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Cost–Benefit Analysis of Kaposvár Solar Photovoltaic Park Considering Agrivoltaic Systems

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Abstract: In the context of the global energy crisis and crucial issues on food, the development and utilization of agrivoltaic (APV) systems could be a way to solve both the energy shortage and agricultural production at the same time and in the same area. As a combination of photovoltaics (PV) and agriculture, agrivoltaics has broad prospects for the future agricultural development of Hungary. Since especially large-scale PV systems can be considered as a potential basis of APV systems, the Kaposvár Solar Power Plant Project in Hungary was analyzed in this study. Two comparative analyses were used: between APV and PV systems, and between APV and apple plantation. An economic model has been developed. The baseline scenario shows that APV systems in current technological and economic conditions are not competitive with PV systems and are also less attractive for agricultural farmers, due to the long return period of the surplus investment cost. By analyzing uncertain factors and seeking possible solutions, the authors' recommendations for the development, subsidy system and technology might be useful for both farmers and for decision makers to promote APV systems in the future.

Keywords: agrophotovoltaic; solar farming; photovoltaic agriculture; sensitivity analysis; financial return

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1. Introduction

For the fast-growing demand for electricity, food, and resources in the world's economy, the optimization of land use considering environmental, social, and economic effects towards systems that integrate diverse land uses while increasing the total yield of production is desirable. Agrivoltaic systems provide many advantages, such as great development potential, and being clean and recyclable. Countries are paying increasing attention to the research and development of agrivoltaic technology, constantly improving related laws and regulations, and improving the policy environment. There is a huge gap between the energy-saving potential of agrivoltaics with electricity generation and agricultural production and the actual energy utilization. In the actual utilization process, there is a waste of resources, as the conversion of sunlight into electricity by solar panels cannot be fully utilized in rural areas. How efficient is the use of resources in real life? In the absence of government financial support, do agrivoltaic systems provide economic benefits? What are their environmental benefits? These problems affect the use, development, and promotion of agrivoltaic systems in rural areas. This paper takes "agrivoltaic" as an example using a structured sensitivity analysis, evaluates the actual efficiency of the utilization of electricity production, quantitatively analyzes the economic and environmental benefits of agrivoltaic systems for farmers, and presents suggestions for their development. Figure 1 gives a schematic comparison of photovoltaic (PV) and agrivoltaic (APV) systems.

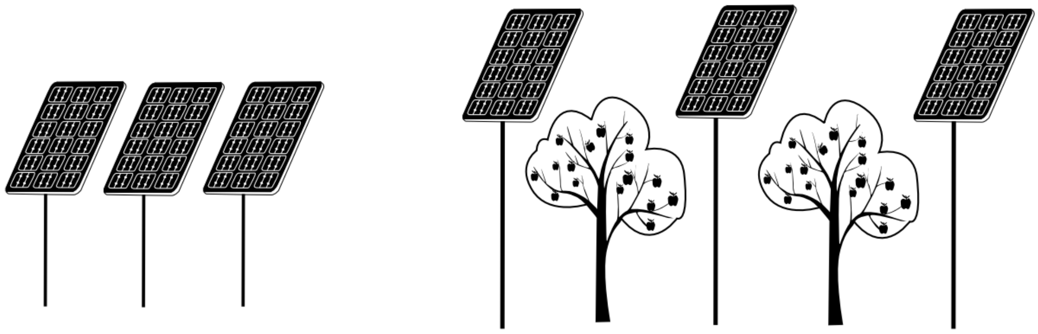

Figure 1. Schematic comparison of PV and APV systems.

Compared to other studies, the novelty of this article is reflected in two aspects: (1) the use of a significant body of literature focused on the existing literature. This paper synthesizes the literature on agrivoltaics not only from international researchers, but also from less published Hungarian researchers. The basis of 48 previous research works clearly proposes that the concept of agrivoltaics should be understood from the essence, connotation, development mode, and other aspects. (2) This paper performs an economic analysis to provide good advice for investing into agrivoltaic technology and to demonstrate the effects on the competitiveness of APV compared to PV and agriculture. This paper shows that without government subsidies or fundamental changes in the economic and technological context, the future development of agrivoltaics is uncertain in the short run.

2. Review of the Literature

The utilization of photovoltaics is older than that of hydro energy and wind energy. According to the statistical data of BP, the utilization of solar energy first appeared in the United States, but the production was small; however, it rose by 22% in 2018. After 2000, large-scale development and utilization began. The world's total solar energy production has rapidly increased from 0.27 Mtoe in 2000 to 314.44 Mtoe in 2021, accounting for 12.6% of the world's total renewable energy consumption [1]. The future development potential of agrivoltaic technology is huge. Although developed countries began to actively encourage the development of PV systems very early, the utilization of solar energy in various countries did not increase significantly before 2008. From 2010 to 2020, the annual renewable electricity consumption of solar PV in the European Union (EU) was 8.8 Mtoe in 2015, and the following year it increased by 9.28 Mtoe; however, there was a noticeable drop in consumption in 2017 (5.44 Mtoe). In 2015, the share of electricity from solar PV in the EU was 28.8% [2]. Since 2009, solar energy utilization has increased rapidly, reaching 23.88 Mtoe in 2020, almost 70 times higher than in 2009, accounting for 18% of global solar energy consumption [3]. The long-term policy of encouraging the development of photovoltaic systems in the United States has begun to take effect [4,5]. Japan's "new sunshine plan" and "new energy promotion program" started in the late 1990s [6]. At the end of the 20th century, the EU began to continuously improve its renewable energy utilization target [7–10]. The solar energy utilization of Germany, Italy, Spain, France, and other major EU countries increased rapidly [11]. In 2020, the gross electricity consumption of the EU accounted for 14% of the global consumption [12]. China's solar energy consumption has increased significantly since 2007 [13]. In 2018, total solar energy consumption reached 40.16 Mtoe [14], accounting for 24% of the world's solar energy consumption and becoming the country with the highest solar energy consumption. Generally, Peng et al. [15] stated that the demand for green energy is inversely proportional to the density of the population and directly proportional to GDP.

Currently, Hungary is a country of energy saving and renewable energy utilization, which is of great significance for its economic development [16]. According to the Hungarian National Bank's (MNB) Green Program, the MNB examined utility-scale renewable energy production within the support opportunities and development to strengthen environmental sustainability in the national financial system [17]. Investment in the Hungarian renewable energy industry, mainly photovoltaic solar power plants, will reach investment needs of HUF 2253B (EUR 6324 M), HUF 1577B (EUR 3889 M) of debt financing, and 12 GW solar PV power capacities are planned by the end of 2040. These are initiated by the new National Energy Strategy and the National Energy and Climate Plan (2030, with an outlook up to 2040) [18]; therefore, the proportion of renewable energy in the total energy consumption will reach at least 45%. From the report released by the National Climate Change Strategy, we know that Hungary plans to increase the share of solar energy as a primary energy from about 5% at present to 21% in 2030 [19]. If the expected target is successfully achieved, Hungary can reduce greenhouse gas (GHG) emissions by nearly 52–85% compared to 1990 levels [20]. The number of large-scale solar power plants in Hungary has continued to increase, so their total installed capacity is already close to 1800 MW, and if household-sized solar power plants are also included, the domestic photovoltaic capacity Is already around 2800 MW. Although this growth may have slowed in the second half of the year, Hungary will reach the 3000 MW limit this year (2022) at the latest, completing half of the planned goal set for 2030 in the energy strategy [21]. The largest solar farm in the country operates in Kapuvár with a capacity of 25 MW. The park is in the hands of an Israeli stock exchange group, which owns a total of three solar power plants in Hungary: Kapuvár, Tuzsér, and Nádasd. Production is continuous in all three areas and the solar collectors operate with a total capacity of 57 MW [22]. The largest solar power plants currently operating in Hungary are represented in Figure 2.

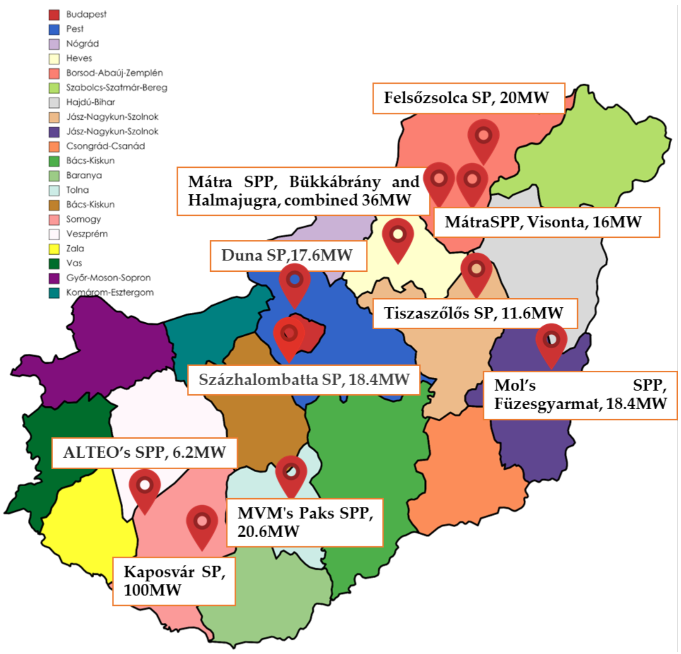

Figure 2. The largest solar power plants in Hungary [22].

Agrivoltaics refers to the radiant energy of sunlight combined with agricultural production, water savings, and the efficiency of electricity production [23]; therefore, this technology can present positive impacts in the food—energy—water nexus [24]. Radiation reduction provides many benefits, for example, it contributes to higher and more stable yields and increased plant resilience [25]. Furthermore, the technology operates in a clean and self-cleaning manner, and no waste is generated during the operation. One of its major advantages is the higher land economy compared either to standalone PV systems or agricultural production [26], and fossil energy and harmful emissions are also reduced. However, because of the late start of the Hungarian photovoltaic industry grid connection, the core technology of solar photovoltaic is still far behind developed countries such as those in Western Europe and North America.

Due to the unstable political situation and current energy crisis in EU countries, the EU strongly emphasizes the huge dependence of the EU on fossil fuel imports and has made the transition to renewable energy resources (RES) since the beginning of 2022 [27,28]. The excessive reliance of the agricultural development process in the EU on traditional fossil energy and large consumption have also caused many problems, such as a high cost of agricultural production, large environmental pollution in rural areas, and low agricultural economic efficiency [29,30]. Agricultural development needs to be transformed. As Tumiwa et al. [31] presented, it is essential to pay attention to the sustainable management of natural resources to continuously increase agricultural productivity and gain a sustainable competitive advantage. Thus, the challenge of agricultural development with the implementation of Industry 4.0 is to maintain harmony between economic, social, and environmental aspects. All sustainability aspects in Industry 4.0 technology should be focused on dealing with many challenges and problems [32]. The development of agrivoltaics plays a very positive role in solving the problems of backward technology, energy shortage, and environmental pollution that agricultural development faces. Foreign scholars have studied agrivoltaics in terms of economic benefits, energy benefits, social benefits, and other aspects, and they affirmed the positive role of developing solar farming [33–36]. The growth of solar farms would cause a conflict of land use with agricultural production. This problem can be solved by the concept of "agrivoltaic", which is the joint development of solar photovoltaic and agricultural land. The economic benefits are outstanding, and it has many incomparable advantages over traditional agriculture. The results show that the economic value of grape farms adopting agrivoltaic systems may increase more than 15 times compared with traditional agriculture, while maintaining the same grape yield [33]. In addition, grape-based agricultural production can be implemented in rural areas to electrify them. The role of agrivoltaics (solar farms) in agricultural and socio-economic development emphasizes that agriculture has a large demand for energy and the advantages of photovoltaic agriculture in energy saving, land saving, and other aspects. Kumpanalaisatit [36] also pointed out that the application scope of photovoltaic technology in agriculture is not wide enough, and the low output–input ratio of agrivoltaics and the high price of photovoltaic-related products are the problems and difficulties in photovoltaic agriculture. Thompson et al. [37] estimated that income from selling agricultural products (basil and spinach) and selling electricity increased the production values by 18% and 113%, respectively. Additionally, the APV systems would produce USD 2.04T in revenue with a simple payback time of 17 years and at the average 2018 electricity price of 0.1053 USD/kWh, the net present value (NPV) is estimated at a 6% (USD 35.72B), 3% (USD 332.93B), and 1% discount rate (USD 678.03B). With similar operating and maintenance costs, the net difference between APV systems and traditional PV systems is estimated to be USD 338.8B over the 35-year project life [38]. Roy and Ghosh [39] compared this to the small capacity of the ms-Si PV plants and larger counterparts, demonstrating that electricity production and crop production minimized the payback period by up to 30–35%. The results showed that the agricultural yields of a-Si and CdTe plants are better than mc-Si plants. The average simple payback period for the agrivoltaic system was 5 and 8 years [40–42]. Agrivoltaics can reduce the variable behavior of apple trees, demonstrating the importance of conducting years of research [43].

According to Eurostat [44], the dependency on energy import of the 27 European countries in 2020 was met by net imports of 57.49% on average, with some examples such as Greece, (81.41%), Ireland (71.30%), Belgium (78.05%), and Germany (63.71%). The highest country-level dependence on energy imports was found in Cyprus (93.07%) and Malta (97.56%), while the lowest share of total energy needs was found in Iceland (11.96%) and Sweden (33.51%), respectively. In this case, a transition to renewable energy systems (RES) is certainly necessary. The technological progress with energy-saving effects and the investment subsidies of output and capital in the energy market to the general equilibrium model set that energy and capital can be complementary in the production process, and new machinery and equipment can reduce the consumption and waste of energy [45]. According to the life-cycle theory, the results show that agrivoltaic systems have a similar environmental performance in comparison to traditional PV installations, the role of capital investment subsidies depends largely on the structure of the energy market [46,47], and the increase in capital is affected by capital investment subsidies and energy consumption prices in the energy market. The social market consumption potential of photovoltaics is based on green electricity savings in Europe and proposed that the use of social marketing methods for solar energy can increase electricity consumption [48,49]. However, there are common barriers to the adoption of agrivoltaics such as limited information on technology, economic aspects, legal issues, financial concerns, and sociodemographic factors [34,50].

The electricity network is inaccessible for more than one billion people around the world [51], and the number of starving people is estimated between 720 and 811 million; the prevalence of undernourishment increased to 9.9% in 2020 [52], slowing down the spread of diseases [53], climate change, and related environmental issues that affect all people globally [54] and should be solved simultaneously and within a short time [55]. Food, energy, and environment can be considered the most important global challenges [56]. All the aforementioned challenges can be influenced to a large extent with more effective agricultural systems. A dichotomy of 'food versus fuel' has misled thinking and hindered the necessary action to build agricultural systems in sustainable ways [57]. We need to produce green energy without endangering food production.

Agrivoltaic systems are promising technologies for combining all three (food, energy, and environmentally friendly) types of land use. Agriculture and solar power generation, at the same time, have the potential to contribute to the sustainable utilization of rural areas. Moreover, farmers have the opportunity to develop new ways to grow their income without losing the productivity of their land. The importance of APV systems is rapidly growing: the worldwide installed capacity was estimated at 5 MWp in 2012 and achieved 2.8 GWp in 2019; however, their technical potential is significantly higher (Germany reaches 1700 GWp year^{-1}) [58].

Compared to ground-mounted configuration, the rooftop PV systems resulted in a 2.9% increase in capacity utilization factor, and up to a 23.7% decrease in the levelized cost of electricity (LCOE) because of mutual shading impact. It showed that a roof PV system installation has many advantages over ground-mounted PV systems, including avoiding land use [59]. Consequently, large-scale ground-mounted PV systems can especially be considered an available option for APV systems. For future spread, APV systems should be economically viable compared to both ground-mounted PV systems and conventional agricultural systems (without PV systems).

The research aimed to show the expected economic impacts of APV systems based on the real data of an operating Hungarian PV project located in the Kaposvár area with the highest capacity in Hungary, the economic data of Schindele et al. [34] about PV and APV systems, and the typical economic data of Hungarian apple production. Based on the baseline scenario, we provide a sensitivity analysis to explain which factors could have the greatest importance for the future spread of APV systems.

3. Materials and Methods

Based on the existing literature, the research content on the sensitivity analysis and comparison with APV and PV investment decision making was used to form the research logic and ideas of this paper. A combination of qualitative and quantitative analysis was also used. The analysis of the factors influencing the investment decision of APV and PV generation belongs to the qualitative analysis, while the collection of data to calculate the investment cost and capital expenditures of APV and PV generation belongs to the quantitative analysis. The combination of qualitative and quantitative analysis provides investors with a quantitative analysis tool, which is conducive to helping them make correct decisions. Based on these comparisons, changes of many economic data can have adverse effects on the real and opportunity costs and revenues of APV systems; the most important are the following: the investment costs of the three above-mentioned systems, PV coverage in APV systems, PV efficiencies, green electricity prices, the effects of shading for agricultural yields, and plant species under APV systems. Regarding plant species, we considered apple plantation for the following reasons:

- Horticultural products might be more efficient in APV systems thanks to their high income in a hectare; long lifetime; extra defense against weather extremities, especially icy rain; and strong summer sunshine.
- Regarding partial coverage, apple yields are similar to the conventional apple production.
- Apple is the most significant plant in Hungarian horticulture.

3.1. Data Sources

The agrivoltaic system data used in this paper are from Schindele et al. [34]. The baseline capacity scenario is 689.66 kWp ha^{-1} with PV-GM and 519.18 kWp ha^{-1} with APV, corresponding to an area utilization of 2 ha, and the basic parameters of the project are shown in Tables 1 and 2.

Table 1. Baseline scenario.

	PV	APV	
Capacity	689.5	519	kWp/ha
Size	2	2	ha
Capital expenditure (CAPEX)	1031	1344	th EUR/MWp
Sunshine hours	1075	1075	h/yr

Table 2. The baseline for an economic comparison analysis for APV and PV-GM systems.

○ Necessary area for 1 MWp PV capacity:	1.45	ha
○ Necessary area for 1 MWp APV capacity:	1.93	ha
○ Unit investment cost for 1 MWp PV capacity:	1031	th EUR/MWp
○ Unit investment cost for 1 MWp APV capacity:	1344	th EUR/MWp
○ Unit investment cost for 1 ha PV capacity:	516	th EUR/ha
○ Unit investment cost for 1 ha APV capacity:	672	th EUR/ha
○ Unit investment cost of 1 ha apple plantation:	5	th EUR/ha
○ Electricity production of 1 ha PV capacity:	741	MWh/yr
○ Electricity production of 1 ha APV capacity:	558	MWh/yr
○ Average electricity price in Hungary:	9.5	EURc/kWh
○ Average income of 1 ha apple plantation:	2	th EUR/ha

For scenario 1, the Kaposvári Solar Power Plant Project is selected in a special case with some plant data (capacity and electricity production). The photovoltaic power generation project investigated in this study is located in Kaposvár (46.36383° N 17.78225° E), southwest Hungary. The framework of the “Kaposvár Solar Power Plant Project” is two solar power plants that were built with a total capacity of 100 MW [60] and constructed by China National Machinery Import & Export (Group) Co., Ltd. (China National Machinery Corporation, Beijing, China), a subsidiary of China General Technology Group. The size of the investment area is 200 ha. On average, the sunniest month is July with 293 h of sunshine, while the lowest amount of sunshine at 59 h is in December in Kaposvár [61]. The current classification of the area in the town planning register is general agricultural land. Since Hungary currently needs significant imports of electricity, the established project is an important element of contributing to environmental protection and the development of green electricity.

3.2. Parameter Sensitivity Analysis

The sensitivity analysis method can find the sensitive factors that have an important impact on the economic benefit index of the investment project from many uncertain factors and calculate their degree of influence [62], which is widely used in the research of investment decisions and farm profits [34,63]. In terms of factors affecting the economic benefits of photovoltaic power generation projects and farm profits, some studies found through a sensitivity analysis that increasing the power generation capacity, farm profit, and loan ratio helps to improve the economic benefits of photovoltaic power generation projects in agriculture, while the increase in construction costs, operating and maintenance costs, and loan interest rates have a negative impact [64]. Furthermore, the negative impact of the attenuation rate of photovoltaic modules and the positive impact of system efficiency [65], annual utilization hours, electricity price, and power generation subsidies [66] have also attracted scholars’ attention. To assess the influence of choice between the APV system and PV, APV system and conventional apple production, we have used a sensitivity analysis in order to identify whether the initial investment cost will return or not. It was assumed that the agrivoltaic systems were replaced with a PV system in Hungary if the lifetime of the agrivoltaic was 25 years, which is the lifetime of the agrivoltaic that we assumed in this study. By using actual references and statistical data, APV systems need the highest investment cost for both PV and apple plantations; therefore, the return of the surplus investment cost is not possible. In contrast, if the electricity generation by the agrivoltaic and PV-GM per year was 500 kWp ha^{-1} and saw an increase in the establishment cost of the apple orchard, which is the same as in the present study, the surplus investment cost can be expected to return. The sensitivity analysis was attempted based on escalation rates in cost and returns. Studying the degree of influence of various uncertain factors on the investment decision of an agrivoltaic system makes it possible to propose some specific suggestions for effectively utilizing the degree of influence.

3.3. Scenario Analysis

The calibrated models for both APV and PV systems were used to conduct a scenario analysis to answer several “what if” questions, including large-scale ground-mounted PV systems with consideration of the potential for agrivoltaic systems, as well as considering traditional farming systems without PV. Finally, it is necessary to increase the yield of various horticultural crops and the quality of the products in a sustainable manner. The analysis was conducted using secondary data.

4. Results

The results of the baseline performance evaluation, agrivoltaics, and PV systems are presented in this section.

4.1. Baseline Performance—Case of Agrivoltaics and Photovoltaic Systems

4.1.1. Results of the Baseline Scenario

The purpose of quantifying the economic evaluation between APV and PV systems, as well as between APV and conventional apple production by using a sensitivity analysis in this scenario, is to obtain the economic impact potential value of each product of APV and PV systems with agricultural production, in our case apple production, to provide a basis for the following technical and cost analyses. In this paper, the electricity production of 100 MW ground-mounted photovoltaic models with a service of 25 years as an example is selected as the functional unit for the economic assessment. The assessment scope includes three stages of investment cost (including surplus investment cost for the APV system), electricity production, and farm income in apple production (Table 3). The average annual generation of the unit is 0.11 MWh, the average tariff rate is 0.137 kWh (with respect to the energy crisis, the tariff rate will potentially increase), and the investment cost is approximately EUR 99.1 M [60]; the annual operation and maintenance cost (O&M) is EUR 4.9 M. Comparing the power generation cost of distributed large-scale PV and APV, it can be clearly seen that under the current conditions, the economic competitiveness of the APV system's distributed surplus investment costs compared with the large-scale PV system will decline, and the surplus investment cost of the APV system will not return after considering apple production income and lost electricity production. This result is close to the actual situation. When the dynamic payback period (DPP) is high, the NPV is higher than the benchmark electricity price without subsidies, but lower than the actual on-grid electricity price with subsidies, and the economic benefits of the case project depend on the degree of subsidies. Previous studies [34,67] have also reached similar conclusions. We identified the following factors:

1. APV systems need more financial sources for investment as regards both PV and agricultural production.
2. The extra income from agriculture does not compensate for the lower income from electricity production due to partial shade, so it cannot be expected that the surplus investment cost will return.
3. However, the extra income from electricity production is significant, but the repayment period is not favorable for investors.
4. Without the subsidization of APV systems, farmers are not expected to choose them.

The cost of the distributed agrivoltaic system is not only that there is no sewage charge and fuel cost, but also that the APV system in the mode of spontaneous self-use and surplus operation has a limited impact on the power grid in terms of the line-carrying capacity and voltage fluctuation, so its transmission and distribution cost can also be ignored. In particular, distributed APV systems can be developed according to local conditions, own power load, and development conditions, which can not only effectively improve the utilization efficiency of green electricity and reduce the pressure of peak shaving of the power grid, but also obtain a certain amount of power sales income in addition to free power consumption, simultaneously, leading to an increase in agricultural production. At the same time, in terms of environmental consequences, CO_2 emissions can be reduced every year after the completion of the APV project.

Table 3. Comparison of the economic differences of the baseline scenario.

Between APV and PV systems			
○	Surplus investment cost (incl. apple):	162	th EUR/ha
○	Surplus (average) income from apple production:	2	th EUR/ha
○	Value of electricity production:	−17	th EUR/ha
○	Static payback period:	endless	y
Between APV and conventional apple production			
○	Surplus investment cost:	667	th EUR/ha
○	Surplus (average) income from apple production:	0	th EUR/ha
○	Value of electricity production:	53	th EUR/ha
○	Static payback period:	12.6	y

4.1.2. Scenario 1—Kaposvár

In this scenario, the lifetime of the large-scale PV-GM system is relatively long at 25 years. Table 4 compares the CAPEX of APV and PV-GM and illustrates their different cost structures [34]. Comparing the results of APV and PV-GM, it can be found that although APV and PV-GM both reflect the economic feasibility of the case project at the CAPEX, there is a difference in the investment cost of APV. From the perspective of APV, the case project can operate at a loss under the current subsidy level, reflecting the uncertainty of its long-term economic benefits, but the APV system could obtain economic benefits for electricity and agricultural production using the same land. From the perspective of PV-GM, the case can still obtain economic benefits considering actual subsidies (Tables 4 and 5).

Table 4. Comparison of APV and ground-mounted PV.

	PV	**APV**	
Capacity	500	376	kWp/ha
Size	200	200	ha
CAPEX	999	1344	th EUR/MWp
Sunshine hours	1075	1075	h/yr

Changes in different economic data will impact the results of the calculation of the real and opportunity costs and revenues of the APV system, thus, affecting the economic benefits of the photovoltaic power generation project. The introduction of investment analysis can further reflect the uncertainty of the long-term economic benefits of the photovoltaic power generation project. With the gradual advancement of the process of the photovoltaic power generation project in Hungary, the investment costs of the three above-mentioned systems, PV coverage in APV systems, PV efficiencies, green electricity prices, the effects of shading for agricultural yields, and plant species under APV systems, the uncertainty of the long-term economic benefits of photovoltaic power generation projects will further increase. We can see these results in Table 6. The benefits of agrivoltaic generation should be considered in a complex way for the adaptation to the subsidy system. Therefore, we should not only pay attention to the economic benefits of agrivoltaics, but also consider the environmental benefits it brings, both benefiting land users and not having investment in hail protection and shade-growing systems for the determination of the future subsidy system. The economic benefits of agrivoltaics are mainly determined by the amount of electricity in the grid and the price in the grid of the PV system. Of course, the grid connection of PV system generation will also generate a series of taxes, such as value-added tax, enterprise income tax, etc. As an experimental APV system in Germany, it sets the feed price higher than the traditional energy market price for photovoltaic power generation projects and adjusts the incentive level over time [68].

Table 5. Economic data of large-scale Kaposvár PV systems compared to the APV system.

○	Necessary area for 1 MWp PV capacity:	2.00	ha
○	Necessary area for 1 MWp APV capacity:	2.66	ha
○	Unit investment cost for 1 MWp PV capacity:	999	th EUR/MWp
○	Unit investment cost for 1 MWp APV capacity:	1344	th EUR/MWp
○	Unit investment cost for 1 ha PV capacity:	500	th EUR/ha
○	Unit investment cost for 1 ha APV capacity:	672	th EUR/ha
○	Unit investment cost of 1 ha apple plantation:	5	th EUR/ha
○	Electricity production of 1 ha PV capacity:	538	MWh/yr
○	Electricity production of 1 ha APV capacity:	405	MWh/yr
○	Average electricity price in Hungary:	9.5	EURc/kWh
○	Average income of 1 ha apple plantation:	2	th EUR/ha

Table 6. Economic results of the comparative analyses in the baseline scenario.

Between APV and PV systems			
○	Surplus investment cost (incl. apple):	177	th EUR/ha
○	Surplus (average) income from apple production:	2	th EUR/ha
○	Value of electricity production:	−12.6	th EUR/ha
○	Static payback period:	endless	y
Between APV and conventional apple production			
○	Surplus investment cost:	667	th EUR/ha
○	Surplus (average) income from apple production:	0	th EUR/ha
○	Value of electricity production:	38	th EUR/ha
○	Static payback period:	17.4	y

4.2. Sensitivity Analysis

The study has many assumptions, and it is necessary to analyze the sensitivity of some crucial parameters regarding financial indicators. The first step of the sensitivity analysis is to select uncertain factors and determine the deviation degree of each influencing factor from the economic value. The factors that affect the cost of agrivoltaics include initial investment cost, electricity price, power generation efficiency, and financial cost, which will have a certain impact on the cost and benefit of considering APV systems implementation. This section calculates and analyzes the degree of change in income from apple production, sunshine hours, capacity, electricity price, and investment cost with various uncertain factors under the condition that other influencing factors remain unchanged and expresses them with sensitivity change. A Table of Sensitivity Analysis was drawn to reflect the above results. Based on the analysis of the cost and income of each APV, PV system, and conventional farming, this paper selects the Kaposvár Solar Power Plant Project for the sensitivity analysis. The results are shown in Tables 7 and 8 below.

Table 7. Sensitive parameters for PV-GM and APV systems.

	PV	**APV**	
Capacity	500	500	kWp/ha
Size	200	200	ha
CAPEX	999	1344	th EUR/MWp
Sunshine hours	1075	1075	h/yr

Table 8. Calculation of PV and APV benefits.

○	Necessary area for 1 MWp PV capacity:	2.00	ha
○	Necessary area for 1 MWp APV capacity:	2.00	ha
○	Unit investment cost for 1 MWp PV capacity:	999	th EUR/MWp
○	Unit investment cost for 1 MWp APV capacity:	1344	th EUR/MWp
○	Unit investment cost for 1 ha PV capacity:	500	th EUR/ha
○	Unit investment cost for 1 ha APV capacity:	672	th EUR/ha
○	Unit investment cost of 1 ha apple plantation:	5	th EUR/ha
○	Electricity production of 1 ha PV capacity:	538	MWh/yr
○	Electricity production of 1 ha APV capacity:	538	MWh/yr
○	Average electricity price in Hungary:	9.5	EURc/kWh
○	Average income of 1 ha apple plantation:	2	th EUR/ha

If the capacity of PV and APV are equal, coverage is 100% (Table 7). As we can see in Table 9, surplus investment cannot be expected to return, and it is not profitable for either PV developers or farmers. The price of an hour of kilowatt power is also a main factor that affects the income of APV enterprises. This is very strict on the investment boundary, which not only produces the cost pressure of investment income accounting to PV developers, but also creates great challenges to the farmers. When building APV in farms, power generation enterprises should focus on the relevant APV subsidies and PV electricity price policies issued by the government. The government should also maintain the stability of the subsidies and electricity price of kWh to encourage enterprises to invest in renewable energy generation. We assume that one time capacity with units ranging from 2 kWp to 50 MWp may apply an investment subsidy, which might cover 24% of the investment cost based on the APV investment cost in our baseline scenario to leave the repayment period of the APV investment under 10 years. The government might consider the available tax rebates on operational costs and net investment costs. All the suggestions mentioned above might increase the competitiveness of APV compared to PV.

If we assume that the surplus investment cost for apple plantations is increased with a V-shaped system (highly intensive), then farmers will have the opportunity to invest their income in agrivoltaic technology.

Due to the higher densities utilized by V-systems, the yields of V-shaped systems are often higher than other systems. The disadvantages of the V-system are that the investment cost for apple plantation and initial tree training is expensive, and possible disadvantages, i.e., the fruit size of the V system is smaller than the vertical axis planting system [69]. Specifically, the cost of photovoltaic power generation in different regions is quite different, and the layout of the photovoltaic industry can be reasonably optimized by comprehensively considering factors such as light, climate, and land cost. The cost of photovoltaic panels and the cost of establishing an apple orchard have a great impact on the total investment cost. If the total cost decreases enough, the cost of photovoltaic power generation will be greatly reduced. According to the analysis of this article, the investment in construction has a greater impact on the cost of photovoltaic power generation and the apple orchard, while the interest expenditure has a smaller impact. However, due to a large amount of construction investment and other reasons, financial institutions are less willing to invest in agrivoltaics. Therefore, in the early stage of production, agrivoltaic plants need government support because production costs are too high (Table 10).

Table 9. Economic results of the comparative analysis in the scenario with equal capacity of APV and PV systems.

Between APV and PV systems		
○ Surplus investment cost (incl. apple):	177	th EUR/ha
○ Surplus (average) income from apple production:	2	th EUR/ha
○ Value of electricity production:	0.0	th EUR/ha
○ Static payback period:	88.7	y
Between APV and conventional apple production		
○ Surplus investment cost:	667	th EUR/ha
○ Surplus (average) income from apple production:	0	th EUR/ha
○ Value of electricity production:	51	th EUR/ha
○ Static payback period:	13.1	y

Table 10. Comparative indicators of the economic viability of different production systems.

Between APV and PV Systems		
Surplus investment cost (incl. apple):	187	th EUR/ha
Surplus (average) income from apple production:	7	th EUR/ha
Value of electricity production:	0.0	th EUR/ha
Static payback period:	26.8	y
Between APV and conventional apple production:		
Surplus investment cost:	657	th EUR/ha
Surplus (average) income from apple production:	0	th EUR/ha
Value of electricity production:	51	th EUR/ha
Static payback period:	12.9	y

Hungary has been ranked among the top ten most attractive countries among Central Eastern European and South-Eastern European countries based on the assessment of favorable conditions for investment in the development of solar PV systems [70]. Moreover, the development of agrivoltaics has improved the land utilization rate of photovoltaic power generation projects in Hungary. The project conforms to the government legislation, has strong pertinence, and conforms to the clean energy development plan. After the completion of the project, it will play a great role in driving the development of agrivoltaics, promoting the income of residents, and improving the exploration of agricultural diversification. Additionally, agrivoltaics plays a great role in promoting the application of the agriculture industry and solar energy industry in the field of renewable energy.

5. Discussion and Conclusions

In order to solve the classical "food or energy" debate, agrivoltaic systems should deal with the competition and cooperation between photovoltaic power generation and agricultural production, and improve agrivoltaic benefits and land use efficiency based on Schindele et al.'s [34] economic data and conclusion. In our results, many factors affect the output of agrivoltaic systems. These are explored and discussed, analyzed, and verified by the example of a photovoltaic power station (Kaposvár Solar Power Plant Project). By selecting the relevant data for the photovoltaic power station in the typical day type, the single influence factor and the historical data for the photovoltaic power output are plotted and analyzed to visually observe and compare with APV and PV systems, APV, and conventional apple production. Then, the principle of the sensitivity analysis is described in detail. Sensitivity analysis is a commonly used method in statistics to analyze multiple influence factors for predicting the outcome of a decision, and it is more scientific and reasonable than a simple correlation analysis. Finally, the sensitivity analysis method is used to identify the effects of the competitiveness of APV compared to PV and agricultural production. Through the analysis of the relevant factors that economically affect APV compared to PV and agricultural production, the foundation is laid for the selection of the main influencing factors as the prediction input of the photovoltaic power generation prediction model.

The result obtained for the over-10-year-old "Golden Delicious" apple orchard when the APV shed is oriented due to the south of France is in line with Juillion et al. [43], which, for the organic APV canopy potato described by Schindele et al. [34], obtained a total CAPEX for the installation and commissioning of APV. This amounts to EUR 1,343,850 and for PV-GM, EUR 1,031,035 and the internal rate of return is 1.6% lower than the weighted average cost of capital. In a broader sense, Robinson [69] concluded that V-systems have very high apple yield efficiency to allow a good balance between cropping and vegetative growth; however, it depends on their economic performance. From the inception of our study, we conclude that both the APV system and the cost of establishment of an apple orchard also depend on financial concerns. It was envisaged that a negative factor for APV system profitability would be the high CAPEX compared to conventional PV-GM power plants. Malu et al. [33] noted that the cost per unit of land (e.g., acre) is lower for the installation of an APV system than for a conventional PV system because the packing ratio of PV is lower for a solar farm (APV) than for PV-GM farms. According to the authors, the lack of profitability in some combinations of the examples analyzed here does not detract from the potential profitability of APV systems. The fruit orchard is protected from hail and sunburn damage [71] allowed by APV shading and, most importantly, this increases the diversity of farmers.

Farmers also face even more problems and difficulties in the development of agrivoltaics in Hungary, because the development needs to comprehensively consider the investment costs and benefits compared with the government's legislation towards it. Therefore, farmers should standardize their own behavior, constantly carry out scientific and technological innovation, and optimize their agricultural production structure, and PV developers may adjust the profit model for farmers, seek various forms of cooperation with farmers, and provide a more professional system guarantee for the development of APV systems. In the future, with society's (including farmers) deepening understanding of agrivoltaics and the continuous development of modern agriculture in Hungary, the reduction in photovoltaic power generation costs and the energy-saving potential of agrivoltaic use are of great significance for the promotion and use of agrivoltaics with solar energy and agricultural production in rural areas. Different factors affecting the implementation of the APV system were shown in our calculation, such as the high investment cost, lower income for farmers, and the investment cost which cannot be returned to investors. However, government support is needed to build an APV system in Hungary because the production cost is too high.

Limitations

The scope of the research is large, the data are limited, the future trend of APV development is uncertain in Hungary, and the extraction of the research content in the paper is still insufficient, which needs to be continuously improved in the follow-up research work.

The paper only takes the Kaposvár Solar Park as an example to conduct research in Hungary, lacking comparison in different regions with different electricity and agricultural yields. The comparison of APV and PV systems with a conventional apple plantation in different rural regions and the actual utilization efficiency of APV and PV systems forms need to be further explored. Currently, the APV system is not competitive in Hungary without state subsidy, and our results may be used for determining the regulations for APV systems. Due to limited statistical data and incomplete survey data, it is difficult to obtain the same comprehensive data on rural household energy consumption on a large-scale PV system. In future work, we need to accurately track the preface of relevant research, strengthen data collection, conduct in-depth research, and make a more comprehensive assessment of rural PV energy with agricultural production. If an APV system is implemented in the future in Hungary with state and private support, then we will have the opportunity to consider and use the actual data of a farm-level APV system.

Hungary (like the EU) is in a critical period of energy transformation. There are great uncertainties in the future socio-economic development and APV utilization. Based on the absence of an exciting long-term national development plan, the article forecasts the future structure and investment of APVs for the implementation of APVs, but the prediction accuracy needs to be verified and improved. More timely data should be obtained, and different methods and models should be used to supplement and revise the prediction results of rural APV systems with electricity generation and agricultural production from the perspectives of electricity consumption influencing factors, PV to APV transformation in rural areas, and APV technological progress. When this paper studied the assessment of the development potential of APV systems, it only considered the power generation capacity and investment cost of the system and ignored many factors of the cost calculation of the cost benefit analysis, such as the uncertain price of electricity, transportation cost, the equipment of APV and PV installations, the considered agricultural species and their yields, and production functions in different regions. Additionally, the area where the plant will be installed, the hours of sunshine, and the quality of the PV panels should be considered to find the best location. It is hoped that this can be improved in future work.

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Abbreviations

APV	Agrivoltaic
PV-GM	Ground-mounted photovoltaic
PV	Photovoltaic
LCOE	Levelized cost of electricity
DPP	Discounted payback period
CAPEX	Capital expenditures
O&M	Operation and maintenance cost
NPV	Net present value
MNB	Hungarian National Bank ("Magyar Nemzeti Bank" in Hungarian)
SPP	Solar power plant
GDP	Gross domestic product
GHG	Greenhouse gas

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