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GUIDE TO CHOOSING THE RIGHT AGRI-PHOTOVOLTAIC MOUNTING SYSTEM

VODIČ ZA IZBOR PRAVOG SISTEMA ZA MONTAŽU AGRO-FOTONAPONSKIH SISTEMA

Momir TABAKOVIC, Mihajlo KESERIC
University of Applied Sciences Technikum Wien, Höchstädtplatz 6 1200 Wien
e-mail: momir.tabakovic@technikum-wiena.at

ABSTRACT

The aim of this work is to create a guide for the selection and planning of an agri-photovoltaic mounting system. The mounting systems available on the market were analysed and those that can be used in agri-photovoltaics were selected. Since there are many mounting systems on the market and there are hardly any technical differences between them, four systems were selected and described in this work. The systems are those that almost every manufacturer offers in a modified form. Through this collected knowledge about mounting systems, it was possible to create a questionnaire, which was then sent to farmers. The online questionnaire was sent via e-mail to the desired target group throughout Austria. It was sent to as many farmers as possible to obtain a large database. The data resulting from the questionnaire made it possible to create a guideline to support technicians in the planning of new Agri-PV systems.

Keywords: *agri-photovoltaic, mounting system, guide, farmers, questionnaire.*

REZIME

Cilj ovog rada je kreiranje vodiča za izbor i planiranje Agro-fotonaponskog montažnog sistema. Analizirani su montažni sistemi dostupni na tržištu i odabrani su oni koji se mogu koristiti u agro-fotonaponskim sistemima. Budući da na tržištu postoji mnogo sistema za montažu i da među njima nema tehničkih razlika, u ovom radu su odabrana i opisana četiri sistema. Opisani su sistemi koje veliki broj proizvođača na tržištu nudi u modifikovanom obliku. Kroz prikupljeno znanje o sistemima za montažu, bilo je moguće napraviti upitnik, koji je potom poslat poljoprivrednicima. Online upitnik je poslat putem elektronske pošte željenoj ciljnoj grupi širom Austrije. Poslat je većem broju farmera kako bi se dobila velika baza podataka. Podaci dobijeni iz popunjenih upitnika omogućili su kreiranje smernica za podršku tehničarima u planiranju novih agri-fotonaponskih sistema. Takođe su predstavljene prednosti i mane Agro-fotonaponskih sistema, izazovi i trendovi. Rezultatima istraživanja literature utvrđeni su sistemi montaže na tržištu. Sa ključnim podacima sistema, izabran je sistem montaže. Nakon što su određene dimenzije površine na kojoj je trebalo da se izgradi fotonaponska elektrana, agrofotonaponski sistem je mogao da se dimenzioniše i simulira njegov rad. U delu za diskusiju predstavljeni su prvi realizovali Agro-fotonaponski projekti u Austriji i sumirano finansiranje za fotonaponsku tehniku. U Austriji se finansiraju investicioni troškovi za fotonaponske elektrane, posebno za Agro-fotonaponske elektrane za sada nema dodatnog finansiranja.

Ključne reči: *agro fotonaponski sistemi, montažni sistemi, vodič, farmeri, upitnik.*

INTRODUCTION

Global carbon emissions from fossil fuels have significantly increased since 1900. This in turn has a strong influence on the global climate. This can be felt every summer, for example, because summers are getting hotter every year. This is not only a problem for humans, but also for our plants. They need more water so that they don't dry out during hot periods, which increase every year. Furthermore, climate change leads to increasingly violent thunderstorms and heavy winds, which not only destroy or damage crops but can also injure animals.

To curb the effects of the growing energy demand, a switch to renewable energies is unavoidable. These can cover the energy demand, save CO2, and thus combat climate change. Photovoltaics play a central role in this energy transition. Since the use of roofs for photovoltaics is increasing strongly and not all roofs, can be used, new and innovative approaches must be found. One of these approaches is agri-photovoltaics. Here, areas intended for agricultural use are additionally equipped with photovoltaics, so that the photovoltaics help the plants and the area receives an additional benefit *(Čorba et al. 2009)*.

Without agri-photovoltaics, also known as agri-PV, there could be competition between food and electricity production. In a research project conducted by the Fraunhofer Institute in 2017, an area of one hectare was considered. If this area was used without agri-PV, one could either only plant vegetables or only install PV. If the same area is now considered with the use of agri-PV, utilization efficiency of up to 186 % can be achieved. Whereby 103 % of the area could be used by potatoes and 83 % by PV. By using agri-PV, an agricultural harvest increase of 3 % could be achieved, with additional electricity also being generated *(Schneider et al., 2019)*.

But to be able to provide this help and this dual use, the mounting systems of photovoltaics must harmonize with the cultivation methods of the plants as well as with the agricultural machines of the farmers.

MATERIAL

First, a basic knowledge of Agri-PV and the existing mounting systems had to be built up. For this purpose, literature research was carried out, which enabled the systems available on the market. Based on this an online questionnaire for the farmers was designed and sent out to over 70 farmers in Austria. Based on the questionnaire evaluation the guideline for the agri-PV mounting system was elaborated.

Additionally, a simulation of an agri-PV power plant was done by using the software "PV*SOL Premium R2 2021" *(PV*SOL 2021)*. For that, the mounting systems for agricultural photovoltaics currently available on the market are examined.

The good sides of the application of agri-photovoltaic systems are:

– the electricity demand can be produced locally;
– independence from fluctuating electricity prices;
– reduction in the use of fossil fuels in farming when switching to electrical machines;
– use of existing land potential to create a renewable energy supply;
– stopping land from being sealed for energy production;
– avoiding land competition between food and electricity production;
– increasing land efficiency through the dual use of land for agricultural production and electricity generation;
– reduction of the evaporation rate and thus longer humidity and cooling of the soil due to the shade of the PV modules - especially important in a climate-heating climate;
– higher crop yields of shade-tolerant crops such as potatoes, spinach, hops;
– protection of arable crops against drought damage and weather influences through the photovoltaic;
– active nature conservation through the creation of diverse and varied living and retreat areas;
– creation of local jobs through maintenance of the system and cultivation of the land;
– new income opportunities for farmers through electricity production or leasing of the ground for Agri-PV;
– encouraging the use of innovative concepts and new technology applications from Europe.

Challenges and trends in agriculture are:

– adaptations to the climate crisis;
– digitalization;
– electrification (e.g. for agricultural machinery, equipment in stables, lighting, ventilation, etc.);
– automation (irrigation systems, smart farming, machinery, etc.) and sensor technology;
– ecological farming;
– change in agricultural use;
– farmers as energy hosts: production and sale of energy, but also for their own supply enables income and cost reductions on the farm;
– new storage options for emergency power supply.

(Bundesverband PHOTOVOLTAIC AUSTRIA 2021).

METHOD

Various categories of Agri-PV

The technical approaches for the integration of PV in agriculture could be in various categories. Agri-PV classification as “cropland”, “grassland”, and “greenhouses” is possible. Agri-PV with cultivated plants, such as permanent or annual and perennial crops, typically requires specialized support systems for the PV modules that are adapted to cultivation, while conventional mounting structures for ground mount photovoltaic systems, sometimes with minor adaptations, are generally used for agri-PV on grassland. Figure 1 shows an example of a vertically bifacial photovoltaic mounting system.

Simulation

With the results of the literature research mounting systems on the market were determined. With the key data of the system, the mounting system has been selected.

With "Google Maps", "Google Earth" and "Google Earth Pro" the position of the power plant is chosen. The presence of 3D images and a street view made it possible to determine the dimensions of the shading objects. Once the dimensions of the area on which the PV plant was to be built had been determined, the agri-photovoltaic system could be dimensioned and simulated. With the help of the program "PV*SOL Premium R2 2021" *(PV*SOL 2021)* the system could be simulated and displayed (Figure 2). Furthermore, the shading analysis can be carried out with the help of this software *(Malinek et al. 2015)*.

The software is not optimized for Agri-PV, so not all parameters are included and possible to simulate.

In the second part, the mounting systems for agricultural photovoltaics currently available on the market are examined.

Fig. 1. Mounting system with vertically erected bifacial photovoltaic modules.

RESULTS

The placement and alignment as well as the inclination of the modules can be seen in Figure 1. The modules used are installed horizontally and thus two modules are used on top of each other.

As shown in Figure 2 six rows are formed. In the first three rows from the left, there are 20 modules, which together have an output of 6.4 kWp. The remaining three rows consist of 16 modules, which together have an output of 5.12 kWp. All PV generators face south and have an inclination of 20°. The ideal inclination of 30° cannot be selected here, as the mounting system does not support this. A distance of four meters was left between all rows so that agricultural use can take place there and a tractor can drive through. A space of four meters was also left between the first three rows and the property boundaries so that it is possible to turn around there with a tractor.

In the rear rows, the distance to the property boundary was increased. Here, a distance of eight meters is maintained. The distance was increased mainly because of shadows, but also because of the possibility of rotating. However, the distance to the other property line was left at four meters. It would have been possible to place some modules behind the northernmost row.

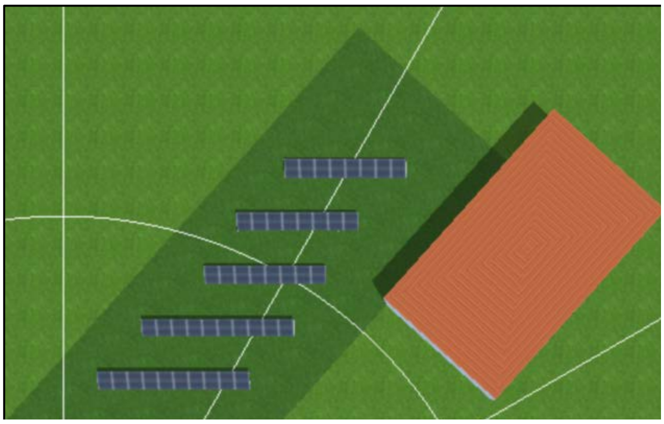

Fig. 2. Placement of the photovoltaic modules for the simulation.

This was not done, however, because otherwise the modules could not be distributed evenly along the alternating rows. In conclusion, there are three rows with 20 modules each and three rows with 16 modules each. This results in a total output of 34,6 kWp, which is supplied by 108 modules. The simulation results of the power plant are shown in Table 1.

Table 1. Simulation results of the agri-PV plant

Description	Value
PV generator output	34,6 kWp
Spec. Annual yield	1.142,35 kWh/kWp
Plant utilisation rate	85,80%
Yield reduction due to shading	4,0 %/a
PV generator energy (AC grid)	39.502 kWh/a
Self-consumption	18.025 kWh/a
Grid feed-in	21.478 kWh/a
Self-consumption share	45,60%
Avoided CO_2 emissions	18.555 kg/a
Consumption(inverter)	23 kWh/a
Total consuption	48.800 kWh/a
covered by PV	18.025 kWh/a
covered by grid	30.775 kWh/a
Solar coverage	36,90%

Evaluation of Agri-PV mounting system

To determine the requirements of the farmers for an Agri-PV mounting system, an online questionnaire was created and sent to farmers with different types of farming in Austria. This made it possible to determine both the requirements for the different types of cultivation as well as to identify optimization measures for the systems already on the market.

The website Question star *(Question star)* was used to create and distribute the questionnaire. Through this site, the questionnaire could be modeled, and the automatically generated link was sent via e-mail. After the questionnaire was answered, the results were included in the work. There were 30 responses in total.

To support the planning of Agri-PV systems, a guide based on the farmers' responses is developed. This is presented below in the form of a list of the most frequent and best-justified answers from the farmers.

Planning of Agri-PV with cropland

When planning, care should be taken not to shade the plants too much, as they are partly dependent on high, direct sunlight.

The mounting system that should primarily be used for planning is the mounting system with vertical-bifacial-photovoltaic modules (Figure 1).

The module height, when using an elevated system, must be higher than the farmer's highest machine. A minimum height of 5 m is recommended.

The distance between the outermost modules of a row and the property boundary also depends on the machinery used. Here a distance of 20 m is recommended.

A row spacing of 15 m is recommended. However, this also depends on the width of the machines used.

Copper and galvanized iron are recommended as materials for the construction of the mounting systems. However, it should be clarified with the manufacturer of the mounting system and the farmer which chemicals are being used.

The resistance of the modules should be clarified.

The integration of watering systems into the mounting system should be considered.

The use of sun-transmitting PV modules should be considered.

The cables should be buried at a depth of at least 80 cm. If special deep looseners are not used, a depth of 50 cm is also sufficient.

If the wires are not going to be buried, they must be installed far enough, so that they do not obstruct the equipment. An installation height of 5 m is recommended.

The exact resistance to chemicals should be clarified with farmers and cable manufacturers. Resistance to organic manure, sprays and fertilizers is recommended.

The restoration of the vegetation and humus layer after diggings as well as the lying in a grid-like structure should be taken into consideration.

Planning of Agri-PV with a cultivation area

It is recommended to use the mounting system with vertically-erected-bifacial-photovoltaic modules.

When used as a fence, the module height depends on whether an electrified fence is used or not. If used, a module height of 0.5 m is sufficient, however, care must be taken to avoid the module's pollution. Installation at 1.5 m is recommended.

It is possible to bury the wires at a depth of 20 cm.

If the wires are not buried, as few masts as possible that are out of the reach of the animals should be used for cable routing.

The cables do not need to be resistant to any special chemicals. However, they should have protection against bites and last 30-40 years.

DISCUSSION

Realized Agri-PV projects in Austria

Last year the construction of the largest PV power plant in Austria began. It has 11,5 MWp on an area of 12,5 hectares. This power plant should not only be used for the production of energy but also host 150 sheep *(Solarthemen Media GmbH, 2021)*. This sheep will also be used as a natural lawnmower to keep the grass low for the PV to operate ideal. Under the 25,780 photovoltaic modules also agricultural farming should be possible. This will be possible with the use of 500 vertically erected bifacial photovoltaic modules. Those will be set up in east and west direction to let a tractor pass through. The power plant was finished in March 2021 and should produce 13 GWh of energy. *(APA-OTS 2021).*

Funding for Agri-PV in Austria

Funding is available for grid-connected PV-power plants on buildings, with or without electricity storage. There is no difference between business or residential buildings. For open spaces, provided that they are not agricultural land or nature conservation areas. The maximum subsidized PV power is between five and a maximum of 50 kWp. Also, the subsequently of electricity storage in existing agricultural PV systems is funded. The funding limit for electricity storage is 4 kWh of usable storage capacity. The upper funding limit is 3 kWh/kWp.

For free-standing PV systems/rooftop systems between five and a maximum of 50 kW peak, the subsidy flat rate is 275 €/kWp. Building-integrated PV is supported with 375 €/kW in the range between five and 50 kWp. Agri-PV in Austria is not supported. *(Klima und Energiefonds 2019).*

One of the mounting systems can be used in Agri-PV due to their adaptable row lengths and row spacings as well as the variable module inclination. The mounting systems described here are not the only ones on the market, because, as already mentioned, the systems hardly differ from each other technically. They are similar and hardly differ from each other. The quick and easy installation as well as the possibility of integrating a sun tracking system into one of the three systems make them ideal for use. The mounting system of a manufacturer, which uses vertically constructed bifacial photovoltaic modules, is another, but unique system, as it is only used by this manufacturer. It finds its use in Agri-PV, as it can be used as a common mounting system as well as a fence. Also with this system, the row lengths and the row spacing are adjustable. Sun tracking and variable module inclination are not possible here, but it takes up the least space, which is an advantage over the other systems. This also emerged from the questionnaire, as the surveyed farmers found this system the most suitable.

With the help of the questionnaire, it was possible to create the guide. The guide is intended to make it easier for planners to design and dimension Agri-PV systems and to know the needs of the farmers. By interviewing the system users, the farmers, their requirements were identified, summarized and then incorporated into the guide. Although the requirements for row spacing, maximum row length and resistance to chemicals are still project- and user-specific, it is possible to make rough assumptions with the help of the guide. Requirements were not only identified in the area of the mounting system. The data obtained in the area of cabling was also incorporated into the guide. Information on cable routing, burial depth and resistance to chemicals can be found in the guide. The guide can be used in both parts of the Agri-PV. The first part deals with the agricultural use of the area, while the second part deals with it'ş use as pastures.

CONCLUSION

As the results have shown, there are a number of things that need to be considered when planning Agri-PV systems. From row spacing to module height to installation requirements, every detail must be clarified with the system users, the farmers, in order to successfully plan an appropriate Agri-PV system.

Agri-PV is a powerful weapon in the fight against climate change. Not only can CO2 emissions be reduced, but it is also possible to stop the competition between food and energy production. But more research would be needed, as some institutes are already doing, to take a significant step against global warming.

For the sake of research, more farmers should agree to share their requirements so that further conclusions can be drawn for the future. This would make it possible to provide further and more precise information to planners in the form of an improved guide. In addition, people from other sectors could be consulted. The acceptance of Agri-PV among farmers could be surveyed. It would also make sense to specialize in one area of Agri-PV and investigate it in detail. Furthermore, the lack of opportunities for simulation of Agri-PV was also recognised. This is an area that still needs to be implemented in the software for PV.

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