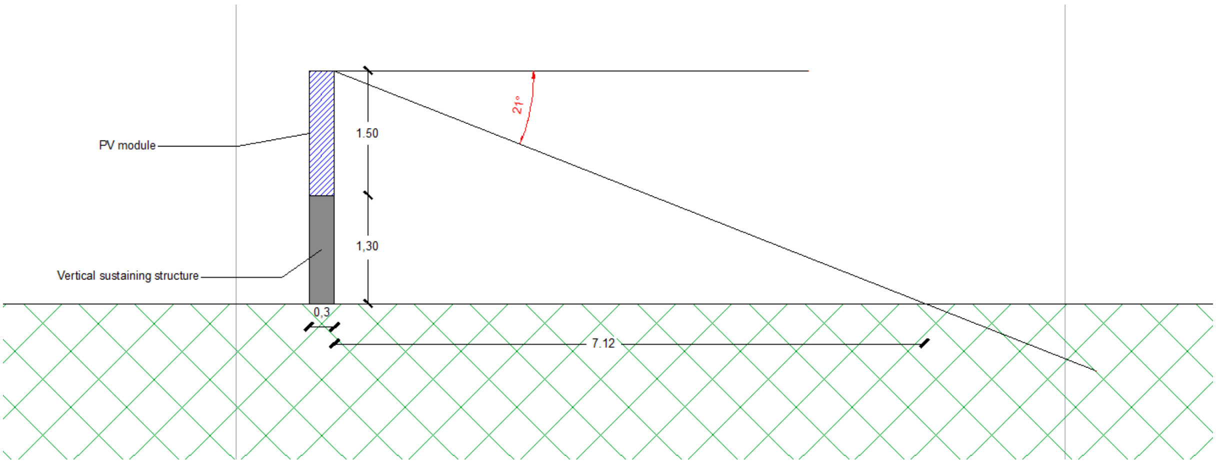


Figure 35: Rendering of the vertical mounted bifacial PV modules' structures – 1 row.

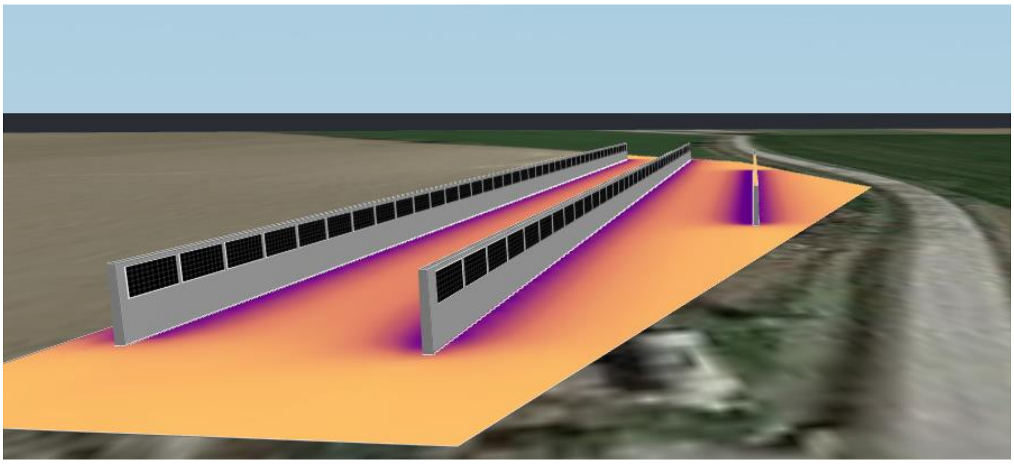
Even though the graphic representation states that 7,12 meters are sufficient in order not to excessively affect the irradiation percentage hitting the soil and the next PV row, it was decided to keep a 10 meters distance as interrow pitch. It was indeed decided to preserve the agricultural or breeding activities keeping irradiation levels above the average's values presented in literature. At this point, the APV configuration was decided, all the required parameters have been clarified and that is why the first sizing attempt started. To proceed with the sizing process, Erreci has adopted in the last 5 years a software called SolarDesigner, developed by the company SolarEdge. SolarEdge is a worldwide leader in terms of manufacturing PV components, from PV modules to inverters and optimizers. The software allows both a 2D first and 3D afterwards representation. Then, it allows the designer to insert PV modules over the hypothesized structure. For seek of simplicity, at this step it was supposed a row length of 10 meters for what concerns the structure, then each structure can be repeated as many times as wanted. It was designed a configuration 2D with 2 rows of 100 meters length overall and 1 row of 50 meters length due to land area's space boundaries. Dealing with the 3D representation of the plant, the previously mention parameters were kept:

- Height = 2,8 meters
- Depth = 0,3 meters
- Length = 50/100 meters

In figure 36 is highlighted the first draft of the project.

Figure 36: 3 rows, vertical mounted APV. In red is signed the well's location (LEFT). 3D structure (RIGHT).

Finally, the first draft of the APV plant layout was done. The final azimuth angle was set at -73° while the tilt one equal to 90°. Between each module 0,08 meters were kept, accounting the vertical sustaining structure. Thank to SolarDesigner, it was even possible to represent the overall irradiance projected on the ground as shown in figure 37. In addition, figure 37 also represents the plant configuration with PV modules visible. In this step was decided to use the JAM72D30 550/MB/1500V from JA Solar as PV module. With the space available and the selected module, it was possible to size 105 PV modules with an overall nominal power of 57,75 kWp. With all the given values, SolarDesigner estimated a yearly production of 53,22 MWh. To complete the APV plant, was selected the inverter SUN2000-50KTL-M3 from Huawei. At a first glance, it may be strange the fact that the inverter selected has a capacity lower than the overall power of the plant. On the contrary it was chosen on purpose; indeed, the plant will never reach production peaks equal to its nominal power due to its azimuth. Indeed, the two peaks will be in the morning and in the afternoon, but both will have an equally distributed production lower than the peak of 57,75 kWp. In figures 37, the final layout is shown together with the irradiance.



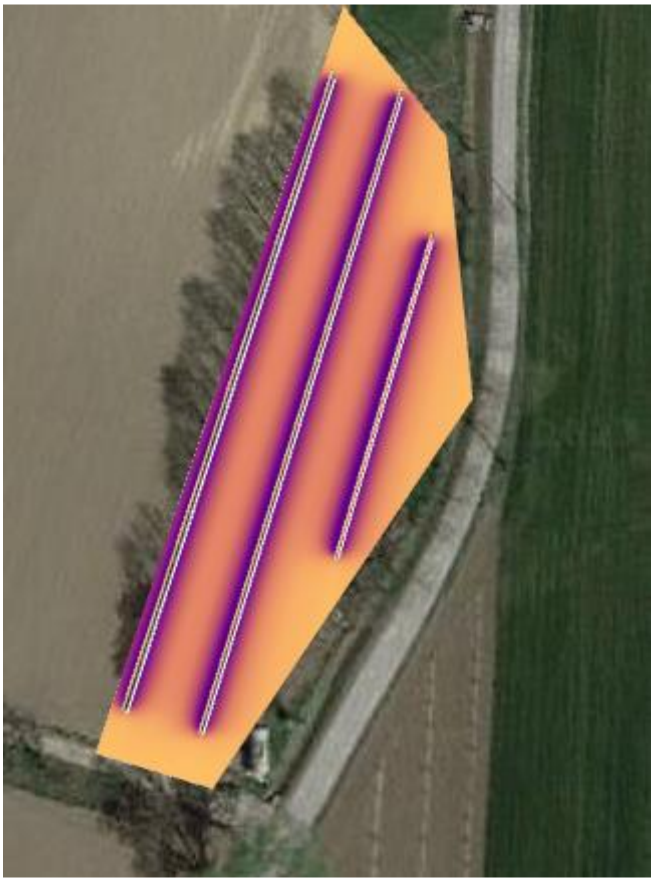


Figure 37: Rendering of the solar radiation incidence – Purple/dark equals lower than 50% - Yellow equals normal incidence.

It may be questioned why these two products were selected within the thousands of possibilities that are nowadays available on the market. Indeed, in the last 25 years since the PV technology gained momentum, many companies entered the business becoming producers of that specific products' technology. Moreover, it is worth saying how at the beginning Europe and USA where leaders in the production, while in the very recent past Asia basically obtained an almost monopolistic control of the market. Indeed, most PV modules, inverters, optimizers, storage systems are produced in Asia, where raw matters are abundant and labour costs still lower than everywhere else. This issue went on top of newspapers with covid-19 when, due to the lower production due to the pandemic in Asia, products shortages were caused in all Europe as in the rest of the world. After this preamble, it comes to state the high quality of both JA Solar and Huawei as producers. In addition, the two of them can combine low costs and high quality with a rather good availability. Indeed, SolarEdge is undoubtedly still the worldwide leader in terms of quality but first its costs are higher than its Asian competitors and mostly its supposed Order Cycle Time (OCT) is unaffordable in the market due to endless expected delivery time which may reach even 12/18 months at the time of writing. On top of that, the choice was nothing but an opportunistic one. Indeed, Erreci has been working with JA550 bifacial and Huawei inverters for many years since specific characteristics which are really appreciated by customers and therefore made products easy to be sold.

Figure 38: Monocrystalline PV modules from JA Solar – Model used within all the projects proposed in the paper [40].

Starting from the PV modules, two are the most interesting ones: the module efficiency and the temperature coefficient of P_{MAX}. The former is equal to 21,2%, it says how given 100 the amount of sun radiation hitting the module, including direct, diffuse and reflected components, 21,2 of this radiation is transformed in electricity. The value is higher than the average of the modules generally available one the market. The atter is not as famous as the modules efficiency but is equally important. Indeed, it declares which is the power loss of the module due to high temperature, specifically when the module temperature rises above 25 degrees. Since even in the considered latitude, it is quite common from April to October that the temperature of the module overtakes the threshold, the lower the coefficient the better because it would highlight lower losses. In this product the coefficient is equal to -0,350%/°C. Hypothesizing a temperature which in July and August may reach 45° on the modules, the maxim power loss will be restricted to 7%. In addition, being the PV modules bifacial ones, that product will grant to the RES plant an energy production of both sides and the modules, at explained previously. The albedo coefficient of green grass, which will be all around the hypothetical APV plant will be set equal to 0,15. The value is slightly lower than the reference ones in literature, when dealing with such aa surface. Nevertheless, the aim of the paper if giving to the reader an evaluation as cautious as possible. Moving to the inverter side, this product accounts one of the highest efficiency rates in the market landscape with a maximum conversion efficiency up to 98%. Nevertheless, the most appreciated characteristic in this case is the number of MPPTs (Maximum Power Point Tracker). MPPTs' number which represents the flexibility that the inverter gives to the installer while setting up the electric strings' configuration. In addition, flexibility is also granted by MPPTs during the plant working time by the capability of the inverter to better fit the energy and voltage paths. Indeed, the higher number MPPT the easier will be for the installing company to configure the PV, or in this case APV, plant. In the Huawei 50KTL – M3, it is possible to exploit up to 4 MPPT. After this layout, which granted a high enough installed power to satisfy the well's needs, a second layout was studied. The second option thought was the one of raising a second level of PV modules in each row, from a plant's features point of view this solution would have doubled all the parameters: 210 PV modules, 2 inverters and a nominal power of 115,50 kWp. Probably, these dimensions would have been exaggerated for the currents needs and the APV would have been over dimensioned. Nevertheless, the possible configuration was never completed since the emergence of two problems: the shading effect caused by the PV modules' rows and the wind load. The former was, as previously done, computed using the software GstarCAD. It was added another level of PV modules with the same assumptions of before in terms of sustaining structures and shade effect in the worst case, 21st of December. Unfortunately, here a higher impact emerged. Indeed, if the 7,2 meters of the one level configuration were affordable and were even necessary to allow an easy movement of animals and small machines on the field, in this case minimum pitch distance of 11 meters was found as shown in figure 39. As before, the agricultural entrepreneurs were consulted to better understand their opinion and how would have they reacted to the possibility. The feedbacks were not enthusiastic, indeed they declared how 11 meters could have been too much for small agriculture of breeding. According to both Erreci and the entrepreneurs' opinions, expanding too much the distance and rising the global height of the rows would have damaged the idea of APV within the community opinions, much cared by the customers. Nevertheless, the hypothesis of two levels per row was abandoned not much for this issue rather for the second one, which resulted being a more practical and concrete one from a technological and constructive point of view.

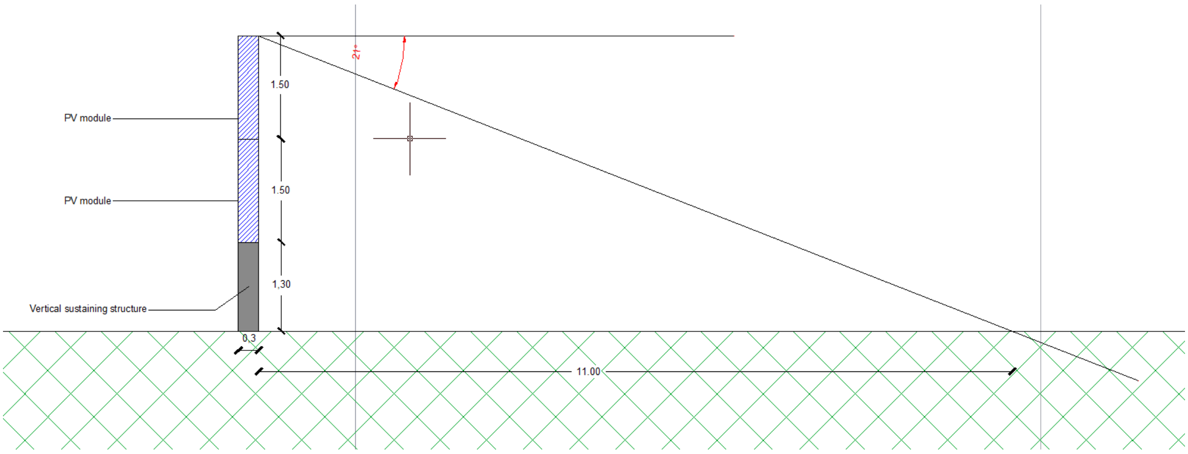


Figure 39: *Rendering of the vertical mounted bifacial PV modules' structures – 2 rows.*

Indeed, the latter was analyzed thanks to the software Dlubal, which required the coordinates in terms of latitude and longitude, the heigh of the structure and the infixion depth, which was hypothesized equal to 1,7 meters as done by Erreci in past plants, it was possible to state how 4,3 meters as height is way too high for Erreci to release a warranty over the plant. Indeed, the pressure exerted by wind and the sail effect caused would have put in danger the structures. Wind speed maximum was set at [38 m/s], values that could easily be overtaken not in wintertime but rather in summer storms which are more and more frequent in Piacenza area. Danger which was not excepted by the company since releasing a plant warranty would have exposed Erreci to a point that the company didn't want to reach. The entrepreneurs on the other hand wanted that specific insurance and therefore this latter configuration was not implementable. Since enough power was already reached in the first layout, it was not a big problem in this case. The situation will be different in the second APV plant analyzed as it will be detailed.

After an overall agreement was reached, the plant layout was plotted into the software Barbarasa previously mentioned. It requires as input data the number and type of PV modules and of the inverter. Moreover, it asks the tilt and azimuth angles of the modules' configuration. Then, it requires the hourly load curves of the point of delivery in a matrix form [365x25] and it computes the production of the hypothesized plant with the PVGIS data from the database PVGIS-SARAH 2016. In figure 40 the yearly path is represented. As extra detailed sample two generic days were taken, one weekday, the 14th of July 2022 and one weekend day, the 21st of August 2022. In the first case, in a summer working day the well exploits all the energy produced by the plant, the energy fed into the grid by the system is zero. In the second case, on Sunday, the well is not working and therefore almost all energy produced is fed into the grid. The attempt was the one of benchmarking as done before the production, the insertion, and the consumption curves but this time no more with a generic PV plant as reference but with the detailed APV plant under analysis. The self-consumption percentage will be equal to the 22,80%. Such a value is not extremely consistent. Indeed, I industrial plants usually PV installations are aimed at reaching at least the 50% of self-consumption, due to the higher economic value possessed by this energy in opposition to the one fed into the grid. Nevertheless, in this case the self-consumption could not be too high since the well works only for some months during the year. Winter months are not exploited. In addition, when it works, the well does not account any day-night preference and thus a big share of its consumption happens during night, when it is impossible for a whatsoever PV plant to produce energy. The APV plant will be localized around Rivalta, (PC) – Italy.

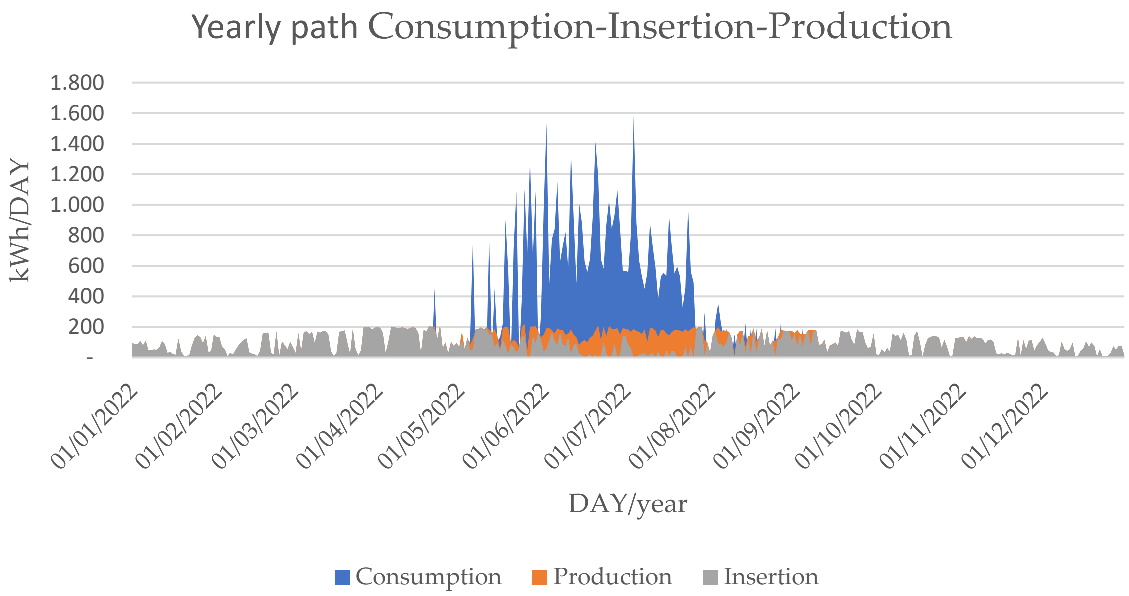
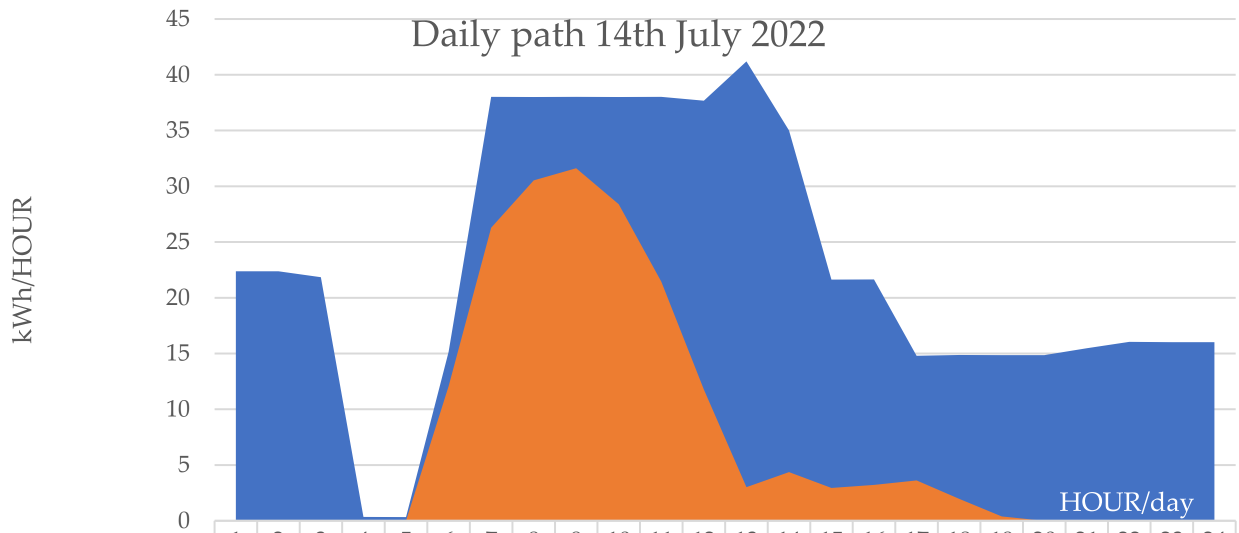
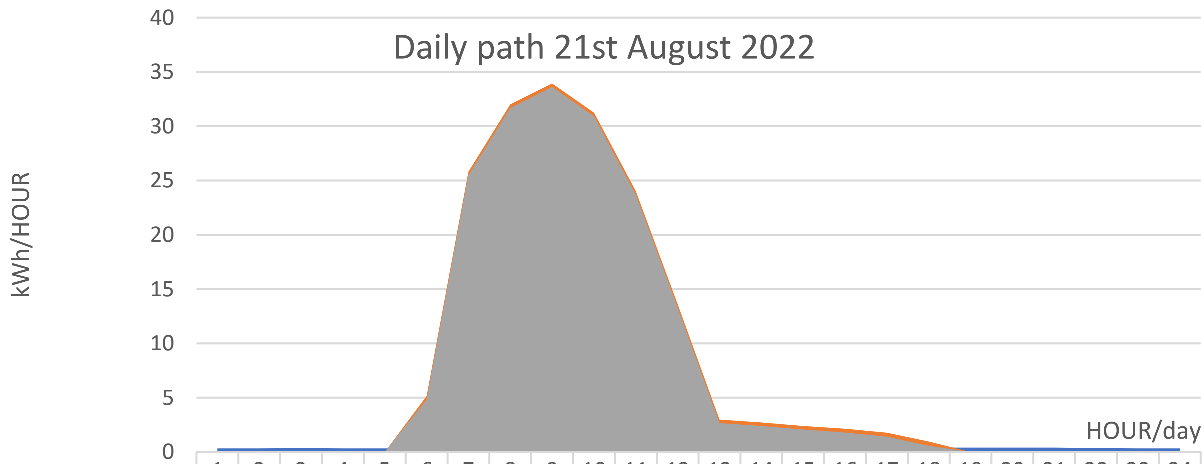


Figure 40: 57,75 kWp plant; Consumption curve=blue; Insertion curve=grey; Production curve=orange.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	22	22	22	0	0	15	38	38	38	38	38	38	41	35	22	22	15	15	15	15	15	16	16	16
Production	0	0	0	0	0	12	26	31	32	28	21	12	3	4	3	3	4	2	0	0	0	0	0	0
Insertion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 41: Daily path 14th July 2022.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production	0	0	0	0	0	5	26	32	34	31	24	14	3	3	2	2	2	1	0	0	0	0	0	0
Insertion	0	0	0	0	0	5	25	32	34	31	24	13	3	2	2	2	1	1	0	0	0	0	0	0

Figure 42: Daily path 21st August 2022.

Incentive scheme's compliance

In this chapter which explain the Italian prerequisites a table was made to sum up all the prerequisites which must be compliance to for an APV lant to grant itself access to incentive schemes. In this case, the table 7 is recalled and further explained in each subcomponent. The hypothesized plant will have a year 1 production equal to 53.219 kWh according to the PVGIS database. Thus, the expected specific yearly electric production will be equal to 921 kWh/kWp installed for a total power installed of 57,75 kWp. Looking to the requisites posed by the Italian regulator to access the incentive schemes, there will be no problem for what concerns the agricultural surface left after the APV implementation, indeed more than the 90% of the initial surface will remain available even afterwards. Talking about the LAOR parameter, each PV module will have an area of 2,7 m^2, which mean a total occupied area of 285,6 m^2. Adding the sustaining structures' bulk, the overall APV area is equal to 317,1 m^2, considering 0,3 m^2 of bulk for each PV structure, which is the parameter used for the ratio indicating the area remaining available for agriculture. Instead, the LAOR is equal to 10,2%, well beyond the thresholds of 40% maximum considering only the surface of PV modules.

$$LAOR = \frac{285{,}6 m^2}{2.800\ m^2} = 0{,}102$$

The monitoring system will be installed and be set according to the parameters imposed by the government. As well, since 1,3 meters were left from the ground to the bottom border of the APV installation, breeding activities will be the ones fitting the agricultural side of the business. Again, the continuity of the agricultural activity which used to be performed on the field will be granted following the CREA-GSE rules and even improved since before the main activity on the land was the one of extracting firewood while with the APV a more sophisticated one will enhance higher incomes and a better exploitation of the soil. The specific electric production, as explained, will be equal to 921 kWh/kWp installed. Then, a reference value of the same PV module and from the same PVGIS database was extracted. A tilt angle of 10° was considered, South oriented installation on ground as detailed by the prerequisites. A value of 1208,5 kWh/kWp installed was collected. The ratio out of the comparison states how the efficiency of APV is equal to the 67% of the reference case, value which is high enough to satisfy the requisite. Expressing all data in MWh/ha/year as required in the guidelines, results indicated 190 MWh/ha/year in the APV case and 248 MWh/ha/year in the reference case. Once again, a ratio equal to 76%. Also, the LER parameter was computed as:

$$LER = \frac{Y_{APV} * \propto}{Y_{REF}} + \frac{E_{APV}}{E_{REF}} = 1{,}34$$

As specified in the previous chapter, E states the energy yield for both the reference case with a South-oriented ground PV plant and in the APV case. Then, Y indicates the agricultural yield, values which were suggested by the entrepreneurs. Finally, α indicates the ratio of unused land area due to APV structures. The last requisite listed by the regulator is the toughest one to be satisfied and, honestly in this case it was not possible to satisfy it. Indeed, it is required that to access incentive scheme the minimum nominal power installed of an APV plant is equal to 300 kWp, way far from the current 57,75 of this first proposed study. Nevertheless, the reasoning behind the willingness of going thought all these steps is the idea that during the current year this threshold will be decreased to 50 kWp installed as minimum dimension. The reason why is straightforward and articulated as well. Indeed, on the one hand, in September 2022 the Italian government changed and the requisites list was an output of the old one. The new government, to be compliant with UE rules and targets announced massive interventions in all the energy-related market to simplify procedures. On the one hand, with the market of Renewable Energy Communities, it has already released a new document which simplifies the state of the art, with the declared attempt of increasing the number and speeding up implementations. Since, Agrivoltaic can be considered a relative of the REC concept, it is thought in this paper how this wall could be abated in the short term. In addition, the Italian landscape is characterised by the so-called PMI, 'Piccole Medie Imprese' which occupy a dominant position in the market. The number of PMI present on the Italian territory is bigger than multinational companies in all the market segment, agriculture is not an exception in the rule. Thus, investments required to install hundreds of kWp in plants may be feasible for multinational enterprises but not for family-businesses which are dominant in Italy. Agrivoltaic, as other RES typologies, have not broken into the scene due to these kinds of constraints imposed too often by an unwise regulator. Therefore, if the idea is really the one of exploiting European funds properly, parameters must be release an thresholds decreased. It is a conviction of the paper that by the end of the year, which is the best-case timespan of the project to start, things will be modified for the better. A lower limit will allow even small-scale entrepreneurs entering in the conversations around the business and this case is nothing but an example.

The previous hypothesis, which was made at the beginning of the project analysis, was than confirmed by the new law decree released between April and May 2023.

Economic analysis

First, while tackling the economic feasibility and eventual profitability of the plant, it must be specified as the AS IS situation, called Scenario 1 in the scenarios' benchmarking process, there is not a single economic activity performed on the area thought for the implementation of APV1. Therefore, the NPV of the reference case is equal to zero. Thus, any kind of designed investment which will enhance a positive gain in terms of economic NPV will represent a better case than the actual one. In other words, there is not an opportunity cost over the land area of this first precautionary approach which is required to be accounted. Once all the sizing process was done, the technological issues were defined both from the investors' perspective and from the company one, the APV plant first draft layout was ready. The precautionary document was completed for what concerned the technological aspects, the compliance with the regulatory framework and the hypothetic yield from electricity and agriculture sides contemporary. Although all these steps were performed and the process seemed to be well positioned to be completed, one step was still missing, and probably one on the most important one. Indeed, it has been mentioned how the entrepreneurs had been, since the beginning of the project, clear explaining how the process could start if and only if the economic perspective would have been satisfied on their terms. Consequently, all the economic feasibility of the process should be evaluated. Once again, the software Barbarasa was helpful concerning the pure PV aspects. Indeed, it kept updated PV modules and inverters quotations, according to the real time best price available on the market. At this point, an economic analysis was carried out and a prospect developed. First, it should be stated clearly which CAPEX and OPEX were considered within all the analysis.

CAPEX:

- Full investment cost of the APV plant, which is made by:
    - PV modules
    - PV inverter
    - Sustaining structures
    - Grid-connection
    - Bureaucratic procedures
    - Field settlement
- Inverter substitution

OPEX:

- Maintenance cost
- Insurance cost

PV modules' cost was estimated to be equal to 181 €/PV module installed. Overall, a total cost of 19.057 € was referred to PV modules. Furthermore, the Huawei inverter was quoted equal to an expense of 2.567 €. In the final full budget costs for the vertical sustaining structures were inserted. Erreci has a long-term agreement with a German producer which offers many solutions concerning with structures: from traditional structures to fix rooftop PV, to the grounded mounted PV and moreover structures for APV plant. Since the bifacial configuration vertically installed PV, no trackers were required and therefore the initial investment costs on this perspective were not as high as expected. Unless APV structures were computed being on average way more expensive than the traditional rooftop ones, the solution here chosen was undoubtedly the least expensive. A total amount of 8.000 € was precautioned for the sustaining structures. Overall, a total cost of 62.256 € was computed for the APV plant investment. First, it was thought to calculate the overall cost in terms of €/kWp installed, the reason why is that it was reflected how having that parameter could be a first rough occasion to benchmark the cost of an APV plant with a traditional PV one. The result was a cost of 1.078 €/kWp installed, which was reflected being placed in an average position at the state of the art of PV plants' costs if benchmarking both the cost variable and the dimension one. In addition, stepping back for a moment, here another aspect of the regulatory compliance comes into the game. Indeed, the regulator set a maximum amount dealing with the economic cost of APV installation, which was expressed in €/kWp installed. The upper allowed ceiling is equal to 1.500 €/kWp installed. Therefore, even this very last requisite was accomplished.

It must be underlined how in the economic evaluation this value will be decreased by 40% which is the number of incentives granted by the Italian government in the PNRR scheme if the requisites listed in the 'Linee Guida in materia di Impianti Agrivoltaici' will be respected. Well, the line of reasoning underpinning all the work has always been the one of doing whatsoever but getting the incentives. It meant scarifying some configurations and other limitations but now it comes to the reason why. Therefore, the CAPEX at year 0 for the investment will be equal to 37.353 €. Moreover, costs to set up the field, some trees should be removed, and to flatten the ground were decided to be accounted to the investors since their previous ownership of suitable machines to perform the work. All of them were included in the extra costs dealt by Erreci. As well, a reflection was made about the inverter. Indeed, the granted lifetime is of 15 years, and consequently an extra CAPEX for the inverter replacement is considered in year 15. An expense of 2.823 € was accounted for the inverter, to compute it, it was taken the current cost of the inverter and it was incremented by a 10%. The idea was to consider an expected inflation over the years. Finally, an amount of 32.631 € was estimated as an amount required to cover costs of levelling the field before the plant construction, building a fence perimeter around the plant with both safety and insurance reasons, the piling process of the PV sustaining structures, bureaucratic procedures with GSE and the custom duties office and the company's profit.

Dealing with OPEX, an insurance cost of 3 €/kWp/year and a maintenance one of 22 €/kWp/year. For what concerns the maintenance cost, an incremental factor equal to 1%/year was considered, to account the progressive obsolescence of the plant which will complicate maintenance activities in the mid-term. With the very same reasoning, an incremental coefficient equal to 0.5%/year was introduced on the insurance expense's side. Erreci does not bound the client to sign an insurance and maintenance contract, indeed the client is left free to scan the market looking for the best deals from its perspective. These two are simply two costs to make the precautionary document more reliable. In table 14 a detailed summary of CAPEX and OPEX and their subdivision is performed.

Table 14: Costs structure's subdivision, CAPEX and OPEX sides - APV1 – Scenario TO-BE1.

CAPEX	% of the overall CAPEX	
PV modules	19.057 €	30,6%
PV inverter	2.567 €	4,1%
PV structures	8.000 €	12,8%
Other plant set up expenses (Leveling the field, fence perimeter, bureaucratic procedure with GSE)	32.631 €	52,4%
Inverter substitution (year 15)	2.823 €	
OPEX		
Maintenance cost	22 €/kWp/year	
Maintenance cost increment rate	1%/year	
Insurance cost	3 €/kWp/year	
Insurance cost increment rate	0,5%/year	
Tax rate	30%	
Ke	7%	

Then, to further develop the full budget analysis it was necessary to estimate the APV plant's energy production, the self-consumption share of the overall and the energy fed into the grid. With the idea in mind of being as realist as possible, a production's reduction index rate was considered, it was taken equal to 0.45%/year due to a loss of efficiency of the installed PV components. This step was undertaken to show a certain reliability to the customers and to let them understand the effective mid-/long-term perspective of the plant. In addition, as explained before, summers in the area are becoming more and more dry every year and therefore, always with the attempt in mind of getting a result as realistic and concrete as possible it was thought to account even an index which would consider a consumption increment over time. The index was set equal to 0.5%/year. The load curves of energy production were computed with an hourly time frame using both PVGIS software and Barbarasa. Then, the consumption curves, always with the hourly time frame, were computed and comparing the two of them it was possible to extrapolate both the self-consumption curves and the insertion ones. The initial value of the self-consumption index was computed equal to the 22,8% at year 1. Unfortunately, it must be said how the percentage is far from being comparable to the usual index in an industrial context. Indeed, it is common finding investments for PV plants in industry which will obtain a self-consumption rate equal to the 70% onward. This fact could be a problem during the economic feasibility analysis since the bigger gains in the sector come from the missing acquisition cost of electricity.

Finally, the most sensitive point was tackled. Indeed, the biggest question mark of all the economic feasibility assessment of the project laid around the value of electricity, nowadays and in all the years to come. Indeed, Covid-19 pandemic and the Russia-Ukraine war caused, between 2021 and 2022, energy prices' rise to unforeseeable values. Nevertheless, it would be silly to develop economic assessment using those prices since the idea, and somehow even the hope of people, is the one that prices will keep on decreasing as it is happening in these first months of 2023. Although it is quite reasonable that prices will not remain equal to 400/550 €/MWh in the long run, it is also true how quite difficulty prices will go back to values equal to 80/100 €/MWh as it was until 2020. Therefore, the idea of this paper is the one of remaining on the logic and reason side, and as so, an average PUN value equal to 120 €/MWh will be taken as reference one. Given that this paper has the willingness of being as broader as possible, during the calculations it will be used the PUN instead of the PZ. The reason why is that using a PUN value, economic results may be applied in all Italy, and they will also be more horizontally applicable on other projects. Pun value is computed as:

$$PUN = \frac{\sum_{i=1}^{n} PZ_i}{n} \qquad (20)$$

To do that, data of 2023 were downloaded from the GME portal. January, February, March, and April hourly values of the PUN were downloaded and there were multiplied with the load curves of the hypothetical year 1 of the economic analysis. Even though it is not a yearly analysis, 2860 PUN values were computed. In addition, the final output is almost in the middle of the before 2022 values, equal to 80/90 €/MWh and, 2022 ones when the PUN reached an average value equal to 304 €/MWh. In addition, trying to satisfy the same reasoning and logic of before, an increment rate was accounted even regarding the PUN. The increment was supposed being equal to 1.5%/year. At last, a twofold approach was undertaken to compute the full budget voices regarding the 'Energy expenses' reduction due to self-consumption' and the voice regarding 'Earnings from energy fed into the grid'. Indeed, the economic valorisation of the energy quote fed into the grid was computed multiplying the amount of energy for the incentive tariff given by the regulatory framework, 85 €/MWh. The national PZ average is reflected into the PUN value which will be used in the analysis because of the willingness of evaluating the economic perspective with a broader perspective. And again, the average PZ together with the taxes and system expenses which are summed up into a parameter to assess the acquisition cost of electricity avoided by the self-consumption quota. It must be underlined how, as explained before, due to calculations performed over the load curves extrapolated before the self-consumption is equal to 22,8% at year 1. In addition, given both the progressive decrement of production and the increment in consumption, at year 20 the self-consumption rate will hypothetically reach a value of 23,87%. On the other hand, the energy quote self-consumed by the well is valorised multiplying the energy amount by the sum of PUN value plus the sum of other expenses like distribution costs, system management and maintenance costs and taxes. This newly introduced amount is the Italian system to account all the system expenses (transportation, distribution ones and further taxes expenses). Consumers pay the amount when they buy energy from the grid, and therefore for seek of completeness this earning, which is a missing cost in practice, for the company must be accounted in the latter part. In the former one instead, the regulator does not pay the economic summed value over the energy fed into the grid by the APV plant. In other words, it is only one-way system which favours the regulators somehow. The value was not significantly impacted by all the geopolitical evets which have happened lastly. It was insert in some discussion regarding its elimination in the energy bills to contrast the skyrocketing effects of energy prices but then it was reintroduced quickly. The reason why is that the electric grid needs constant maintenance and monitoring to allow a correct working pace. Therefore, taxes and fundings are needed by the public authority. As initial amount, the full value was set equal to 65 €/MWh. Once again, since the reality will flow and there is no chance that the value will remain constant in the following years, an increment rate was considered as previously done for many parameters. The increment itself was set equal to 1,5%/year. A time horizon of 20 years was considered since it is the granted lifetime of the incentive schemes even though it must be made a reflection here about the fact that PV modules which would be installed will have a longer life. Indeed, PV modules possess an expected efficiency which will not significantly decrease in the first 25 years of their life. Moreover, after the twenty-fifth years the plant will remain at its position and future incomes will be generated. Therefore, the economic analysis here will be limited to the incentivised period. Lastly, a tax rate of 30% was considered to compute the Net Cash Flow (NCF) and a cost of equity Ke equal to 7% to compute the discounted NFC. To conclude the overview of earnings' streams due to the plant investment, an amount equal to 1.500,00 € was considered for the agricultural side of the business. Inserting this value was a decision taken together with the agricultural investors and potential clients. A net value was thought, already decreased by all costs needed to accomplish the yearly activities over the field. In this first draft, the agricultural activity concorded was a breeding activity of chicken, hens, and goats. First, a reflection was made on with investment evaluation method would have been the best one fitting the situation. Thus, since entrepreneurs have stated from the beginning how their intention would have been the one of self-financing the investment with equity capital only, a shareholder's perspective was picked and therefore a Levered DCF perspective. Then, with a PUN equal to 0,12 €/kWh, an incentive tariff over the energy fed into the grid equal to 0,085 €/kWh and expenses amount over the missing acquisition cost of the energy equal to 0,065 €/kWh, with all the increment and decrement coefficients for years two to twenty-five, with the previously mentioned situation about CAPEX and OPEX, results of the reference scenario were analysed with three main parameters:

- Net Present Value (NPV)

$$NPV = \sum_{t=0}^{T} \frac{CF_{(t)}}{(1+i)^t} - \frac{I_{(t)}}{(1+i)^t} + \frac{V_T}{(1+i)^T} \qquad (21)$$

Where CF indicates the discounted cash flows for each year from t=0, when the investment is carried out to T=20, which is the overall investment duration, is the initial investment and V_T is the terminal value of the asset, which nevertheless is usually considered equal to 0 when dealing with RES plants' investments. Finally, the i coefficient indicates the cost of capital, which in this scenario is equal to Ke= 7% since all the investment would be financed by equity capital.

- Internal Rate of Return (IRR)
The IRR coefficient is another crucial indicator which must be accounted in the economic evaluation since it provides the rate of return of an investment over a determined period. Usually, the investment should be undertaken if and only if the IRR is higher than the cost of capital, whether the cost of capital refers to the equity only Ke of to the average between equity and debt WACC.

- Pay Back Time (PBT)
As expressed in the name, the indicator PBT highlights the number of years required to recover the initial cash investment. It is a matter of how patient could be the investor which decides, often, whether an investment will or will not be done.

In figure 43, a graphic representation of the PBT and of a cumulative distribution of the Discounted NCF are given. Then, in table 15 all the parameters referring to the reference scenario analysed in the paper are reported.

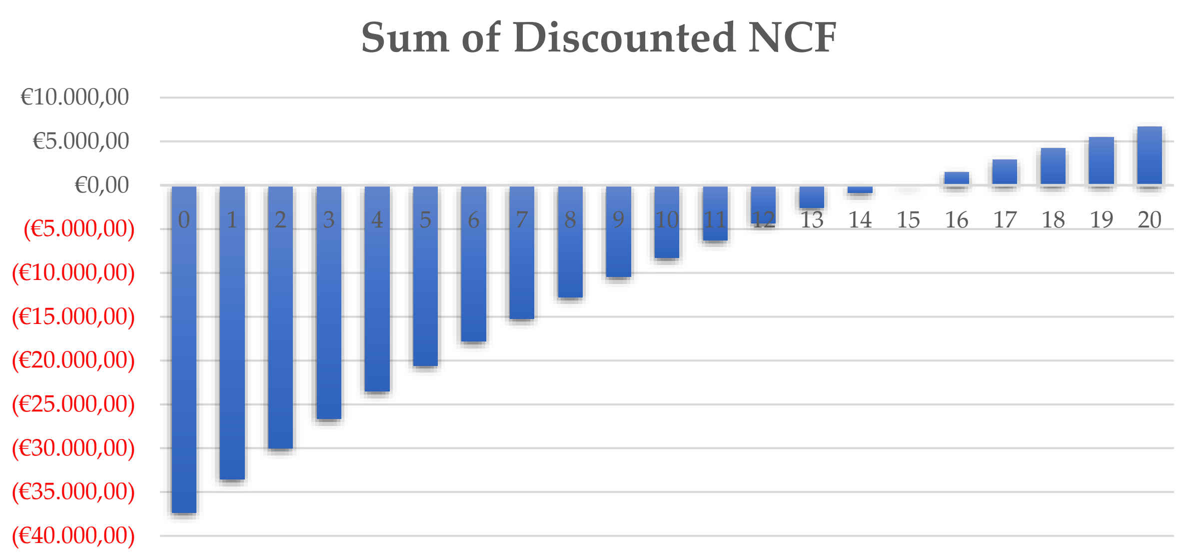


Figure 43: Sum od Discounted NCF – Scenario TO-BE1 with accounted incentive schemes – APV1.

Table 15: Economic assessment's results – Main parameters accounting for incentive schemes.

NPV	6.647 €
IRR	2,05%
PBT	15
LCOE	0,07037 €/kWh

Reasoning over the results, it is evident how the investment in the APV may be carried out with a satisfying ROI. Indeed, the traditional decision-making rule is that an investment should be undertaken if and only if the final NPV is positive. Well, in this case NPV is positive and even with a certain margin. Also, the IRR is affordable, and it is positive with some security margin. Finally, the PBT is probably the less attractive indicator over the three of them. Indeed, nowadays some entrepreneurs and investors reason that if an investment is not repaid in 4/5 years, it is not good investment and it will probably be a better way and place where invest the money. Nevertheless, it is also true that after year 15 all the money generated by the RES plant will be a positive income for the investors and again, 20 years is the expected lifetime of the plant considered here even though after that amount of time PV modules do not self-destroy themselves. Indeed, their efficiency will start decreasing significantly but incomes will be generated even after the end of the period. Moreover, since the inverter substitution is already considered here.

Year	Energy produced [kWh/year]	Consumption [kWh/year]	Self-consumption [kWh/year]	Energy fed into the grid [kWh/year]	Self consumption %	Average expected PUN 2023-onward [€/kWh]	CUsf [€/kWh]	Incentive tariff	expenses' reduction due to self-consumption	Earnings from energy fed into the grid	Agricultural income	Maintenance expenses	Insurance expenses	Inverter's substitution	CF	Net CF - Taxes:30%	Discounted NCF - Ke: 7%	Sum of Discounted NCF
0																-37.353,60 €	-37.353,60 €	-37.353,60 €
1	53.219	58.598	12.135	41.084	22,80%	0,1200	0,0650	0,1030	2.245,02 €	4.231,63 €	1.500,00 €	1.270,50 €	173,25 €	0,00 €	6.532,90 €	4.573,03 €	4.273,86 €	-33.079,74 €
2	52.980	58.891	12.110	40.869	22,86%	0,1218	0,0660	0,1030	2.273,98 €	4.209,55 €	1.530,00 €	1.283,21 €	174,12 €	0,00 €	6.556,20 €	4.589,34 €	4.008,51 €	-29.071,23 €
3	52.741	59.185	12.085	40.656	22,91%	0,1236	0,0670	0,1030	2.303,32 €	4.187,57 €	1.560,60 €	1.296,04 €	174,99 €	0,00 €	6.580,46 €	4.606,32 €	3.760,13 €	-25.311,10 €
4	52.504	59.481	12.060	40.444	22,97%	0,1255	0,0680	0,1030	2.333,02 €	4.165,71 €	1.591,81 €	1.309,00 €	175,86 €	0,00 €	6.605,68 €	4.623,97 €	3.527,61 €	-21.783,49 €
5	52.268	59.779	12.035	40.233	23,03%	0,1274	0,0690	0,1030	2.363,08 €	4.143,96 €	1.623,65 €	1.322,09 €	176,74 €	0,00 €	6.631,86 €	4.642,30 €	3.309,90 €	-18.473,60 €
6	52.032	60.077	12.010	40.022	23,08%	0,1293	0,0700	0,1030	2.393,53 €	4.122,31 €	1.656,12 €	1.335,31 €	177,62 €	0,00 €	6.659,03 €	4.661,32 €	3.106,04 €	-15.367,56 €
7	51.798	60.378	11.985	39.813	23,14%	0,1312	0,0711	0,1030	2.424,40 €	4.100,76 €	1.689,24 €	1.348,66 €	178,51 €	0,00 €	6.687,23 €	4.681,06 €	2.915,13 €	-12.452,43 €
8	51.565	60.680	11.960	39.605	23,19%	0,1332	0,0721	0,1030	2.455,68 €	4.079,30 €	1.723,03 €	1.362,15 €	179,41 €	0,00 €	6.716,46 €	4.701,52 €	2.736,33 €	-9.716,10 €
9	51.333	60.983	11.936	39.397	23,25%	0,1352	0,0732	0,1030	2.487,39 €	4.057,93 €	1.757,49 €	1.375,77 €	180,30 €	0,00 €	6.746,74 €	4.722,72 €	2.568,85 €	-7.147,26 €
10	51.102	61.288	11.911	39.191	23,31%	0,1372	0,0743	0,1030	2.519,55 €	4.036,65 €	1.792,64 €	1.389,53 €	181,20 €	0,00 €	6.778,11 €	4.744,68 €	2.411,95 €	-4.735,30 €
11	50.872	61.594	11.887	38.985	23,37%	0,1393	0,0754	0,1030	2.552,15 €	4.015,46 €	1.828,49 €	1.403,42 €	182,11 €	0,00 €	6.810,57 €	4.767,40 €	2.264,96 €	-2.470,35 €
12	50.643	61.902	11.862	38.781	23,42%	0,1414	0,0766	0,1030	2.585,08 €	3.994,41 €	1.865,06 €	1.417,46 €	183,02 €	0,00 €	6.844,07 €	4.790,85 €	2.127,20 €	-343,15 €
13	50.415	62.212	11.838	38.578	23,48%	0,1435	0,0777	0,1030	2.618,37 €	3.973,49 €	1.902,36 €	1.431,63 €	183,94 €	0,00 €	6.878,65 €	4.815,06 €	1.998,08 €	1.654,93 €
14	50.188	62.523	11.813	38.376	23,54%	0,1456	0,0789	0,1030	2.652,03 €	3.952,70 €	1.940,41 €	1.445,95 €	184,86 €	0,00 €	6.914,34 €	4.840,04 €	1.877,05 €	3.531,97 €
15	49.963	62.836	11.788	38.175	23,59%	0,1478	0,0801	0,1030	2.686,14 €	3.932,00 €	1.979,22 €	1.460,41 €	185,78 €	2.823,70 €	4.127,47 €	2.889,23 €	1.047,19 €	4.579,16 €
16	49.738	63.150	11.763	37.975	23,65%	0,1500	0,0813	0,1030	2.720,64 €	3.911,42 €	2.018,80 €	1.475,01 €	186,71 €	0,00 €	6.989,14 €	4.892,40 €	1.657,22 €	6.236,39 €
17	49.514	63.466	11.737	37.776	23,71%	0,1523	0,0825	0,1030	2.755,52 €	3.890,97 €	2.059,18 €	1.489,76 €	187,64 €	0,00 €	7.028,26 €	4.919,78 €	1.557,48 €	7.793,87 €
18	49.291	63.783	11.712	37.579	23,76%	0,1546	0,0837	0,1030	2.790,78 €	3.870,64 €	2.100,36 €	1.504,66 €	188,58 €	0,00 €	7.068,55 €	4.947,98 €	1.463,93 €	9.257,80 €
19	49.069	64.102	11.687	37.383	23,82%	0,1569	0,0850	0,1030	2.826,49 €	3.850,42 €	2.142,37 €	1.519,71 €	189,52 €	0,00 €	7.110,05 €	4.977,03 €	1.376,19 €	10.633,99 €
20	48.848	64.422	11.661	37.187	23,87%	0,1592	0,0863	0,1030	2.862,68 €	3.830,28 €	2.185,22 €	1.534,90 €	190,47 €	0,00 €	7.152,80 €	5.006,96 €	1.293,89 €	11.927,88 €

Figure 44: Economic computations and reasoning – same structure kept in all scenarios.

In the example above, it is reported the economic calculations performed to carry out the economic analysis, considering all the assumptions previously mentioned both fro a technical and economical point of view. The same structure is kept in all the scenarios, with the APV2 which will not have the self-consumption section and therefore the revenue stream differently from here. Once positive considerations have been expressed, it is also needed to reason over negative implications of the analysis. Indeed, it must be underlined how these numbers are output of a process which includes 40% of non-repayable incentive over the CAPEX value of the plant. Being a new technology, APV requires these strong incentives to self-sustain itself otherwise it would be rather impossible to come out with positive results favouring the investment. To support this conviction, a computation was performed excluding both the incentives, therefore accounting the full CAPEX amount and as economic valorisation value of the energy fed into the grid 120 €/MWh. No other parameters were modified from the Reference scenario.

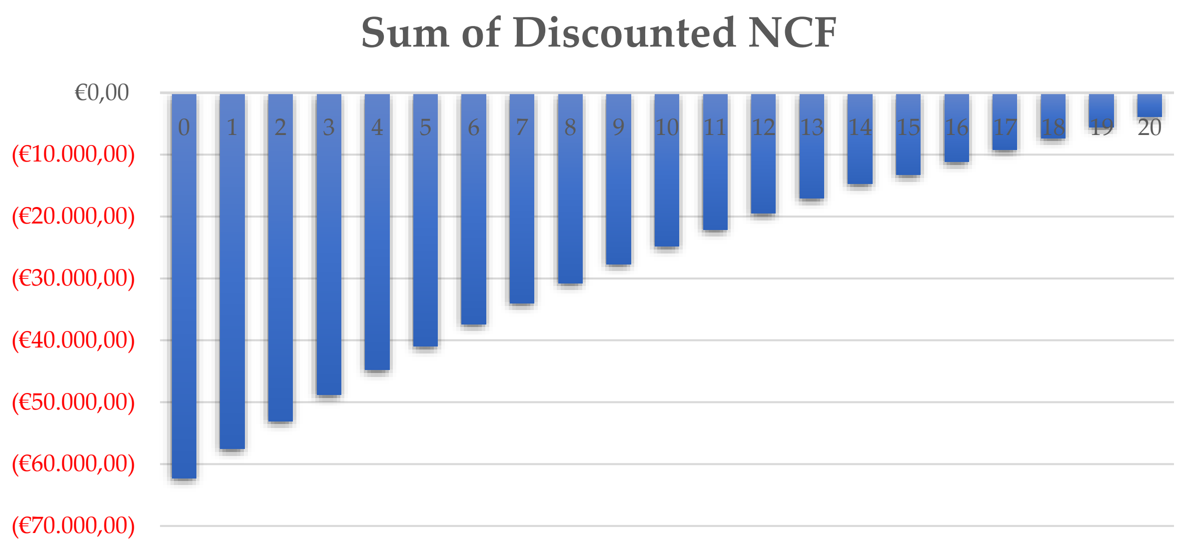


Figure 45: Sum od Discounted NCF – Scenario TO-BE1 without incentive schemes – APV1.

Table 16: *Economic assessment's results – Main parameters without incentive schemes.*

NPV	-3.897 €
IRR	-0,74%
PBT	21
LCOE	0,09479 €/kWh

In table 16 it is reported that the investment will not be convenient without incentives, with a negative NPV, an IRR negative and with a PBT which does not even recover the initial investment in the period analysed without even starting the discussion about positive incomes. Having cleared the perimeter around the importance of incentives in these technological installations, there is one point left which according to the reasoning undertaken during the entire paper should be tackled: the electricity price.

Indeed, if the extra expenses' parameter value can be considered with a certain degree of certainty that it will remain stable over time, the consideration is not true anymore looking at the value of electricity, the one used to valorise energy fed into the grid. Indeed, players acting in the energy market, from energy brokers to RES plants installer, struggle when it comes to forecast a price to use in a full budget computation. Indeed, who knows whether the price will remain in the range of 110 to 170 €/MWh as today or if will go back to 60/70 €/MWh as it was in 2019. Or again, if every year during the autumn and wintertime, due to low availability of raw material it will going up and down as a rollercoaster? Honestly, no one with a technical background will unbalance him/herself over this topic and therefore it was thought here to develop a reasoning which would evaluate the investment without accounting economic earnings. Thus, the LCOE values were computed. The parameter states which will be the cost of electricity produced by the RES plant of the investment evaluation. Benchmarking different LCOE of electricity produced with different technologies, it is possible to understand the state of the art of the technologies, where mature ones will have a lower LCOE than the new emerging ones. Indeed, the mature ones, like gas turbines to generate electricity, have already reached the top of the S shaped curve of development. Maximum efficiency levels have been obtained and, in the future, no big changes in the paradigm are forecasted. On the other hand, new and emerging technologies are just at the beginning of the S shaped curve and, in this case yes, advancements are foreseeable, and costs will decrease due to an increment of efficiency levels. Efficiency with is in this case linked to the conversion factor from the raw material to energy. APV solutions fall in the second family previously illustrated. Therefore, it is likely that APV's LCOE will result higher than traditional ones, but it must be understood why and how higher. LCOE in this work was computed as

$$LCOE = \frac{\sum_{i=0}^{T} Costs_i}{\sum_{i=0}^{T} Energy\ produced_i} \qquad (22)$$

Where T is equal to 20, the time horizon considered. Maintenance, insurance, and inverter substitution were considered as expenses. The total estimated amount of energy produced in the time frame is equal to 1.020.083 kWh while the complete sum of the forecasted OPEX is equal to 34.433 €. These two values are equal in both cases, indeed, whether incentive scheme will be gained these two numbers will not be affected by the event. The difference-maker factor is the CAPEX. Indeed, in the case where the 40% of CAPEX will be granted to the entrepreneurs towards a capital account incentive, the CAPEX which will be used I the formula will be equal to 37.353 €. In this first case, which can be seen as a best-case scenario, an overall LCOE resulted equal to 0,07037 €/kWh. As it is foreseeable, LCOEs related to Agrivoltaic installations are currently higher than the ones assessing traditional photovoltaic plant, whether installed on the ground or on roofs. Indeed, the former one is an emerging technology which requires incentive schemes to be cost competitive, while the latter are two mature technologies which are close to their development ceiling, according to literature and contemporary research. The huge advantage given by the LCOE computation is the one of being able to eliminate the aleatory which characterise the electricity prices nowadays. Finally, the very same reasoning was applied to the case without incentive schemes being granted and therefore accounting the full CAPEX amount equal to 62.256 €. An LCOE equal to 0,09479 €/kWh is computed as output. As expected, higher than the incentive case. This value significates how for the next twenty years the investors are assuring themselves a fixed price regardless of all the possible variations in both positive and negative directions. With the study of LCOE it is possible to reason over the investment cutting out the aleatory conception embedded in the energy market as in all the economic businesses nowadays. In other words, considering the LCOE of the plant is like signing a Power Purchase Agreement (PPA) with a fixed price equal to 94 €/MWh. In addition, all costs are included here, and no transportation fares should be accounted as it happens in other evaluations.

For seek of completeness, after the new law decree was released during Spring 2023, the same economic analysis was performed accounting. If for the revenue stream regarding the energy self-consumed it was always considered a PUN equal to 0,12 €/kWh plus the expenses due to taxes and similar, in this case as premium tariff it was considered the fixed amount of 103 €/MWh as stated in the regulatory framework. Amount which was set and left fixed for the entire time horizon. The LCOE value remained the same equal to 70 €/MWh since no modifications were made from the technical point of view. In this case, no minimum amount regarding the peak power installed are considered as it was in the previous law decree which required a minimum installed power of 300 kWp. Economic constraints were relaxed, indeed for a plant having a peak power installed equal to 57,75 kWp the maximum was incremented to 1.700 €/kWp installed. Table 17 highlights higher coefficients respect to the previous ones which makes sense having increased the tariff from a fixed amount of 85 €/MWh to 103 €/MWh. On the other hand, PBT resulted being 2 years shorter than the previous case.

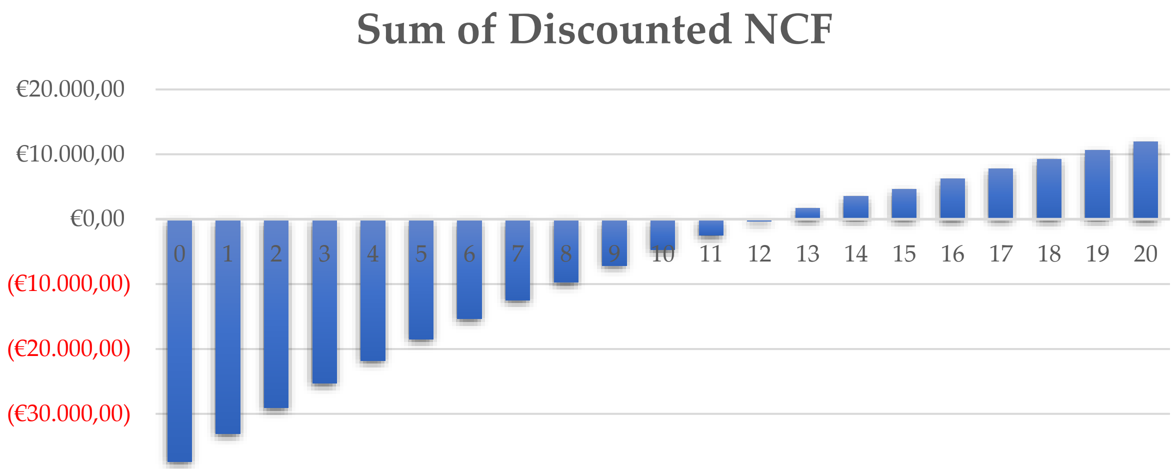


Figure 46: Sum od Discounted NCF – Scenario TO-BE1 with UPDATED incentive schemes – APV1.

Table 17: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	11.927 €
IRR	3,60%
PBT	13
LCOE	0,07037 €/kWh

3.3.2 Scenario TO-BE2

Even in this scenario, cost and technological criteria which were considered remained the same as in scenario TO-BE1. Although criteria remained unchanged, the technological configuration was completely changed from the installation point of view. Indeed, it is considered here a Slilt-mounted APV technology with one tracker embedded to the PV modules. In this case, there will be no problems at all for what concerns the compliance with the Italian prerequisites from a height of PV modules' point of view. Indeed, searching within the already existing configurations it was decided to instal the APV plant at a height equal to 5 meters from the soil level. Thus, either agricultural or breeding activities may be performed here without any further constraint. In addition, the consideration in this case was also the one that most agricultural machines utilised in the daily activities have an overall height generally lower than 5 meters, therefore an entrepreneur who might implement the APV plant on his field would not be obliged to substitute his already in place instruments.

Once again, the first step was the one of understanding physical distances that the hypothesized plant would have kept to allow a sufficient ASR hitting the solid surface without affecting the agricultural yields. Since the configuration in this case accounts tensile structures the computation was performed to avoid a shadow effect from one pole to another and not within the tensile structure. Indeed, according to literature since the PV modules are equipped with trackers their position will change constantly over the day and this will not cause a degradation effect for crops beneath. A different matter is the sustaining poles which are required, to be positioned one the one hand to correctly sustain the APV implementation and, on the other hand, to avoid an excessive shadow effect over the soil surface. It was computed, as detailed in figure 47, that a satisfying distance from one pole to another could have been approximately 10,5 meters, using the same computation method as Scenario TO-BE1. Therefore, for seek of security a distance equal to 12 meters was kept, considering a cautious approach and 5 block made by PV modules and tracker were insert from one pole to another. Furthermore, pitch's distance was considered equal to 10 meters. Within the beginning and the end of the APV block, tensile cables are needed to connect PV modules on the horizontal level but from a vertical perspective no other poles hammered into the ground are required. The company suppliers also confirmed the hypothesis about the intra PV modules shade effect and therefore a graphical representation was designed to understand the minimum distance needed between each vertical sustaining structure.

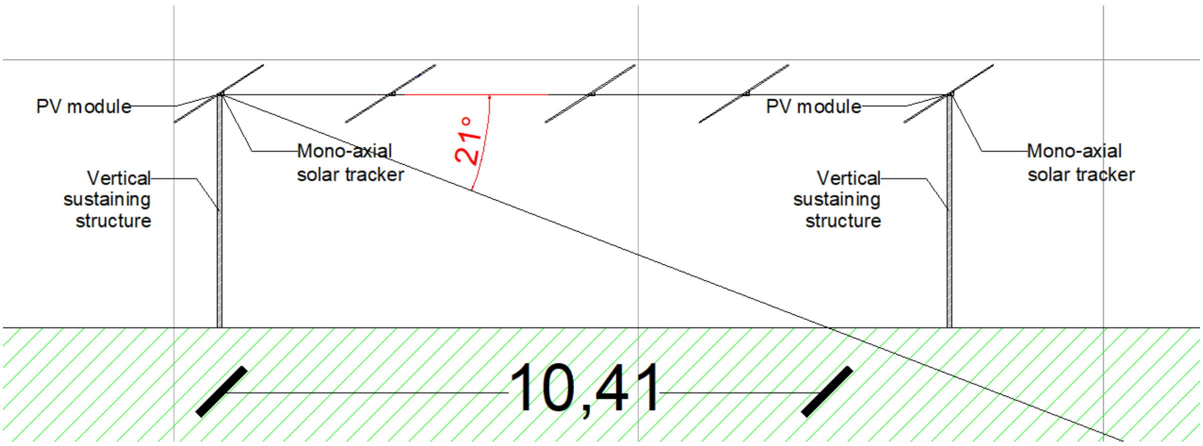


Figure 47: Rendering of the Stilt mounted bifacial PV modules' structures – Elevated configuration's view.

As previously mentioned, the methodology to simulate the shadow effect is in this case the same one of scenario TO-BE1, thus the maximum length of the shadow considered on the 21st of December was considered and to do that an inclination angle of 21° was here accounted too. The reference instrument utilised is GstarCAD provided by Erreci. The dimensions of the PV module were considered, which are equal to 2,279x1,134x0,035 meters for the product JA Solar 550 bifacial. A height of 5 meters from the soil level was included. In addition, for what concerns the wind load, a further analysis over the software Dlubal was performed to assure to both the customers and Erreci the insurance over the security of installation in the area [41].

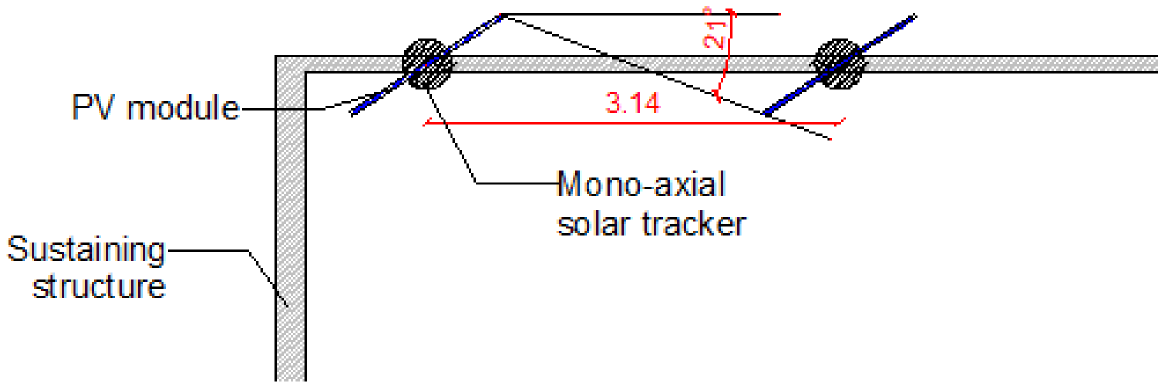


Figure 48: *Rendering of the Stilt mounted bifacial PV modules' structures – 3D configuration's view.*

Having understood the minimum distance from one pole to another and the pitch absolute value, it was precautioned the distance required from one block composed by PV modules and solar tracker to another. Indeed, the aim was the one of avoiding contemporary an excessive shadow effect from one PV module to another and towards the ground. Thus, a computation was performed as detailed in figure 48 and the decision was the one of projecting one block every 3 meters. Once reached this step of the design phase, the work turned into the SolarEdge software. An overall graphic representation was attempted trying to have a clear rendering of the hypothetical APV plant. The logic here was to maximise the exploitation of the area, being the soil area limited. Thus, over the soil area of 2800 m^2 a sky view as the one of figure 49 resulted, with the figure 49 representation of the irradiance and shading perspectives. Maximizing the occupancy of the available area, it was possible to precaution 88 PV modules installed, with a nominal peak power equal to 48,5 kWp. Since the type of PV modules has not changed from the previous scenario and neither are the kind of surface where the APV will lay over, the albedo coefficient accounted in the energy computations will be kept equal to 0,15. SolarEdge also forecasted a yearly production equal to 72 MWh. In this case it was thought how a single inverter Huawei SUN 2000-50KTL-M3 could have been once again the optimal solution for the plant prospected layout. The same technical features were granted in this analysis, with an inverter overall efficiency equal to 98% in the process of transforming DC into AC and the presence of 4 MPPT, factor which may grant a certain flexibility in the hypothetic moment of configuring the electric strings and connections.

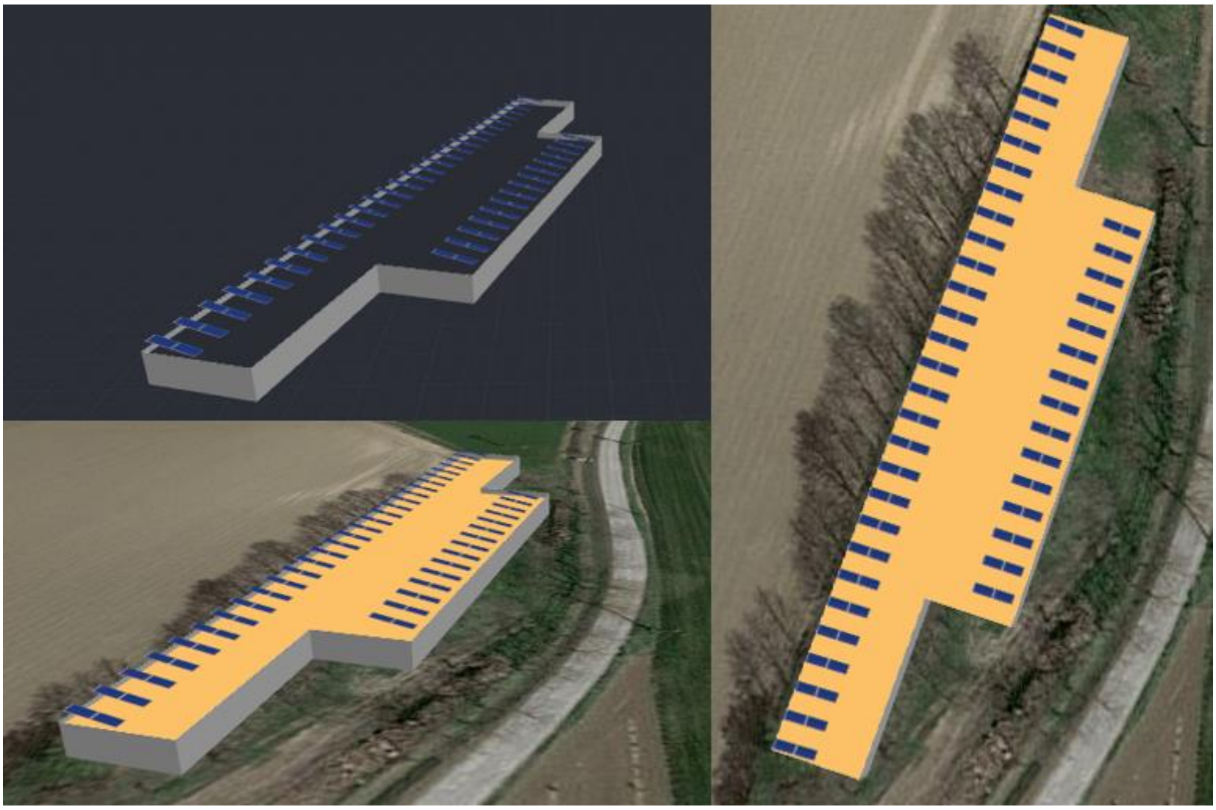


Figure 49: Stilt mounted layout/design. 3D and upper view – Solar radiation incidence upper view.

Then, an energy analysis was performed with data taken from the PVGIS database, specifically PVGIS-SARAH 2016 and then re-elaborated on the company's software Barbarasa. Load curves were extrapolated and graphically represented to understand energy flows. In the PVGIS were plotted information about the presence of mono-axial tracker, latitude, and longitude of the soil area. The same days were taken to benchmark with scenario TO-BE1.

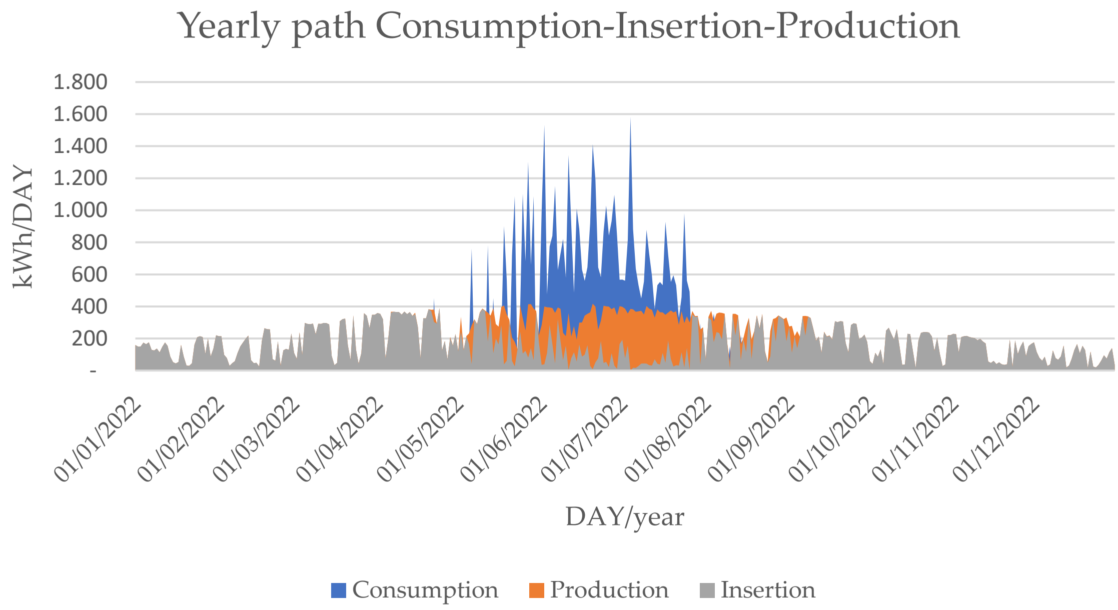
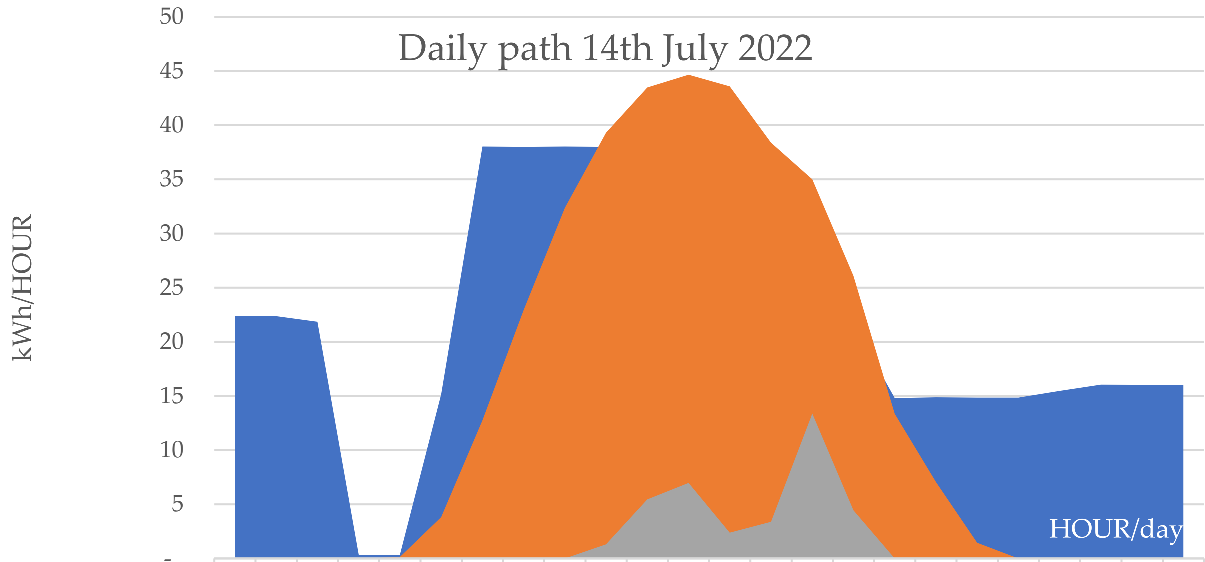


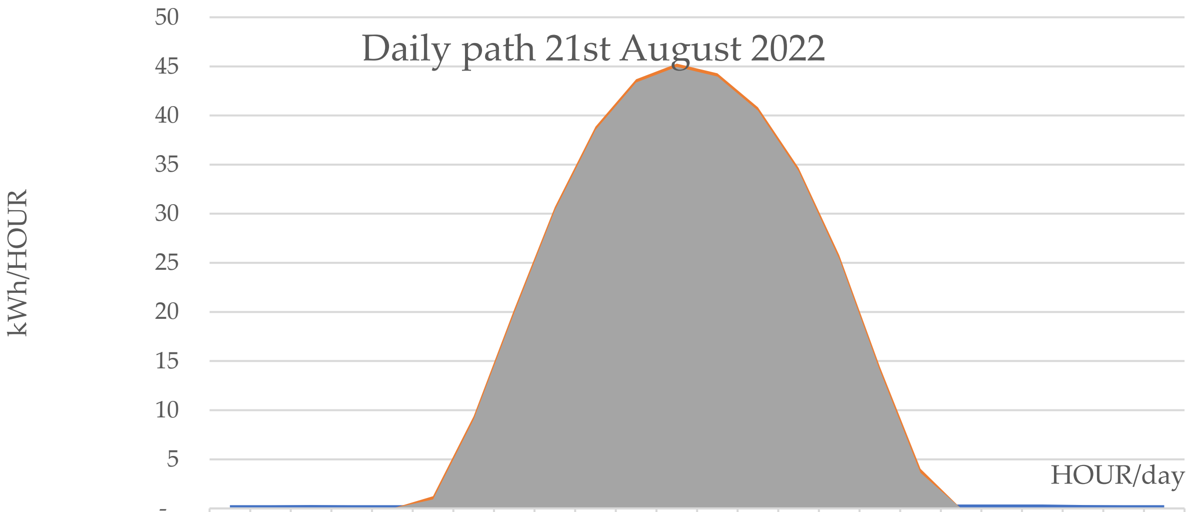
Figure 50: 48,5 kWp plant; Consumption curve=blue; Insertion curve=grey; Production curve=orange.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	22	22	22	0	0	15	38	38	38	38	38	38	41	35	22	22	15	15	15	15	15	16	16	16
Production	-	-	-	-	0	4	13	23	32	39	43	45	44	38	35	26	13	7	1	-	-	-	-	-
Insertion	0	0	0	0	0	0	0	0	0	1	5	7	2	3	13	4	0	0	0	0	0	0	0	0

Figure 51: Daily path 14th July 2022.

In this second graph, representing the weekly day energy landscape, it must be underlined how differently from the previous case, there is a quote of energy fed into the grid, represented by the grey curve, even during summertime when the well is working at its maximum capacity. This fact is caused by the higher power installed. This fact is due to the higher productivity than this configuration has in comparison with scenario TO-BE1, and it is confirmed by the bigger orange curve, which represents the amount of energy produced by the plant.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production	-	-	-	-	-	1	9	20	31	39	44	45	44	41	35	26	14	4	-	-	-	-	-	-
Insertion	0	0	0	0	0	1	9	20	30	39	43	45	44	41	34	25	14	4	0	0	0	0	0	0

Figure 52: Daily path 21st August 2022.

One big difference in this scenario from the previous one is the fact that it is possible, due to bigger plant dimensions and therefore installed peak power, to experience a higher self-consumption rate. In this case is computed equal to 25,9% at year 1 and as before, to maintain the same assumptions and creating a non-differential framework it was supposed that the self-consumption quote will increase over time due to higher energy consumptions and lower amounts of energy produced due to a loss of efficiency the PV components. Therefore, this situation goes on a positive direction from an economical point of view, being the self-consumed energy the most precious type of energy when talking about RES plants and relatives. Indeed, it is valorised at a price equal to the sum of PUN/PZ and taxes and other expenses value, which mean the raw material value plus all the connected costs related to the Italian legislation as the transportation one, taxes and others. Final value of 27,3% is forecasted to be reached at the end of the period analysed, which is still la low value if compared to traditional factories case' installations.

Incentive scheme's compliance

The PVGIS database estimates that the proposed plant would produce 72.959 kWh in year zero. Thus, for a total installed power of 48,5 kWp, the anticipated specific yearly electric production will be 1.504 kWh/kWp. Started tackling the constraint imposed by the regulator over the area remaining available for agricultural usages after the hypothetical APV implementation, here the total occupied are of PV modules will be equal to 237,6 m^2, since the area of each single PV module remained 2,7 m^2 but here we do have 17 modules less than scenario TO-BE1. Then, other 280 m^2 will be taken from agricultural aims due to the space occupied by the vertical sustaining structures. Having said so the ratio will be that more than the 82% of the area will remain available for agriculture. Although the constraint is still satisfied, indeed the lower limit is set equal to 70% of the initial area left available, the difference from scenario TO-BE1 is almost equal to the 10%. LAOR parameter is here computed equal to 8,48%. Again, below the limit imposed equal to 40%.

$$LAOR = \frac{318{,}6m^2}{2.800\ m^2} = 0{,}0848$$

Installed and configured in accordance with the restrictions imposed by the government, the monitoring system. Additionally, since a 5 metres space was left between the ground and the APV installation's bottom border, whatever agricultural activity will fall under the purview of the agricultural sector of the business. Again, the continuation of the agricultural activity that was previously carried out on the field will be permitted in accordance with the CREA-GSE rules and even improved because previously, the primary activity on the land was the extraction of firewood, whereas with the APV, a more sophisticated activity will enhance higher incomes and a better exploitation of the soil. According to the explanation, the precise electric production will be 1.504 kWh/year/kWp installed. Then, a reference value was taken from the same PVGIS database and the same PV module. The criteria specified a South-oriented placement on the ground with a tilt inclination of 10°. The measured value was 1208,5 kWh/kWp installed. According to the ratio of the comparison, APV's efficiency is equal to 124% in the reference example, a value that is high enough to meet the requirement. Precisely, the electricity production of scenario TO-BE2 is higher than the reference one and this fact is due to the present of solar trackers over each PV module. Results showed 260 MWh/ha/year in the APV instance and 280 MWh/ha/year in the reference scenario when all data were expressed in MWh/ha/year, as specified by the guidelines. Finally, the LER parameter was computed attempting at the comprehensive evaluation of the opportunities given by the APV plant. Indeed, merging electric and agricultural yields of this scenario, it resulted a coefficient equal to 1,49. The result, as happened in the previous configuration is in line with the actual literature values. Nevertheless, this value resulted being higher than the one of Scenario TO-BE1 due to higher electric yields. In this case as well, the limit of 300 kWp installed is not satisfied as in the previous scenario. Nevertheless, with the very same reasoning it is highlighted here how this constraint is expected to be overtaken in the upcoming period.

Economic analysis

As highlighted in the previous chapters, the AS-IS scenario in this case is characterized by an unutilized land area which means that any economic profitability gained by the proposed APV configuration will be a better situation. Thus, a comparison will be needed between scenario TO-BE 1,2 and 3. Therefore, the same economic parameters will be computed in this case for what concerns the economic analysis embedded. The reasoning undertaken in this case is the same as the previous scenario even for what regards the costs subdivision, between OPEX and CAPEX and the economic variables which end up being the decision-making ones. Photovoltaic costa and parameters are PV modules, inverters, sustaining structures, and all the costs related to the plant installation on the CAPEX side, then maintenance and insurance if the perspective is the OPEX one. First, it is worth stating how the final precautioned cost for the solution, with a turnkey configuration resulted being equal to 78.165 €. It is immediately clear how the cost is way higher than scenario TO-BE1, situation which is mainly caused by the different kind of sustaining structures. Nevertheless, even the fact that due to the different layout it was possible to predict a higher final peak power of the APV plant influenced the final cost. Second, it must be clear from the beginning how insurance and maintenance costs will be higher. The latter is a consequence of the more complicated type of plant which will negatively influence the maintenance operations complicating them by countless levels. Thus, in this computation it was considered a value of 35 €/kWp installed/year. The former is due to the situation which depicts a more fragile installation which will be keener to damages, from both human side's errors and catastrophic climatic weather events. Consequently, in the case here shown it was considered a value of 6 €/kWp/year Clearly, these higher costs are not effortless, indeed their presence is more than justified by the higher energy productivity which is granted by the different configuration in this case, stilt-mounted, than the previous one with a vertical-mounted configuration. The task of the economic assessment is evaluating whether these higher costs are covered or not by the bigger amount of energy produced.

After the brief description phase, it is necessary to state how costs are subdivided within the final plant cost. For the sustaining structure, including all the vertical poles and the tensile cables posed horizontally at 5 meters form the ground, it was precautioned a total cost of 35.000 €. Accounting the mono-axis tracker, which was offered by an Erreci supplier at a cost of 150 €/piece, the datasheet specified how one tracker could maneuver 2 PV modules and therefore 44 trackers were required in the configuration. Overall, the cost assigned was computed equal to 6.600 €. Having the willingness to benchmark the €/kWp installed parameter both within the scenarios analysis and on the external market, even that parameter was computed. It resulted equal to 1.611 €/kWp installed. The value is way above the upper limit imposed by the regulator to access the incentive scheme which was equal to 1.500 €/kWp installed. In an initial moment, it was evaluated the plant feasibility without any kind of incentive scheme. Indeed, it is unclear in the preliminary documents published by the Italian government whether the incentive over the CAPEX will be granted even to plants where the ratio is higher but the different from 1500 €/kWp installed to the real value will not be considered in the 40% of CAPEX which will be given in capital account or not. Thus, for a first analysis it was decided to account the entire CAPEX amount and considering a PUN value to valorize the energy fed into the grid, rather than the premium tariff posed by the Italian government. Since caution is always the best solution according to this paper when evaluating investments, it was considered that the inverters package must be substituted at year 15 and therefore a cost of 2.824 € was accounted. Having 88 PV modules precautioned in the designed layout in this case, a cost equal to 19.005 € was due to the PV modules. Other assumptions, like the increment rates mainly caused by inflation effects were left as in scenario TO-BE1 since it was reasoned that they are considerable as non-differential parameters.

Table 18: Costs structure's subdivision, CAPEX and OPEX sides - APV1 – Scenario TO-BE2.

CAPEX	**% of the overall CAPEX**	
PV modules	19.005 €	24,3%
PV inverter	2.567 €	3,3%
PV structures	35.000 €	44,8%
PV trackers	6.600 €	8,4%
Other plant set up expenses (Levelling the field, fence perimeter, bureaucratic procedure with GSE)	14.993 €	19,2%
Inverter substitution (year 15)	2.823 €	
OPEX		
Maintenance cost	35 €/kWp/year	
Maintenance cost increment rate	1%/year	
Insurance cost	6 €/kWp/year	
Insurance cost increment rate	0,5%/year	
Tax rate	30%	
Ke	7%	

With the non-differential parameters' assumption in mind, it was decided to maintain the same value for what regards the economic valorization of the electricity fed into the grid and the amount of electricity self-consumed by the well. Indeed, because of the attempt to benchmark as much as possible the scenarios presented in the paper; it was thought not being logical modifying these data. Thus, the PZ here will be accounted equal to 120 €/MWh and the other expenses parameter equal to 65 €/MWh. Dealing with agricultural yields, with a stilt-mounted configuration, regardless of mono- or bi-axial trackers it was suggested by the entrepreneurs to raise net incomes to 2.000€ in this case. Finally, earning from energy fed into the grid and energy self-consumed were computed as in scenario TO-BE1 but the amount due to self-consumption resulted higher as explained in the previous section thanks to loas curves.

As in scenario TO-BE1, economic parameter which were considered difference-makers in a detailed economic analysis were Net Present Value (NPV), Internal Rate of Return (IRR) and Pay Back Time (PBT). As reasoned in the previous paragraph, this second scenario analysed did not respect the maximum amount, in terms of CAPEX/kWp installed posed by the Italian regulator. Indeed, with a maximum accepted amount of 1.500 €/kWp the computation here ended up being equal to a value required of more than 2.100 €/kWp. Thus, a first evaluation was performed without accounting any incentive scheme, neither the non-repayable amount equal to a maximum of 40% of the CAPEX value, neither the incentive tariff applied over the energy produced and fed into the grid. In addition, other than parameters, a progressive analysis of the Discounted Net Cash Flows was computed. As shown in table 19 and figure 53, results do not allow or encourage the realization of the investment. As it is expressed by the NPV value and contemporary by the graphical representation of the Discounted NCF, this scenario resulted sustainable even without accounting any incentive scheme. Indeed, the consistent share of self-consumed energy together with a PUN set equal to 120 €/MWh at year 1, made possible recovering the investment, even without any CAPEX percentage obtained through the capital account method. Even though positive values arose from the analysis, it must be underlined how these values are just slightly sufficient to recover then investment and the PBT is gained at year 19. From the point of view of the entrepreneurs it may be possible finding ways to invest their money with higher cashbacks.

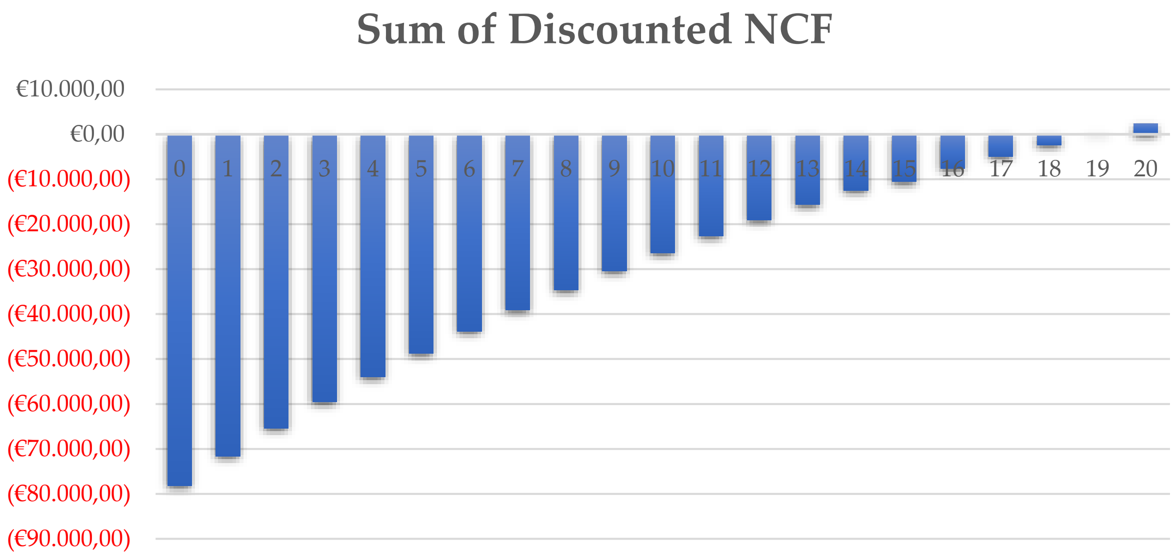


Figure 53: *Sum od Discounted NCF – Scenario TO-BE2 without incentive schemes – APV1.*

Table 19: Economic assessment's results – Main parameters without incentive schemes.

NPV	2.773 €
IRR	0,41%
PBT	19
LCOE	0,08990 €/kWh

Furthermore, the LCOE coefficient was estimated with the idea of benchmarking as much as possible all the different scenarios even from the point of view of this parameter, which does not financially evaluate the profitability of the plant itself but on the other hand it sums up the ratio between all the costs which are supposed to be required by the APV plant during its lifetime and the entire amount of energy which the plant is expected to produce. The final value in this situation presents an LCOE equal to 0,089901 €/kWh. The resulting value is lower than the one computed in the scenario TO-BE1, which was equal to 0,09479 €/kWh. The reasoning performed in this paper is how this fact highlights how even if the peak power installed resulted lower, the capability of producing bigger yearly amounts of energy thanks to the installation of solar trackers which enhances a higher specific production in terms of kWh/kWp installed covers the higher costs correlated and resulted giving a better LCOE from the entrepreneurs' perspective. Thus, in relative terms, higher costs needed in this configuration are offset by higher quantity of energy produced and the result comparing the two of them favours this second scenario TO-BE2. Subsequently, an attempt was made to carry out another hypothesis for what concerns the economic perspective of this scenario. Indeed, since the preliminary document released by the Italian regulator was far from being definitive, it was hypothesised in the paper that, as the limit of 300 kWp concerning the minimum peak power required could drop, as well the constraint over the maximum expenditure allowed could have been relaxed. The second idea indeed was the one of accounting the incentive over the CAPEX of the APV plant even if the specific cost in terms of €/kWp resulted being higher than 1.500 €/kWp. Summing up, the resulting CAPEX was computed equal to 46.899 €, considering the 40% of capital account incentive over the initial precautioned CAPEX. Having explained this assumption, all other considerations were left unchanged from the first analysis of scenario TO-BE2. In table 20 and figure 54 are summed up economic results of this situation. It is straightforward how decreasing the CAPEX thanks to the initial incentive only over a part of it, but still a rather significant one, the economic scenario changed completely. Indeed, here over than the Pun value considered to valorise the energy self-consumed, the incentive premium tariff equal to 85 €/MWh was considered for the energy fed into the grid and sold. All parameters which were evaluated are reasonable and attractive from the point of view of the entrepreneurs. If compared to the scenario TO-BE1, NPV and IRR are higher while PBT is in this case lower than before. For seek of completeness, a higher NPV is also offset by a way bigger required initial investment. It is worth underlying how form an LCOE point of view there is also a significant improvement in the situation. Indeed, since the energy produced by the plant during the 20 years period under analysis remained the same but the overall sum of all the costs sustained, CAPEX plus OPEX, decreased by almost 32.000 €, the LCOE has decrease. The LCOE in this case resulted equal to 0,06665 €/kWh produced. Value that indicates how the energy produced by the plant, regardless any fluctuation of electricity prices in the future will cost to the entrepreneurs approximately 67 €/MWh.

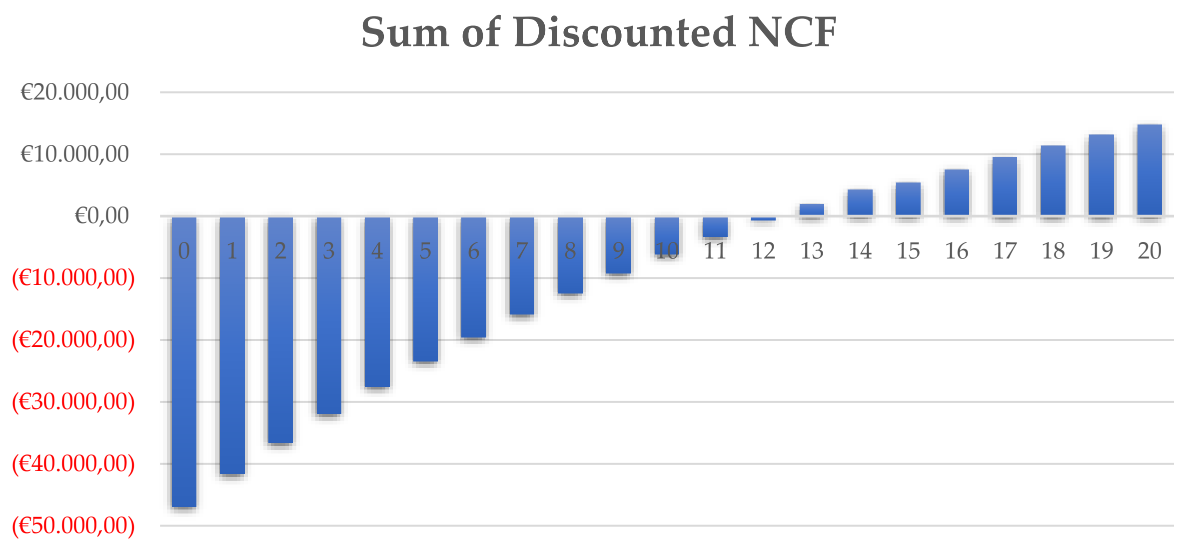


Figure 54: *Sum od Discounted NCF – Scenario TO-BE2 accounting for incentive schemes – APV1.*

Table 20: *Economic assessment's results – Main parameters accounting for incentive schemes.*

NPV	15.177 €
IRR	3,61%
PBT	13
LCOE	0,06665 €/kWh

As in the Scenario TO-BE1, a reviewed version of the economic analysis was performed at the end of the first semester of 2023, when the updated version of the law decree regarding the APV market was released. On the one hand, the peak power of the plant did account a minimum value anymore, thus no assumptions were required anymore over the peak power installed. On the other hand, the PUN was left equal to 120 €/MWh while the new tariff granted for the 20 years' time horizon, with these specific characteristics, was considered equal to 103 €/MWh. Other assumptions were left unchanged in the review, having the willingness of tackling only the economic aspects of the project. In table 21 and figure 55 are summed up the new results.

Table 21: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	26.428 €
IRR	6,07%
PBT	10
LCOE	0,06665 €/kWh

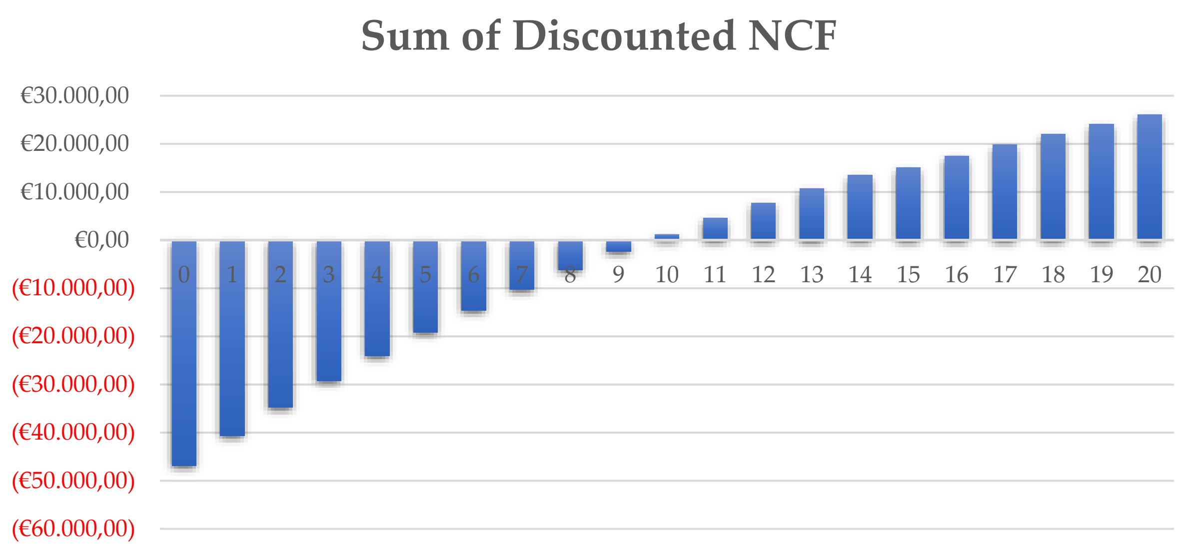


Figure 55: Sum od Discounted NCF – Scenario TO-BE2 with UPDATED incentive schemes – APV1.

This new configuration is the one which depicts the most favourable outlook for the two entrepreneurs. Indeed, within this scenario, NPV and IRR are at their maximum values while the PBT is at its lowest peak. This positive situation is caused by the new regulation, which granted the elimination of two hurdles faced in the previous version of the law decree. From the LCOE perspective, the value remained equal to 0,06665 €/kWh as it was in the previous analysis. Fact which is reasonable since no technical aspects were touched in the law decree's transition.

3.3.3 Scenario TO-BE3

For what concerns the design phase and the technical decision variables accounted here there will be no differences from the scenario TO-BE2. As reference layout it was kept, even in this configuration, the one explained by figure 47 and 48 in the previous chapter. The very same reasoning will be made for what concerns shadows and solar radiation hitting the ground, as well as the PV modules type and quality and the inverters ones. The peak power which may be installed will remain 48,5 kWp and the design configuration will be the same as figure 49. the introduction here of the bi-axial tracker bounded with each single PV module will not affect in any way the layout configured in the previous scenario. Thus, even from an electrical point of view, 88 will remain the number of PV modules installed as well as one SUN 2000-50KTL-M3 the inverter. Although form the design and technical layout point of views the project will be specular to scenario TO-BE2, a big difference will step into the scene talking about the energy perspective. In fact, the presence of the different tracker will allow the APV plant being even more efficient for what concerns with the energy production and thus the energetic analysis was conducted once again. The PVGIS software was the lighthouse of the process in this case as well, and then the local software Barbarasa was exploited too. Then, all the information gathered were fed into Barbarasa which was able to give reasonable and reliable results. In the following graphs results of the energy analysis are shown. To enhance a better benchmark within technologies, once again the same days were kept as reference.

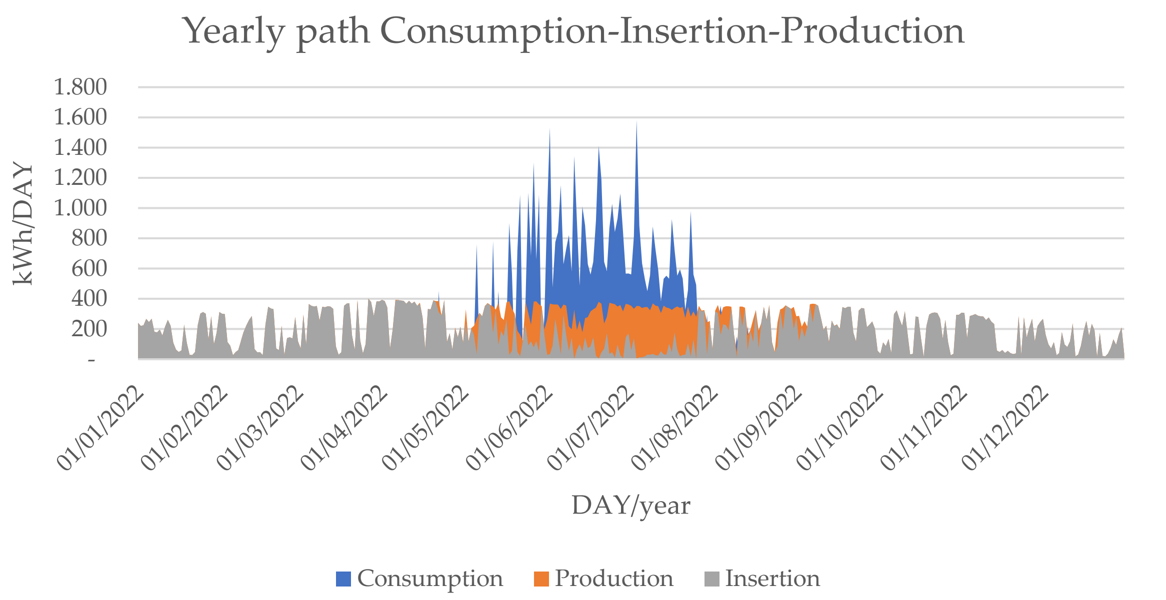
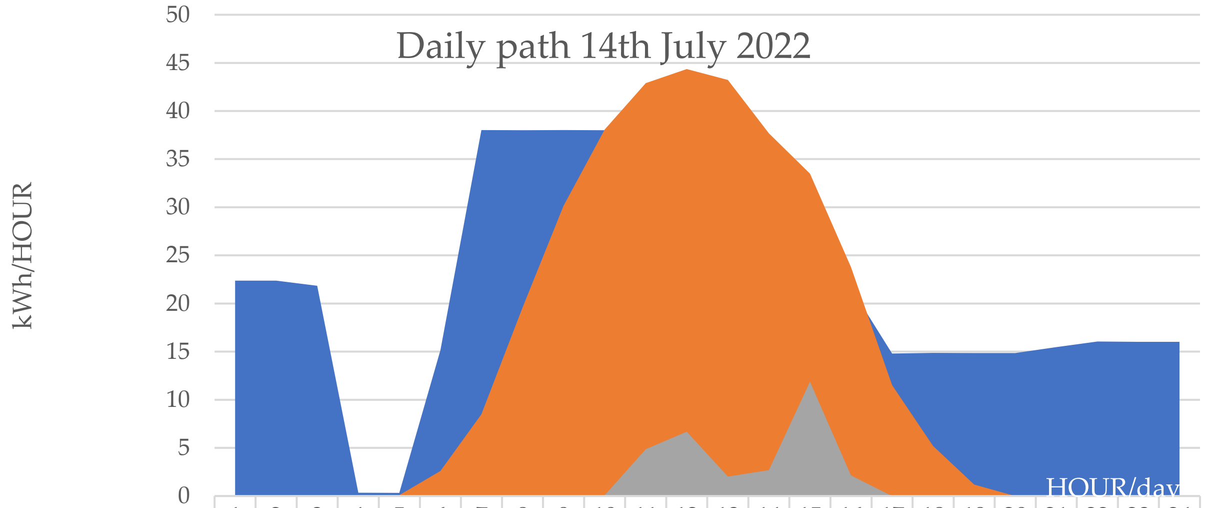
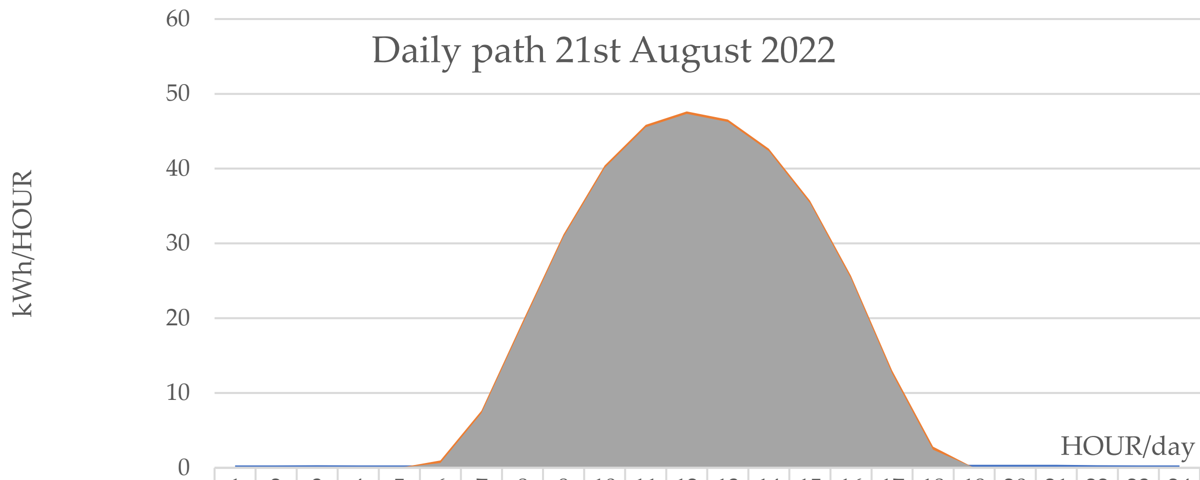


Figure 56: 48,5 kWp plant; Consumption curve=blue; Insertion curve=grey; Production curve=orange.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	22	22	22	0	0	15	38	38	38	38	38	38	41	35	22	22	15	15	15	15	15	16	16	16
Production	0	0	0	0	0	3	9	20	30	38	43	44	43	38	34	24	12	5	1	0	0	0	0	0
Insertion	0	0	0	0	0	0	0	0	0	0	5	7	2	3	12	2	0	0	0	0	0	0	0	0

Figure 57: Daily path 14th July 2022.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production	0	0	0	0	0	1	8	20	31	40	46	48	47	43	36	26	13	3	0	0	0	0	0	0
Insertion	0	0	0	0	0	1	7	19	31	40	46	47	46	42	35	25	13	2	0	0	0	0	0	0

Figure 58: Daily path 21st August 2022.

The possibility of experiencing a greater self-consumption rate due to larger plant dimensions and consequently installed peak power is one significant distinction between this scenario and the TO-BE1. To maintain the same assumptions and construct a non-differential framework, it was assumed that the self-consumption quote would rise over time because of higher energy consumptions and lower amounts of energy produced because of a decline in the efficiency of the PV components. In this case, this figure was computed to be equal to 23,0% at year 1. Immediately, it may be underlined how even though the bi-axial trackers were introduced, and the energy produced is more in this scenario than the TO-BE2, the self-consumed quote is an amount of energy lower than the one gained with this APV configuration, even if expressed in percentage terms. This aspect highlights how the optimal value to maximize the self-consumption of the well is lower than the one produced in this scenario TO-BE3. Even though results and values here are lower than scenario TO-BE2, they are still higher and more profitable in economic terms than scenario TO-BE1. Indeed, it must be underlined how from an economic perspective, the situation is favorable because, when discussing RES plants and relatives, self-consumed energy is the most valuable form of energy. It is valued at a price equal to the product of PUN/PZ and the sum of all the other system expenses, which represents the value of the raw material plus all associated costs relevant to Italian law, such as those associated with transportation, taxes, and other fees. At the end of the time under consideration, a final value of 24,2% is anticipated, which is still a low figure when compared to the installations of traditional enterprises.

Incentive scheme compliance

The PVGIS database estimates that the proposed plant would produce 79.783 kWh in year zero. Thus, for a total installed power of 48,5 kWp, the anticipated specific yearly electric production will be 1.645 kWh/kWp. Since the layout of the APV plant does not differ from the scenario TO-BE2, moreover the electric components and sustaining tensile system are the same, the LAOR and the percentage of soil area left available to agriculture after the APV implementation remain the same as scenario TO-BE2. Values are respectively equal to 8,48% and 82%. Keeping the very same reasoning, all kind of agricultural activities are allowed under the installed plant, since the minimum height is respected. Then the monitoring system which would be installed will be sized and programmed to respect all the requisites imposed by the regulator through the CREA-GSE. Finally, the energy production benchmark needs to be undertaken to check its compliance with the prerequisite imposed. In this scenario the APV's efficiency is equal to the 136% of the thresholds imposed with the 10° tilt angle and South-oriented case. A 12% more than the scenario TO-BE2 which is due to the introduction of the different type of tracker. Overall, the energy produced here is equal to 285 MWh/ha/year with the reference case which remain equal to 280 MWh/ha/year. Thus, the lower limit of 60 % is far from being a problematic topic. As happened in the two previous scenarios, the LER parameter was computed here. The α coefficient resulted equal to 0,538 as happened in Scenario TO-BE2 and it was computed as:

$$\propto = \frac{1 - Unused\ area}{Available\ area} \tag{23}$$

After that, the final LER value resulted equal to 1,53, higher than the previous one. The difference can be found in the slightly higher electric production since the technical configuration remained the same. It is worth underlying how it is always present the alarm of the 300 kWp lower limit as peak power installed.

Economic analysis

In this scenario, many of the structural characteristics are equal to scenario TO-BE2. Indeed, for what concerns the vertical and horizontal structures which will have the task to sustaining the PV modules, the hypothesized configuration remained the same as in the previous scenario. In addition, the computation of NPV, IRR and PBT will be the decision-making activity together with an analysis of the LCOE obtained with this configuration. Tackling the CAPEX perspective, a final APV plant cost was computed and resulted equal to 81.250 €. The first configuration that may be undertaken is the one that the final cost is quite comparable with the one of scenario TO-BE2. Indeed, as mentioned, most of the design phase remained untouched. The biggest difference which must be explained is the introduction of bi-axial trackers in place of the monoaxial ones. Bi-axial trackers will remain subdivided one each 10 PV modules as the monoaxial ones but their cost in this case increased. The unitary cost of a bi-axial tracker, according to what was offered to Erreci, is equal to 220 €/piece. Altogether, the amount of 9.680 € will be imputed to trackers component. From the OPEX side, as for the inverter substitution at year 15, maintenance and insurance costs were left unchanged from scenario TO-BE2. Indeed, parameters included in the design phase are equal to the ones of scenario TO-BE2. In table 22 is reported and summed up all costs and hypotheses undertaken.

Table 22: Costs structure's subdivision, CAPEX and OPEX sides - APV1 – Scenario TO-BE3.

CAPEX	**% of the overall CAPEX**	
PV modules	19.005 €	23,4%
PV inverter	2.567 €	3,1%
PV structures	35.000 €	43,1%
PV trackers	9.680 €	11,9%
Other plant set up expenses (Levelling the field, fence perimeter, bureaucratic procedure with GSE)	14.993 €	18,5%
Inverter substitution (year 15)	2.823 €	
OPEX		
Maintenance cost	35 €/kWp/year	
Maintenance cost increment rate	1%/year	
Insurance cost	6 €/kWp/year	
Insurance cost increment rate	0,5%/year	
Tax rate	30%	
Ke	7%	

Afterwards, it was computed the specific costs of the plant related to the number of kWp installed. The resulting value was equal to 1.675 €/kWp. As happened in scenario TO-BE2, the sum is higher than the ceiling imposed by the Italian regulatory framework, which is equal to 1.500 €/kWp. Thus, the initial economic analysis was performed living out the incentive scheme of 40% of the amount over the CAPEX which is supposed to be granted following a non-repayable scheme. In addition, also the incentive premium tariff for the energy fed into the grid was not recognised since at the current state of the art this designed APV plant does not result compliance with the prerequisites to access incentives. All other parameters were left unchanged, allowing this paper of performing a benchmarking scheme with as many non-differential parameters as possible. A progressive study of the Discounted Net Cash Flows was also conducted in addition to parameters as NPV, IRR, PBT. Results show a similar path compared to the same situation of scenario TO-BE2 for APV1. Indeed, here as before it was computed a sustainable investment even without any incentive scheme supporting it. Nevertheless, the investment resulted being sustainable but only in the very long run and this do not grant nay certainty with regards to the entrepreneurs' willingness to undertake it. The final outcomes are depicted in table 23 and figure 59.

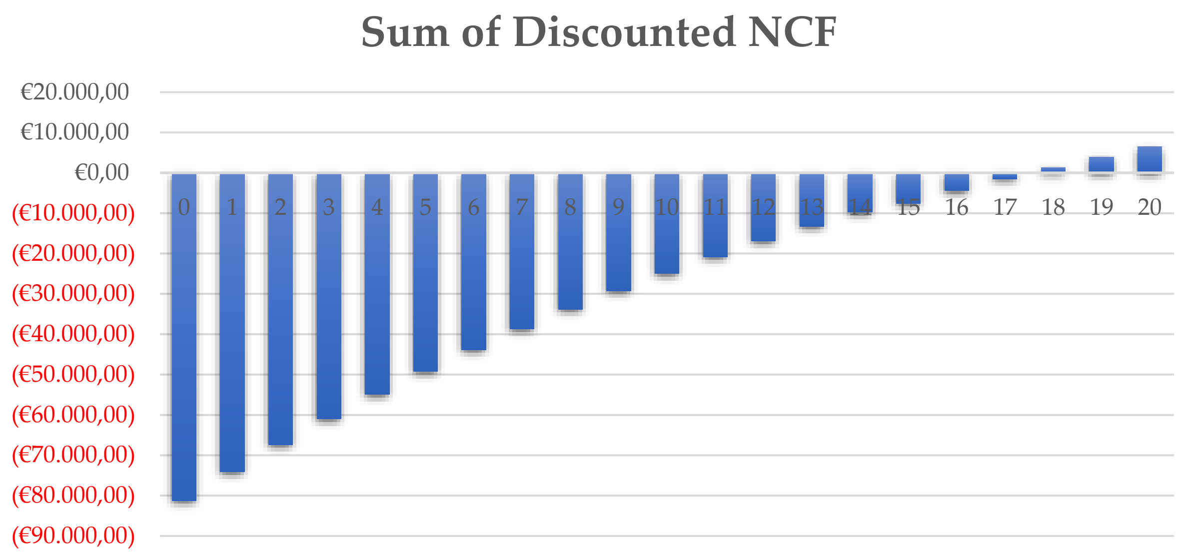


Figure 59: Sum od Discounted NCF – Scenario TO-BE3 without incentive schemes – APV1.

Table 23: Economic assessment's results – Main parameters without incentive schemes.

NPV	5.960 €
IRR	0,83%
PBT	18
LCOE	0,08341 €/kWh

Additionally, the LCOE coefficient was calculated with the intention of comparing as many different scenarios as possible from the standpoint of this parameter, which does not financially assess the profitability of the plant itself but, on the other hand, totals up all the costs that are anticipated to be incurred by the APV plant over the course of its lifetime in relation to the total amount of energy that the plant is anticipated to produce. In this case, the scenario displays an LCOE of 0,08341 €/kWh. According to this paper, it is interesting highlighting how this case presents the lowest LCOE within all the scenarios presented for APV1 without incentive schemes. The difference from the scenario TO-BE2 is not extremely relevant while it is more significant when it comes to benchmarking with scenario TO-BE1. The difference between this scenario and the second is explainable because, even though costs are higher in this case and economic parameter only are worse, the energy produced is bigger here since the specific electric productivity is higher in terms of kWh/kWp installed/year. In other words, the higher electric productivity is more impactful than higher cost from the LCOE point of view. Furthermore, keeping in mind the same uncertainty level which underpins the regulatory framework, the very same reasoning of scenario TO-BE2 was undertaken. As previously done, the investment was evaluated including all the incentives present on the field, regardless of initial constraints. Therefore, the CAPEX considered here was equal to the 60% of the precautioned one: 48.750 €. It is obvious how, by reducing CAPEX with the help of the initial incentive, even though it covered only a small portion of it, the economic environment drastically transformed. All the factors that were considered are by far improved here and appealing from an entrepreneur's perspective. As expressed in table 24, NPV is better when compared to previous scenarios. To be thorough, a larger NPV is likewise counterbalanced by a higher necessary initial investment. It is important to note that the situation has significantly improved from an LCOE perspective as well. In fact, the LCOE has fallen since the amount of energy produced by the plant over the 20-year period under consideration stayed constant, but the total amount of all costs incurred, considering CAPEX plus OPEX decrement. In this instance, the LCOE came out to be 0.06216 € per kWh produced. Value that represents the cost to the business owners of the energy produced by the plant, irrespective of future changes in electricity rates, at around 61 €/MWh. As in the analysis without incentive, LCOE of scenario TO-BE3 resulted being the lowest of all the scenarios considered.

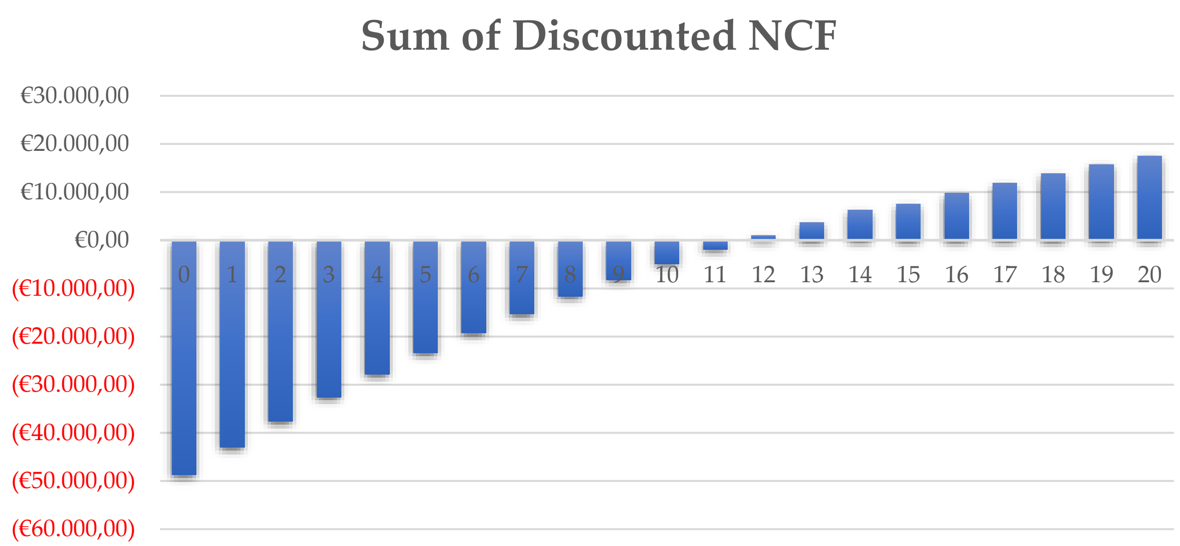


Figure 60: Sum od Discounted NCF – Scenario TO-BE3 with partially accounted incentive schemes – APV1.

Table 24: Economic assessment's results – Main parameters partially accounting for incentive schemes.

NPV	17.003 €
IRR	3,89%
PBT	12
LCOE	0,06216€/kWh

In this last point, it was considered the updated law decree released between April and May 2023 and the economic parameters were modified. Specifically, the analysis kept all the technical aspect while it was changed the FiP (Feed in Premium). This time it was considered the two-part tariff equal to 103 €/MWh in place of the old one which fixed the remuneration at 85 €/MWh. Noticeable to underline how once again bot the peak power limit together with the €/kWp one dropped. The former does not exist anymore, with all peaks power authorised, the latter is now set to 1.700 €/kWp which is respected in this case. All the economic parameters improved, higher NPV and IRR while it was computed a one-year shorter PBT. Results are shown in figure 61 and table 25. LCOE remained set equal to 63 €/MWh.

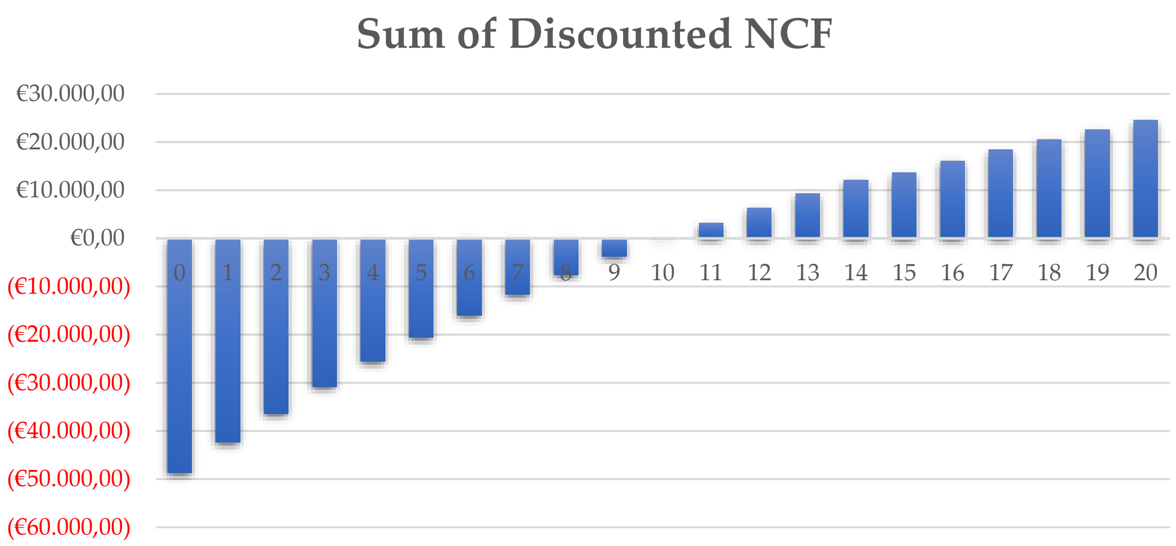


Figure 61: Sum od Discounted NCF – Scenario TO-BE3 with UPDATED incentive schemes – APV1.

Table 25: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	24.895 €
IRR	5,58%
PBT	11
LCOE	0.06216€/kWh

3.4 Agrivoltaic plant 2

3.4.1 Scenario AS-IS

As described and discussed in the previous chapter, a Scenario 0 was considered during the investment evaluation. This scenario represents the AS IS case, therefore without any discussion over APV technologies. Differently from the case of APV1 where the land area is currently unutilized, in this case the entrepreneurs are exploiting the area for economic activities. At the state of the art, the entrepreneurs exploit the soil area, which is over 4 hectares, specifically 4,2 ha, with a traditional crop rotation. The information collected by the two of them states how, after all the expenses sustained in the agricultural processes a net income of 2.000 €/ha is extrapolated. With a simple calculation, the overall year net income of the business is equal to 8.400 €/year. Thus, the reasoning underpinned here is the one that entrepreneurs will undertake the APV project whether it will grant a higher ROI than the actual state of the art. So, as a first step of the evaluation it was needed to compute the current NPV of the area, with no changes. An inflation rate equal to 2%/year was considered and a cost of capital, once again summed with the Ke parameter equal to 7% as in all scenarios. The idea was to one of levelling as much as possible to initial assumptions and conditions while evaluating.

Table 26: Economic assessment's results - Scenario AS-IS, case APV2.

Agricultural income - AS IS case (Scenario 1)	
Inflation rate	**2%/year**
Agricultual income	**2.000 €/ha**
Land area	**4,2 ha**
Ke	**7%**
NPV	**106.503 €**

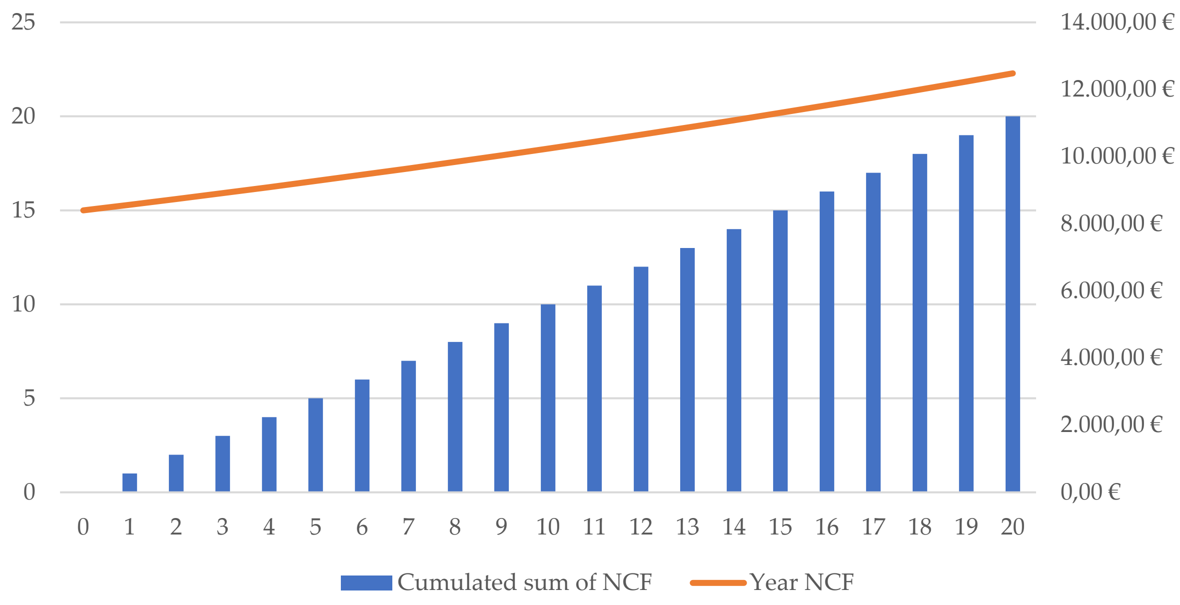


Figure 62: Year and cumulated NCF pathway – Scenario AS-IS.

In table 26 parameters are summed up and the output's NPV is expressed. Thus, the value of 106.503,05€ is the threshold parameter which will be our reference guideline during the analysis. The decision-maker rule can be seen as that the APV investment will be carried out whether it will grant a higher NPV. Otherwise, from a rational perspective the entrepreneurs will lack the willingness to even reason over the precautionary document. The reflection which must be considered here is the one that, customers will be willing to invest in the APV2 plant project if and only if a consistent insurance over future economic returns will be granted as it is in the agricultural state of the art of the business. In case that the APV solution will not be sustainable, the entrepreneurs will turn to other ideas on how to exploit their land surface.

3.4.2 Scenario TO-BE1

Deep diving the discussion over the APV2 project, it must be immediately said how the very same technological configuration accounting vertical-mounted bifacial PV modules will be used in the precautionary process of the scenario TO-BE1. Indeed, the scenario analysis previously performed remain the same. Thus, the line of reasoning behind the project was once again the one of looking for easiness of management of the APV plant, once it would be implemented. Again, the first pillar was accessing the government's funds, 40% of the overall value of the plant obtained through a non-repayable incentive. To conclude, agricultural ideas and vision of the entrepreneurs were considered, and a discussion was made, at the very same level of APV1, about installing something which would not have precluded any usage opportunity in the long run of the ground area to the customers.

Therefore, with the selected technology in mind, having a clear picture understanding of the limitations introduced by the vertical mounted bifacial APV systems in terms of height of the rows and pitch distance between rows, a sizing process was underpinned. Stepping back for a while, the situation in this case is the one that customers do not possess any POD close to the studied area, no factories or even houses belonging to them are present and therefore all the part of self-consumption of the electricity which would be produced is left out here. The investment was thought as a total energy production with the attempt of selling energy to the system. Thus, the logic behind the precautionary approach here was not, as done previously, the one of sizing the plant according to the needs, in order to maximizing the self-consumption quote, whereas the idea was the one of maximizing the power installed. Therefore, a so-called power plant would eventually born here.

Once again, the SolarEdge software was used as a reference software for the modelling and sizing part. In this case, differently from what happened in APV1 the area is not a unique one all connected. Indeed, the overall area of almost 42.000 m^2 is subdivided in three sub areas. The three fields are directly neighbours, separated by two canals only. Nevertheless, due to this heterogeneity in the land surface, the doubt which came to mind during the precautionary step and during the making of this paper was about the sustaining structure layouts. Indeed, in APV1 two types of structures were hypothesized, with a row's lengths equal to 50 m the shortest and 100m the other two. Unfortunately, it was immediately clear how some modifications would have been needed in this new precautionary approach and therefore the idea was the one of contacting the selected supplier asking for its level of construction flexibility, with the reason why of understanding whether or not it would have been available to realise structures even with different layouts. The feedback was quite straightforward and quite positive as well. Indeed, the only constraint posed was the one of respecting 5 meters' multiples in the rows' lengths. With this extra insurance, keeping again as reference products for the PV modules the JAM72D30 550/MB/1500V from JA Solar, a first attempt was made as sizing precautionary process. With a complete outlook, 1574 PV modules were precautioned in this first graphic layout. In figure 63 the graphical representations of the hypothetic layout are shown.

Figure 63: Project APV2 layout, multiple views.

Due to the final nominal power projected, it was thought in this phase that it would have been better to change the inverter type. First, using again as in APV1 the 50 kWp size ones would have meant installing 17 inverters, which are way too many. Indeed, the more inverters installed the higher probability of out of order events in one of the machines which would require an expensive maintenance intervention. Second, from a practical point of view it is easier collecting all the electric cables in a lower number of machines. Third, installing 17 inverters in a field would have required the construction of a huge sustaining structure, usually a cement box is built in PV ground installation to host and shelter inverters, electric cells and other delicate components which cannot be left outside. Nevertheless, the bigger the structure required, the more expensive both in economic and special terms. Thus, a different type of inverter was selected for this project. The reasoning behind the type of decision was taken trying to offer the same brand as in APV1 to the customers. Furthermore, Huawei is a worldwide known brand which accounts countless business units, and it is well positioned in many technological markets, over than the PV components' one. Therefore, the SUN2000-100KTL-M1 inverter produced and commercialized by Huawei was picked. The product here, due to its bigger power may reach a maximum conversion efficiency higher than the one thought in configuration APV1, with a ceiling equal to 98,6%. As well, it is once again well-equipped in terms of MPPT number allowing a maximum flexibility to the company in the installation process. Indeed, the 100KTL-M1 offers 10 MPPT connection points for the electric string. Finally, having 8 inverters rather than 17 will positively impact on maintenance costs all over the lifespan of the plant.

Figure 64: Blue box representing section 1, red box representing section 2 and yellow box representing section 3.

Furthermore, as previously mentioned, the plant was divided in three subsections during the precautionary approach. The reason why was to simplify the management process of all the electric part. Indeed, during the attribution of PV modules to respective PV inverters and, consequently the electric subdivision of the plant, five inverters were attributed to section 1, one was assigned to section 2 and two were attributed to the remaining section 3. As well, due to the land's conformation and geometry, the logic was the one of predispose PV structures as similar as possible, at least within each different section to decrease the complexity and thus the costs.

- In section 1, twenty-six rows with a length of 90 m are present. Each row accounts 38 JA550 PV modules and the total nominal power of the area is 543,4 kWp. The total number of PV modules installed in this section is equal to 988. The azimuth angle decided for the PV modules in this section is equal to -85°, the tilt one is again equal to 90° as in the project of APV1.
- In section 2, four rows with a length of 60 m are present together with six other rows slightly shorter, with a length of 55 m. Each row accounts respectively 25 and 23 JA550 PV modules and the total nominal power of the area is 130,9 kWp and a total amount of PV modules of 238 pieces. In this case, the tilt angle is always 90° while the azimuth one resulting is -96°.

- In section 3, seven rows with a length of 85 m are present together with six other rows with a length of 40 m. Each row accounts respectively 36 and 16 JA550 PV modules and the total nominal power of the area is 191,4 kWp. In this last section, 348 PV modules are precautioned. Here the same parameters of section 1 are adopted concerning the azimuth and tilt angles.

Incentive scheme's compliance

The hypothesized plant will have a year 0's production equal to 801.254 kWh according to the PVGIS database. Thus, the expected specific electric production will be equal to 931 kWh/kWp installed for what concerns the sections 1 and 3 of the projected APV where the azimuth angle of the PV modules is the same and 895 kWh/kWp installed concerning section 2. Overall, a total power installed of 865,70 kWp was precautioned. Immediately, it is evident that the azimuth angle shows here its influence over the energy produced. Indeed, a reflection should be performed on the lower productivity gained here due to its effects benchmarking APV2 here with the APV1 work. Regarding the requirements set forth by the Italian regulator to access the incentive programs, there won't be any issues with the agricultural surface that is left following the implementation of the APV; in fact, more than 90% of the initial surface will still be available. As done before, tackling now the LAOR parameter, each PV module will have an area of 2,70 m^2, since it has been precautioned the usage of the same PV module type, which mean a total occupied area of 4.249,80 m^2. Adding the sustaining structures' bulk, the overall APV area is equal to 4.753,48 m^2, considering once again 0,3 m^2 of bulk for each PV structure. Therefore, the LAOR is equal even in this hypothesis to 11,3%, well beyond the thresholds of 40% maximum.

$$LAOR = \frac{4.753{,}48\ m^2}{42.000\ m^2} = 0{,}11317$$

Installed and configured in accordance with the restrictions imposed by the government, the monitoring system. Additionally, since a 1,3 meters space was left between the ground and the APV installation's bottom border, breeding activities will fall under the purview of the agricultural sector of the firm. Again, the continuation of the agricultural activity that was previously carried out on the field will be permitted in accordance with the CREA-GSE rules and even improved because previously, the primary activity on the land was the extraction of firewood, whereas with the APV, a more sophisticated activity will enhance higher incomes and a better exploitation of the soil. The LER coefficient was computed considering all the values listed above with the formula previously expressed and resulted equal to 1,29.

The specific electric production, as explained, will be twofold and equal respectively to 931 and 895 kWh/kWp installed. Then, with the very same procedure of APV1, a reference value was taken from the same PVGIS database and the same PV module. The criteria specified a South-oriented placement on the ground with a tilt inclination of 10°. The measured value was 1208 kWh/kWp installed. According to the ratio of the comparison, APV's efficiency is equal to 63% in the reference example, a value that is high enough to meet the requirement. Results showed 190 MWh/ha/year in the APV instance and 248 MWh/ha/year in the reference scenario when all data were expressed in MWh/ha/year, as specified by the guidelines. An additional ratio of 76%. As before, it is here an occasion to reflect on how the azimuth angle massively impact over electric productivity. Indeed, a little shift in the remaining predominant East/West orientation and big differences could be perceived from the productivity perspective. Differently from APV1, no problems in terms of plant size are faced in this case. Indeed, the APV2's size is way higher than the limit posed by the regulatory framework which, as today, poses it equal to 300 kWp installed minimum power.

Economic analysis

After having carried out this initial design phase even for the APV2, as done in the APV1 case, the economic side of the project was tackled. As a matter of fact, here due to the plant size with is more than one order of magnitude bigger than APV1, numbers should be evaluated even with more detail and caution. As before, with the attempt of offering a clear picture over the evaluation process' criteria, CAPEX and OPEX considered are listed as strategic leverages.

CAPEX:

- Full investment cost of the APV plant, which is made by:
  - PV modules
  - PV inverter
  - Sustaining structures
  - Grid-connection
  - Bureaucratic procedures
  - Field settlement
- Inverter substitution

OPEX:

- Maintenance cost
- Insurance cost

The reason why of offering a detailed list where all the costs will be listed is to offer the customers all the possible opportunities to evaluate the coefficient and parameter used, both in an operative level and in a strategic one. The same PV modules used in APV1 were hypothesised here with an individual cost of 181,50 €/piece. Despite the bigger size here, no economies of scale were thought in the purchasing process of Erreci for seek of precaution. Indeed, it was reflected how it would have been better to stay on the reason side of the business avoiding overexposing the company. The Huawei inverters were forecasted with an individual cost of 4.610 €/piece. The overall sums of the cost of the PV modules were computed equal to 285.681 €, while the inverters one to 36.880 €. Proceeding with the sustaining structures' precautionary approach, a cost of 125.000 € was extracted as an average value within different offers from Erreci's historical suppliers, performing the very same process of APV1. Having noticed how even with this different type of Huawei's inverter product the granted lifetime efficiency was 15 years, it was considered a replacement cost for all the inverter group. The cost was equal to 40.568 € obtained accounting the current cost of the inverter group and increasing it by 10% which was thought being a fair inflation rate of the product cost. Summing up all the voices, the final plant cost was expected being equal to 653.603 €. Having the overall cost and the nominal power of the plant, equal to 865,70 kWp it was computed the average cost of one kWp installed which is a common parameter which may be benchmarked on the market. The value resulted equal to 755 €/kWp. The first point which deserves to be highlighted is the big difference in term of cost per kWp with the APV1. Almost 300 €/kWp difference is the result of the order of magnitude of difference which interplays between the two. Indeed, economies of scale's effects are gained here in opposition with the APV1 case. Furthermore, it is worth noticing how even in APV2 work, the project remains well beyond the maximum ceiling imposed by the Italian government to access the incentive schemes, which set the limit equal to 1.500 €/kWp installed. OPEX costs include a maintenance cost of 15 €/kWp/year and an insurance cost of 3 €/kWp/year. In the maintenance cost, once again it is possible to notice the economies of scale's effects here rather than in APV1 case. An additive factor of 1%/year was considered for the maintenance cost to account for the plant's increasing obsolescence, which will make maintenance tasks more challenging in the long run. On the insurance expense side, an incremental coefficient of 0.5%/year was added using the same logic. The client is allowed to shop around for the best offers from its perspective and is not required by Erreci to sign an insurance and maintenance contract. These two are only two expenses to increase the trustworthiness of the cautious document. In table 27, a recap of the costs voices is reported.

Table 27: Costs structure's subdivision, CAPEX and OPEX sides – APV2 – Scenario TO-BE1.

CAPEX		% of the overall CAPEX
PV modules	285.681 €	43,7%
PV inverter	36.880 €	5,6%
PV structures	125.000 €	19,1%
Other plant set up expenses (Leveling the field, fence perimeter, bureaucratic procedure with GSE)	206.042 €	31,5%
Inverter substitution (year 15)	40.568 €	
OPEX		
Maintenance cost	15 €/kWp/year	
Maintenance cost increment rate	1%/year	
Insurance cost	3 €/kWp/year	
Insurance cost increment rate	0,5%/year	
Tax rate	30%	
Ke	7%	

Since APV2 is nothing but, a plant thought without any link with self-consumption aims but rather a complete insertion into the grid of the energy produced, no further reasoning about self-consumption of energy and cost of energy acquisition are needed. As well, in the full budget process it will not be present the income related to the missing acquisition cost of the energy. On the other hand, a detailed discussion over the opportunities to feed the energy into the grid and its valorisation should be carefully carried out since the entire decision-making process on whether performing or not the investment will lay around the amount at which it will be possible to valorise the energy fed into the grid. Furthermore, as APV1 even in this case the agricultural activity which will be considered is the breeding one. In fact, limitations imposed by the Italian government were respected by the minimum height of the PV modules from the ground is, as for APV1, 1,3 meters which is not sufficient to be compliant for agriculture prerequisites. Dealing with the energy perspective, a decrement in the productibility of the APV plant was accounted for seek of realism. It was parametrized equal to a decrement of 0,45%/year of the overall quantity of energy produced. The incentive tariff recognized by the government to the APV energy fed into the grid is 85 €/MWh even with a different nominal power of the plant, it remains the same reasoning of the public auction which will decide the value starting from 85 €/MWh. In addition, even the 40% of the initial investment was again considered as a non-repayable incentive. In the first economic evaluation, a Levered DCF perspective with a plant fully financed by equity capital will be considered. For seek of a dual approach between each proposal, a Ke equal to 7% will be considered here as well and the same for the 30% of tax rate. An amount equal to 10.000 € was taken into consideration for the agricultural side of the business to round out the overview of revenue streams related to the plant investment.

Once the reasoning has arrived here, it has been depicted all the costs conditions present here from both the CAPEX and the OPEX perspective. Then, the fiscal procedures and the incentive framework has been clarified, highlighting the presence or not of differences in comparison with APV1. The final point which needs to be stated is the economic value of the electricity generated, which will be valorised at a value equal to 85 €/MWh as granted by the regulatory framework. From an analytical perspective, NPV, IRR and PBT were again the parameters considered for a first draft evaluation. In table 28 they are reported.

Table 28: Economic assessment's results – Main parameters accounting for incentive schemes.

NPV	48.898 €
IRR	1,51%
PBT	16
LCOE	0,05034 €/kWh

As a matter of fact, numbers here are nothing but good ones, even though not incredibly good ones. Indeed, starting from the bottom, the PBT is equal to 16 years, started counting from year 0, meaning that the investment will experience at least 4 years of positive incomes during the analysed period. All those positive incomes are summed in the positive value of NPV. Nevertheless, even though in literature it is often reported that a positive NPV is the rule of the game when it comes to decide if undertaking an investment or not, it is also worth stating how the entrepreneurs may ask themselves if there is on the market a way to invest today almost 750.000 € and getting higher returns in 20 years' time. The previous sentence does not even account the aleatory nature of the energy market. Again, companies and big investor groups accept no more than 5 years as PBT of an investment nowadays, whatsoever type of investment, due to the uncertainty which lies in every business branch. With the previous reasoning, the attempt is not the one of perceive the entire range of opportunities presented here as a negative and hopeless one. Indeed, the investment has many positive aspects which were highlighted in the analysis. The idea here is the one of remaining cautious, especially as in APV2 case where, differently from APV1, the sum of money on the table is sensitive. With the attempt of enhancing the investment decision, it is worth noticing how the NPV related to the APV2 plant is more than the double of the NPV given by the AS IS scenario with the land area exploited only for agricultural activities. In figure 65, a graphic representation of the PBT and of a cumulative distribution of the Discounted NCF are given.

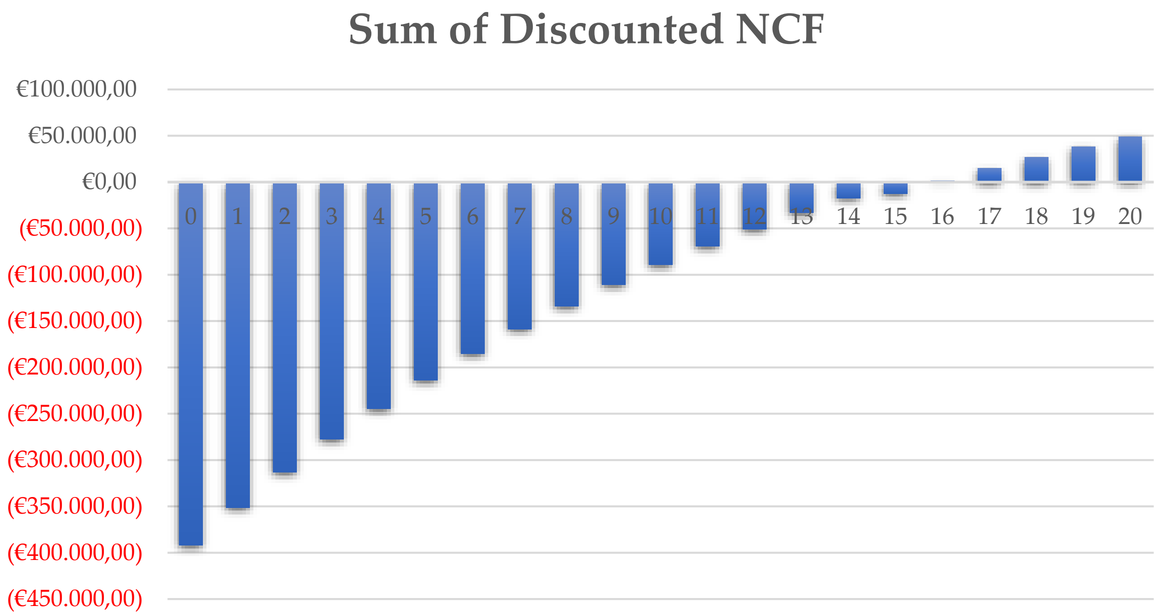


Figure 65: Sum od Discounted NCF – Scenario TO-BE1 with incentive schemes – APV2.

As done in APV1, a way to cut out all the uncertainty diffused and getting a chance to see things with nothing but certainties during its evaluation, the LCOE coefficient was considered. APV2 is expected to produce 15.358.162 kWh during the analysed period and the total sum of all OPEX costs expected is 380.980 €. The LCOE in this case is computed equal to 0,05034 €/kWh. It is worth noticing how the LCOE decreased from APV1 to APV2 with the same technological scheme from a design plant point of view. This fact is due to the higher economies of scale achieved with a was bigger peak power installed. With this aspect in mind, it was thought to compute the investment projections without any king of incentive schemes granted by the government. Therefore, the full CAPEX amount was considered and contemporary the value of electricity fed into the grid was computed equal to 120 €/MWh. The same PUN value was taken as APV 1 – Scenario TO-BE1.

Table 29: Economic assessment's results – Main parameters without incentive schemes.

NPV	69.190 €
IRR	1,20%
PBT	17
LCOE	0,06736 €/kWh

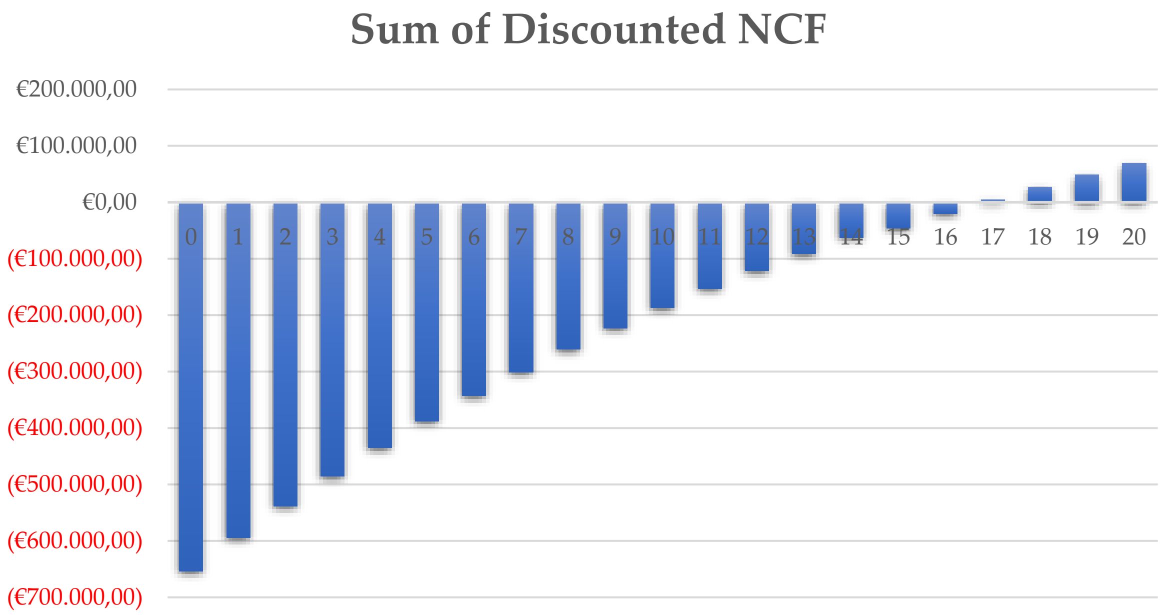


Figure 66: Sum od Discounted NCF – Scenario TO-BE1 without incentive schemes – APV2.

Table 29 reports the reality of how, due to the current PUN value, the investment could be sustainable even without any type of incentive scheme. This result is completely in opposition with the ones founded in the APV1's analysis. Indeed, the bigger plant dimension let the specific cost/kWp decreasing and therefore accounting 120 €/MWh as remuneration is possible to reach the break-even point within the time horizon considered. It must be underlined how even if economic parameters as NPV and IRR resulted quite like the case where incentives were accounted, in this situation uncertainty and risk are way bigger. Indeed, on the one hand there is the GSE granting a certain determined tariff for a time horizon, regardless of what will happen in the geopolitical landscape. On the other hand, it is an investment evaluation based on the current energy price, and no one knows what will happen in the energy market in one year, not even thinking in ten, fifteen or twenty. In this second case, without any type of incentive schemes, the LCOE was computed equal to 0,06736 €/kWh. Value way higher than before and more in line with the historical data about LCOEs of emerging technologies. Nevertheless, as in the case with incentives, this value is lower than the LCOE of APV1 – Scenario TO-BE1 without incentives due to the achievement of economies of scale (EOS). It is interesting noticing how, even though economic results are quite similar between the two cases, their LCOE values are quite different. The explanation can be found in the fact that in the case accounting incentives, the CAPEX is reduced by the 40% and therefore is the total sum of the costs. Whereas, in the case without incentives it is accounted the entire amount of CAPEX and economic results are similar due to the difference between the premium tariff and the Pun value accounted.

Subsequently, even in this case it was performed an economic evaluation regarding the new law decree with the new incentive scheme. In this case, the threshold of 300 kWp as peak power installed has been overtaken by the precautioned project. Thus, as granted tariff it was used 95 €/MWh. The limited cost in terms of €/kWp installed was respected having a precautioned CAPEX equal to 755 €/kWp while the maximum allowed cost is regulated at 1.500 €/kWp.

Table 30: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	106.406 €
IRR	3,20%
PBT	13
LCOE	0,05034 €/kWh

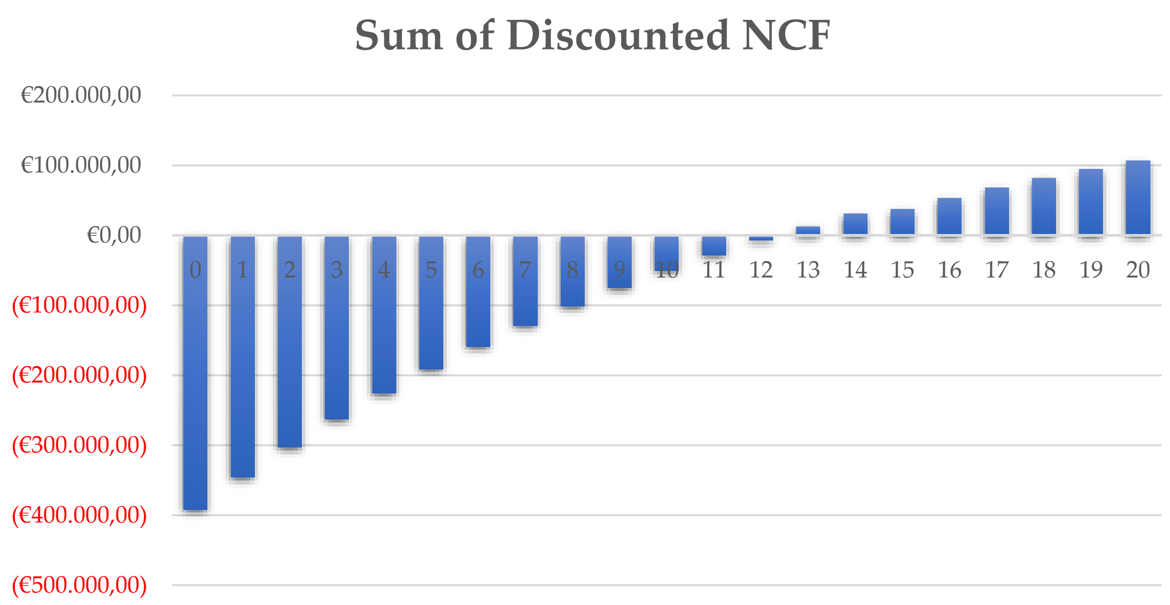


Figure 67: Sum od Discounted NCF – Scenario TO-BE1 with UPDATED incentive schemes – APV2.

In table 30 and figure 67 are reported economic results coming from the updated economic analysis. In this case, without any self-consumption discussion the tariff applied over the energy fed into the grid impacts more than in case APV1 – Scenario TO-BE1 where for a share of the total amount the changed tariff was harmless. Here, if compared with results of the old analysis, NPV and IRR are higher and thus the investment is more attractive. PBT is shorter granting a higher number of years of positive incomes. Noticeable to say, it is how the NPV is more than twice the NPV computed with the 85 €/MWh tariff while the IRR is only slightly higher. Finally, the

LCOE is not touched by the different economic valorisation of the energy produced as happened in APV1 – Scenario TO-BE1. LCOE remained approximately equal to 50 €/MWh.

3.4.3 Scenario TO-BE2

Even in this scenario, the same technological and financial parameters as in scenario TO-BE1 were considered. The technological configuration was totally altered from an installation standpoint, despite the criteria remaining unchanged. In fact, it is regarded as a Slilt-mounted APV technology in this context with a single tracker integrated inside the PV modules. In this instance, there won't be any issues at all with respect to PV module height compliance with the Italian criteria. In fact, after looking through the pre-existing arrangements, it was chosen to install the APV plant 5 metres above the soil. Therefore, there are no further restrictions and either agricultural or breeding activities may be carried out here. The fact that most agricultural machines used in daily activities have an overall height that is typically less than 5 metres was also considered in this case, so an owner who installed an APV plant on his property would not be required to replace any existing equipment. For what concerns the design phase, everything was taken from the case of APV1 scenarios TO-BE2 and TO-BE3. Thus, figure 47 and 48 remained the polar star of all computational procedures from a design point of view.

Figure 68: APV2 overview of Scenario's TO-BE2 layout and design.

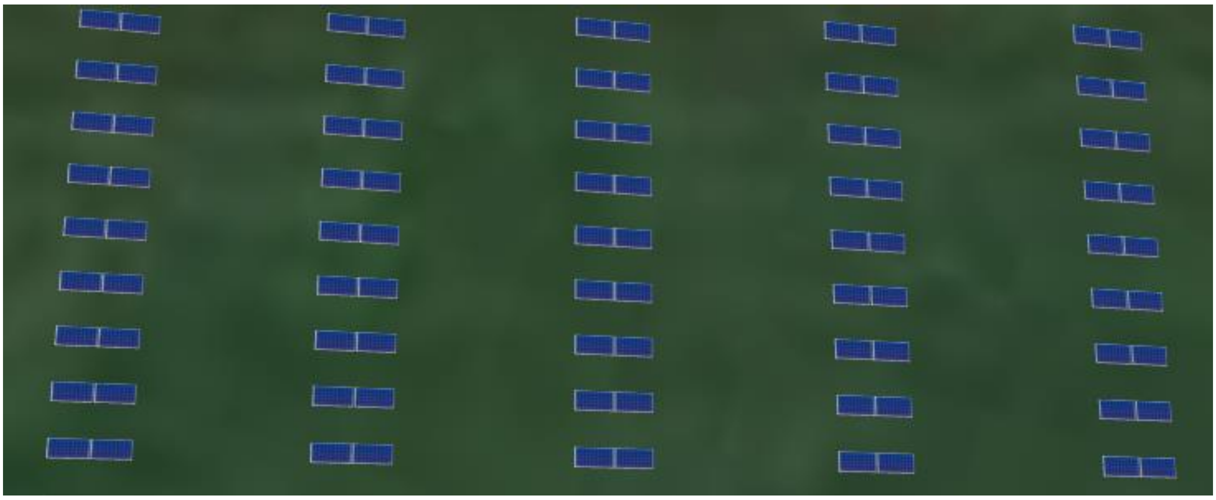


Figure 69: Scenario TO-BE2, APV2 – Subdivision between PV modules' horizontal rows and vertical sustaining structures' occupied space.

Figure 68 depicts the entire APV plant, laying on the same are as scenario TO-BE1, while figure 69 shows the subdivision between one vertical structure to another allowing the movement of agricultural machines. Due to the different technological configuration, as happened in APV1, even in this study a higher peak power resulted installable on the field with respect to scenario TO-BE1, APV2. Indeed, it was precautioned the installation of 1948 PV modules, JAM72D30 550/MB/1500V from JA Solar, divided in two sections as detailed in figure 70. the obtained peak power was computed equal to 1,071 MWp. Huawei was taken as inverter provider. Since the specific electric productivity in this scenario is way higher than the TO-BE1 due to the presence of mono axial solar tracker, the idea was the one of matching as bets as possible the peak power installed in each section with the available power of transformation of the inverter machines. Thus, in section 1, the one noted in light-blue, two SUN2000-100KTL-M1 of Huawei were hypothesised. The reasoning behind the decision of keeping the same materials as all the previous cases analysed even though in this situation the plant possible peak power is was bigger in on one hand due to the conviction about the high quality level of proposed products and, on the other hand, it was due to the attempt of reducing as much as possible the number of variable parameters, trying to exploit as much as possible a non-differential logic.

A total of 298 PV modules were sized divided in 7 rows. In the idle of the plant, it was dimensioned the available space for machines movements. The rows' length was planned equal to 70 meters, having in this section 7 rows. Whereas, in the second section, the red noted one, eight machines were sized. Furthermore, 1650 PV modules were hypothesised in this second section. In this case, 10 rows were designed over the ground area, with 5 of them 20meters longer than the other half. Rows' lengths were precautioned equal to 240 and 260 meters, with structural interruptions. In other words, the idea was the one of dimensioning one inverter for each vertical sustaining section of the APV plant to allow the maximum flexibility possible. Indeed, in case of maintenance or failures, the operator could switch off one section only at a time, isolating it from the rest of the plant and allowing the plant keeping on its working operations. The total peak power precautioned was therefore equal to 1.071 kWp, approximately the 20% more power than scenario TO-BE1. Dealing with energy production aspects, an albedo coefficient of 0,15 was considered as the reference one for grass and soil are, as happened within the entire paper.

Figure 70: APV2- Scenario TO-BE2, sections' subdivision. Section 1: light-blue one; Section 2: red one.

Incentive scheme's compliance

According to the PVGIS database, the proposed plant will produce 1.611.385 kWh in year zero. The predicted specific electric production will be equal to 1.504 kWh/kWp installed for those sections, as it was in APV1 – Scenario TO-BE2, where the type of trackers installed were precautioned being the same as in this case. It is highlighted how the presence of mono-axial solar trackers made the electricity production skyrocketing. Dealing with the portion of soil area left available for agriculture after the supposed installation of the APV plant, in this specific case, the space occupied by vertical sustaining structures will be equal to 10.200 m^2 given by eight rows occupied by the tensile sustain framework, accounting both section one and two of the projects. Thus, having 42.000 m^2 available, the area untouched is equal to the 75,72%, higher than the minimum amount required of 70%. In addition, the LAOR coefficient was computed.

$$LAOR = \frac{2{,}70m^2 * 1948\ PV\ modules}{42.000m^2} = 12{,}52\%$$

Again, value way beyond the maximum allowed of 40%. Furthermore, since the height of installation will be around 5 meters, no issues in terms of minimum height to be respected will be posed. All activities, either agricultural or breeding ones will be performed. In the moment of the APV plant construction it will be installed also a monitoring system in compliance with the prerequisites asked by the Italian regulator. Dealing with the monitoring system, parameters imposed by the CREA-GSE dualization will be respected. Reasoning over the electricity produced, or at least its forecasts, according to PVGIS database, SARAH2 – 2016, the average production will be equal to 1504 kWh/kWp which is way higher than the 1.208,5 kWh/kWp installed imposed by the regulator which asked to benchmark the APV plant with a traditional grounded mounted one with a South orientation, 20° as tilt angle. In other words, in this case APV plant will grant, thanks to the presence of trackers, a productivity higher than almost the 24%. Checking the per ha productivity, the computation made in the previous chapters highlighted a productivity of 248 MWh/ha/year in the reference case imposed by the regulator. Here, an overall production of 1.611 MWh is expected from the entire APV plant, which resulted in a production of 383 MWh/ha/year, which satisfies the prerequisites. Finally, no problems are foreseeable for what regards the peak power installed, indeed the power here is way above the 300 kWp. As extra parameter the LER value was computed. In this scenario, with the previously listed energy values, and keeping information given by entrepreneurs for the agricultural yield's side of the business, the LER resulted equal to 1,54. The alpha coefficient resulted lower than Scenarios TO-BE1, but the higher energy yields offset the situation.

Economic analysis

As highlighted in the economic analysis of scenario TO-BE1, in the case of APV2, differently from APV1, there is also a AS-IS scenario to consider which has a current profitability. Thus, even this scenario will be evaluated benchmarking it with the previous ones. For seek of simplicity, as many parameters as possible will be left unchanged to allow a better comparison within scenarios. Having said so, NPV will be the starting coefficient being computed followed by IRR and PBT. Finally, an overview and a reasoning over LCOE will be given. CAPEX and OPEX will remain the same as scenario TO-BE1. First, it is worth saying how the overall precautioned CAPEX for the entire installation, turnkey solution, of the APV plant will be equal to

1.270.680. Different physical sustaining structures which will enhance higher costs but contemporary higher earnings in terms of energy produced. Second, it needs to be made clear right away how increased insurance and maintenance expenses will be. The latter is a result of the more complex plant type, which will adversely affect the maintenance activities by greatly increasing their complexity. Thus, a value of 35 €/kWp installed/year was used in this calculation. The first is because the circumstance shows a more delicate installation that will be more vulnerable to damage from both human mistake and extreme climatic weather events. Consequently, it was estimated to be worth 6€/kWp/year in the instance that is being illustrated. It is obvious that these increased costs are not inevitable; in fact, their existence is more than justified by the higher energy productivity made possible by the current configuration, which is stilt-mounted rather than the prior one's vertical mounted. The objective of the economic analysis is to determine whether the greater amount of energy produced is sufficient to offset these increased expenditures. It is vital to explain how costs are broken up within the overall plant cost after the brief description phase. A total of 550.000 € were budgeted for the supporting structure, which included all vertical poles and tensile cables positioned horizontally at a height of 5 meters above the ground. The datasheet for the mono-axis tracker, which an Erreci supplier sold for 120 €/piece, said that one tracker could move a couple of PV modules, hence 974 trackers were needed in the setup. The assigned cost was calculated to be 112.880 € overall. Even that parameter was calculated with the intention of benchmarking the €/kWp installed parameter both within the analysis of the scenarios and on the outside market. All other sustained costs were computed thanks to the company's software: Barbarasa. The outcome was 1.186 €/kWp installed. With the latter calculation, it was checked an important constraint imposed by the Italian regulator, to be able to access economic incentives: the ceiling of 1.500€/kWp installed. Thus, no uncertainty will lay around this aspect has happened in scenario TO-BE2 and 3 for APV1. Table 31 summarizes all the most important voices when dealing with CAPX and OPEX.

Table 31: Costs structure's subdivision, CAPEX and OPEX sides – APV2 – Scenario TO-BE2.

CAPEX	% of the overall CAPEX	
PV modules	331.160 €	26,1%
PV inverter	49.930 €	3,9%
PV structures	550.000 €	43,3%
PV trackers	112.880 €	8,8%
Other plant set up expenses (Levelling the field, fence perimeter, bureaucratic procedure with GSE)	226.710 €	17,8%
Inverter substitution (year 15)	54.923 €	

OPEX	
Maintenance cost	35 €/kWp/year
Maintenance cost increment rate	1%/year
Insurance cost	6 €/kWp/year
Insurance cost increment rate	0,5%/year
Tax rate	30%
Ke	7%

It was determined to maintain the same value for the economic valuation of the electricity fed into the grid in accordance with the non-differential parameters' assumption. In fact, because the scenarios in the article were benchmarked as much as feasible, it was believed that changing these facts was illogical. The reference will be the FiP tariff of 85 €/MWh for the energy fed into the grid. The entrepreneurs proposed increasing net revenues to 17.000€ in this situation while dealing with agricultural yields, with a stilt-mounted structure, and regardless of mono- or bi-axial trackers. Since the scenario here analyzed, as the previous one does not account for any self-consumed energy, due to the nature of the APV2 project, all energy produced will be sold to the electricity grid. Like scenario TO-BE1, the economic parameters Net Present Value (NPV), Internal Rate of Return (IRR), and Pay Back Time (PBT) were deemed differentiators in a thorough economic analysis.

Table 32: Economic assessment's results – Main parameters accounting for incentive schemes.

NPV	7.966 €
IRR	0,13%
PBT	20
LCOE	0,05710 €/kWh

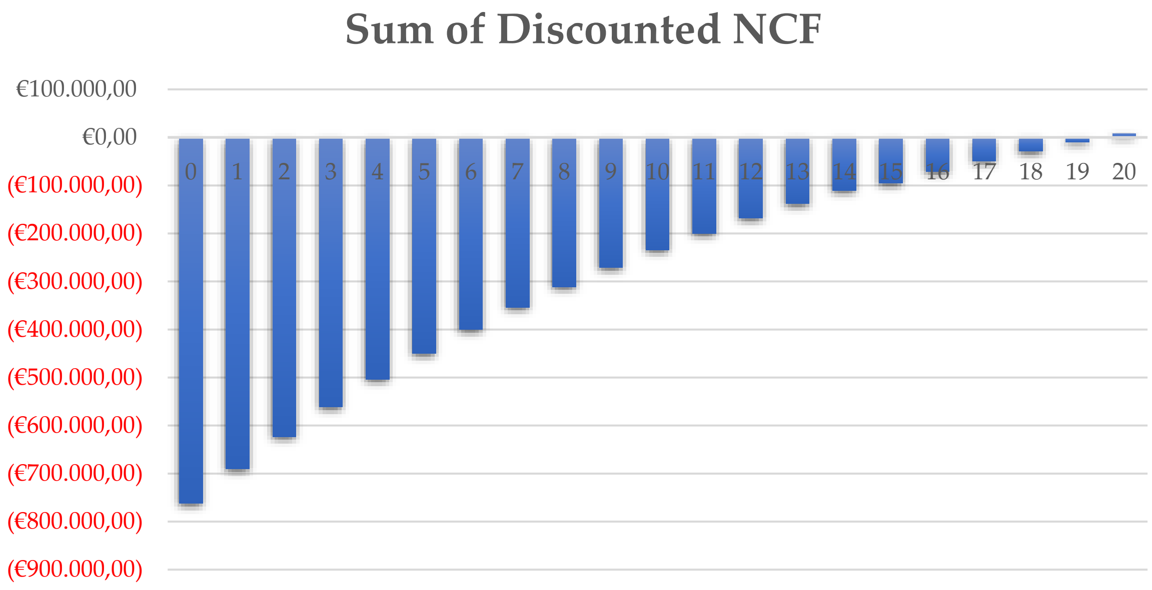


Figure 71: Sum od Discounted NCF – Scenario TO-BE2 with incentive schemes – APV2.

The PBT compute in this case is one of the highest in all the analyses performed in this paper considering the incentive framework. Indeed, it seemed that the fact of having all the electricity produced fed into the grid and not used for any self-consumption use penalized the economic investment. Also, the NPV and the IRR parameters were computed with values which were nothing more than satisfying. The LCOE coefficient was considered, as it was in APV1 and in the scenario TO-BE1 of APV2, as a means of eliminating all diffused ambiguity and obtaining an opportunity to view things with just certainties during its evaluation. During the studied time, APV2 is anticipated to produce 30.886.463 kWh, with a total estimated cost of 2.281.728 €. Both numbers are bigger than all the ones previously managed. Indeed, OPEX and CAPEX will conduct the plant toward higher energy production due to the different technological layout seen. In this instance, the LCOE is calculated to be 0,05710 €/kWh. It is worth underlying how this value is lower than the one of scenario TO-BE1 meaning that the higher production is capable of repaying, counterbalancing and even overtaking the higher costs. In addition, a value of approximately 50 €/MWh as LCOE is a value which could be benchmarked with LCOEs of grounded PV installed with a traditional South orientation and with rooftops PV. Decreasing the LCOE of a technology has always been the final goal of studies and research performed in the sector. Indeed, the market will always tend toward the technology which offers the lowest LCOE possible, regardless environmental aspects. Thus, governments and regulators had to introduced incentive schemes 15 years ago to favor the implementation of roof PV plants until their LCOEs started decreasing, then incentives were decreased first and completely removed afterwards. Nowadays, the same path is happening with Agrivoltaic technology, as it has been reflected and reasoned over in this paper.

It was decided to compute the investment predictions without using any government-sponsored incentive programs to tackle the point discussed above. Indeed, as a result, the complete CAPEX amount was considered, and the current value of power delivered into the grid, the LCOE coefficient, was calculated to be equivalent to 0,07355 €/kWh.

Table 33: Economic assessment's results – Main parameters without incentive schemes.

NPV	66.283 €
IRR	0,60%
PBT	19
LCOE	0,07355 €/kWp

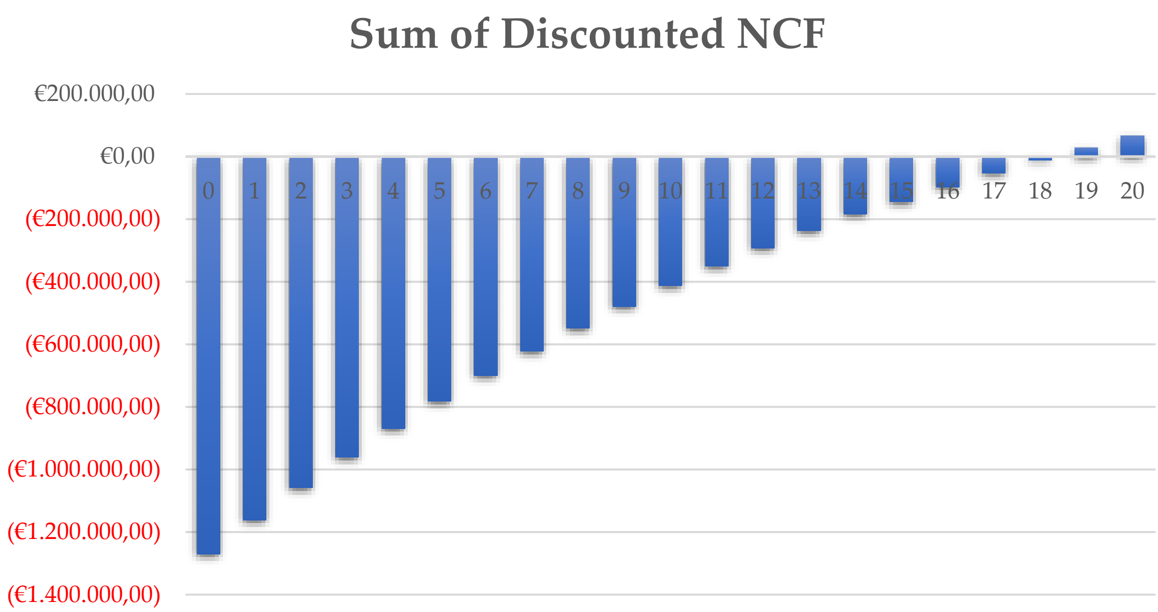


Figure 72: Sum od Discounted NCF – Scenario TO-BE2 without incentive schemes – APV2.

Table 33 and figure 72 are the graphical and numerical representations of how the investment without any incentive scheme offers a better economic analysis as happened in the Scenario TO-BE1 of APV2. Indeed, computing the investment with a PUN equal to 120 €/MWh offered the opportunity to offset the entire payment of the initial CAPEX. Although economic parameters computed resulted more attractive in this second case, it should be underlined how the uncertainty and risk embedded in this case are way higher than the situation in which the GSE grants the economic valorization of the energy produced. Nevertheless, it is possible noticing how values in this case are less negative than the one of scenario TO-BE1, in the case without incentives. Even LCOE in this case was computed equal to 0,07355 €/kWp, confirm the hypothesis that the higher amount of energy produced covers the higher costs resulting in better outputs than scenario TO-BE2. As noted within the paper, accounting incentives the LCOE resulted significantly lower than the one obtained without considering incentives. This fact is due to the presence of a lower sum of costs, reduced by the 40% of CAPEX amount.

Finally, an economic evaluation was provided even with the updated version of the law decree, where in this case it was affected only the incentive tariff granted which moved from 85 to 95 €/MWh. All other technical and economic requirements were not touched.

Table 34: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	123.620 €
IRR	1,95%
PBT	15
LCOE	0,05710 €/kWh

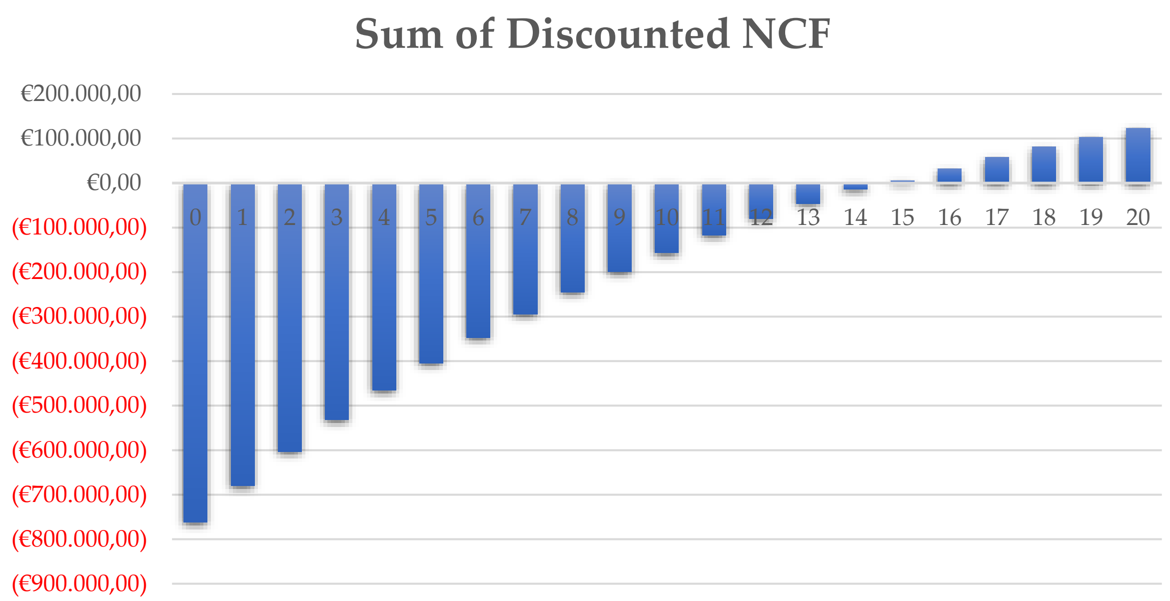


Figure 73: Sum od Discounted NCF – Scenario TO-BE2 with UPDATED incentive schemes – APV2.

While the LCOE value remained equal to 57 €/MWh as it was in the previous case, indeed no costs of technical aspect were touched, NPV IRR and PBT resulted being in this situation the best-case scenario within the three computed in this configuration. This fact can be perceived as a positive move performed by the Italian government to help the spread of APV configuration. It is hope of this paper the fact that the European Union will not change it and it will be speeded up the process.

3.4.4 Scenario TO-BE3

There will be no variations from the scenario TO-BE2 in terms of the design phase and the technical decision variables considered here. Even in this setup, the reference layout shown in figures 68 and 69 from the previous chapter was preserved. The same justification will be used to discuss shadows, solar radiation that hits the ground, PV module type and quality, and inverter types. The design configuration will be the same as figure 70 and the maximum installed power will stay at 1.071 kWp. The arrangement set up in the earlier case will not be affected in any way by the insertion of the bi-axial tracker linked with each individual PV module in this instance. Therefore, even from an electrical standpoint, 1948 PV modules and eight SUN2000-100KTL-M1 inverters will still be erected. Although the project will be specific to scenario TO-BE2 from the architectural and technical layout points of view, a significant divergence will emerge when discussing the energy perspective. In actuality, the addition of the new tracker will enable the APV plant to produce electricity even more efficiently, leading to the need for a second energy analysis. The local software Barbarasa was also exploited after the PVGIS program served as the process's lighthouse. It must be noted that both the PVGIS database and the program SolarEdge only offer the option of estimating energy production using a mono-axial tracker. As a result, a literature review and research were done regarding the unique productivity of the facility, and some Erreci trackers' suppliers were interviewed. Then, all the data was entered into Barbarasa, which was able to produce accurate and trustworthy findings. The results of the energy analysis are displayed in the following graphs. The same days were once more used as references to improve a better benchmark within technologies. As in all the previous scenarios, either for APV1 or APV2, also in this last scenario analysed as albedo coefficient a value equal to 0,15 was considered.

Incentive scheme's compliance

The PVGIS database estimates that the proposed plant will generate 1.762.453 kWh in year zero. Sections 1 and 2 of the intended APV have identical technical specifications from the trackers point of view, hence the expected specific electric production for those sections will be 1.645 kWh/kWp installed. It could be noted down how the shift from mono-axial solar trackers to bi-axial ones did not turned upside down the productivity. Indeed, as it was possible seeing a huge difference between the vertical mounted system with the elevated one with mono-axial trackers, it is not so relevant the change from one to another type of tracker. Regarding the area of soil that would still be suitable for farming after the installation of the APV plant, in this case, the space taken up by vertical support structures will be equal to 10.200 m^2, given by the eight rows that the tensile support framework will occupy, accounting for both sections one and two of the projects. As a result, with 42.000 m^2 available, the area that is undeveloped is equal to 75,72%, which is more than the minimal need of 70%. The LAOR coefficient was also calculated.

$$LAOR = \frac{2{,}70m^2 * 1948\ PV\ modules}{42.000m^2} = 12{,}52\%$$

Again, value far more than the 40% upper limit. Additionally, as the installation would be about 5 meters high, there won't be any problems with respecting the minimum height requirement. All tasks, whether agricultural or breeding-related, shall be carried out. To meet the requirements, set by the Italian regulator, a monitoring system will be installed at the same time as the APV plant is being built. The CREA-GSE dualization's restrictions on the monitoring system will be adhered to. The LER coefficient was in this case computed being equal to 1,57. Until now, all the coefficients and parameters were computed equal to the ones of scenario TO-BE2, since the layout of the supposed APV plant is the same. Reasoning about the electricity generated, or at least its forecasts, PVGIS database, SARAH2 - 2016 indicates that the average production will be equal to 1.645 kWh/kWp, which is significantly higher than the installed 1.208 kWh/kWp imposed by the regulator who asked to benchmark the APV plant with a traditional grounded mounted one with a South orientation and 20° as tilt angle. In other words, in this instance, the APV plant will provide a productivity greater than roughly 40% due to the existence of trackers. When calculating the per-ha productivity, the calculations from earlier chapters showed that the reference scenario set by the regulator had a productivity of 248 MWh/ha/year. Here, a total output of 1.762 MWh is anticipated from the complete APV facility, which produced 419 MWh/ha/year and met the requirements. Even here, it is possible noting how the performance improvement is not too impactful. Finally, there are no known issues with the installed peak power; in fact, the power is much more than 300 kWp.

Economic analysis

All the assumptions undertaken in the scenario TO-BE2 were kept on this case. Thus NPV, IRR and PBT were computed and as well a reflection was mase over the LCOE parameter. Since PV modules, inverters and the vertical plus horizontal tensile sustaining structures were not changed, the first big different lays in the cost of trackers as only PV component which was changed. Indeed, in this scenario there was the shift from a mono-axial to a bi-axial tracker type. Thus, it must be underlined how the bi-axial tracker was precautioned costing 220 €/piece. Since the datasheet remaining like mono-axial ones, being the same supplier of Erreci, 974 trackers were precautioned, one every 2 PV modules. Overall, a total cost of 194.280 € was accounted. The final CAPEX amount was computed equal to 1.356.392 €, slightly higher than the previous scenario but, as described in table 35, the only difference stands in the cost of acquisition of PV trackers. Since the peak power installed remained unchanged from the previous scenario but the cost of the APV plant increased, there was the risk of breaking the maximum ceiling of the incentive schemes, set equal to 1.500 €/kWp installed. Indeed, the resulting value came out equal to 1.263 €/kWp and thus within the threshold. Since the difference was not equal to hundreds of €/kWp as it was in APV1, configuration TO-BE2 and TO-BE3, the company together with the entrepreneurs decided to decrease the acquisition cost of the plant, with the dual willingness to get the access to incentive schemes. As in scenario TO-BE2, a degree of uncertainty was eliminated with this decision.

Table 35: Costs structure's subdivision, CAPEX and OPEX sides – APV2 – Scenario TO-BE3.

CAPEX	**% of the overall CAPEX**	
PV modules	331.160 €	24,4%
PV inverter	49.930 €	3,7%
PV structures	550.000 €	40,5%
PV trackers	194.280 €	14,3%
Other plant set up expenses (Levelling the field, fence perimeter, bureaucratic procedure with GSE)	231.022 €	17%
Inverter substitution (year 15)	54.923 €	
OPEX		
Maintenance cost	35 €/kWp/year	
Maintenance cost increment rate	1%/year	
Insurance cost	6 €/kWp/year	
Insurance cost increment rate	0,5%/year	
Tax rate	30%	
Ke	7%	

In accordance with the non-differential parameters' assumption, it was decided to keep the economic valuation of the electricity fed into the system at the same value. In fact, it was thought that modifying these facts was unreasonable because the scenarios in the essay were benchmarked as closely as was practical. In this instance, the 85 €/MWh FiP tariff was kept. The business owners suggested dealing with agricultural yields, using a stilt-mounted structure, and ignoring the use of mono- or bi-axial trackers in this scenario to increase net revenues to 17.000 €. Due to the nature of the APV2 project, all energy produced will be sold to the electrical grid since the scenario being examined here, like the one that came before it, does not account for any self-consumed energy. Like scenarios TO-BE1 and 2, a detailed economic analysis determined that the economic variables Net Present Value (NPV), Internal Rate of Return (IRR), and Pay Back Time (PBT) were differentiators.

Table 36: *Economic assessment's results – Main parameters accounting for incentive schemes.*

NPV	48.701 €
IRR	0,73%
PBT	18
LCOE	0,05373 €/kWh

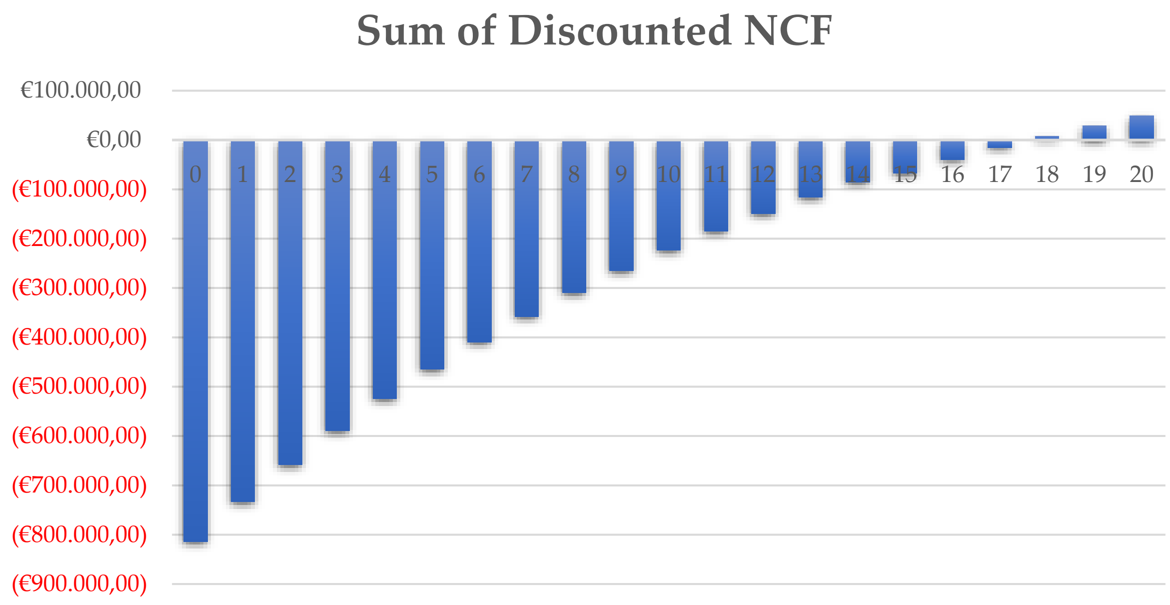


Figure 74: *Sum od Discounted NCF – Scenario TO-BE3 with incentive schemes – APV2.*

NPV, IRR and PBT of this scenario were all computed with positive values. The investment, with the listed conditions is profitable and could be attractive for the entrepreneurs. Moreover, LCOE is here computed equal to 0,05373 €/kWh. In this situation, the resulting value is almost equal to the one of scenario TO-BE2.

Table 37: Economic assessment's results – Main parameters without incentive schemes.

NPV	125.851 €
IRR	1,05%
PBT	18
LCOE	0,06979 €/kWh

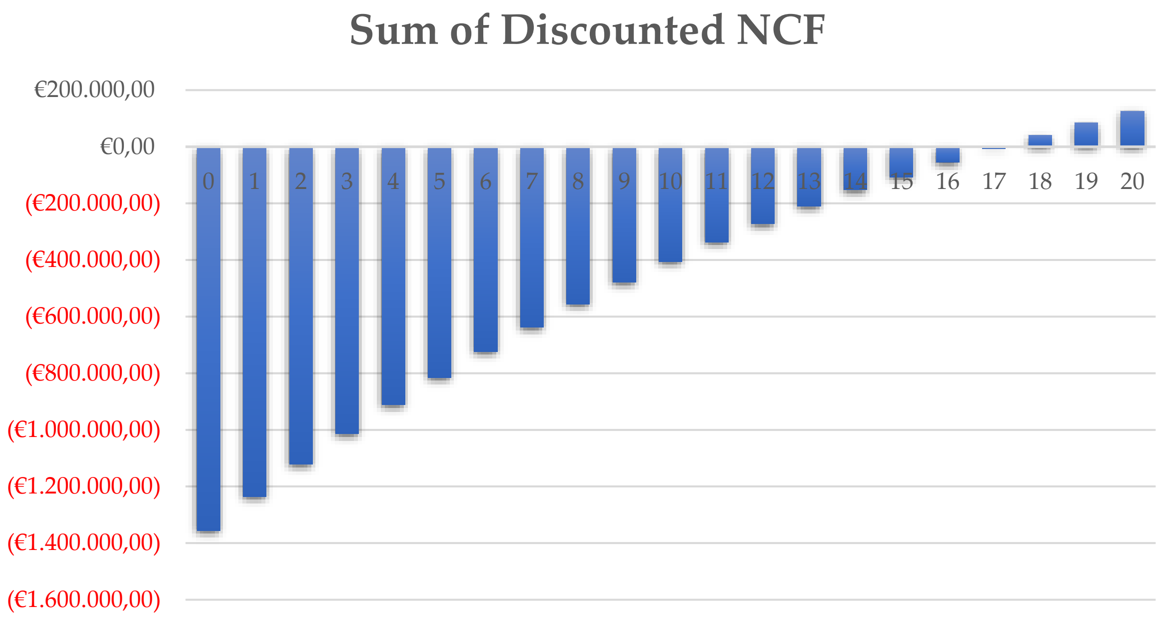


Figure 75: Sum od Discounted NCF – Scenario TO-BE3 without incentive schemes – APV2.

In the table and the figures mentioned above it is clearly stated how, as happened in the previous scenarios, even without considering any incentive scheme, results are positive and sometimes even better than the case with incentive. This fact is due to the Pun value for the electricity remuneration, kept equal to 0,12 €/kWh. The LCOE computed here is equal to 0,06979 €/kWh. The value here is lower than the scenario TO-BE2, stating how for what concerns the LCOE, with a similar cost structure, the higher the amount of energy produced by the RES plant, the better. In addition, the usual consideration should be underlined reasoning over the LCOE: indeed, even though with incentives economic results are worse than the case without, the LCOE acted in the opposite way favouring the situation with higher certainties given by the regulator rather than the traditional market characterised by price fluctuations.

Finally, despite the legislative decree's amendment, which in this case simply impacted the incentive tariff granted, which increased from 85 to 95 euros per megawatt hour, an economic evaluation was provided. Other technical and financial criteria remained unaffected. NPV, IRR and PBT ended up being in this case the best-case scenario among the three computed in this configuration, even though the LCOE value stayed at 53 €/MWh as it was in the prior example and no technical expenses were changed. This fact may be viewed as a successful effort on the part of the Italian government to promote APV configuration. This report is motivated by the hope that the European Union won't alter it and that the procedure will go quicker.

Table 38: Economic assessment's results – Main parameters accounting for UPDATED incentive schemes.

NPV	175.197 €
IRR	2,56%
PBT	14
LCOE	0,05373 €/kWh

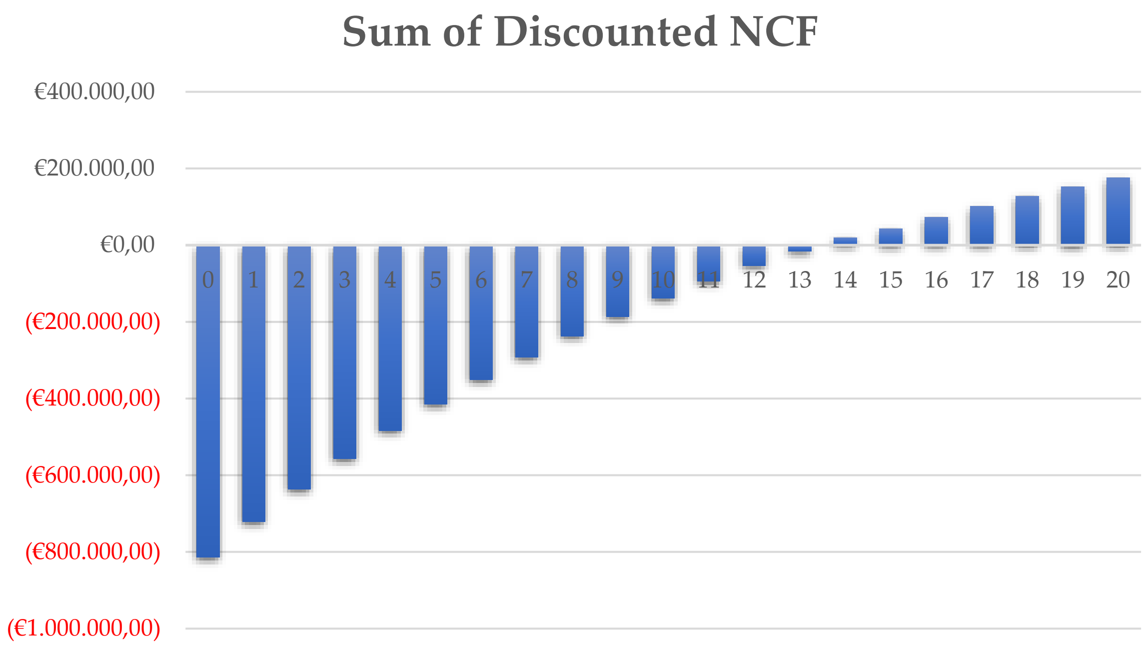


Figure 76: Sum od Discounted NCF – Scenario TO-BE3 with UPDATED incentive schemes – APV2.

4. Agrivoltaic projects' discussions and critical analyses

Once all the scenarios were listed and explained, a discussion was made between entrepreneurs and Erreci. Indeed, on the one hand there were better solutions in terms of economic numbers as scenarios TO-BE2 and 3, for both APV1 and 2 which were studied. On the other hand, scenario TO-BE1 resulted being less attractive from the point of view of both economic and technical parameters, but at the same time it was highlighted how from the management point of view as well as from the dimension of the initial CAPEX requirements, scenario TO-BE1 resulted being less complicated than others to be undertaken, at least according from this first evaluation. Therefore, since the chosen one resulted being the configuration with vertical mounted bifacial PV modules for both projects APV1 and 2, it was decided to deep dive the sensitivity of these projects. In addition, it is worth stating how all the scenarios carried out observed economic results which were precautioned being better than scenario AS-IS. In the case of APV1, the field is currently unutilized and thus it is straightforward as within an economic assessment and evaluation of a possible investment, one of the biggest problems which must be faced is the uncertainty embedded. Indeed, since the dawn of time uncertainty has always characterized the decisions undertaken by human being first and entrepreneurs second. Nowadays, taking decisions is even more complicated if we consider the fact that digital technologies and innovation have speeded up the pace of changes in all the market sectors. A higher pace means that what is true today may be partially wrong tomorrow and completely wrong the day after tomorrow. Thus, assumptions and hypotheses are the baseline in the twenty first century daily life. This fact is even more acute in business like the energy sector, where not only people are voluntary researching to improve efficiency and efficacy of the products offered but this research is continuously forced by policy makers which must face climate change and shelter themselves from its unpredictable manifestations. Therefore, forecasting a selling price for the energy produced by the APV plant which may be realistic in a time span of 20 years is nothing but complex. It may even happen that this activity falls in the chaotic realm since events which influence the electricity price fluctuations are often out of human control. The idea of this paper was the one of forecasting a valorisation amount for the energy fed into the electric grid in the base case scenario according to benchmarked values already available on the market.

Consequently, in the reference scenario forecasting a price from 2023 onward, an energy valorisation price equal to 0,12 €/kWh was accounted for APV1 and APV2, for APV2 it is referred to cases where the FiP tariff was not considered, with economic results shown in the previous chapter. Then, a second and a third hypotheses were considered and developed to broader as much as possible the big picture overview. It was thought here to assess the projects according to how the situation was before Covid-19 pandemic and the Ukraine-Russia war. Therefore, a reference period corresponding to year 2015-2019 was considered and averages were computed. An average of PUN equal to 0,05 €/kWh was computed. All other hypotheses regarding increment and decrement rates were left unchanged. It was considered an increment rate of the energy price over time considering possible inflation effects. In table 39 a recap of result founded is presented. The sensitivity analysis was computed first for the APV1 where, due to the self-consumption quote of the energy produced, even with the reign of FiP tariff incentive scheme, equal to 85 €/MWh recognised to the entrepreneurs over the energy fed into the grid, the PUN will matter considerably.

Table 39: Economic assessments' results with a PUN value equal to 50 €/MWh – APV1 – Scenario TO-BE1.

	PUN 120 €/MWh – Reference case	**PUN 50 €/MWh – Variation**
NPV	6.647 €	-287 €
IRR	2,05%	-0,09%
PBT	15	21
LCOE	0,07037 €/kWh	0,07037 €/kWh

From results listed here it is possible to make some interesting considerations. First, the most evident one is that, considering energy prices referred to a period prior to the current energy scenario, which is suffering worldwide in terms of decarbonisation of the energy sector, energy efficiency and energy security of the supply contemporary, the prospect of investment are no more feasible. Indeed, the recomputed NPV value went negative with a PUN equal to 50 €/MWh. Another consideration could be the one that the IRR confirmed the NPV result being negative. This second economic analysis reflected the fact that if prices will go back to values before the Covid – Ukraine war binomial, the convenience for the entrepreneur will fall. Since the cost structure was not touched during the sensitivity, as it was not the technical layout, it did not surprise the fact that LCOE parameter remained the same. At the end of the first semester 2023, with the updated decree, the same computation was performed accounting this time 103 €/MWh as FiP tariff instead of 85 €/MWh for the valorisation of energy fed into the grid.

Table 40: Economic assessments' results with a PUN value equal to 50 €/MWh, UPDATED incentive scheme - APV1– Scenario TO-BE1.

	PUN 120 €/MWh – Reference case	PUN 50 €/MWh – Variation
NPV	11.927 €	4.991 €
IRR	3,60%	1,57%
PBT	13	16
LCOE	0,07037 €/kWh	0,07037 €/kWh

In this second situation, with the updated incentive framework, the LCOE value remained untouched, confirming the fact that if costs and technical assumptions are maintained, it did not perceive any change. In addition, it is highlighted here how even with a PUN equal to 50 €/MWh the investment reached the break-even within the time analysed and thus in any case the investment resulted sustainable and economically convenient from the entrepreneurs' point of view. NPV, IRR and PBT are all convenient in the reference case, as previously discussed, as in this new one deep dived with the sensitivity analysis. The interesting aspect of this analysis is understanding how the Italian government moved in the correct direction while changing the incentive scheme making sustainable an investment in a wider perspective which was not so considering the previous scheme.

The third price scenario considered was developed over a completely different hypothesis. In the case, the average for APV1 was computed with a period referred to years 2018-2022, thus completely accounting the new waves of instability which tackled the worldwide ecosystem. Then, a different hypothesis was made dealing with the outlook over energy prices. Indeed, it was thought that starting from year 0 which could be 2023, the electricity price was decreased by the 2%/year, differently from all other ideas where the price was always increased due to inflation. In this case inflation was considered, indeed the decrement rate was posed equal to 2%/year and not bigger, but the underpinning idea was the one of accounting a future hope for a renewed stability in economy. An average of PUN equal to 0,304 €/kWh. In table 41 a recap of result founded is presented.

Table 41: Economic assessments' results with a PUN value equal to 304 €/MWh – APV1 – Scenario TO-BE1.

	PUN 120 €/MWh – Reference case	PUN 304 €/MWh – Variation
NPV	6.647 €	24.483 €
IRR	2,05%	6,94%
PBT	15	10
LCOE	0,07037 €/kWh	0,07037 €/kWh

This sensitivity analysis depicted how by considering a higher PUN value, economic results improved consistently. Indeed, the different value of the PUN tackled the revenue stream gained through the self-consumption amount of energy. Moreover, even though the PUN value is more than doubled from the reference scenario, economic coefficients did not double proportionally. This aspect confirmed the previous reasoning stating how the biggest impact within the economic analysis is occupied by the incentive tariff FiP which accounted for the energy fed into the grid, more than the 70% of the plant hypothesised production. Finally, it should be underlined how once again the LCOE value remained fixed with respect to the initial configuration.

Then, an updating analysis was carried out as it has been done for the variation. The update version accounted the new FiP tariff, equal to 103 €/MWh for APV plants with this size and peak power installed and located in the Nort of Italy.

Table 42: Economic assessments' results with a PUN value equal to 50 €/MWh, UPDATED incentive scheme - APV1– Scenario TO-BE1.

	PUN 120 €/MWh – Reference case	PUN 304 €/MWh – Variation
NPV	11.927 €	29.763 €
IRR	3,60%	8,34%
PBT	13	9
LCOE	0,07037 €/kWh	0,07037 €/kWh

Thanks to this further analysis, it is confirmed the constant value of the LCOE of the plant. In addition, it is possible understanding how if compared to the reference scenario which considered the updated incentive framework too, the Italian government moved a step forward towards the right direction to enhance the diffusion of the APV technology and business market. The PBT value, equal to 10 years started going close to an interesting value, surely for small investors and entrepreneurs but even for big companies willing to invest in the new market niche. Although in this case numbers and optimistic perspective seem to be countless, it must be noted once again how the paradigm here was built over an assumption which none can offer securities about. The reason why of these computations is because the outlook which is awaiting humanity is so unpredictable and complex that in this paper it was considered logic computing numbers even in this direction. It must be noted how it was thought to leave untouched economic gains in agriculture in all the scenarios studied as described before. The reason why is that specific competences were missing in such a business, and it was decided not to modify values given by people who were on the other hand historical experts of the market with documented successful activities.

4.1 Sensitivity – Technical: production decrement coefficient's rate

Leaving the energy price and market valorisation perspective, the next step undertaken what the one of tackling a sensitivity analysis from a more technical point of view. Indeed, till now it has been performed a sensitivity analysis mainly on economic aspects. Now, a reflection over technical aspects is made and thus a leverage parameter, which could be consider a strategic level, is searched because the eventual investments would have been more attractive and trustworthy according to the reasoning developed here if such an analysis would have been attached to the precautionary document. Therefore, the idea was looking for a driver which could represent the energy production first, and straightforwardly its variability. Consequently, it was thought that the most impactful parameter could have been the rate of loss in efficiency experienced by the PV modules on the hypothetical APV plants. In the reference scenario, for both the projects was selected a decrement rate equal to 0,45%/year which is a rate indicated by PV modules most famous and settled producers like JA Solar, LONGi and Jinko. Although the PV modules are a quite affirmed technology which has reached in the last years incredible levels of efficiency and accuracy, and again, where many studies have been performed confirming such an average value, it was thought here to try to assess the projects with a worst-case scenario. Indeed, with a similar idea as in the economic analysis, if the precautionary document would have shown a feasible investment here, the results would have encouraged entrepreneurs to consider limited risks. Having explained the reflection behind, an efficiency loss in production index equal to 1%/year was considered and an analysis performed in both APV1 and APV2. In this case, differently from the previous sensitivity where the PUN value affected only APV1, even APV2 is affected by a different efficiency loss parameter. Furthermore, since the energy produced is more in APV2 than APV1, effects caused by a faster production's efficiency loss will impact more. All other hypotheses were left unchanged. In table 43 results are shown.

Table 43: Economic assessments' result with different production's decrement values– APV1.

	NO incentive scheme		**OLD incentive scheme**		**UPDATED incentive scheme**	
Decrement rate	*-0,45%/year*	*-1%/year*	*-0,45%/year*	*-1%/year*	*-0,45%/year*	*-1%/year*
NPV	-3.897 €	-6.260 €	6.647 €	4.931 €	11.927 €	10.008 €
IRR	-0,74%	-1,22%	2,05%	1,56%	3,60%	3,11%
PBT	21	21	15	16	13	13
LCOE	0,09479 €/kWh	0,09977 €/kWh	0,07037 €/kWh	0,07408 €/kWh	0,07037 €/kWh	0,07408 €/kWh

Overall, results shown here demonstrate how, in all the economic cases over which a reflection was made, NPV values in output of the process remained all positive if incentive schemes are considered, fact which indicates how even with higher decrement rate investments remained feasible. Nevertheless, all parameters computed here decreased as expected before having performed all the computations. Since no other hypotheses were touched, all economic parameters decreased by a comparable percentage, regardless of the specific case. Indeed, weather considering the updated, the old one of no incentive schemes no one resulted being immune to the lower amount of energy produced.

Table 44: Economic assessments' result with different production's decrement values– APV2.

	NO incentive scheme		**OLD incentive scheme**		**UPDATED incentive scheme**	
	-0,45%/year	*-1%/year*	*-0,45%/year*	*-1%/year*	*-0,45%/year*	*-1%/year*
NPV	69.190 €	37.624 €	48.898 €	30.050 €	106.406 €	85.341 €
IRR	1,20%	0,68%	1,51%	0,96%	3,20%	2,66%
PBT	17	19	16	18	13	13
LCOE	0,06736 €/kWh	0,07091 €/kWh	0,05034 €/kWh	0,05299 €/kWh	0,05034 €/kWh	0,05299 €/kWh

In the case of APV2, since there is not present the self-consumed part of energy and all profits come from the selling of energy to the national grid, the lower amount of energy produced has a harder impact on economic profitability. Values in APV2 decreased more than in APV1 in relative terms. The case where no incentive schemes are considered particularly has decreased till a borderline situation between being sustainable or not with a higher production decrement rate. PBT fell till 19 years and the IRR parameter went just above the lower ceiling equal to 0. In the cases accounting incentive schemes, economic profitability generally decreased but it remained still interesting considering these results. On the other hand, also LCOEs were processed in these two scenarios. Indeed, it LCOEs were not affected by variations in energy prices, in this case since it has been altered the total amount of electricity produced in the time horizon, also LCOE parameter will be affected. A brief first reflection is the one that LCOEs in this case are expected to grow since costs, stationing at numerator of the ratio, will not be touched in the formula while the denominator, total number of kWh produced will be decremented. It is possible noticing how, as for APV1 as for APV2, the LCOE value experienced the same increment moving from one decrement rate to another regardless the incentive schemes. Indeed, economic valorisation of the energy affected the economic results but not the LCOE since no technical parameters were touched. Furthermore, increments were more consistent in APV1, with an average of 0,004 €/kWh versus the average of APV2 which set between 0,002 €/kWh and 0,003 €/kWh. This fact could be explained through plants dimensions. Indeed, with a bigger peak power installed, negative effects were distributed on a wider base rather than a small one as it was APV1.

4.2 NO incentive – PUN value benchmark

With the willingness of remaining within the sensitivity analysis applied to the energy price, which was the variable identified as the most unforeseeable one, it was reflected in this paper to attempt to evaluate the possible APV investments looking for the minimum price required to reach the break-even point in the period analysed. In addition, since incentive schemes are not yet been clarified neither by the European Union nor by the Italian government, the computation searching for the minimum price required was carried out in the case without considering any incentive scheme. In other words, it all started from the worst-case scenario, no incentive granted at all, and then from there it was understood a reference threshold required to make the investments sustainable. The analysis was undertaken modifying the valorisation price of energy, the market price gained for the energy fed into the grid. As previously detailed, this value was called PUN in the paper even though from a theoretical point of view and for seek of precision the PZ is the value which should be accounted. In the base case scenario, for both situations APV1 and APV2, the starting point was setting the PUN equal to 0,12 €/kWh. It was highlighted how neither one resulted feasible without incentives with such a PUN. Thus, a sensitivity evaluation was made let the PUN vary and noticing when the 'Cumulated sum of Discounted Cash Flow' path would have broken the break-even point.

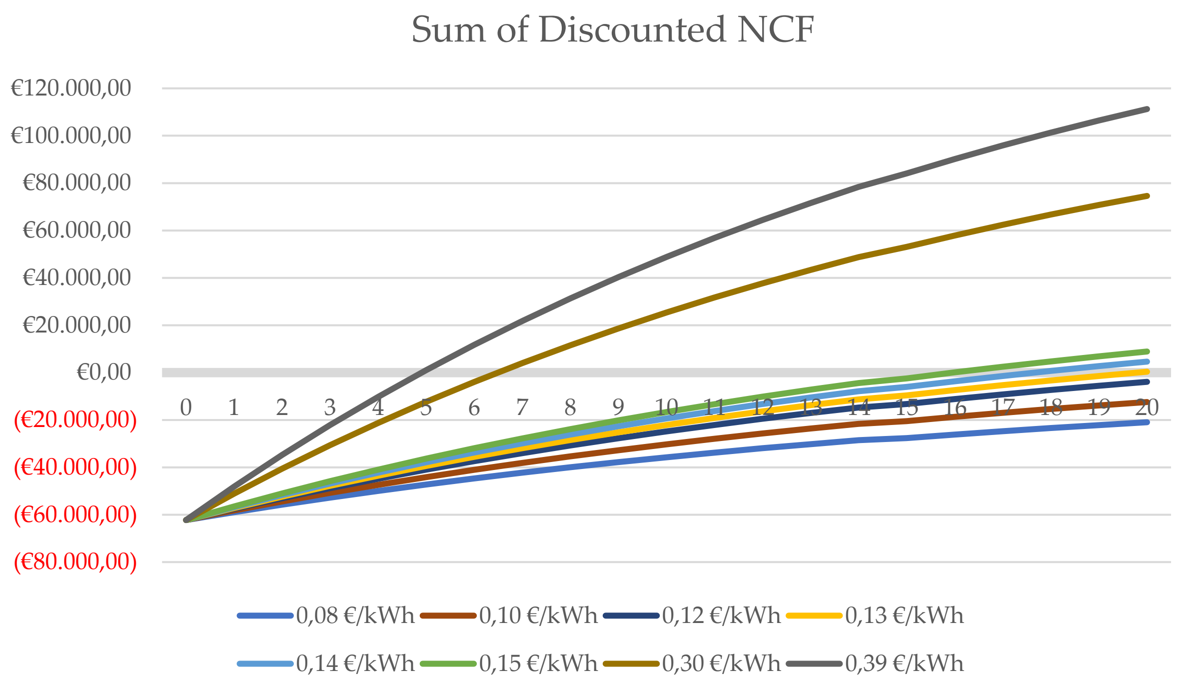


Figure 77: PUN value's variations in APV1 investment evaluation.

In figure 77 it is highlighted how until a PUN equal to 0,12 €/kWh the APV1 investment is not sustainable and the PBT is longer than the maximum period of 20 years analysed here. Setting the PUN value equal to 0,13 €/kWh, the break-even point is reached at year 19. Therefore, the searched value is comprised between 120 and 130 €/MWh, way closer to 130 €/MWh. In addition, it was expressed in the graph the path related to a PUN equal to 0,08 €/kWh and 0,30 €/kWh, which are the two hypotheses made before. Finally, with a more industrial logic in mind, it was searched the minimum value which would have been able to set a PBT equal to 5 years, which is often considered as the maximum PBT acceptable by big multinational companies. The output is far from being encouraging; indeed, it resulted a value equal to 0,39 €/kWh without accounting for taxes and other system fees, left equal to 0,065 €/kWh in all cases. Well, such a higher value was not reached neither during the worse energy crisis even experienced in the last three years and it is hoped by this paperwork that it will never be reached. The same analysis was performed for the case of APV2 investment evaluation. In this occasion, the same goals were attempted. Starting from the bottom of the process, the price required here to obtain a PBT equal to 5 years resulted being at least 0,34 €/kWh, slightly lower than the previous case. Although it came out a lower value, 340/MWh are still a huge amount which will hopefully never be reached in certain conditions. Moreover, it was though that the lower value required is probably due to the scale effect which is gained thanks to the higher amount of electricity generated in this case rather than APV1. Finally, the second important value looked for was the minimum price required to obtain a PBT lower than 20 years. In this case it resulted that the value was comprised being between 0,11 and 0,12 €/kWh, even though closer to 0,12 €/kWh. The hypothesised reason in this situation of having a higher value than APV1 could have been the higher incidence of CAPEX over the amount of energy produced. All results are shown in figure 78. It is interesting noticing how, in this second project, even without any incentive over the CAPEX, the hypothesis of having a PUN equal to 120 €/MWh for the time being analysed it is sufficient to get a positive PBT, within the 20 years' period even if equal to 19. The consistent amount of energy fed into the grid, if remunerated at that level, will enhance to overcome the initial gap of not having the 40% of CAPEX as capital account money.

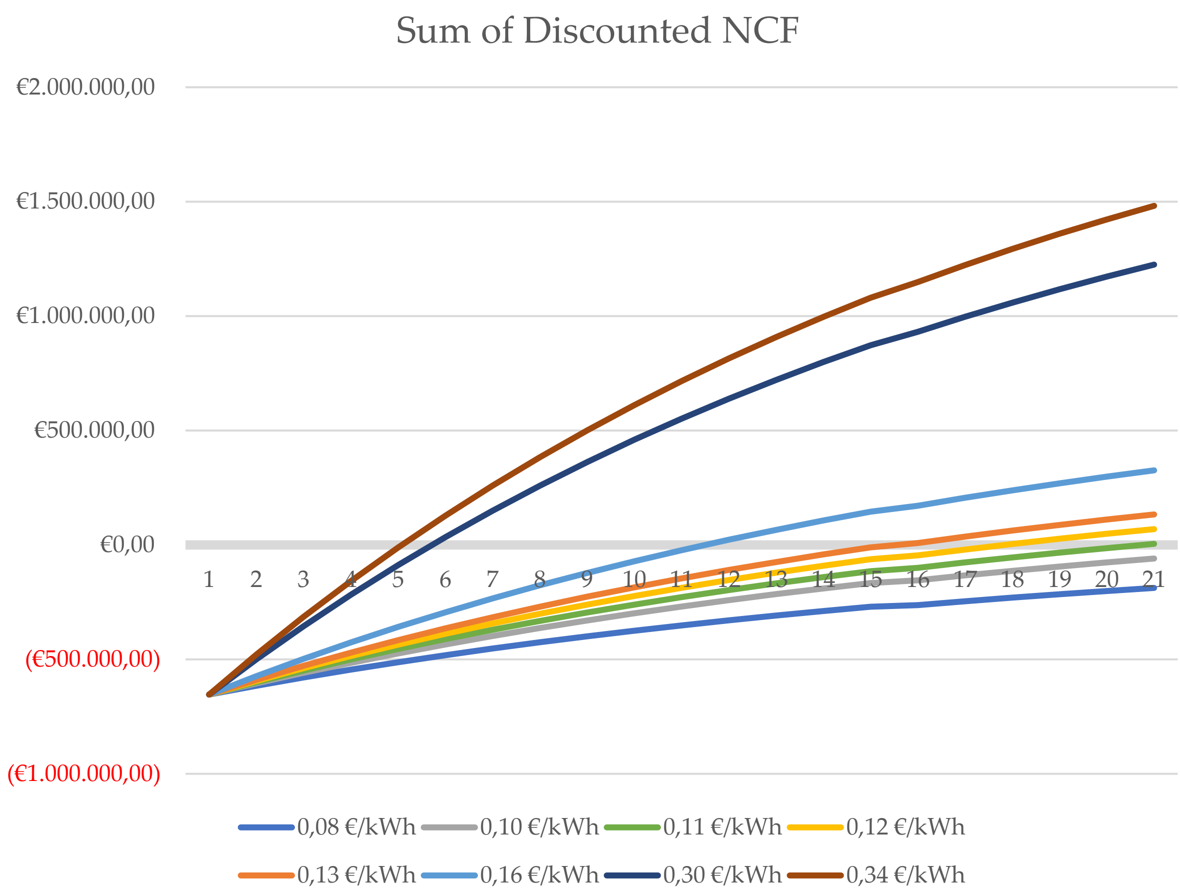


Figure 78: PUN value's variations in APV2 investment evaluation.

4.3 Cost of capital - Variation

Dealing once again with the economic sensitivity analysis, a factor which could heavily influence the sustainability of an investment is the cost of capital. To compute the cost of capital, entrepreneurs always consider the cost of debt and equity, having usually as output the WACC value: Weighted Average Cost of Capital. In the last years, costs of capital experienced by entrepreneurs have been quite low, due to a favourable economic period where the attempt was the one of favouring and enhancing investments and higher economic movements. Nevertheless, in the last year, due to a higher inflation which is still growing nowadays, costs of capital have started increasing again trying to moderate the uncontrolled inflation all around the word. In the paper, a cost of capital equal to 7% was considered, defined as Ke instead of WACC since the entrepreneurs are willing to invest with their own capitals and not asking financial loans. The logic in the base case was the one of hypothesising the worst case situation, to offer to the potential customers an evaluation considering a prudential approach, instead of offering attritive results but with higher risks and uncertainties embedded. Nevertheless, it is interesting even evaluation investments with a lower Ke, hoping that in the mid-term these costs will came back to values experienced in the recent past. In table 45 and 46 are reported economic KPIs resulted from the analysis performed over the selected plants, Scenarios TO-BE1 for both APV1 and APV2.

Table 45: Economic KPIs – APV1 – Scenario TO-BE1.

Ke	7% - Reference case	5% - Update1	3% - Update2
NPV	11.927 €	20.673 €	31.991 €
IRR	3,60%	5,57%	7,62%
PBT	13	11	10
LCOE	0,07037 €/kWh	0,07037 €/kWh	0,07037 €/kWh

Table 46: Economic KPIs – APV2 – Scenario TO-BE1.

Ke	7% - Reference case	5% - Update1	3% - Update2
NPV	106.406 €	191.503 €	301.104 €
IRR	3,20%	5,17%	7,21%
PBT	13	11	10
LCOE	0,05034 €/kWh	0,05034 €/kWh	0,05034 €/kWh

4.4 Traditional ground PV - Benchmark

As expressed within the entire project, nowadays the Agrivoltaic concept has gained momentum. It has achieved success and media's attention due to its positive effect brought to the agricultural perspective, thing which is not present in the consolidate idea of round PV. Indeed, in the last fifteen to twenty years the ground PV has developed and increased its efficiency as well as decreased its LCOE. Nevertheless, it does not offer any solution in terms of agricultural preservation. On the contrary, it is though as the maximum possible occupation rate of the soil, where shades are precisely computed according to the geometric shapes of PV structures, since every centimetre matters to increase as much as possible the peak power installed over the square meter. Therefore, using mostly [40], thus remaining within Erreci's competences, it was thought of benchmarking a power plant installed with the traditional South oriented PV structure, with a tilt angle of 20° and a pitch distance of 4 meters computed to maximise the power installable. In the following table, it will be highlighted the cost/MWp installed, the area required to install one MWp nowadays in the case of a plant realised within 2022 by Erreci and all the configurations of Agrivoltaic project 2 precautioned in the paper.

Table 47: Benchmark between Agrivoltaic scenarios and traditional ground PV [40].

	Traditional ground PV	**APV2 – Scenario TO-BE1**	**APV2 – Scenario TO-BE2**	**APV2 – Scenario TO-BE3**
Area needed to install 1 MWp [ha]	1,4	4,85	3,92	3,92
CAPEX without any incentive schemes [€/MWp]	890.000	755.610	1.186.442	1.266.472
Electricity production [MWh/year]	1.280	801	1.611	1.762
Specific electricity production [MWh/ha]	914	165	411	449
LCOE [€/MWh]	43	67	73	69
LER [#]	1	1,29	1,54	1,57

In the upper table, LCOEs value were computed without considering incentive schemes, for the APV scenarios. As expressed, the land area required to install one MWp with an APV configuration is way more than the area required for a traditional ground PV. On the other hand, with the utilisation of trackers, specific energy yields are granted even though higher costs are required for the installation structures. According to [40] as well as [44], solar trackers are the most sustainable future for APV configurations, even though peak power installed must be higher than one, one and a half MWp to achieve strong economies of scale. LER values are in all cases higher than one, meaning that the APV solutions are implementable.

4.5 Sensitivity over agricultural income

Since the agricultural income is one of the few income stream of the APV plant business model, together with the income coming from energy fed into the grid and, if present, income, which is a missing cost, due to energy self-consumed, it has been decided in the paper to tackle a sensitivity analysis to assess the robustness of the economic results weather this revenue stream would change. Indeed, agricultural incomes are subjected not only to computations of expected yield performed according to the irradiation granted by the APV plant but also from the weather. There are dry seasons and floods, as well as hailstorms and droughts. APV plant may moderate these latter ones, but it cannot delete them completely.

Therefore, at the beginning it was computed the incidence of agricultural earnings over the total earning at year 1, for APV1 and APV2 in scenarios TO-BE1:

- In APV1 case, the amount hypothesised for agricultural earning was computed equal to 1.500 € at year 1.
  Having an overall earning amount of 7.976 €, the incidence of the former one resulted being equal to 18,8%.
- In APV2 case, the amount hypothesised for agricultural earning was computed equal to 10.000 € at year 1.
  Having an overall earning amount of 86.119 €, the incidence of the former one resulted being equal to 11,6%.

Then, it was performed a sensitivity analysis on both projects, with an increment and decrement of 50% over the agricultural earning, as reported in table 48 and 49.

Table 48: Economic KPIs – APV1 – Scenario TO-BE1

	Reference scenario	-50% agricultural income	+50% agricultural income
NPV	11.927 €	5.459 €	18.395 €
IRR	3,60%	1,71%	5,36%
PBT	13	16	11
LCOE	0,07037 €/kWh	0,07037 €/kWh	0,07037 €/kWh

Table 49: Economic KPIs – APV2 – Scenario TO-BE1

	Reference scenario	-50% agricultural income	+50% agricultural income
NPV	106.406 €	63.286 €	149.526 €
IRR	3,20%	1,96%	4,39%
PBT	13	15	11
LCOE	0,05034 €/kWh	0,05034 €/kWh	0,05034 €/kWh

As foreseeable, the project Agrivoltaic 1 is more impacted by eventual changes in agricultural incomes, meaning that it is more exposed to meteorological risks. Indeed, changes are present in all cases, but the biggest differences are perceived in APV1 rather than APV2. This fact might by explained because of the biggest share or revenues represented by agricultural incomes, which is equal to 18% in APV1 and 11% in APV2. In other words, APV2 resulted being a solution more robust than APV1 to unexpected and unforeseeable events. Another fact, which deserves to be highlighted is the one of LCOE, which is not affected by the modifications apported to agricultural earnings.

5. Conclusion

5.1 Project

This paper has been carried out within a Master of Science thesis program attended in the company Erreci Impianti Srl. The project was developed during an internship program of six months. Most of the time the work has been done in the second office of the company, in Fiorenzuola d'Arda (PC), Italy. Nevertheless, it was possible to build relationships even with the headquarter of the company in Busto Arsizio (VA), Italy. In addition, meeting and opinions benchmarks were possible with the startup Renewable Community Società Benefit and Repower Italia which are both bounded to Erreci, with different level of implication. The company, which has been operating for twenty years in the field of photovoltaic installations, offering rooftop and ground solutions has recently decided to expand the business. To do that, the idea was the one of attempting the entrance in a new market as the Agrivoltaic one. The idea was born between the end of 2022 and the beginning of 2023 when two agricultural entrepreneurs contacted the company asking for an evaluation of all the possible solutions. The entrepreneurs pointed out two areas, with rather different features. On the one hand, the first case, named Agrivoltaic plant 1, is a small-scale dimension of PV as nominal power installed, which has been studied with the traditional feature of photovoltaic solutions: the self-consumed energy quote. On the other hand, the second case, Agrivoltaic plant 2, has been developed as a significantly bigger case. Indeed, the surface from the first case to the second one, available for the study of the technology, is fifteen times bigger. The regulatory framework operative in Italy at the beginning of 2023 was the starting point, indeed the compliance of the projects with the incentive scheme released by the government was a starting point for any economic analysis, according to both Erreci and the entrepreneurs. Moreover, at the end of the first semester of 2023, the Italian government sent to Brussel and specifically to the European commission a reviewed version of the law decree containing the incentive schemes framework. Therefore, the paper updated its results with the addition of this new economic analysis, where some parameters and values were modified. Then, from the compliance at a regulatory level, the project was moved to a technical and economic sizing procedure. Indeed, first all technical aspects were computed and accounted, mainly exploiting the relationships and the existing supply chain of Erreci. Data and information were collected and fed into the process analysis. Finally, the economic sustainability was tackled and judged.

5.2 Convenience of Agrivoltaic – Italian Regulatory Framework

After the mentioned analyses, the two entrepreneurs together with Erreci discussed all the economic and technical results with the willingness of finding a preferable solution over which focusing their attention. The decision fell over the technology of ground Agrivoltaic, with a configuration of vertical mounted bifacial PV modules. Indeed, it was agreed upon the fact that those was the best trade off possible between economic gains and technical complexity of the solution. In table 50 are reported results for APV1.

Table 50: Economic results' summary – OLD, UPDATED and NO incentives considered – APV1 – Scenario TO-BE1.

	NO INCENTIVES	OLD regulatory framework	UPDATED regulatory framework
NPV	-3.897 €	6.647 €	11.927 €
IRR	-0,74%	2,05%	3,60%
PBT	21	15	13
LCOE	0,09479 €/kWh	0,07037 €/kWh	0,07037 €/kWh

Reading results, it is clear how important incentives are for this hypothesised plant. Indeed, without considering any incentive, neither over the initial CAPEX amount nor over the FiP tariff, the investment ended up being unsustainable. Furthermore, the LCOE without incentives is far from being competitive if benchmarked with the ones of todays' electricity produced with traditional fossil fuels energy vectors. On the other hand, in both cases where incentives are considered the plant resulted being sustainable, with a considerable economic improvement from the old to the updated regulatory framework. In addition, if considering the old, hypothesised, incentive framework, the plant could not even access the incentive scheme since the minimum power was set equal to 300 kWp as peak power installed but an assumption was made about the fact that in the coming future that threshold would have been removed. Indeed, it was exactly what happened in the updated version which made the projected plant both economically and technically sustainable. Finally, it must be noted how the LCOE value did not change from one to another incentive regulation since it was modified just the economic side of the business, dealing with remuneration, and not the technical one or the cost perspective. In table 51 are then reported results of APV2.

Table 51: Economic results' summary – OLD, UPDATED and NO incentives considered – APV2 – Scenario TO-BE1.

	NO INCENTIVES	OLD regulatory framework	UPDATED regulatory framework
NPV	69.190 €	48.898 €	106.406 €
IRR	1,20%	1,51%	3,20%
PBT	17	16	13
LCOE	0,06736 €/kWh	0,05034 €/kWh	0,05034 €/kWh

In the case of APV2, the same technological layout was applied over a bigger soil area. Here, something different resulted from the project of APV1. It is interesting noticing how, IRR values are higher in APV1 while LCOE coefficients are lower in APV2, due to the economies of scale gained with bigger plant dimensions. Due to the different CAPEX amount precautioned, confronting the NPV values was not thought being meaningful. Furthermore, it was computed how even without incentive schemes available, the investment resulted sustainable and profitable, if considering a PUN value equal to 0,12 €/kWh which valorised the energy fed into the grid. Indeed, it happened how the higher economic valorisation given to the energy produced by the plant was able to overtake the incentive granted by the Italian government over the CAPEX amount. Both the cases considering incentives had better economic results than the one without but not massively better. Although it is undoubtedly true how the investment today could be undertaken even without incentives granted, it must be underlined in this portion of the analysis how 2 warning points were present. First, the LCOE of the case without incentives, due to the absence of the 40% of the CAPEX granted in capital account, resulted way bigger than the other two values. It meant how the energy would cost more in this case rather than the other two. Second, aspect which is strictly correlated with the first one, the sustainability of the investment was granted due to the PUN value currently experienced by Italian citizens in 2023. An elevated Pun which was able to offset even the higher LCOE if the RES plant. Nevertheless, no one can predict what will happen in the future, which will be the cost paid for electricity and therefore uncertainty, unpredictability and risks are present. An investment characterised by unforeseeable events and subjected to risk is less likely to be sustained then an investment where the government will assure a certain remuneration for the next 20 years, even though if at the beginning the remuneration granted will result lower than the market values. Indeed, pursuing this second path, all assumptions will be replaced by insurances and certainties, which is the way that entrepreneurs has traditionally embraced across the entire human history.

5.2.1 Best suitable crop types

Solutions like large-leaves vegetables, grapes and fruits are the best one from a point of view of value added brought from the agricultural side to the overall investment convenience. Indeed, many of the experiments and case studies which have just started in Europe deal with these kinds of crops. In addition, structures are already required to sustain crops like grapes, apricot and similar, thus integrating PV modules results easier since a structure is already thought in the plantation. It is more difficult find case studies regarding large field production, but still possible. Indeed, traditional field agricultural is still feasible from an economic point of view, nevertheless, benefits from the shading effect brought by PV modules is lower than the one experienced by fruits and thus even water savings.

5.3 Future outlooks, Perspectives, Hurdles and Opportunities

Stepping back for a while, the framework which is behind the structure of this paper started with a detailed analysis of the literature regarding the actual state of the art interesting the theme of Agrivoltaic. This new concept, which is in its initial phase of development, has been on the market for the last 40 years without being overexposed or particularly noticed. Nevertheless, recently most of the regulators and public authorities worldwide have started a process of analysis which looks towards a fast scale development of the technological concept, both in terms of number of installations and in terms of R&D activities to further develop the related technologies. The attention which nowadays has gained the Agrivoltaic concepts is mainly because the solution responds to one of the biggest challenge humanities is facing: enhancing the sustainable energy transition. Agrivoltaic has the potential to let agriculture and energy production coexist on the same land area, and, with a more accurate look, even improve their performances respect to a standard case. Indeed, the reasoning behind the project performed in this paper is the one of understanding if and why a lower ASR hitting the soil surface, due to the presence of PV modules, may cause a reduction in agricultural yields of the crop present. Again, another doubt was the one of understanding if different tilt and azimuth angles, in comparison with the traditional ones of grounded mounted PV, could have worse the quantity of energy produced. In other words, in the project commissioned in this case, as, more in general in literature, it is under analysis understanding whether carrying out an Agrivoltaic project may be fruitful or not. Sustainability is everything but not a charity activity, and whatever technology or business model will be abandoned if it will lack a certain economic gain for the investors, regardless the entity of its positive impact from the environment and energy transition, even if the impact could be massive. For this purpose, the analysis described in this paper was commissioned, having the two entrepreneurs a genuine intention of entering the business of Agrivoltaic. They were both stimulated by the significant incentive scheme created by the Italian legislator and at the same time by the willingness that a new breed of technological development is required, today more than ever, if the humankind has a real interest in granting a future to its next generations. In addition, in case of a positive outcome of the precautionary process the two of them will be seen as pioneers in the market in the Piacenza area. Being both quite dedicated to preserve a positive imagine and opinion to enhance new business opportunities, being the first entrepreneurs of the new breed to undertake such complex and noble investments would be a great booster even in terms of credibility within colleagues in the nearby area. It can be said how economic and philanthropic interests were merged in the conviction that Agrivoltaic may be not the only solution, but rather one of those. Two parallel precautionary processes were performed, analysis two situations in two different land area, comparing different scenarios before finding the one which best fitted all the needs and requirements posed on the table. Many technological criteria and variables were accounted and listed, trying to develop a solution which could be perceived as effective as flexible at the same time, being fully aware, since the beginning, of the work that there is and there will always be room for development.

Having described many positive and negative aspects as well related to the Agrivoltaic concept, having said how there could be an economic profitability if the incentive scheme foreseen will be confirmed and implemented in a stable way in the next years, it must also be explained how unfortunately in the Italian landscape much work is yet to be done. Indeed, a significant uncertainty level is still present for what concerns the requirements needed for an APV plant implementation. It might be taken as example that fact that even within the writing process of this thesis, the regulatory framework changed its economic terms, and it is currently uncertain if the new document will be authorised and accepted by the European Union or if further modifications will be required. Also, for many actors operating in the sector it is not clear yet the distinction between Agrivoltaic and Agrisolar. A massive informative champaign must be structured to allow people reflect on these technological opportunities having a clear understanding of the big picture. Bureaucracy in Italy has never been straightforward and the Agrivoltaic business is once again confirming the assumption. Shadows are nowadays present in terms of technical requirements: will the ones present in the preliminary document confirmed of there will be modifications? How will the administration machine work in the incoming future to simplify grid connections procedures and installation's authorizations? In addition, even once having assessed all these questions related to a political and legal point of view, questions are there for what concerns the electricity price. Indeed, its fluctuations will affect plants' profitability and consequently the increasing or not willingness of entrepreneurs to further implement new APV plants in years to come.

To conclude, looking for the 'So, what?' of the entire discussion, it should be reported how the Italian government over Agrivoltaic has concrete objectives, reaching 1,1 MWp installed by 2026, and therefore it put on the table concrete money and economic opportunities which, if exploited properly and with the rightful timing, can lead to a consistent payback. Nevertheless, shadows are still present but nothing less or nothing more than the traditional characterisation of a new RES technology. As it is true that many doubts are still evident and many questions are unanswered, this paper has often stressed the actual need of sustain the green energy transition, regardless of all the embedded costs. Indeed, climate change is knocking louder and louder to humanity with the time flowing, human beings cannot remain paralyzed waiting for an epiphany which will unfortunately never show up. Time to act is now, a stable conviction is required together with a brief willingness to take risks which will pay back tomorrow.

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