

A Czech Republic Case Study on Agrivoltaics for Electricity and Green Hydrogen

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Abstract: *This study explores the role of agrivoltaic systems in advancing renewable energy integration and decarbonization in the agricultural sector, with a focus on the Czech Republic. Agriculture, a significant emitter of greenhouse gases, faces mounting pressure to transition to sustainable energy sources under the Green Deal objectives. Vertical agrivoltaic systems, characterized by their dual-use of land for crop cultivation and electricity production, were analyzed across multiple scenarios: self-consumption, grid supply, and hydrogen production. Findings reveal that while agrivoltaics offer environmental benefits, the economic viability remains contingent on substantial investment support and specific conditions, such as location and project scale. This research underscores the potential of agrivoltaics to contribute to decarbonization and renewable energy goals, but highlights the need for favorable policies and additional technological advancements.*

Keywords: agriculture, agrivoltaics, decarbonisation, green hydrogen, natural gas

1 Introduction

Agricultural production is facing increasing pressure to reduce greenhouse gas emissions while maintaining economic viability and food security. At the same time, the ongoing decarbonisation of the energy sector requires the expansion of renewable electricity generation and the development of flexible energy systems capable of integrating variable sources. Agrivoltaic systems, which combine agricultural production with photovoltaic electricity generation on the same land, represent a promising approach to addressing both challenges simultaneously.

Agrivoltaics have been widely studied over the past decade, primarily with respect to their agronomic performance, land-use efficiency and microclimatic effects. Previous research has demonstrated that agrivoltaic systems can preserve or even

enhance crop yields while increasing overall land productivity [1-4]. In addition to conventional horizontal configurations, recent studies have explored vertical agrivoltaic systems using bifacial photovoltaic modules, which offer advantages for open-field agriculture, including reduced shading of crops and improved compatibility with agricultural machinery [5][6].

From an energy systems perspective, many agrivoltaic studies focus primarily on electricity generation potential or economic performance under feed-in tariff schemes, often assuming full export of the generated electricity to the grid. In contrast, a substantial body of literature has examined photovoltaic self-consumption strategies and the integration of battery energy storage systems (BESS) in residential, commercial, and community-scale applications [7-9]. However, these approaches are rarely applied in the specific context of agrivoltaic systems or agricultural enterprises.

More recently, hydrogen production from renewable electricity has been increasingly discussed as a pathway for deep decarbonisation, particularly in sectors that are difficult to electrify directly. Existing studies on power-to-hydrogen systems predominantly address large-scale or industrial applications [10][11]. Only a limited number of studies have begun to explore the coupling of agrivoltaic electricity generation with hydrogen production, typically focusing on community-level or utility-scale systems rather than individual farms [12][13].

Beyond the specific application domain of energy systems, successful modelling approaches have been applied to complex and nonlinear systems in various scientific and engineering fields. These studies highlight the importance of transparent model structure, clearly defined system boundaries, and robust representation of time-dependent and nonlinear system behaviour [14-16].

Similar modelling principles have also proven effective in other application domains, such as robotic navigation, clustering-based system identification, and pneumatic actuator modelling [17-19].

Against this background, an integrated, farm-level assessment of agrivoltaic systems that simultaneously considers electricity self-consumption, battery storage, and hydrogen production remains largely underrepresented in the literature, particularly under Central European conditions. This paper addresses this gap by presenting a unified, hourly-resolved modelling framework applied to a vertical agrivoltaic system at an agricultural enterprise in the Czech Republic. The analysis evaluates multiple electricity utilisation scenarios and assesses their technical performance, economic viability, and emission impacts, thereby providing a comprehensive perspective on the integration of agrivoltaic systems under realistic farming conditions.

The remainder of the paper is structured as follows: Section 2 describes the data and modelling approach, Section 3 presents the case study assumptions, Section 4

discusses the results, and Section 5 concludes the paper, with a discussion of implications and limitations.

2 Data and methodology

This study evaluates the technical, economic, and environmental performance of a vertical agrivoltaic system using a case study of an agricultural enterprise located in the Czech Republic. Based on the literature review, a vertical agrivoltaic configuration is assumed, and alternative utilisation pathways of the electricity generated are analysed. The assessment focuses on an agricultural enterprise engaged exclusively in crop production, without livestock.

Vertical agrivoltaic systems enable the simultaneous production of agricultural crops and photovoltaic electricity, thereby offering potential synergies between energy generation, economic performance, and emission reduction. To capture these effects, four scenarios are analysed:

1. Electricity generated by the vertical agrivoltaic system is fully exported to the grid.
2. Electricity is used to cover on-site consumption, with surplus electricity exported to the grid.
3. Electricity is used for on-site consumption and battery energy storage, with surplus electricity exported to the grid.
4. Electricity is used for on-site consumption, battery energy storage and hydrogen production, with surplus electricity exported to the grid.

For all scenarios, emissions related to electricity consumption, fuel use in agricultural machinery, and fertiliser application are considered. In the hydrogen scenario, the potential substitution of fossil-based hydrogen with green hydrogen is additionally taken into account.

Across all scenarios, electricity allocation follows a fixed priority order. Electricity is first used to cover on-site consumption, followed by battery charging where applicable. Any remaining surplus is then allocated to hydrogen production in the hydrogen scenario, and finally exported to the grid. An hourly temporal resolution is applied throughout the analysis to accurately capture the variability of photovoltaic generation and electricity demand under Czech climatic conditions.

The analysis is based on a case study of a vertical agrivoltaic installation implemented at an agricultural cooperative in the Czech Republic, enabling an integrated assessment of technical performance, economic viability, and emission impacts.

2.1 Land Use Assumptions

This study evaluates a vertical agrivoltaic system based on parameters representative of comparable agrivoltaic installations. A key aspect of the analysis was determining the maximum feasible installed capacity per hectare of land. By setting the spacing between panel rows at 7 meters—identified as the technical minimum to optimize electricity generation—the system achieves an installed capacity of 700 kWp per hectare. This configuration balances the dual objectives of maximizing energy production and maintaining agricultural functionality.

2.2 Economic evaluation assumptions

The economic evaluation of all scenarios was made via Net Present Value (NPV) and Internal Rate of Return [20], assuming the lifetime of 30 years. As the average lifetime of an electrolyser is 80000 hours [21], the electrolyser capacity is therefore selected to achieve approximately 2500 - 3000 annual operating hours, ensuring economically meaningful utilization. All general assumptions used in the paper are presented in Table 1.

Table 1
General assumptions used for vertical agrivoltaics scenarios

Parameter	Value	Reference, note
CAPEX PV	1060 EUR/kWp	[22]
CAPEX BAT	760 EUR/kWp	[22]
CAPEX electrolyser + storage	1000 EUR/kW	[23]
OPEX PV	12 EUR/kWp	[22]
OPEX BAT	4 EUR/kWh	[22]
OPEX electrolyzer	50 EUR/kW	[24]
Fuel consumption	100 l/ha	[25]
Installed PV capacity per ha (for 7m aisle, 620Wp modules)	700 kWp	Based on PVSOL model
Fertilizer consumption	40-130 kg/ha	[26]– depends on each country and farm size
Aisle between module rows	7-10 m	Based on agriculture technology dimensions and module shadows
Diesel emissions	2.7 kg CO ₂ eq/l	[27]
Emissions of fertilizers	5 kg CO ₂ eq/kg	[28]
Amount of hydrogen needed for 1 kg of ammonia	177 g	[29]
Hydrogen produced from fossil fuels	9 kg CO ₂ eq/kg	[30]
Fuel-cell efficiency	50 %	[31]
Battery round-trip efficiency	95 %	[32]
Electrolyzer electricity consumption for H ₂ production	60 kWh/kgH ₂	[30]

2.3 Modelling Approach and Relationships

This study employs a deterministic, hour-resolution simulation model to evaluate the technical, economic and environmental performance of four agrivoltaic scenarios defined above.

2.3.1 Energy Balance

At each hour t , the electricity generated by the photovoltaic system $E_{PV}(t)$, is first allocated to the farm's electricity demand $E_{load}(t)$:

$$E_{load,PV}(t) = \min(E_{PV}(t), E_{load}(t)) \quad (1)$$

where $E_{PV}(t)$ is the electricity generated by the PV system in hour t [kWh], $E_{load}(t)$ is the electricity demand of the farm in hour t [kWh], $E_{load,PV}(t)$ is the part of the farm demand covered directly by PV generation in hour t [kWh].

The remaining electricity is considered surplus $E_{surplus}(t)$:

$$E_{surplus}(t) = E_{PV}(t) - E_{load,PV}(t) \quad (2)$$

In scenarios without storage or hydrogen production, all storage-related and electrolyser-related terms are set to zero.

2.3.2 Battery Energy Storage System

The battery charging energy is constrained by the PV surplus, the maximum charging power, and the remaining storage capacity:

$$E_{BAT_in}(t) = \min(E_{surplus}(t), P_{BAT_max} \cdot \Delta t, SOC_{max} - SOC(t)) \quad (3)$$

where $E_{BAT_in}(t)$ is the energy charged into the battery in hour t [kWh], $P_{BAT_max} \cdot \Delta t$ is the maximum charging/discharging power of the battery [kW], Δt is the time step duration [h] (1 hour), $SOC(t)$ is the state of charge of the battery at the beginning of hour t [kWh], SOC_max is the maximum allowed state of charge of the battery [kWh].

Discharging supports farm demand when PV output is insufficient:

$$E_{BAT_out}(t) = \min(E_{load,PV}(t), P_{BAT_max} \cdot \Delta t, SOC(t) - SOC_{min}) \quad (4)$$

where $E_{BAT_out}(t)$ is the energy discharged from the battery in hour t [kWh], SOC_min is the minimum allowed state of charge of the battery [kWh].

The state of charge evolves according to:

$$SOC(t + 1) = SOC(t) + \mu_c \cdot E_{BAT_out}(t) \quad (5)$$

where μ_c is the battery cycle (charge-discharge) efficiency [-].

The remaining surplus after battery charging is:

$$E_{surplus2}(t) = E_{surplus}(t) - E_{BAT_out}(t) \quad (6)$$

where $E_{surplus2}(t)$ is the PV surplus remaining after battery charging in hour t [kWh].

2.3.3 Hydrogen production

In the scenario including hydrogen production, electricity supplied to the electrolyser is

$$E_{EL}(t) = \min(E_{surplus2}(t), P_{EL_max} \cdot \Delta t) \quad (7)$$

where $E_{EL}(t)$ is the electricity supplied to the electrolyser in hour t [kWh], P_{EL_max} is the rated power of the electrolyser [kW].

Annual hydrogen production is given by

$$m_{H_2} = \frac{\mu_{EL} \cdot E_{EL,year}}{LHV_{H_2}} \quad (8)$$

where m_{H_2} is the annual hydrogen production [kg], LHV_{H_2} is the specific electricity consumption of the electrolyser [kWh/kg_{H₂}], μ_{EL} is the electrolyser efficiency with respect to the lower heating value of hydrogen [-], $E_{EL,year}$ is the annual electricity supplied to the electrolyser [kWh].

Electricity remaining $E_{GRID}(t)$ is exported to the grid:

$$E_{GRID}(t) = E_{surplus2}(t) - E_{EL}(t) \quad (9)$$

2.3.4 Emission evaluation

Emissions are calculated using a standard activity-based approach, expressed as the sum of the products of the respective activity levels and emission factors:

$$Em = \sum_i Q_i \cdot EF_i \quad (10)$$

where Q_i is quantity of energy or material associated with process i (e.g. electricity, fuel, fertiliser, or hydrogen), EF_i is the corresponding emission factor.

2.3.5 Sensitivity and robustness analysis

In addition to the baseline scenario evaluation, a sensitivity analysis was performed for all analyzed scenarios in order to assess the influence of selected key economic parameters on the results. Baseline parameter values defined in Section 2.2 were used as reference values. Electricity prices, investment costs of the photovoltaic system, battery storage and electrolyser, and hydrogen utilization assumptions were identified as the most influential parameters. Each of these parameters was varied independently within a $\pm 40\%$ range around its baseline value, while the remaining parameters, model structure, and dispatch logic were kept constant. The sensitivity analysis was used to evaluate the stability of scenario comparison results and to support the robustness of the qualitative conclusions.

3 Czech Republic Case Study Assumptions

In order to comprehensively assess the economic viability and potential environmental benefits of agrivoltaics, detailed modeling was conducted using PVSOL software. The study focuses specifically on the application of vertical agrivoltaic system within the context of decarbonizing Czech agriculture. Assumptions used for this study in the Czech Republic are shown in Table 2.

Table 2
Country-specific parameters applied in the Czech Republic case study

Parameter	Value	Reference, note
Exchange rate	25 CZK/EUR	[33]
Elec. price distribution tariff	156 EUR	Electricity supply contract
Electricity price feed-in tariff	80 EUR	[34]
Tax	15 %	[35]
WACC	6 %	[36] and author's calculation
Installed capacity	711 kWp	PVSOL simulation
BAT capacity	90 kWh	PV SOL simulation
Fertilizer consumption (selected area)	43.96 kg/ha	[37]
System lifetime = evaluation period	30 years	[38][39]
Electrolyzer operating hours	2700 h	Author's calculation
Czech Energy mix emissions	430 g/kWh	[40]

A range of scenarios was implemented, tailored to the unique characteristics of an agricultural enterprise located in the Czech Republic. Leveraging data provided by the farmer, a representative electricity consumption profile for the farm was

developed, with the area of 1 hectare of cultivated land serving as the benchmark unit for analysis. This approach allows us to accurately evaluate the practical implications and potential advantages of integrating agrivoltaics within the Czech agricultural landscape. The prerequisite for the results was the use of the Trina Vertex N 620W+ Bifacial NEG19RC.20 module with a maximum output of up to 620 Wp. Based on the electricity supply invoice and discussions with the farmer, an electricity supply type diagram has been constructed on an hourly granularity. The diagram shows that the consumption significantly increases during the harvest (July and August).

Table 3
Electrolyser operating hours (own calculations)

Operating hours (h)	Power (kW)
461	50-99
490	100-149
1827	150-200
2778	50-200

4 Czech Republic Case Study Results

Under the given assumptions, none of the four analyzed scenarios result in positive investment decisions under current economic conditions in the Czech Republic (2024). Among the scenarios, the second one—PV self-consumption combined with grid supply—achieves the most favorable outcome, with a Net Present Value (NPV) of -59789 EUR, as shown in Table 4. In contrast, the least favorable results are observed in the fourth scenario, which includes green hydrogen production. This scenario yields an NPV of -282942 EUR, even under the most optimistic hydrogen price assumptions derived from the European Hydrogen Backbone (EHB) findings (see Table 6).

4.1 Scenario 1 and 2

Results for Scenarios 1 (Total PV production) and 2 are shown in the Figure 1 below. The annual production of the agrivoltaics is 760 MWh. With no storage facility assumed such system covers almost 42 MWh of the farmers consumption per year. However, almost 21 MWh still needs to be covered by the grid. Due to the fact that in the Czech Republic the feed-in tariff is lower than the distribution tariff, Scenario 2 has higher NPV (even though still negative).

From an environmental perspective, the solutions are largely similar; the key distinction lies in whether we focus on the farmer's individual carbon footprint or

the global carbon impact. Specifically, in the case of direct consumption, emissions associated with electricity distribution are also avoided.

4.2 Scenario 3

Another scenario analyzed was a combination of agrivoltaics and battery system (90 kWh) in order to better cover own consumption before supplying the grid. Compared to Scenario 2, where no battery is assumed, additional 15 MWh are covered with energy from agrivoltaics. The NPV = -108609 EUR, IRR = 4.6 %. From an environmental point of view, this scenario can be viewed in a similar way to Scenario 2, i.e. the results are slightly worse due to the losses from charging and discharging the battery.

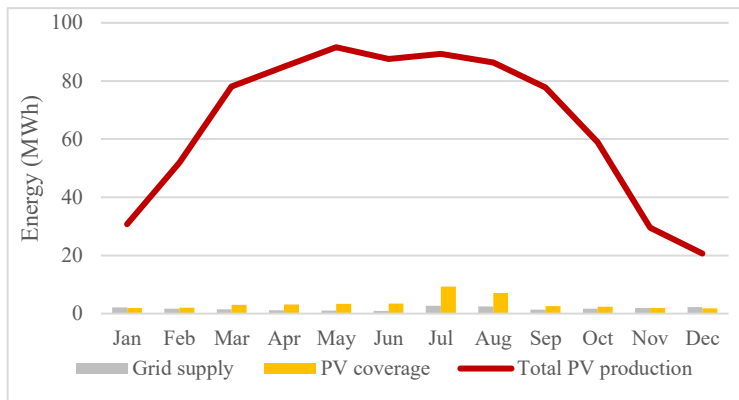


Figure 2

Agrivoltaics share, Scenario 1 and 2 (PVSOL + own calculations)

4.3 Scenario 4

The last scenario analyzed was the combination of agrivoltaics, battery storage system and hydrogen production system. The electrolyser capacity was set aiming to operating hours between 2500-3000 resulting in 200 kW (2700 operating hours). Within this system, 8760 kg of H₂ can be produced and there are still 242 MWh supplied to the grid. An example of the results ranging from 4700 to 6000 hours can be found in Figure 3. NPV = - 282942 EUR, IRR 3 %. However, this scenario also leads to the worst ecological results, especially if such produced hydrogen would be used to produce fertilizers and would replace the grey hydrogen (78.5 tCO₂). However, if such hydrogen would be used in transport, it could save up to 170 tons of emissions. This is also the only scenario where fuel reduction is assumed (hydrogen-powered tractors).

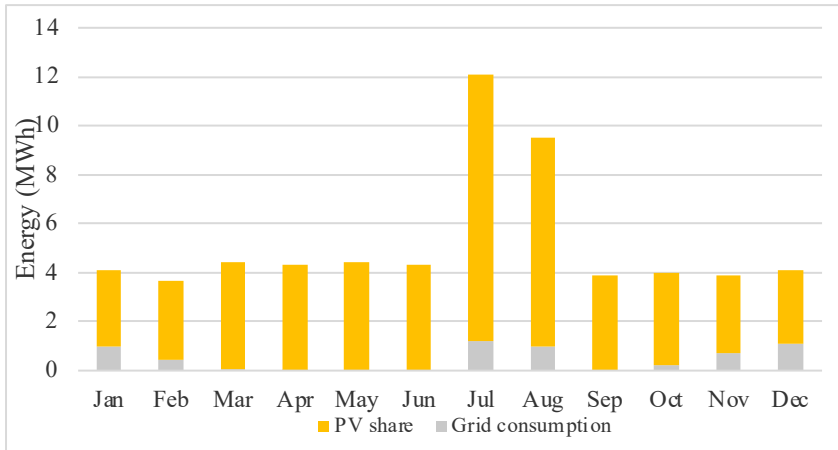


Figure 3

Energy consumption coverage, Scenario 3 (PV+BAT, PVSOL + own calculations)

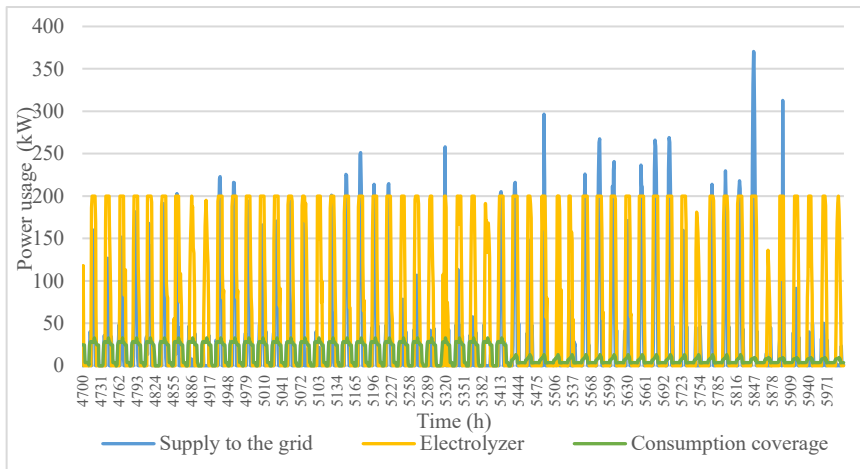


Figure 4

Power usage, Scenario 4 (PV+BAT+H2), 4700-6000 h (PV SOL + own calculations)

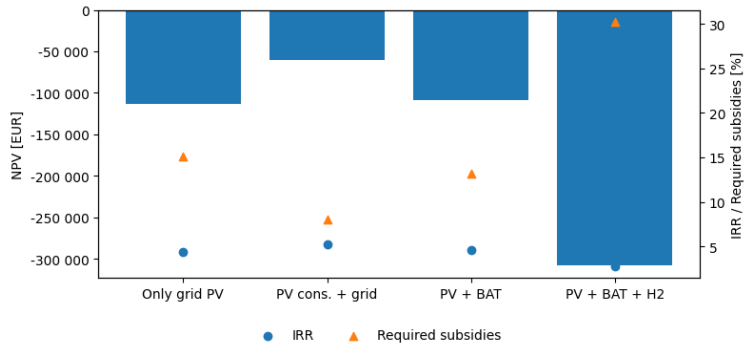


Figure 5
Economic performance of analyzed scenarios (own calculations)

Table 4
Emissions produced within evaluated scenarios (t_{CO_2eq}/y , own calculations)

Scenario	Electricity	Fuel	Fertilizer
No PV	26.9	0.27	0.2198
Only grid PV	26.9	0.27	0.2198
PV consumption + grid	8.9	0.27	0.2198
PV+BAT	2.5	0.27	0.2198
PV+BAT+H2	2.5	0	0.2198

Table 5
Emissions reduced within evaluated scenarios (t_{CO_2eq}/y , own calculations)

Scenario	Electricity local	Electricity global	Fuel (local)	H2 use in transport	H2 use in fertilizer
No PV	0	0	0	0	0
Only grid PV	0	339	0	0	0
PV consumption + grid	18	321	0	0	0
PV+BAT	24.5	310	0	0	0
PV+BAT+H2	24.5	104	0.27	167.9	78.5

4.4 Sensitivity and robustness analysis

A two-parameter sensitivity analysis was conducted to evaluate the robustness of the economic comparison between Scenario 3 (PV + BESS) and Scenario 4 (PV + BESS + hydrogen production). The analysis considers the difference $\Delta NPV = NPV_4 - NPV_3$, across variations in the electrolyser investment cost and the electricity purchase price. The results confirm that Scenario 4 becomes

economically preferable only under a combination of low electrolyser CAPEX and high electricity prices. At reduced electrolyser investment costs, positive Δ NPV values are observed across a wide range of electricity price assumptions. In contrast, increasing electrolyser CAPEX rapidly shifts the preference towards Scenario 3, which remains economically dominant for baseline and higher CAPEX levels.

Electricity price CAPEX electrolyzer	60%		80%		100%		120%		140%	
	60%	224 215 €	196 255 €	168 295 €	140 335 €	112 375 €				
80%	140 033 €	112 073 €	84 113 €	56 153 €	28 193 €					
100%	55 851 €	27 891 €	69 €	28 029 €	55 989 €					
120%	- 28 330 €	- 56 290 €	- 84 250 €	- 112 210 €	- 140 170 €					
140%	- 112 512 €	- 140 472 €	- 168 432 €	- 196 392 €	- 224 352 €					

Figure 6

Sensitivity analysis for Scenario 3 and 4 (own calculations)

The electricity purchase price has a secondary influence on the scenario ranking. Higher electricity prices improve the relative performance of Scenario 4 by increasing the economic value of electricity utilisation, including hydrogen production. However, this effect is insufficient to compensate for high electrolyser investment costs. The sensitivity analysis further indicates that the relative ranking of scenarios remains stable across a wide range of key economic parameters, supporting the robustness of the obtained results.

From an environmental perspective, the sensitivity analysis does not alter the relative emission ranking of the scenarios. Scenario 4 consistently achieves lower emissions due to the additional substitution of fossil-based energy carriers by green hydrogen. Nevertheless, under current economic conditions, the emission benefits of Scenario 4 are obtained at a higher cost compared to Scenario 3. Consequently, the robustness analysis confirms that while Scenario 4 is environmentally preferable, Scenario 3 represents the economically robust solution under present Czech market assumptions.

5 Conclusions

Agrivoltaic systems are associated with additional agronomic benefits, such as improved soil moisture retention and reduced water erosion. However, the results indicate that higher economic performance is achieved when electricity is primarily used on-site or allocated to alternative utilization pathways rather than sold directly on the spot market. In the Czech Republic, land-based photovoltaic plants qualify for investment subsidies, and a support level of 8-15% could significantly improve the economic feasibility of vertical agrivoltaics. Project size, grid connection distance, and the location of electricity consumption further affect financial viability.

Using agrivoltaics for green hydrogen production currently appears less viable, requiring a hydrogen price nearly twice the EHB estimate presented in Table 6 (7.6 EUR/kg) or subsidies covering at least 30.2% of the investment. While further refinements, such as higher temporal resolution of peak power analysis, could slightly affect the results of Scenario 3 and Scenario 4, the applied modelling framework exhibits robust behavior, as variations in key economic parameters do not alter the relative ranking of the analyzed scenarios.

The applied modelling framework exhibits robust behavior, as variations in key economic parameters influence absolute results but do not change the relative ranking of the analyzed scenarios. The main conclusions therefore reflect structural interactions within the system rather than sensitivity to individual assumptions.

Building agrivoltaic systems involves navigating regulatory challenges alongside technical complexities. Obtaining permits and approvals may be time-consuming due to the need to comply with land-use, agricultural, and energy regulations at multiple administrative levels. Additionally, regulatory frameworks related to energy production, grid connection, and incentives for renewable energy projects can impact the feasibility and financial viability of agrivoltaic installations.

Table 6
EHB hydrogen production prices [41]

EHB Corridor	2030 Hydrogen production price
Corridor A	2.1 - 3.8 EUR/kg
Corridor B	2 - 3.8 EUR/kg
Corridor C	1.6 - 3.5 EUR/kg
Corridor D	2.1 - 3.8 EUR/kg
Corridor E	2.5 - 4.5 EUR/kg

In the Czech Republic, the deployment of agrivoltaic systems is further constrained by legislative uncertainty and limited awareness among farmers, energy professionals, and the wider public. These barriers currently represent a major obstacle to the wider adoption of agrivoltaic systems and the decarbonisation of the agricultural sector. Furthermore, renewable energy policies and regulations play a crucial role in facilitating the development of agrivoltaic projects. This includes regulations related to grid connection, feed-in tariffs or incentives for renewable energy generation, and compliance with technical standards for solar installations.

Engaging with local authorities, agricultural stakeholders, and energy regulators is essential to address regulatory requirements, obtain necessary permits, and ensure the successful implementation of agrivoltaic systems in the Czech Republic. Effective collaboration and communication are key to navigating the regulatory landscape and promoting the adoption of sustainable agrivoltaic technologies.

The development of vertical agrivoltaic systems is primarily slowed by the lack of legislation, the lack of information and the general awareness levels of farmers,

energy workers and society. Above all, the lack of legislation, makes it impossible to apply these systems, in practice, is a fundamental problem for the effective and rapid decarbonization of the agricultural sector.

The economic performance of agrivoltaic systems is strongly influenced by farm-specific electricity consumption profiles, as illustrated in Figure 6. Integrating PV with cattle farming improves energy self-sufficiency by better aligning electricity consumption with generation, thereby enhancing overall economic viability. Moreover, electricity surpluses generated by agrivoltaic systems could support local energy communities or be sold at higher-than-standard feed-in tariffs, contributing to decentralized energy systems and carbon neutrality objectives.

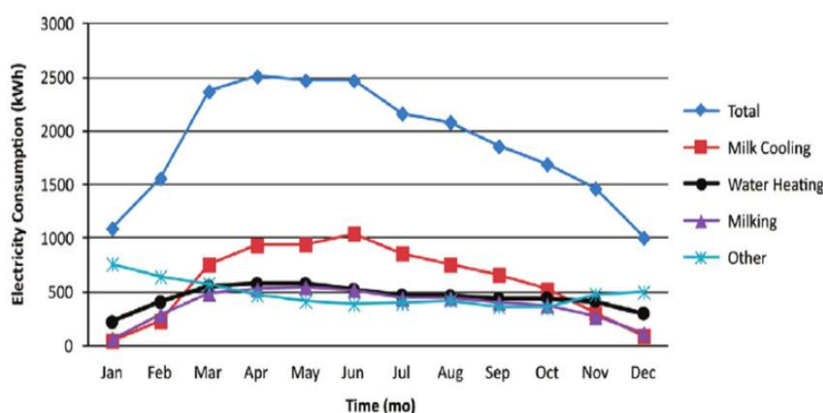


Figure 7

Monthly electrical use for 22 farms, over 1 year, for all major energy-consuming processes [42]

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