Energy Reports 12 (2024) 251–258

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Agrisolar, incentives and sustainability: Profitability analysis of a photovoltaic system integrated with a storage system

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A R T I C L E I N F O

Keywords:
Agrisolar
Battery energy storage
Economic analysis
Photovoltaic
Sustainability

A B S T R A C T

Energy development based on renewable sources is capable of supporting the decarbonization process and must take place compatibly with other needs such as those related to food uses. In this direction, the installation of photovoltaic (PV) systems over farm structures without taking land away from agriculture, contained in the Agrisolar Park Legislative Decree, represents an opportunity to reduce greenhouse gas emissions and promote competitive models. This paper evaluates the profitability of two different technology options: i) a PV system alone and ii) an integrated PV and battery energy storage (BES) system. The analyses confirm that the percentage of self-consumption significantly increases the profitability of these systems, particularly when market scenarios with high prices are present. Similarly, the initial capital incentive can bring important economic benefits and thus is a policy measure that can enable the development of renewable installations in the agricultural sector. In addition, the results show that the use of BES does not always lead to increases in profitability and therefore individual case studies need to be evaluated by examining the potential increase in self-consumed energy that could be achieved. Such solutions can fit into the broader model of sustainable communities by fostering a farm's green image.

1. Introduction

The development of sustainable buildings involves different stakeholders with the goal of identifying the balance between smart solutions, technology and ecosystem protection goals (Vardopoulos et al., 2023a, 2023b). The basic idea is to achieve sustainable communities that include storage, demand configuration and sharing strategies (Manso-Burgos et al., 2022) and the role of sustainable education in the development of sustainable communities is crucial to that goal (Eliades et al., 2022; Suguna et al., 2024). Energy communities through renewable energy production support sustainable communities (Lennon and Dunphy, 2024) and represent new social models for ecological transition (D'Adamo et al., 2023). Energy sharing among buildings results in multiple benefits (An et al., 2023) and its development is not uniform across countries (Ahmed et al., 2024).

Businesses are engaged in a process of digital and sustainable transformation in which several paradigms are shifted, and the use of renewables also determines a drive toward innovation and competitiveness (Jamwal et al., 2022; Kazançoğlu et al., 2024; Khurana et al., 2022). Enterprises that adopt a PV system have an advantage improving their corporate image, support ethical models, and enjoy economic benefits (Bathmanathan and Hironaka, 2016). These benefits, linked to green initiatives, are amplified when there is also a shift in attitudes on the part of consumers who actually recognize this added value in their choice processes (Barbara et al., 2024). In fact, the transformation of customer interaction influences the business model of the enterprise, which can enable greater deployment of PV systems (Shakeel et al., 2024).

PV has an intermittent nature, and the use of lithium-ion batteries are the ones most commonly used to overcome this limitation (de Oliveira e Silva and Hendrick, 2017; Dhundhara et al., 2018; Feng et al., 2022). In turn, batteries need to be examined in the potential of their recycling (Yu et al., 2022) and the availability of raw materials is critical in the strategic perspective (Roy et al., 2022). The cost-effectiveness of battery energy storage (BES) depends on increasing the percentage of self-consumed energy (Ma et al., 2022), but it is not always verified and

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https://doi.org/10.1016/j.egyr.2024.06.033
Received 4 April 2024; Received in revised form 19 May 2024; Accepted 14 June 2024

therefore it may be advantageous to maintain stand-alone PV systems (Beuse et al., 2020). In this direction, a pivotal role is played by the cost of electricity but also by incentive policies that might concern subsidizing the price of electricity (Li and Cao, 2022) or a premium to self-consumption of energy (Zakeri et al., 2021). In addition, this technology can be financially more advantageous in residential communities than the individual consumer because of cost sharing (Chreim et al., 2024).

Within the sustainability of agri-food systems, the integrated farming system can play a key role (Bhagat et al., 2024), the development of sustainable agricultural multi-cropping (Modibbo, 2022) and the balance between food and energy needs to be identified (Morales-García and Rubio, 2024). In this direction, agrivoltaic plants combined with other forms of renewable energy can also support the transformation of some production activities (Temiz et al., 2022). Agrivoltaic systems are composed of PV systems above agricultural land to generate electricity while also enabling crop production (Maity et al., 2023). This topic has a growing interest in the literature (Coşgun, 2021; Schallenberg-Rodriguez et al., 2023). Agrivoltaics supports Sustainable Development Goals (SDGs) 7 and 11 through renewable energy production without harming food production for people (Ghosh, 2023). Some economic analyses show that agrivoltaic systems have higher profitability than conventional crop rotation (Campana et al., 2024); however, the economic viability of such systems depends on regulatory frameworks with high feed-in tariffs or similar support payments (Trommsdorff et al., 2023). Some authors emphasize the crucial role of incentives (Chalgynbayeva et al., 2023). Other challenges include investment costs, professional training, and the absence of clear regulatory frameworks (Vidotto et al., 2024). In particular, it is highlighted that energy justice is useful for the development of co-location of solar energy and agriculture (Taylor et al., 2023). The price of the feed-in tariff is a crucial factor in economic analyses (Chalgynbayeva et al., 2024) and studies conducted on Italy show that such systems may not lead to profitable outcomes even with high-income crops in the absence of adequate support policies (Di Francia and Cupo, 2023). In light of this gap, this paper evaluates the impact of the incentive decree resulting from the Agrisolar Park, an incentive policy implemented by the Italian government in 2023 based on initial capital incentive. In addition, as the literature pays attention to the economic analysis of PV+BES integration for residential use (D'Adamo et al., 2024a) or for offices (Zhao et al., 2023), it is also useful to evaluate the impact of integrated PV+BES systems within farms. This paper evaluates the profitability of an agrisolar plant in two different technological contexts: i) alone and ii) integrated with a BES system. Analyses are conducted according to the Agrisolar park decree and different alternative scenarios (reduced initial capital incentive and no incentive) are evaluated. In addition, different market scenarios (high and low avoided bill costs) are considered. The indicator used is the Net Present Value (NPV) and in order to give robustness to the results obtained, alternative case studies are conducted by varying the energy purchase price, energy sale price, PV investment cost, and BES investment cost. These analyses are replicated according to the percentage of self-consumption, which is the strategic variable of these plants.

The paper is organised as follows. Section 2 describes the methodology and input data, and Section 3 proposes the results of this paper. Initially, the profitability of stand-alone PV plants is evaluated followed by the profitability of BES to arrive at the definition of the cost-effectiveness of integrated PV+BES plants. Section 4 concludes the paper.

2. Materials and methods

This section presents the methodology related to the economic evaluation of a 40 kW PV system aimed at meeting the energy needs of an agricultural enterprise, located in central Italy. The size chosen depends on the type of the farm and its consumption profile. The objective of the proposed analysis is to assess how the application of this sustainable technology can also bring several economic benefits to the farm. In addition, in order to increase the enterprise's energy independence, an additional storage system is proposed that is 40 kWh in size. In this way, a ratio of 1 was chosen between the size of the BES and the size of the PV system. The policy context (Section 2.1), the economic model used in the analysis (Section 2.2), the model input data (Section 2.3), and finally the alternative scenarios (Section 2.4) are presented below.

2.1. Policy framework and policy scenarios

For an in-depth analysis of the implementation of an agricultural PV system, various policy scenarios involving different incentive systems were considered. These incentives constitute not only forms of support currently available to industries in Italy, but could also cover future scenarios in a pessimistic or optimistic version. The policy scenario considered in this study is that available to enterprises in Italy, related to the "Agrisolar Park" call, under which an 80 % initial capital incentive is provided. The aim of this measure is to support investments for the construction of solar power plants in the agricultural and agro-industrial sector, excluding land consumption. This tool provides support for investment in production facilities in the agricultural, livestock and agro-industrial sector in order to remove and dispose of existing roofs and build new insulated roofs, encourage self-consumption of energy, create automated ventilation and/or cooling systems, and install solar panels and intelligent flow and storage management systems. In addition, the results obtained for the baseline scenario were compared with two hypothetical alternative policy scenarios. So altogether there are three policy scenarios considered in this paper:

- the policy baseline scenario (Incentive 80 %) of implementing what is envisioned by the Agrisolar Park;
- the intermediate policy scenario (Incentive 40 %), in which the value of incentives is halved and is 40 % capital;
- the policy scenario with the absence of incentives (Incentive 0 %), aimed at highlighting the impact that incentives themselves have on profitability.

Relative to the storage system, two distinct policy scenarios are analyzed:

- the policy baseline scenario (Incentive 80 %) of implementing what is envisioned by the Agrisolar Park;
- the alternative policy scenario (Incentive 0 %), which does not include any form of incentive.

The policy context distinguishes agrivoltaic and agrisolar. The former is a PV system that adopts solutions aimed at preserving the continuity of agricultural and pastoral farming activities at the installation site. The second involves the installation of PV systems on buildings for productive use in the agricultural, livestock and agro-industrial sectors in order to encourage the energy transition of productive farms, excluding the use of land.

2.2. Economic model

To assess the profitability of the PV plant, an analysis was performed using the Discounted Cash Flow (DCF) method, an approach based on discounting future cash flows, considering the opportunity cost of capital (D'Adamo, 2018; D'Adamo et al., 2022; Guo and Xiang, 2022). Thus, this method is based on three key elements: the expected values of cash flows (CF), their time distribution (t), and the discount rate (r). The financial indicator used is Net Present Value (NPV), obtained by subtracting Discounted Cash Outflows (DCO) from Discounted Cash Inflows (DCI), discounted to the initial period, with the objective of determining the total value associated with the investment. The model proposed in the literature is used (D′Adamo et al., 2024a). DCIs are derived from various revenue items, including:

- the costs of energy saved, quantified as the product of the cost of energy on the bill and self-consumed energy;
- the sale of energy generated but not consumed;
- every form of support considered.

Instead, DCOs include the following items:

- the initial investment cost, which is the most significant element;
- the costs related to maintenance and insurance of the facility;
- the cost associated with replacing the inverter at year 10;
- taxes associated with the revenue obtained from the sale of non-self-consumed energy;
- any financial costs associated with financing the investment cost of the plant.

The economic model adopted considers a useful life of twenty years. In order to perform a more in-depth analysis, two additional tools were calculated for the various scenarios outlined above. The first is the Break Even Point (BEP) method, which indicates the percentage of self-consumption at which the NPV assumes zero value. The second is the Discounted PayBack Time (DPBT), an indicator which represents the number of years required to equalize the sum of discounted cash flows with the initial investment. The profitability analysis related to the configuration with only the PV system was implemented and compared with the integration of a BES. Again, the NPV (BES) was calculated through the economic model already found in the literature (D′Adamo et al., 2024a). The NPV (BES) depends on two key elements, the first represented by the component of revenues net of costs without considering the increase in self-consumption, and the second element related to the increase in the percentage of self-consumption resulting from the installation of storage and the related decrease in the amount of taxes due to lower energy sales. The increase in self-consumption depends on the relationship between the size of the BES and the size of the PV system. According to the findings in the literature, for a B/S ratio of 1, the percentage increase is most likely between 10 % and 20 %, or around 20 % and 30 % but with a lower probability (Cucchiella et al., 2018; Luthander et al., 2015). However, the adoption of more virtuous habits also suggests a more significant increase in the percentage of self-consumption. A final consideration concerns the evaluation of the convenience of integrating the storage system with PV versus the configuration with only the PV system. Considering the NPV of the integrated system NPV (PV+BES) = NPV (PV) + NPV (BES), it can be seen that the solution with storage integration will converge with respect to the PV system alone only when NPV (BES) takes a positive value. It is essential to point out that positive values of NPV (PV+BES) still make the investment profitable.

2.3. Input data

The case study presented concerns the profitability of a PV system with a capacity of 40 kW, intended for farm use. The enterprise considered is located in central Italy, with an average annual irradiance of 1450 kWh/(m^2xy), the useful life of the PV system is set at 20 years, with energy production fluctuating between 56,364 kWh in the first year and 43,387 kWh in the last year due to technological obsolescence. The analyses performed were conducted for self-consumption percentages from 0 % to 100 %. The percentage of self-consumption plays a crucial role in calculating profitability, and in the case of farms, it takes on high values considering that they do most of their work during daylight hours. The analysis conducted considers two main market scenarios, identified on the basis of the value of the cost of energy in bills (pc):

- the first market scenario (MS1), called low market, with a pc of 250 €/MWh.
- the second market scenario (MS2), referred to as high market HM, with a pc of 400 €/MWh.

The selling price of energy (ps) is considered to be 100 €/MWh. The input data are proposed in Table S1 (Cerino Abdin and Noussan, 2018; Chiacchio et al., 2019; D′Adamo et al., 2024a, 2024b; Luthander et al., 2016, 2015; Ramli et al., 2015; Talavera et al., 2019).

2.4. Analysis scenarios

The baseline scenario is analyzed by comparing it with alternative ones. In fact, the economic effects due to changes in one or more of the critical variables in the model are analyzed and by evaluating how these changes might affect the final result. Specifically, sensitivity analysis consists of observing how the variation of a single variable, in an optimistic and pessimistic version, may affect the overall profitability of the project. In the specific context considered, the critical variables selected for this analysis were the unit investment cost of PV, the cost of energy in the utility bill, and the selling price of energy. In addition, a further analysis (called scenario analysis) is proposed that is based on simultaneous changes in several variables, breaking down these changes by the two macro-components of profitability, namely revenues and costs. On the revenue side, the critical variables chosen were the energy bill cost and the energy selling price; while on the cost side, the variables of PV unit investment cost, percentage of insurance cost, and maintenance cost were selected. As with the sensitivity analysis, this analysis considers a pessimistic and optimistic variance of these variables. For these two analyses, a range of self-consumption from 30 % to 80 % was considered. A further analysis involves a risk assessment by application of the Monte Carlo method. It assesses the risk associated with a project by estimating the percentage of obtaining a project with positive profit. This analysis is based on a process of simulating random case studies making use of a normal distribution function for the critical variables considered where the variables of interest are the same as those chosen previously. Finally, possible alternative scenarios were also generated for the BES through a sensitivity and risk assessment.

3. Results

This section evaluates the PV system in both the baseline (Section 3.1) and alternative (Section 3.2) contexts. It then proceeds to calculate the profitability of the BES in the baseline and alternative case studies (Section 3.3) and finally evaluates the integrated PV+BES plant (Section 3.4).

3.1. Profitability analysis of a photovoltaic system - base case scenario

In the analysis conducted, it was examined how NPV (PV) varies in different case studies, considering the self-consumption share (wself) as the critical starting variable in the two base market scenarios, named MS1 (pc=0.25 €/kWh)) and MS2 (pc=0.40 €/kWh), respectively. The energy selling price (ps=0.10 €/kWh) is the same in the two market scenarios. The eleven self-consumption case studies, from 0 % to 100 %, are considered for replicability of the model, although energy sale alone appears to be an unlikely case. In all, sixty-six potential case studies, derived from the previous twenty-two contexts replicated in the three different alternative policy contexts, are considered - Table 1: (i) the current policy adopted, which corresponds to the rules dictated by the Agrisolar Park call for proposals that provide an 80 % initial capital incentive; (ii) an intermediate scenario, in which the amount of incentives is halved and thus equal to 40 % initial capital; and finally (iii) a policy scenario with no incentives.

The results of the base case scenario in the policy context Incentive 80 % shows that profitability is not verified in five case studies, and the

Table 1
NPV (PV) - Baseline scenario. Date in €.

	Incentive 80 %		Incentive 40 %		Incentive 0 %	
ωself	MS1	MS2	MS1	MS2	MS1	MS2
0 %	-44,717	-44,717	-68,368	-68,368	-92,020	-92,020
10 %	-28,364	-15,780	-52,015	-39,431	-75,666	-63,083
20 %	-12,010	13,157	-35,661	-10,494	-59,313	-34145
30 %	4343	42,094	-19,308	18,443	-42,959	-5208
40 %	20,697	71,031	-2954	47,380	-26,606	23,729
50 %	37,050	99,969	13,399	76,317	-10,252	52,666
60 %	53,404	128,906	29,753	105,254	6101	81,603
70 %	69,757	157,843	46,106	134,192	22,455	110,540
80 %	86,111	186,780	62,460	163,129	38,808	139,477
90 %	102,464	215,717	78,813	192,066	55,162	168,415
100 %	118,818	244,654	95,167	221,003	71,515	197,352
BEP	27.3 %	15.4 %	41.8 %	26.6 %	56.3 %	31.8 %
DPBT	5.9 y	2.1 y	14.5 y	6.1 y	>20 y	10.4 y

variable that determines this result is as much the percentage of self-consumed energy as the avoided cost in the bill. Higher self-consumption corresponds to higher total benefits (higher gain in bill and lower gain from sale). However, the second effect will be less than the first because the purchase price on the grid that determines the rebate in the bill is higher than the sale price to the grid. In this regard, the BEP for the first variable is calculated, which shows a value of about 27 % in the MS1 scenario and 15 % in the MS2 scenario. Evidently, the higher power purchase price allows the initial investment to be recovered even at lower self-consumption. Furthermore, evaluating a 50 % self-consumption rate, the NPV is 926 and 2499 €/kW in the MS1 and MS2 scenarios. The NPV increases to 1335 and 3223 €/kW when there is an increase in self-consumption to a value of 60 %. The DPBT, calculated for a wself of 50 %, varies between 2.1 and 5.9 y confirming the differences between the two market scenarios and being particularly attractive for farms.

The analyses of the two alternative policy scenarios provide other useful information. There are eight case studies with negative NPV in the context where the deduction is half that of the base case, and ten when there is no public intervention. The NPV in the Incentive 40 % context is reduced to 335 and 1908 €/kW per wself=50 % and 744 and 2631 €/kW per wself=60 %. in the two market scenarios respectively. In contrast, in the 0 % Incentive context, there is NPV for MS1 and 1317 €/kW for MS2 when wself=50 % and 153 and 2040 €/kW when wself=60 %. BEP, inevitably due to lower political support, registers an increase and varies between 27 % and 56 %. The DPBT, calculated for a wself of 50 %, increases and in the MS2 market context has a value of half the useful life. It is noted that profitability is not verified in the combined MS1 and Incentive 0 % context.

3.2. Profitability analysis of a photovoltaic system - alternative scenario

The next step is to test the profitability of the system in alternative case studies. The analyses focus on intermediate values of the self-consumption share between 30 % and 80 %, and pessimistic and optimistic perspectives are examined. Regarding the sensitivity analysis, the parameters that are varied according to Section 2.4 are the energy purchase price (pc) with a variation of ±0.05 €/kWh, the energy sale price (ps) with the same variation of ±0.05 €/kWh, and the investment cost (Ci) of 100 €/kW - Table 2.

It can be seen that the outcomes of the analysis provide all NPV values are positive in the MS2 scenario, while it turns out to be negative in the MS1 scenario in four case studies characterized by a high amount of energy fed back into the grid. Focusing on the case studies with 50–60 % as self-consumption, the NPV is always profitable and records the following variations in the two market scenarios respectively: 749–1513 €/kW and 2322–3400 €/kW when varying the investment cost, 402–1964 €/kW and 1975–3852 €/kW when varying the purchase price, and 113–937 €/kW and 2211–3454 €/kW when varying the selling price.

Table 2
NPV (PV) - Sensitivity analysis. Data in €.

ωself	OPT Ci	PES Ci	OPT pc	PES pc	OPT ps	PES ps
	MS1					
30 %	11,441	-2754	16,927	-8240	7927	-24,408
40 %	27,794	13,600	37,475	3919	17,776	-9939
50 %	44,148	29,953	58,023	16,078	27,626	4530
60 %	60,501	46,307	78,571	28,237	37,475	18,998
70 %	76,855	62,660	99,119	40,396	47,324	33,467
80 %	93,208	79,014	119,667	52,554	57,174	47,935
	MS2					
30 %	49,192	34,997	54,678	29,511	58,262	25,927
40 %	78,129	63,934	87,810	54,253	84,889	57,174
50 %	107,066	92,871	120,941	78,996	111,517	88,420
60 %	136,003	121,808	154,073	103,738	138,144	119,667
70 %	164,940	150,746	187,205	128,481	164,772	150,914
80 %	193,877	179,683	220,336	153,224	191,399	182,161

As for the scenario analysis (Table 3), again in accordance with Section 2.4, on the revenue side the purchase price of energy and the sale price of energy are varied simultaneously. On the cost side, in order not to have an identical case study as in the sensitivity analysis, maintenance and insurance costs are varied in addition to investment costs. The latter two items vary ± 0.5 %.

The MS2 context always has a positive NPV, while there are four case studies where it is negative in the MS1 context concerning the pessimistic scenarios with self-consumption percentage at 30–40 %. When, on the other hand, wself varies between 50 % and 60 %, we have the following NPV changes: 392–1835 €/kW in cost changes and 113–2195

Table 3
NPV (PV) - Scenario analysis. Data in €.

ωself	OPT Costs	PES Costs	OPT Revenues	PES Revenues
	MS1			
30 %	24,331	-17,037	33,094	-24,408
40 %	40,684	-684	51,333	-9939
50 %	57,038	15,670	69,571	4530
60 %	73,391	32,023	87,810	18,998
70 %	89,745	48,377	106,048	33,467
80 %	106,098	64,730	124,286	47,935
	MS2			
30 %	62,082	20,714	58,262	25,927
40 %	91,019	49,651	84,889	57,174
50 %	119,956	78,588	111,517	88,420
60 %	148,893	107,525	138,144	119,667
70 %	177,830	136,462	164,772	150,914
80 %	206,767	165,399	191,399	182,161

€/kW in revenue changes for MS1 and 1965–3722 €/kW in cost changes and 2211–3454 €/kW in revenue changes for MS2.

Finally, the risk analysis is carried out - Fig. 1, in which the Monte Carlo method with one thousand iterations is applied. The critical variables highlighted above are made to vary, where the mean value is chosen equal to the initial value and the standard deviation is assumed equal to the range calculated for the individual variables. The reference case study is the political context Incentive 80 %

In the MS1 context there is a 58 % probability of having positive NPV for a wself of 30 %. As this variable increases by 10 %, there is a significant increase with a probability of positive NPV of 80 % and reaches 99.3 % in the wself context of 80 %. The situation in MS2 is different, where there is a certain probability when self-consumption is at 50 % and is slightly lower than this value of 97.2 % when wself is at 30 %.

3.3. Profitability analysis of BES

BES allows the use of stored energy and, as a result, increases the share of self-consumption. However, this variable cannot be determined a priori, but depends on the initial value of self-consumption and consumer habits.

Gross NPV (BES) only takes into account all costs and only revenues associated with incentive instruments. Therefore, revenues associated with energy bill savings were not considered at this stage - Table 4.

In all the case studies shown the Gross NPV(BES) is negative. This result is not surprising, since as mentioned earlier it lacks the main cash inflow. The next step is to assess the NPV (BES). It is assumed that the starting point is wself=50 %. Multiple case studies considering the three different BES investment costs, the two policy scenarios (Incentive 80 % and Incentive 0 %), the two market scenarios (MS1 and MS2), and the three increases in self-consumption following BES adoption (10 %, 20 % and 30 %) are considered - Table 5.

In order to understand the results, it is useful to provide a practical example. Starting from 50 % self-consumption with the Incentive 80 % and MS1 context, the NPV (PV) is 37,050 €. Considering a gross NPV (BES) of −23,645 € for an Incentive 80 % and a cost of 600 €/kWh, we find that from a 10 % increase in self-consumption there is an increase in NPV (PV) of 16,354 € resulting in a NPV (BES) of −7291 €. If, on the other hand, the increase in self-consumption is 20 % the increase in NPV (PV) is 32,707 €. This implies that the NPV (BES) is equal to 9062 €.

This comparison confirms the relevance of incentive policy and avoided cost in the bill. The influence of unit investment cost of BES is also confirmed. There are fifteen case studies with negative NPV (BES). The MS1 and Incentive 0 % scenarios with a BES cost of 700 and 800 €/kWh are always unprofitable. In all other case studies with a 30 % increase in self-consumption there is a positive NPV (BES). A similar result is when the increase in self-consumption is at 20 % to which is added the scenario that has a BES cost of 600 €/kWh.

Table 4
Gross NPV (BES). Date in €.

Unitary investment cost of BES (€/kWh)	Incentive 80 %	Incentive 0 %
600	-23,645	-42,566
700	-27,585	-49,660
800	-31,526	-56,754

Table 5
NPV (BES). Date in €.

Unitary investment cost of BES (€/kWh)	Incentive 80 %		Incentive 0 %	
	MS1	MS2	MS1	MS2
Δωself=10 %				
600	-7291	5292	-26,212	-13,629
700	-11,232	1352	-33,307	-20,723
800	-15,173	-2589	-40,401	-27,817
Δωself=20 %				
600	9062	34,230	-9859	15,309
700	5121	30,289	-16,953	8214
800	1181	26,348	-24,047	1120
Δωself=30 %				
600	25,416	63,167	6495	44,246
700	21,475	59,226	-600	37,151
800	17,534	55,285	-7694	30,057

In order to give robustness to the results achieved, the risk analysis is conducted with thousand iterations. The critical variables are the energy purchase price and the sales price, which are made to vary in the same way as in the previous risk analysis. Added to these variables is the unit investment cost of the BES with an average value of 700 €/kWh and a standard deviation of 100 €/kWh. The calculation was made considering a 50 % self-consumption rate and considering 10 % and 20 % increments for both policy scenarios-Fig. 2.

The results show case studies that provide totally different valuations. They go from the Incentive 80 % MS2 Δwself 20 % context with a probability of 100 % profitability to the Incentive 0 % MS1 Δwself 10 % context with a probability of zero profitability. A minimal increase in self-consumption and a MS1 market scenario, even if they predict Incentive 80 % have a low probability of having positive NPV. A similar situation develops in the MS2 market scenario with the policy scenario

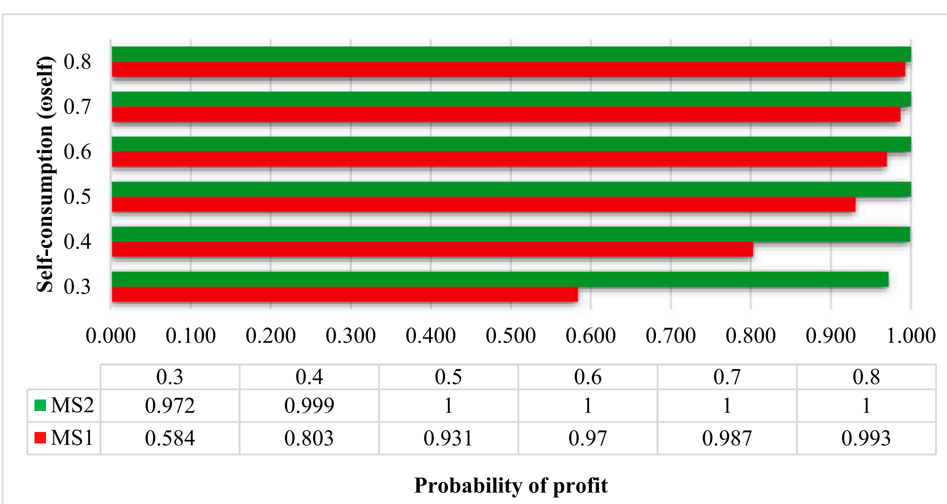

Fig. 1. Risk analysis (PV).

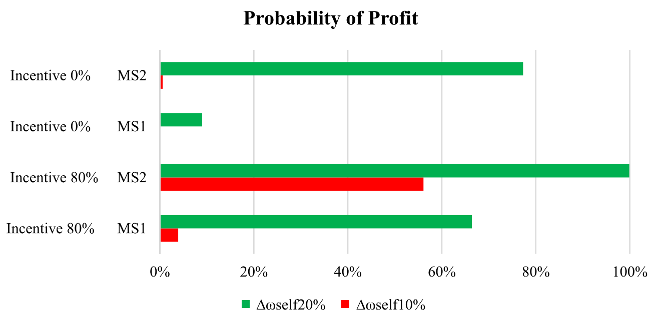

Fig. 2. Risk analysis BES.

0 % Incentive.

3.4. *Profitability analysis of the integrated PV+BES system*

Having defined the profitability of the BES, the analysis is completed with the evaluation of the integrated plant. The condition to be evaluated is whether NPV (PV + BES) > NPV(PV) i.e., whether there is an increase in the profit obtained by the investor due to the implementation of the BES. Fig. 3 highlights when NPV (PV+BES), represented by the bars, is greater than NPV (PV), represented by the straight line. This analysis allows the exact amount of profitability of an integrated plant and its graphical representation to be quantified. In fact, where the NPV (BES) < 0, inevitably the integrated plant will have lower profitability.

The results highlight the difference between the two market scenarios. In fact, although the investment cost of BES is a relevant variable it is evident that the most significant changes are due to the increase in self-consumption and energy market values. A number of case studies are highlighted where from the graph it can be seen that there is not a big difference between the value indicated by the line and that of the bar: NPV (PV+BES) is higher than NPV (PV) in the MS1 Δwself 20 % context with a BES cost of 800 €/kWh (38 k€ vs 37 k€) and in the MS2 Δwself 10 % context with a BES cost of 700 €/kWh (101 k€ vs 100 k€), while it is lower in the 800 €/kWh context (97 k€ vs 100 k€). The results highlight the relevance of incentive policy: fourteen case studies have NPV (PV+BES) > NPV (PV) including eight in the MS2 context when analyzing the Incentive 80 % policy scenario. In contrast, in the 0 % Incentive policy scenario there are seven case studies with such a situation of which six are associated with the MS2 context. However, in the one related to MS1, even with the addition of BES the project still remains unprofitable.

The maximum values of NPV (PV+BES) range between 126 and 134 k€ with a Δwself 20 % and between 155 and 163 k€ with a Δwself 30 % for an 80 % Incentive. These values are 54–68 k€ with a Δwself 20 % and 83–97 k€ with a Δwself 30 % for a 0 % Incentive. All these profits characterize the MS2.

4. Conclusions

Sustainability is composed of multiple challenges, and it emerges that a pragmatic solution is not always easy to identify. Associated with a need to produce green energy is also the need to have agriculture that provides healthy products allowing a proper balance to be identified. The installation of PV panels within fertile land and thus allocable to agricultural land turns out to be an incorrect choice. Similarly,

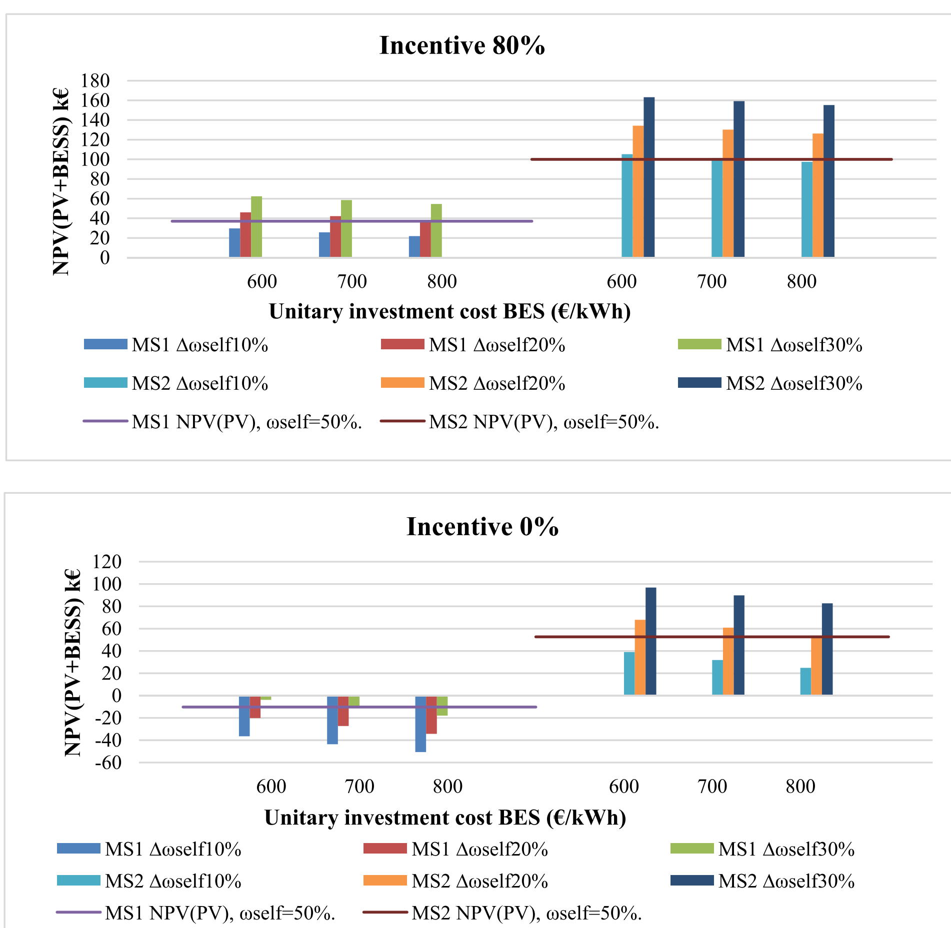

Fig. 3. A comparison of NPV(PV) and NPV(PV+BES). Data in k€.

agricultural enterprises are influenced by changes resulting from international competition and different market rules that do not seem to support a model of fair competition. In this regard, the Agrisolar Park Decree offers important novelties as it proposes the aid of an initial capital incetive of 80 % of the expenses incurred for the implementation of PV systems on buildings for productive use in the agricultural sector. The results of this paper quantify clear economic benefits from this policy choice, which can be quantified as approximately 1183 €/kW. It is shown that the percentage of self-consumption plays a key role. The BEP figure on this variable shows how much the policy scenario affects: 15–27 % for Incentive 80 % and 32–56 % for Incentive 0 %. However, these numbers indicate that the percentage of self-consumption rewards virtuous behavior but likewise this happens when there is a significant purchase price of energy. In fact, MS2 shows a higher economic profitability than MS1 for a range from 944 to 2517 €/kW for wself between 30 % and 80 %. All alternative scenario analyses confirm these results indicating how PV systems on buildings for the agricultural sector can achieve significant economic performance toward achieving SDG 7.

However, the intermittent nature of PV plants, determines the aid of BES. This paper aims to quantify in what contexts the integrated PV+BES system is economically viable for an enterprise that benefits from the Agrisolar Park Decree. The results show an economic advantage between 473 and 631 €/kWh compared to the solution without incentives. The cost of the BES clearly affects the final result, but a greater impact is also intended for the market scenario and the increase in self-consumption in addition to the policy scenario. In fact, it is identified that for a 10 % increase in self-consumption after BES adoption only in the Incentive 80 % and MS2 context there is a significant probability of profitability, which is 56 %. On the other hand, when an increase in self-consumption to 20 % is considered, it shows a certainty of profitability in the combined MS2 and Incentive 80 % context that decreases to 77 % in the combined MS2 and Incentive 0 % and 66 % in the MS1 and Incentive 80 % context.

This paper refers to the Italian context, but the methodology can be easily replicated in other contexts where it can be shown how the incentive decree influences economic performance. It is inferred that an integrated PV+BES system supports greater autonomy of agricultural enterprises, contributes to climate change thus increasing the green brand image with social spillovers as well, and finally offers important economic opportunities. It can therefore be concluded that sustainability is a global challenge and that the energy sector is called upon to make an important contribution to achieving decarbonization in the various sectors involved, including agriculture.

The development of Agrisolar parks can foster collaboration between enterprises, and in addition, the energy side can be combined with activities commonly carried out. This work highlights the economic benefit of a single enterprise from adopting renewable practices but has the idea of extending to sustainable communities that relate not only to collaboration between enterprises but also to the integration between the different activities they carry out in order to increase the competitiveness of a local territory. Such investments support the implementation of solar PV power generation facilities in the agricultural and agro-industrial sector, excluding land consumption. They represent an innovative solution aimed at meeting energy needs and aim to ensure an eco-friendly supply in a context that is increasingly attentive to sustainability issues and oriented toward energy independence and transition.

Author statement

All authors equally contributed to the writing of the paper and its revision.

CRediT authorship contribution statement

Sunil Luthra: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Leonardo Rimoldi:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Idiano D'Adamo:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Massimo Gastaldi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

This study as carried out within the PEACE (Protecting the Environment: Advances in Circular Economy) which received funding from the "Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)" Investimento M4.C2.1.1-D.D. 104.02–02–2022, 2022ZFBMA4 funded by the European Union - Next Generation EU. This manuscript reflects only the authors' views and opinions, and can be considered responsible for them.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.egyr.2024.06.033.

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