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AgriVoltaics in the Wine Industry

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1 ABSTRACT

The increasing detrimental consequences of climate change and the decline in fossil fuel resources are leading to a rise in demand for food and energy. Agrivoltaics (Agri-PV) offers an opportunity to combine space-optimised photovoltaic (PV) use for sustainable agriculture. By feeding solar energy into the grid, PV is regarded a key component of renewable energy systems. Especially, the wine industry is facing increasing challenges due to climate change, particularly in regions where excessive solar radiation and rising temperatures negatively affect grape quality and yield.

In this article we have examined a cost-efficient technical solution that can also be used on a small scale. It is shown that by using mostly standardcomponents without special parts, a modular system with high photovoltaic output and the least possible disruption to agricultural use can be created. Due to bifacial solar modules, which have recently emerged on a massive scale, a cost-effective structure withoptimal use of the sun over the course of the day was realised. Initial resultsof PV utilization, especially in the winter months, with shading and rain influenceshow the technological and economic feasibility of the proposed technology.

Keywords: Sustainable Innovation, Photovoltaics, Climate Change, Food and Energy, Agriculture

2 INTRODUCTION

The synergy of agriculture and photovoltaics is reflected by the Sustainable Development Goals 2 and 7 (SDGs) of the United Nations: "Goal 2 is about creating a world free of hunger by 2030.The global issue of hunger and food insecurity has shown an alarming increase since 2015, a trend exacerbated by a combination of factors including the pandemic, conflict, climate change, and deepening inequalities" (https://www.un.org/sustainabledevelopment/hunger/); "Goal 7 is about ensuring access to clean and affordable energy, which is key to the development of agriculture, business, communications, education, healthcare and transportation(https://www.un.org/sustainabledevelopment/energy/).Sustainable innovations increasing the efficiency, resilience and profitability by cost saving and photovoltaic inspired quality improvement solutions might contribute to strike a balance to a currently prevalent existential crisis of vineyards in the Palatinate, the setting of the experiment in the South West of Germany, and the neighbouring wine region of Baden-Württemberg,which both suffer due to low wine prices and high cost burdens (Rheinpfalz, 2024; Suedkurier, 2024). A deterioration of wine quality, a 'death' of Winemakers and/or wine regions lying fallow will have very negative repercussions for tourism and wine and/or regional branding of the region in question (Correia Loureiro and Kaufmann, 2012; Kaufmann and Durst, 2008).

Prolonged heat stress can lead to reduced acidity and altered sugar content of grapes, as well as to an overall decline in wine quality, putting economic pressure on winemakers. Traditional shading methods offer only limited protection, and water-intensive irrigation strategies are becoming less sustainable due to increasing drought conditions.Agri-photovoltaics (agrivoltaics) presents a promising solution to mitigate these issues by integrating photovoltaic (PV) systems into vineyards. By providing partial shading, Agri-PV can help regulate microclimatic conditions, reducing heat stress while simultaneously generating renewable energy (Zha et al. 2022; Ferrara et al., 2022). Recent advancements in bifacial PV technology further enhance this approach. Bifacial modules, which capture sunlight fromboth sides, are particularly well-suited for vineyard applications, as they can utilize light radiationthrough diffusion optimizing energy yield without significantly compromising agricultural productivity.The east-west orientation of the bifacial solar systems also offers advantages in terms of feeding electricity into the grid structure. The change in energy production during the day, with peaks in the morning and afternoon, is counteracted by conventional south-facing solar systems (Guo et al. 2013; Thomas Rosenzopf, 2022). This results in a more balanced feed-in of electricity generated by solar systems throughout the day. However, a major challenge in the widespread adoption of Agri-PV systems is the cost of implementation. Many existing Agri-PV installations rely on custom-built components, making them economically viable only in large-scale projects with high production volumes. This limits accessibility for smaller vineyards that could benefit from the technology but cannot justify the high initial investment. Therefore, this study focuses on the use of cost-effective, standardized components that enable small-scale Agri-PV installations to be financially viable even in low-volume production.

As a foundational step in this study, existing Agri-PV concepts will be examined based on the guidelines outlined in DIN SPEC 91434. The current state of technology will be analyzed through two key examples: commercially available Agri-PV solutions, such as those provided by Next2Sun, and research-based installations like the system developed by Krinner Carport GmbH as part of the HyPErFarm project. Additionally, concepts proposed by the energy provider RWE will be considered, even though they currently exist only as design renderings without real-world implementations.

Following this analysis, the advantages and disadvantages of these existing systems will be evaluated to determine which elements can be integrated into a novel prototype for a new Agri-PV concept. A key focus will be on cost-effective construction methods that enable small-scale feasibility. This includes the incorporation of standardized components, such as trusses from the event industry and steel cables as a low-cost mounting alternative. The latter offers significant structural benefits, particularly by reducing the impact of wind forces through the elimination of bending and torsional moments. These design optimizations aim to improve both economic and structural efficiency, making Agri-PV more accessible for smaller vineyards while maintaining high energy yield and agricultural productivity.

3 THEORY

The aim of agrivoltaic systems is targeted use on agricultural land that allows agricultural use to be largely unrestricted so that a wide variety of crops can continue to be grown. The photovoltaic system then offers an additional environmentally friendly way of generating electricity while protecting the plants from excessive solar radiation through shading. Intelligent irrigation systems can also be installed, allowing rainwater to be collected from unfavourable areas and used in a targeted manner on the planted areas. The dual utilisation of agriculture and electricity generation is illustrated in Figure 1. With an optimal and favourable set-up, the yield of agricultural crops can be significantly increased for the same usable area, while the electrical energy can either be sold or used for own consumption.

The system can be customised to the respective agricultural area of use. Agri-PV systems are categorised into different types of structure, which are suitable for specific areas of use and plant varieties.

The German DIN (German Institute for Standardisation) for specification 91434 distinguishes between two categories of Agri-PV: Agri-PV systems with an elevation with a clear height are designated as category one while category two systemshave an elevation close to the ground.

The design of an agricultural PV system must be such that the PV modules are evenly distributed across the height of the roof. In category 1, a minimum height of 2.10 m is required to comply with health and safety regulations and to allow agricultural use of the area. The area lost to the installation must not exceed 10% of the total usable area. In addition, it must be ensured that the area can continue to be cultivated and, depending on the crop, can be driven over if necessary. Light availability should meet the needs of the crops and be evenly distributed over the area. Potential shading should be checked. Water availability also plays a key role: either a targeted irrigation system must be integrated, or the system must be designed to allow rainwater to reach the crops unhindered. Measures must also be taken to prevent soil erosion and siltation, for example by using suitable drip edges on the PV modules, and the ability to completely disassemble and remove the modules without leaving any residue must not be the focus of the prototype. Economically, the concept must be designed in such a way that the combination of energy production and agricultural use remains profitable for the farmer. Finally, a high level of land use efficiency should be aimed for, with the crop yield after installation of the agrivoltaic system being at least 66% of the original reference yield.

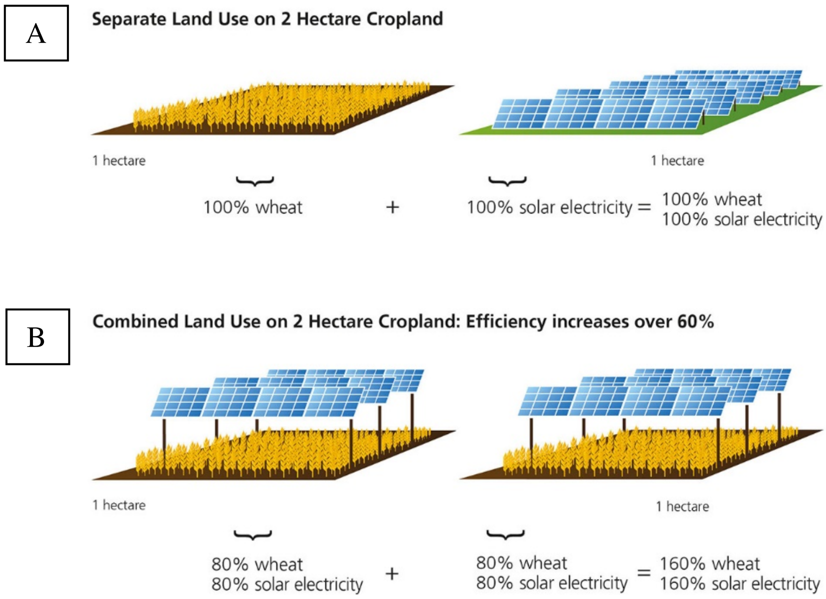

Figure 1: Theoretical benefits of agrivoltaics on an agricultural field: Separate use of agriculture and photovoltaics (A); combined use of agrivoltaics and agriculture (B)(Metsolar.eu, 2021)

The utilization area of Agri-PV systems is divided into four utilization categories based on agricultural requirements:

A: Permanent crops and perennial crops

B: Annual and perennial crops

C: Permanent grassland with cut use

D: Permanent grassland with pasture use

Permanent crops are plants that grow on agricultural land for at least five years and provide recurring yields during this time. These do not count in the crop rotation. Permanent grassland is not part of the crop rotation for at least five years and can either be used with cut grass for yield or as fodder for farm animals.

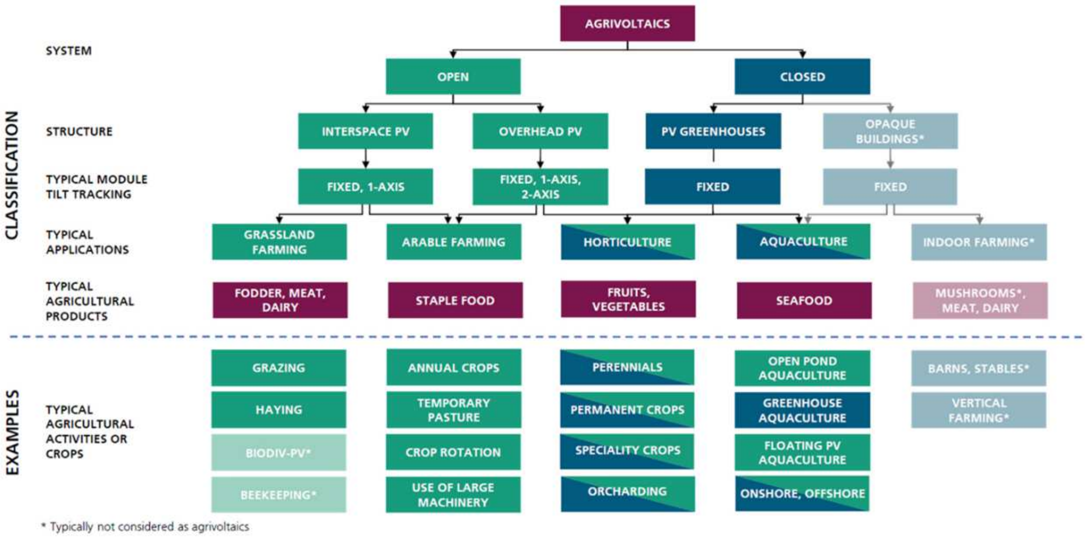

Figure 2: Classifcation of agrivoltaics system with different fields of application (Gorjian et al. 2022)

Furthermore, agrivoltaics can be categorised into two distinct systems: open and closed. Closed applications pertain to greenhouses and are classified as fixed solar systems mounted on the uppermost structure. These systems facilitate the cultivation of a diverse range of crops, including fruits, vegetables, and aquaculture. As illustrated in Figure 2, open solar systems are further subdivided into the two previously delineated categories. Additionally, there exist various mounting variants, such as fixed and tracked configurations. The scope of application encompasses grassland and arable farming, as well as areas where closed agrivoltaics systems are employed in a complementary manner.

The current technical state of Agrivoltaics

The provider “Next2Sun” presents its ground-level agrivoltaic systems, which are placed on agricultural land like a kind of fence system. As can be seen in Figure 3, the PV modules are mounted in a frame system that provides for two transversely aligned modules one above the other, which are attached at both ends with two posts protruding vertically from the ground. According to the manufacturer, who specifies a patented mounting system, the posts are hydraulically driven into the ground. The advantage is the installation of bifacial modules, which can generate electricity on both sides of the modules through solar radiation. According to Next2Sun, the modules are optimally aligned to the east and west, which results in the highest energy yield in the morning and afternoon to early evening. According to the company, this results in significantly better power generation than with conventional south-facing PV installations. Luxor and Akcome silicon modules from China are used. The strips between two PV rows have a width of ten meters, which can be used for agricultural purposes. Next2Sun states the following about the shading: “The partial shade of the PV modules reduces the evaporation rate of the area. [...] In addition, higher crop yields can be expected in arable farming for shade-tolerant crops such as potatoes, spinach, carrots, etc.”

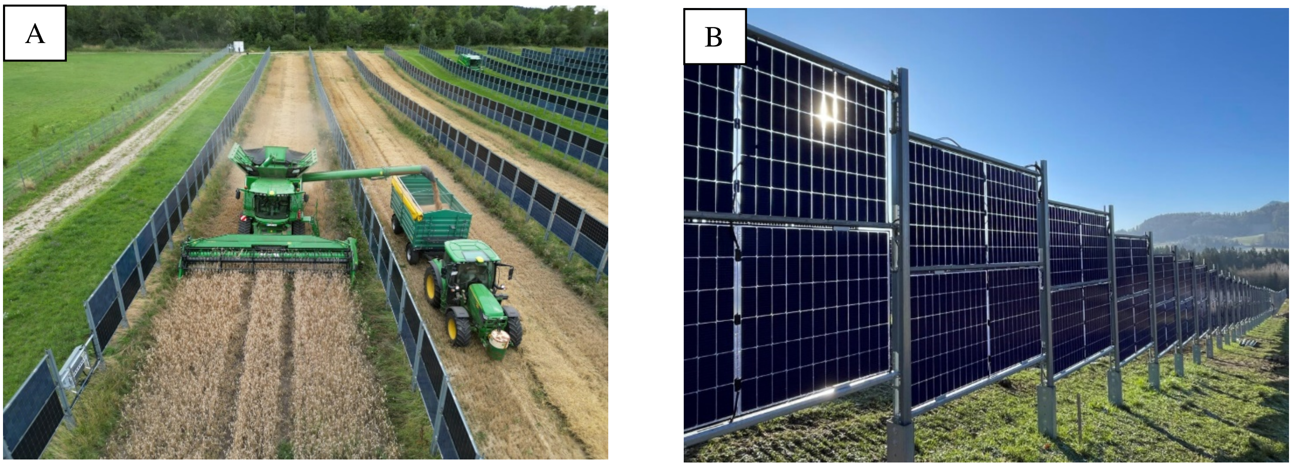

Figure 3. (A) Next2Sun agrivoltaics concept with arable farming (B) Next2Sun concept with grassland farming (Next2Sun, 2024)

The solar carport manufacturer Krinner Carport GmbH from Straßkirchen is presenting another agrivoltaic concept. Two demonstration systems have already been built here as part of the HyPErFarm research project, which involves the Fraunhofer Institute for Solar Energy Systems and a large number of other investors and companies. The publication by Asa’aet al.(2024) shows that this is a trackable PV system. As shown in Figure 4, this is a category one agrivoltaic system mounted at a clear height. The PV modules are mounted on a twelve-metre-long beam, which is mounted on two posts as a pivot axis. Galvanized steel is used as the material, and the steel beams are mounted on the posts using a custom-made suspension system. The length of the girder results in a construction on which 12 modules are installed per girder. The construction can be varied in its length by adding further cross beams and supports of the same dimensions (Figure 3B). The support pillars are inserted into a sleeve driven into the ground and braced with wire ropes at the edges of the Agri-PV system. The height of the structure is not specified, but according to Figure 4B it is large enough to ensure that the agricultural land can be driven on. The pivot axis results in a system that can be tracked. Figure 4A shows a grass strip in the line of the support pillars, which cannot be harvested by commercial vehicles. However, it is stated that these green strips, which make up 10% of the total area, can increase biodiversity as a flowering meadow by providing natural food sources for insects. Krinner Carport GmbH states that by tracking the module bridges, both the snow and wind load can be reduced and at the same time electricity generation is improved by tracking solar radiation.

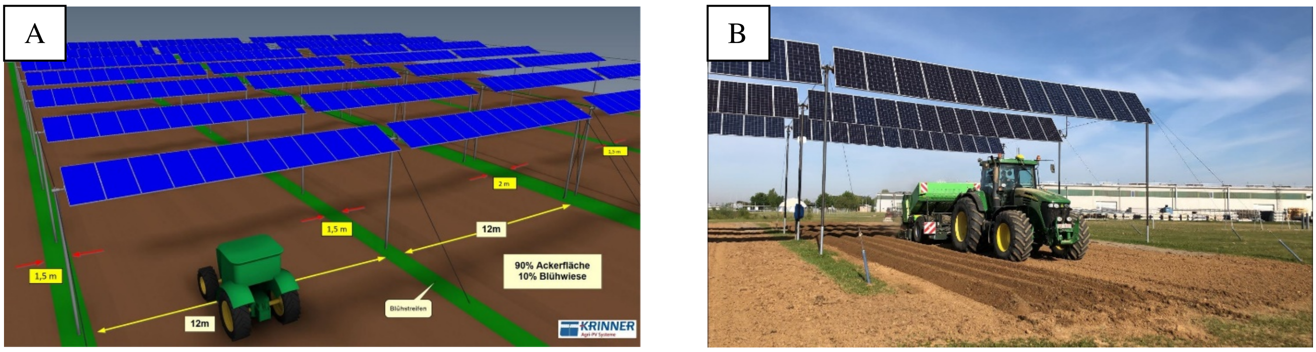

Figure 4. (A) Krinner Carport GmbH agrivoltaics concept (B)Krinner concept realization (Krinner Carport GmbH, 2024)

The RWE demonstration plant at the Garzweiler opencast mine near Bedburg is investigating the advantages of agrivoltaics in different concepts and systems. In co-operation with the Institute of Plant Sciences at the Jülich Research Center and the Fraunhofer Institute for Solar Energy Systems, a large-scale plant with 6100 modules and three different concepts was constructed. The plant has a capacity of 3.2 MWpeak and was built on an area of seven hectares. A ground-level system with a vertical module arrangement, a ground-level system with single-axis tracking and a highly elevated system constructed in a frame design with cross beams and support pillars as well as PV modules inclined at 45 degrees.

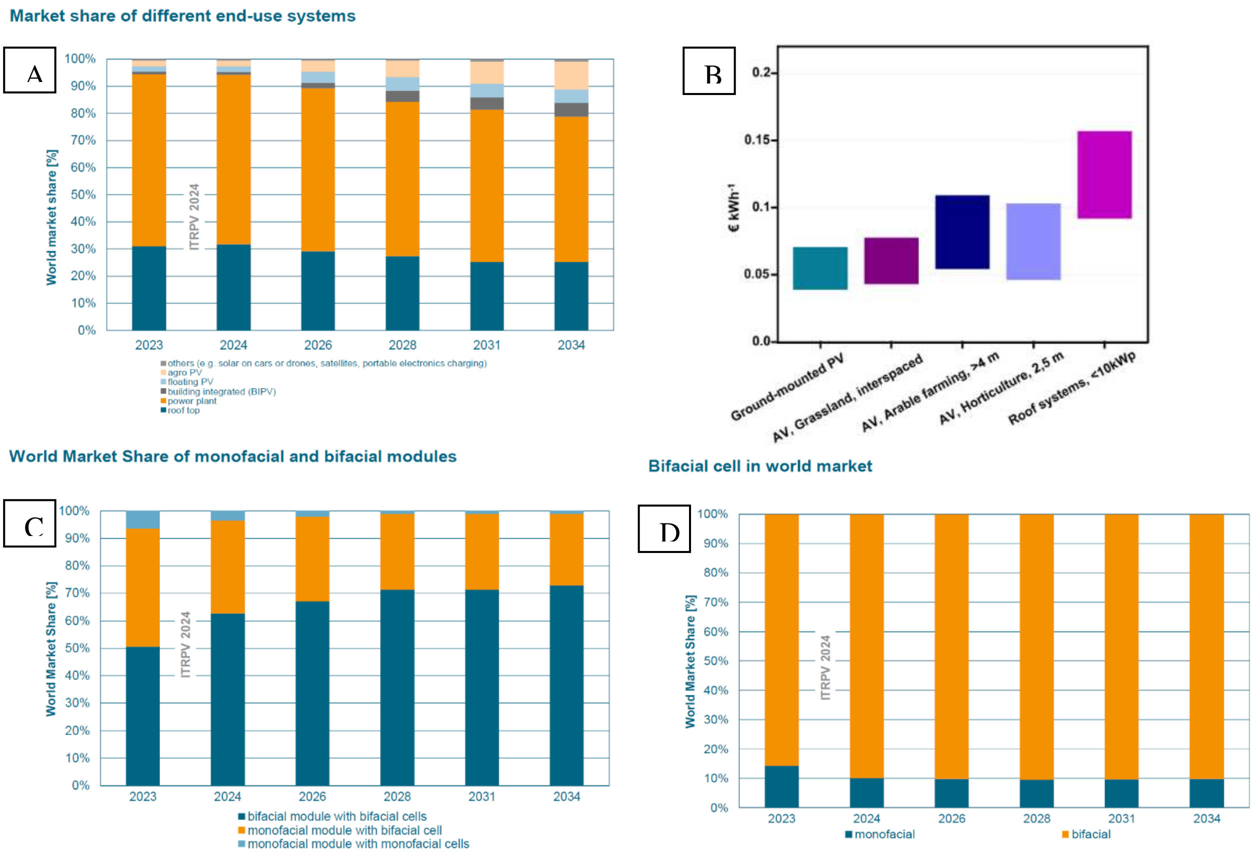

Figure 5. (A) world market share of differend end use systems (B) energy costs of different photovoltaic systems (C) world market share of monofacial and bifacial modueles (D) market share of bifacial cells(ITRPV, 2024; Trommsdorf et al., 2023)

The current market situation

Agri-photovoltaic systems that utilize bifacial PV modules offer significant advantages over traditional monofacial modules, especially when combined with an east-west orientation. Bifacial modules are capable of capturing light from both sides of the module – not only direct sunlight but also light reflected from the ground or surrounding environment. This results in higher energy production, as the reflected sunlight enhances the overall output of the modules, which is particularly beneficial in agricultural applications where reflected light from crops or the soil can be utilized. The east-west orientation maximizes energy production throughout the day and provides more consistent energy output compared to traditional south-facing setups.In contrast, conventional monofacial silicon solar cells only capture direct sunlight, limiting their efficiency as they cannot harness reflected rays. Whilst a significant proportion of conventional monofacial c-Si cells are still being manufactured at present, Figure 5D demonstrates a favourable forecast for the escalating production of bifacial solar cells. Furthermore, an augmentation in the utilisation of bifacial modules is also predicted (Figure C).

Additionally, there are concentrating optical solar systems that rely on lenses or mirrors to focus sunlight onto small, high-performance solar cells. While these systems offer high efficiency, they are generally designed for specialized environments or large-scale installations and may be less practical for agri-PV applications, as they are not optimized for use in agricultural fields. Another emerging technology is tandem solar cells, which use multiple layers of different materials to absorb a broader spectrum of sunlight. However, tandem solar cells are still in the development phase and are currently less widespread and economically accessible compared to monofacial or bifacial systems.

By incorporating bifacial modules and an east-west orientation, the potential of agri-PV can be maximized, combining higher energy production with a more sustainable and efficient use of agricultural land.With increasing projections for renewable electricity production from agrivoltaic systems (Figure 5A), which are expected to account for over 10% of total solar electricity production by 2034, the focus must be on the price and viability of these systems. At the current stage of this work, category one open agrivoltaic systems represent the most expensive share of non-rooftop industrial electricity production (Figure 5B).Substructures for agrivoltaic systems in arable farming cost an average of 400 eurosper kWp (Landverpachten.de; 2024).

Materials and methods in the presented concept

In order to develop a cost-effective prototype, various aspects of the design were given due consideration. These included the design of the statics for weather influences, the optimal choice of solar modules for good efficiency, and the development of a construction system that is easy to assemble.

The wind pressure WD is calculated using the dimensionless pressure coefficient cp, the density ρ of the air and the wind speed v. The dimensionless pressure coefficient for vertical surfaces has a value of 1, which is assumed for simplification in the following calculations. Similarly, for wind speeds with a Mach number < 0.3, air is assumed to be an incompressible gas, which results in the density as a function of temperature and air pressure. The wind pressure is calculated as follows:

$$W_D = c_p \cdot \frac{\rho}{2} \cdot v^2$$

Free-standing solar installations must be able to withstand wind speeds of up to 151 km/h, i.e. 42 m/s, with their elevation. As the density varies with the temperature over the year and a safety margin is added for all mechanically and statically stressed components, a density at 20 °C and standard atmospheric pressure is assumed here.

$$W_D = 1 \cdot \frac{1{,}204\ kg \cdot m^{-3}}{2} \cdot \left(42\ \frac{m}{s}\right)^2 = 1058\ \frac{N}{m^2}$$

This considers a gale force wind of over 118 km/h with a safety margin for Germany, ensuring that the photovoltaic systems are stable in all weather conditions.

Agrivoltaics setup

The prototype, which was designed as part of this work, consists of two vertically aligned trusses (Global Truss F34400) with a height of 400 centimeters, which were set up eleven meters apart. These are set up on a base plate from the same manufacturer (Global Truss F34BASE). To ensure the stability of the trusses, two concrete foundations with dimensions of 50 x 50 cm and a depth of 80 cm were poured, reinforced with steel to enhance flexibility. Four ground anchors from Igel GmbH, model Spirafix, measuring 30 x 300 mm, were cast into the concrete to secure the base plates to the concrete foundations, thereby ensuring the necessary stability. To ensure the secure installation of the Agri-PV system, a system consisting of three guy ropes per truss, offset by 90° around the truss, was installed. The wire ropes for tensioning the trusses, manufactured by Drahtseile24, have a thickness of eight millimetres and a winding of 7x19 strands, with a tensile strength of 1960 N/mm2. These ropes were anchored to the ground using Spirafix ground anchors (50x1540 – AC type – M16 thread), with each anchor capable of supporting 1400 kg. Additionally, high-strength eye bolts (Igel GmbH eye bolt – M16 thread for AC type) were utilized, with each bolt possessing a tensile strength of

4000 kg. Two wire ropes, with a spacing of one meter, were attached horizontally between the trusses to suspend the solar modules. All wire ropes were mounted using wire rope clips from the manufacturer Drahtseile24, which correspond to the tensile strength of the wire ropes. Photovoltaic modules from the manufacturer Solarwatt were attached to the horizontally tensioned wire ropes with four quick-connect links each, which have a load capacity of 140 kg per bracket. The brackets are attached to the mounting holes of the module frames and then hooked into the wire ropes. Additional clips serve as spacers.To comply with safety standards for work and buildings, solar modules with appropriate overhead glazing certification were selected to prevent safety measures such as nets.

Due to pragmatic concerns, simplifications were implemented for the prototype, with the utilization of more cost-intensive materials enabling enhanced flexibility in operation and the modification of extensions. For instance, 400-centimeter trusses were procured in lieu of the originally specified 500-centimeter trusses, a decision that was made to facilitate the assembly process. However, these trusses can be extended with additional modules, thereby enhancing their functionality. Additionally, higher-priced clamps were utilized in lieu of inexpensive seals for tensioning the wire ropes, a choice that facilitates expeditious removal of the wire ropes.

Figure 6. left side:Impression during construction phase; without PV modules;right side: first preliminary installation of the first raw of modules.

Materials

- Trussing: Global Truss F34400
- Base Plate: Global Truss F34BASE
- Steel Cable: Drahtseile24 DS10103.245 8mm / 7x19 (flex)
- Wire rope clips: Drahtseile24 wire cope clips stainless steel DIN 741 DS10025.5
- Photovoltaics-Holder: Drahtseile24 Quick connectorstainless steel DIN 56927 form BDS10174.2
- Ground anchor: Igel GmbH -spirafix ground anchor – 50 x 1540mm – AC-Type – M16 thread
- Eyebolt: Igel GmbH High-strength eyebolt with M16 thread for 50mm AC anchor
- Photovoltaic module: SOLARWATT Panel vision GM 3.0 construct (370 Wp) PERC-Module

Measurement setup

- Ambient light sensor: VEML7700
- Soil moisture sensor: Seed Studio Grove – Capacitive Moisture Sensor with NE555DR Chip

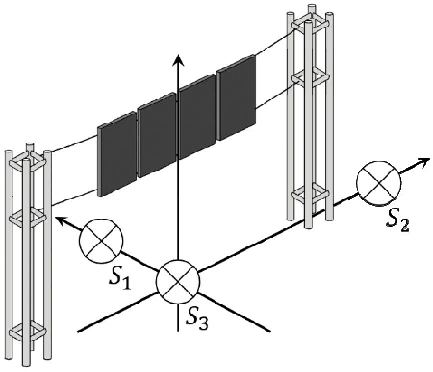

Figure 7. Sensor position diagram

4 EXPERIMENT AND UPSCALING

The prototype system developed and tested as part of this work demonstrates the suitability for upscaling to a large-scale agrivoltaics system.The chosen construction, consisting of two vertically erected trusses with three guy ropes per truss, forms a stable basis for a flexible expansion of the system (Figure 8).A key feature of this design is the ability to arrange the trusses one behind the other at a constant distance of 11 metres. This linear configuration facilitates the establishment of a route of any specified length, with the capacity to accommodate 8 to 10 solar modules between the crossbars.The total energy yield for a designated agricultural area is contingent on the parameters p (distance between the tracks) and h (height of the solar modules) (Figure 8) (Riaz et al. 2020).The ratio p/h exerts a dual influence on both the level of plant shading and the number of solar module tracks within a specific area (SOURCE). In order to optimise material efficiency and reduce the effort required to stabilise the structure, the bracing system was adapted (Figure 3): while the two end trusses of a route still need to be secured with three guy ropes, it is sufficient to fix the intermediate trusses in between with just two guy ropes. This significantly reduces the amount of material used and the installation costs per unit without compromising the structural integrity of the overall system.

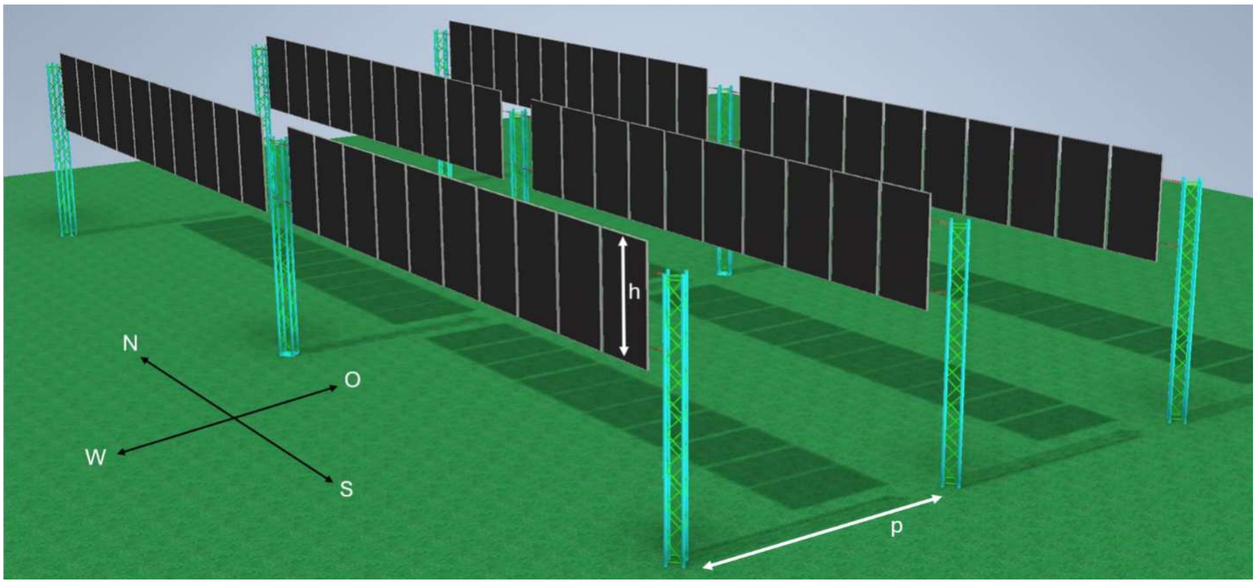

Figure 8. Visualization of the east-west oriented bifacial agrivoltaics concept in a scale up with a pitch (p) of five meters and a solar module height (h) of 1.7 meters

In the event of the agrivoltaic system being simulated within an agricultural area measuring one hectare, utilising a scale-up model, the following data is generated:Within an area of one hectare, with an edge length of 100 x 100 m, a total of 20 traverses can be configured with a pitch of five metres. Given a photovoltaic section length of 11 metres between traverses, this results in 9 sections, each with eight modules mounted on a single section. This calculation yields a total of 1455 solar modules per hectare.Utilising SOLARWATT Panel vision GM 3.0 construct solar modules with a nominal output of 370 Wp results in a total output of 538 kWp. For the test region of the prototype in the Southern Palatinate, approximately 1000 full-load hours of sunshine are estimated per year. According to current data, the sale of a kilowatt hour in Germany is valued at 8 – 9.5 cents, with an average value of 8.75 ct, equating to a total of € 47090 for an annual yield of 538 MWh. Given the yield generated, the ROI (return on investment) of the pilot project is 10.3 years. The production costs for the prototype are €900 per kWp, and no labour hours are included in the cost breakdown, which results in pure material costs. For the real conditions of series production, the costs for labour must be taken into account, but the costs of the components are estimated to fall by two thirds in large-scale production.

The potential income for the farmer should be compared with a normal yield from wheat with up to 9 tons per hectare and a price of 300 € per ton. So the income from electricity is much higher, than the income from wheat.

The aforementioned synergistic effect of agriculture and photovoltaics is even more enhanced when the installation of photovoltaic systems on agricultural land improves ground conditions by the implicit shading effect. In these cases, the shading, while simultaneously generating energy, provides protection for crops and can lead to higher crop yields in selected regions. Such a positive combined effect is currently also occurring in wine-growing regions, where, for example, white wines are grown in areas affected by global warming. The warmer summers and autumns result in higher alcohol levels, which are not desired or expected by customers. Rain shading continues to be a key aspect in the development of Agri-PV. It can be desirable or undesirable. The different objectives lead to different proposed solutions. Last but not least, the price and the possibility of small-scale application play a role in the design decision. Often, however, current proposed agrivoltaics systems are almost exclusively associated with customised parts, which only makes large-scale production economically viable. For this reason, in the project presented, we focus on applications that can also be used on a small scale, where the sun shading effect is desired and rain shading is undesirable, and the total installation makes economic sense for the farmers or winemakers. This brings us to a solution approach that appears very simple in terms of design, but nevertheless exactly corresponds with an optimum of the required properties mentioned. An agrivoltaics prototype was designed and built, using bifacial photovoltaic modules with vertical orientation and low-cost standard components. These components are easily available everywhere and do not need an exclusive supply chain. After an analysis of current research in the agrivoltaics sector and the global market share of photovoltaic technologies (Metsolar, 2024; Asa'a et al., 2024; Ogobomo et al., 2017), the advantages of low agrivoltaics systems were combined with bifacial modules and high-mounted agrivoltaics systems. The developed system relies exclusively on standard components such as stage trusses and offers a raised height with fixed modern Passivated Emitter and Real Cell (PERC) modules, which makes the coverage of a wide range of agricultural space possible.

5 RESULTS AND DISCUSSION

The system set up on the area of the SIZ site in Neustadt/Weinstrasse currently undergoing testingallowsvarious aspects of the type of agri-PV proposed by the authors to be investigated. The yield tests to date have mainly covered the winter months, which are actually unfavorable in Germany. Nevertheless, useful energy harvests can be achieved here. The energy yields to dateextrapolated to the year as a whole is approximately 20-30% above theexpected value for monofacial PV modules. This can also be seen in the daily progression in figure 9A, which shows a long, uniform power delivery. Over the course of the month there are verystrong daily fluctuations according to varying cloud cover in the winter months.

Despite the extremely cost-saving design, the system withstood the winter storms without any problems.Several moisture sensors (figure 10) were positioned in order to be able to make statements about the rain distribution. It was found that an increased amount of water was registered directly below the vertically suspended modules. This is probably due to the oblique rainfall, which runs down the modules and drips off. Effects on the vegetation must therefore be taken into account.

From a business model perspective, the system's modular expandability ensures scalability, accommodating both small and large-scale agrivoltaics systems with efficiency. The tested prototype offers a robust foundation for upscaling, characterised by its simple expansion options, reduced guy ropes per intermediate traverse, and targeted spacing adjustments. These features position the system as a promising solution for large-scale agrivoltaics installations. The p/h ratio exerts a substantial influence on the implementation of the system as a scale-up, with a pitch of 5 metres and a solar module height h of 1.7 metres resulting in a ratio of 3 (Riaz et al. 2020). This indicates that the agrivoltaics system provides optimal shading conditions and efficient electricity production.With an estimated return on investment (ROI) of approximately 10 years, this can be further optimised through cost reductions achieved by purchasing in larger quantities. The system's economic viability is further enhanced for small and medium-sized farmers, making it a viable option for a wide range of agricultural applications.The PERC modules in particular are notable for their rapid response to increased sunlight, achieving maximum energy yield even during the winter months, a trait that is a consequence of their inherent characteristics.

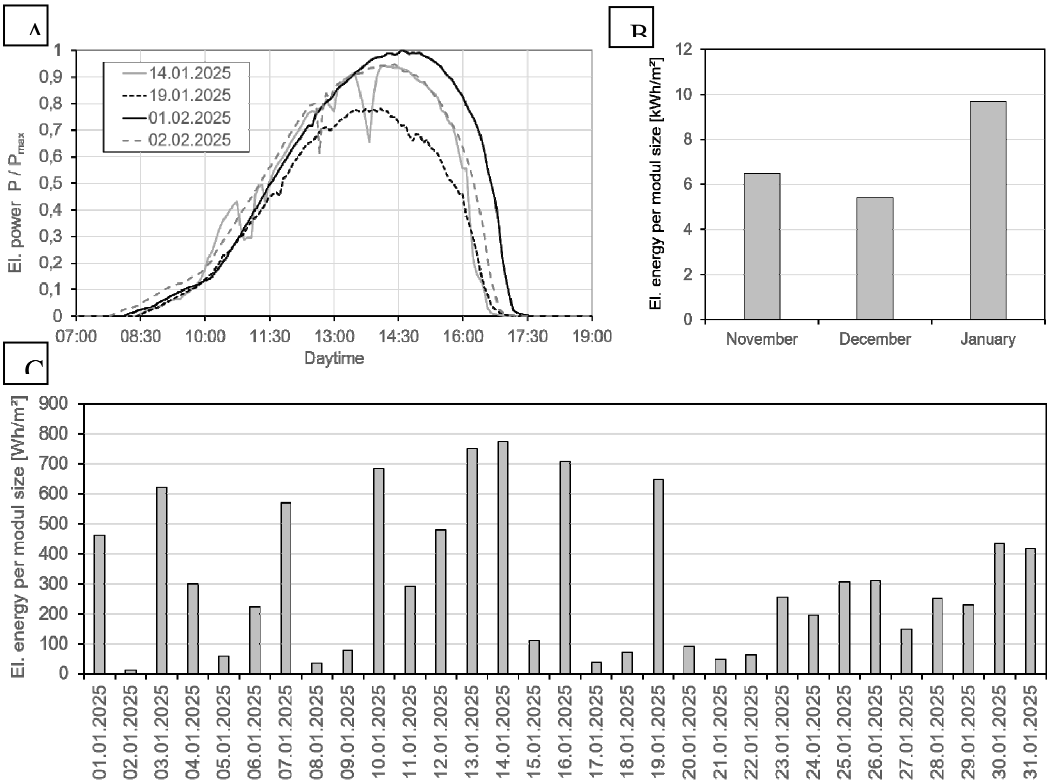

Figure 9: (A) Typical trend of electrical power on sunny days in January and February(B) Electrical Energy generated in winter months (C) daily energy generation for January

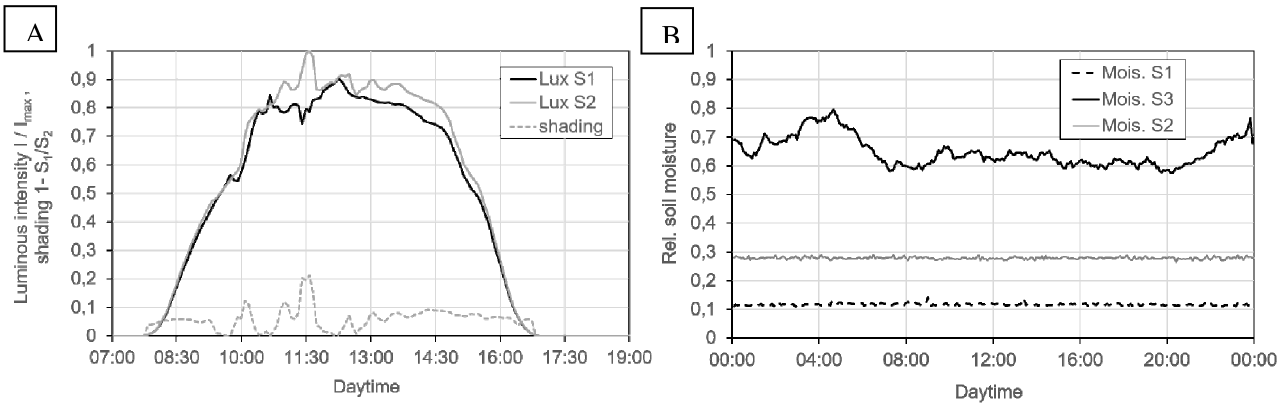

Figure 10:Measurement data according to the sensor positions fromFig. 7(A) Typical daily light intensity curve and shading in case of diffuse light (B) Exemplary course of soil moisture

In addition, a business model design of the small scale wineries whose existence is threatened, must include wine marketing, wine tourism as well as networking perspectives embracing all the stakeholders of a wine region ecosystem (Koch, Martin and Nash, 2013). In more detail, whilst a higher level of resilience against the ‘heat stress’and higher level of renewable energy use to be achieved by the introduced agrivoltaics system,will positively affect the product brand(acidity and sugar content; sustainability), other organisational-level branding (i.e. family, winery, friendliness), regional branding (i.e. place of origin, regional image)and, last but not least, emotional consumer aspects (i.e. brand love) should be considered in an integrated manner (Johnson and Bruwer, 2007; Panovic, Obermayer and Kovari, 2022;Kaufmann and Durst, 2008; Correia Loureiro and Kaufmann, 2012).

6 CONCLUSIONS

This paper aims to provide an innovative albeit economical contribution for the winemaking industry by developing a prototype of a system which exploits synergistic effects of agriculture and photovoltaics for winemakers currently facing a daunting economic future. In this respect, this paper presents the results of an experiment to develop a prototype of an invention to micro scaling a developed prototype for wine makers to possibly increase their resilience and "diversify their risk by entering into the business of bioenergy production and intelligent agrivoltaics (Fiorillo, Lo Zoppo and Saputo (2023, p.54). This experiment in progress will provide detailed figures on efficiency key performance indicators, area output as well as typical geometrical positions of the developed system. The synergy effect on agricultural and energy efficiency by agrivoltaics systems are regarded a promising basis for successful sustainablebusiness models for small scale wineries including multifaceted and multi-stakeholder branding strategies.

7 REFERENCES

Asa'a S, Reher T, Rong´e J, Diels J, Poortmans J, Radhakrishnan HS, Daenen M. 2024. A multidisciplinary view on agrivoltaics: future of energy and agriculture. Renew Sustain Energy Rev;200:114515;https://doi.org/10.1016/j.rser.2024.114515Correia Loureiro, S.M. and Kaufmann, Hans Rüdiger. 2012. Explaining love of wine brands. International Journal of Pormotion Management, Vol. 18 (3), pp. 329- 343.

Ferrara G, Boselli M, Palasciano M, Mazzeo A. 2023. Effect of shading determined by photovoltaic panels installed above the vines on the performance of cv. Corvina (Vitis vinifera L.).ScientiaHorticulturae;308:111595. https://doi.org/ 10.1016/j.scienta.2022.111595.

Fiorillo,V., Zoppo, M., and Saputo, A. 2023. Innovation trends in the AgriBusiness Supply Chain. In: Gatti, S., Chiarella, C. and Fiorillo, V. Agriculture as anAlternative Investment. The Status Quo and Future Perspectives. Springer. Switzerland.

Gorjian S, Bousi, E. , Özdemir, Ö.E., Trommsdorff, M., , Kumar, N.M., Anand, A., Kant, K., Chopra, S.S. 2022.Progress and challenges of crop production and electricity generation in agrivoltaic systems using semi-transparent photovoltaic technology. Elsevier Ltd Renew Sustainable Energy Reviews, Vol. 58 (C). https://doi.org/10.1016/j. rser.2022.112126.

Guo, S., Walsh, T.M., Peters, M. 2013 Vertically mounted bifacial photovoltaic modules: A global analysis. Elsevier Energy, 61 (2013) 447-454. http://dx.doi.org/10.1016/j.energy.2013.08.040

Kaufmann, H.R. and Durst, S. 2008. Developing inter-regional brands. EuroMed Journal of Business. Vol. 3., Iss. 1., pp.38-62

Koch, J., Martin, A. and Nash, R. (2013), "Overview of perceptions of German wine tourism from the winery perspective", International Journal of Wine Business Research, Vol. 25 No. 1, pp. 50-74.

Krinner Agri-Photovoltaik, in: https://www.krinner-solar.com/apv, Accessed: Dec 04, 2024 [Online]

Landverpachten.de, in https://www.landverpachten.de/post/agriphotovoltaik#:~:text=Unterkonstruktionen%20f%C3%BCr%20Agri%2DPhotovoltaik%2DAnlagen,75%20Euro%20pro%20kWp%20l%C3%A4gen. Accessed: Dec, 2024 [Online]

Metsolar. 2024, in:https://metsolar.eu/blog/what-is-agrivoltaics-how-can-solar-energy-and-agriculture-work-together/Accessed: Jan, 2025 [Online]

Ogbomo OO, Amalu EH, Ekere NN, Olagbegi PO. 2017.A review of photovoltaic module technologies for increased performance in tropical climate. Renewable and Sustainable Energy Reviews, Vol.75, pp. 1225–1238. https://doi.org/10.1016/J. RSER.2016.11.109

Paunovic, I., Obermayer, N. and Kovari, E., 2022. Online Branding strategies of family wineries: a Hungarian- German comparative study. Journal of Family Business Management. Vol. 12 No. 3, pp. 450-467.

Rheinpfalz.2024. Winzer in der Krise: die Angst vorm großen Weingut- Sterben in: https://www.rheinpfalz.de/pfalz_artikel,-winzer-in-der-krise-die-angst-vorm-gro%C3%9Fen-weingut-sterben-_arid,5717028.html

Riaz, M. H., Imran, H,m Zafar Butt, N. 2020. Optimization of PV Array Density for Fixed Tilt Bifacial Solar Panels for Efficient Agrivoltaic Systems. Institute of Electrical and Electronics Engineers, DOI: 10.1109/PVSC45281.2020.9300670

Energie-experten.org, in https://www.energie-experten.org/erneuerbare-energien/solarenergie/solarzelle/konzentratorAccessed: Jan, 2025 [Online].

Rosenzopf, T. 2022. Studie – Analyse innovativer Anlagendesigns für ein strommarktoptimiertes PV-Portfolio. enervisenergyadvisors GmbH.in https://enervis.de/publikationen/Accessed: Dece 2022 [Online]

RWE Agri-Photovoltaik, in: https://www.rwe.com/forschung-und-entwicklung/solarenergie-projekte/agri-pv/, Accessed: Dec 10, 2024 [Online].

Next2Sun Agri-PV, in: https://next2sun.com/agri-pv/, Accessed: Dec 04, 2024 [Online]

Suedkurier. 2024. RIerhttps://www.suedkurier.de/ueberregional/wirtschaft/mehr-geld-fuer-obstbauern-katastrophale-lage-fuer-winzer-in-bw;art416,12263667

United Nations. Sustainability goals, in: https://www.un.org/sustainabledevelopment/ accessed at 17.12.2024

International Technology Roadmap for Photovoltaics (ITRPV) – 15th Edition, Results 2023, VDMA Photovoltaic Equipment." Accessed: Dec. 19, 2024. [Online]. Available: https://www.vdma.org/international-technology-roadmap-photovoltaic

Victoria, M.,Pullens, J., Torma, G., Lindhardt, M., Niazi, K., Jahangirlou, M., El Khoury, Y., Aschemann-Witzel, J., Ottosen, C.O. and Jørgensen, U. 2024. Vertical Agrivoltaics in a Temperate Climate: Exploring Technical, Agricultural, Meteorological, and Social Dimensions. Research Square; https://doi.org/10.21203/rs.3.rs-5358908/v1

Zha Q, Yin X, Xi X, Jiang A. 2022. Colored shade nets can relieve abnormal fruit softening and premature leaf senescence of 'Jumeigui' grapes during ripening under greenhouse conditions. Plants,11(9). https://doi.org/10.3390/ plants11091227.