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STUDY ON THE IMPORTANCE OF USING AGRIVOLTAIC SYSTEMS TO REDUCE THE EFFECTS OF CLIMATE CHANGE

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Abstract

Climate change, global warming are phenomena that have changed the face of the world and that have a direct impact on agricultural production and food security, given that the world's population is growing from one year to the next, without the possibility of growth and natural resources. Another worrying phenomenon is the production of greenhouse gases and their destructive effect on the planet. That's why the technology that is being perfected every day tries to find solutions that simplify both the efforts made to obtain food, but also the possibility of increasing the efficiency of production processes. In this way, in the agricultural field, the idea of developing dual systems appeared, which would protect both agricultural crops, with the aim of increasing productivity, but which would also contribute to obtaining solar energy, necessary not only for own consumption, but also to be included in consumer networks, the proposed concept being that of the AgriVoltaic system. The idea that appeared in 1981 began to be developed, currently reaching the development of a technology that is starting to be adopted in many countries of the world, including Romania. In the current paper, we propose to analyze the opportunity of using AgriVoltaic technology, its advantages and disadvantages, but also the way in which it could contribute to increasing the profitability of agricultural farms. At the same time, increasing the degree of awareness regarding the advantages of introducing agricultural systems and the method of implementing the systems is another objective of the current work. Starting from the analysis of the specialized literature, we outlined the term Agrivoltaic technology and continued the study with an analysis of the possibilities of implementing this technology in Romania, due to the solar energy potential that it benefits from. The research methodology assumed on the one hand the bibliographic analysis, and on the other hand the analysis of the development potential of the system, taking into account the existing agricultural areas and crops suitable for this system. As a result of the research carried out, it turned out that although there are confirmed advantages of using AgriVoltaic technology, it does not yet benefit from sufficient visibility or high accessibility among farmers. Also, the existing legislation at the level of Romania does not yet make possible the development of the dual system. Among the disadvantages of using agrivoltaic systems are the still high costs, but the measures to protect the rural landscape, which occupies an important place in sustainable development, even if the energy produced is renewable.

Key words: *AgriVoltaic, climate change, agriculture, greenhouse gases*

INTRODUCTION

Agrivoltaic systems represent a concept, which has the role of ensuring a better use of agricultural land, on the one hand for the purpose of food production, and on the other hand for the production of energy needed by humanity in ever-increasing quantities. The two objectives can be achieved simultaneously, and those who laid the foundations of this concept, which appeared in 1981, were the German physicists Adolf Goetzberger and Armin Zastrow, and it appeared as a solution to the situation in which humanity began to be increasingly concerned about the effects of warming global and climate effects, it was developed [8]. Another researcher, Akira Nagashima, introduced in 2004 the notion of "solar sharing", as a technology applied to the cultivation of plants located under photovoltaic modules, and which led to results that encouraged the Japanese government in the direction of granting support schemes for farmers, starting with 2012 [30]. The country that has the largest capacity of Agrivoltaic systems is China, which started to develop this system starting in 2014.

In Europe, the first country to start using Agrivoltaic systems was France, which, starting in 2017, implemented the use and support of the use of solar energy for agriculture. At this moment there are many other countries of the world such as America, Canada, India, South Korea, Italy, Germans, etc., which are joined by Romania that have implemented or intend to implement the use of Agrivoltaic systems, as well as some schemes of government support to encourage their use on a wider scale.

In 2021, the capacity of AgriVoltaic systems installed globally amounted to almost 14 GWp. The use of AgriVoltaic energy is possible due to its existing potential in most subtropical and semiarid regions of the world. With all these advantages, the technology has remained largely unknown, but its use appears at this moment as a necessity, considering the measures that must be taken at the global level in the context of climate change that require the adoption of policies to contribute to the reduction their effect. Thus, at the level of the European Union, there have been and continue to be initiatives aimed at achieving climate neutrality. The European climate law, which is part of the European Green Pact, aims to reduce greenhouse gas emissions by 55% by 2030 and achieve neutrality by 2050. In this sense, various measures entitled "Prepare for 55 in 2030" and which interconnects 13 laws and 6 proposed laws that will contribute to achieving this objective [5].

It can even be appreciated that the war in Ukraine and the measures taken against Russia with regard to the ban on the import of fossil fuels, have in turn contributed to speeding up the transition of the European Union states to the Green Transition.

Europe occupies the 3rd place in the world, after China and the United States of America, in terms of the production of greenhouse gases, but India, Japan and Russia occupy the following places. As far as the countries of the European Union are concerned, the largest producers of greenhouse gases are Germany, France, Spain, Italy, Poland, these coming primarily from the energy sector. Industry occupies the 3rd place in this ranking, being overtaken by agriculture.

Statistical data highlight the fact that half of the world's population is actually affected by climate change and are vulnerable due to the fact that they live in risk areas, as a result of heat waves that affect their lives, water shortages or, on the contrary, due to floods . If until 2020, the increase in temperatures compared to the pre-industrialization period had an average growth rate of 1.1 degrees, an increase that would exceed a threshold of 1.5 degrees would have extreme effects, and this can be reduced by trying to reduce by 50% the GHG until 2030.

These risks reduce agricultural production and affect food security, and in addition to measures to reduce greenhouse gases, it is possible to intervene through nature conservation technologies [12].

Another initiative of the European Union was the one from May 2022, when the RePowerEU plan was launched, which aims to achieve an independent infrastructure from an energy point of view, with a role in accelerating the ecological transition, this being achieved both through the efficiency of consumption energy, by diversifying energy suppliers, but also by stimulating the production of alternative sources of green energy. Regarding solar energy, the objective is to reach 320 GW in 2025 and 600 GW in 2030 compared to the 136 GW obtained in 2020 [6].

At the level of the European Union, there are 14 states that have included in the application of the Common Agricultural Policy legislative elements regarding their strategic plans regarding the use of photovoltaic panels.

The use of agrivoltaic systems thus contributes to achieving a synergy between green energy and precision agriculture, elements that belong to the practice of a modern agriculture, adapted to the 21st century, whose purpose is to ensure food security and adapt to climate change,

objectives of the European Union's policies, but also of other countries of the world [21].
In this context, the purpose of the paper is to describe the opportunity of using AgriVoltaic technology, its advantages and disadvantages, how it coudl be utilized in agricultural farms for increasing the profitability.

MATERIALS AND METHODS

The research methodology involved a systematic review of specialized literature aimed at identifying and analyzing research in the field regarding the definition of the concept of agrivoltaic and the possibility of integrating this technology within agricultural farms. In this way, the international experiences regarding the integration of voltaic systems in agricultural activities could be analyzed. At the same time, the existing legislation in Romania regarding the implementation of agrivoltaic systems was analysed, but its limitations were established, which if aligned with the international one, would allow increasing the efficiency of their use.
The calculation of the yield of the use of solar panels simultaneously with agricultural production is determined with the help of the land equivalence ratio (LER), adapted to the concept of agrovoltaic system, it is done starting from the classic model that measures the land required to obtain two crops in comparison with monoculture:

LER = mixed $yield_1$/pure $yield_1$ + mixed $yield_2$/pure $yield_2$ [19]

In the case of agrovoltaic systems, the LER (Land Equivalent Ratio) is determined as follows:

LER = crop yield in AV/monocrop yield + electricity yield in AV/PV yield [4]

where:
AV - agrovoltaic
PV - photovoltaic

In other words, LER represents the ratio between the surface area of the agrovoltaic installation and the total area required to obtain agricultural production and energy produced by the agrovoltaic systems.
A value greater than 1 for the LER means that the productivity of the land increases under the conditions of the use of agrovoltaic panels and agricultural crops, in relation to their separate use.
Primary factors which have a direct influence on both agrivoltaic production and crop yield are shading, photosynthesis, that's why we also analyzed their importance.

RESULTS AND DISCUSSIONS

As mentioned before, the concept of agrivoltaic system is already one that is gaining more and more applicability worldwide. As shown in a study carried out by Precedence Research, at the level of 2021, the global market was valued at approximately 3 billion USD, and the growth rate until 2030 is estimated to be over 12%, which will make for the market to reach a value of nearly USD 9 billion [25]. The factors that contribute to the growth of the market, in addition to those already mentioned, are related to the increased need for electricity, but also to a decrease in the production costs of the voltaic panels as a result of the innovations in the field and the growing number of producers, among in which the Chinese have an important share.

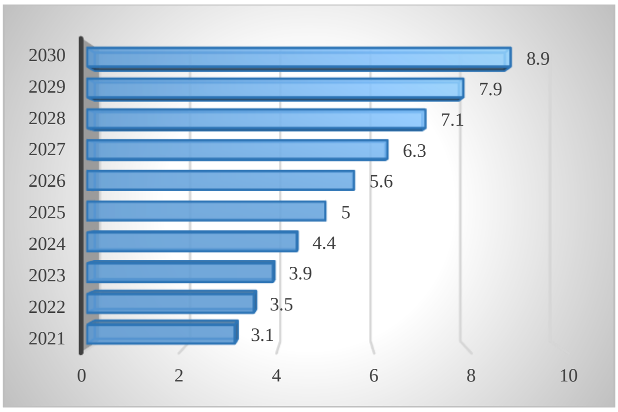


Fig. 1. Evolution of the agrivoltaic systems market
Source: own processing after Precedence Research [25]

By region, it can be seen that in 2021, the largest market share was held by North America, which is among the first countries to implement this technology (33%), followed by Europe (29%), where among the countries where the system works well include France (which uses the system successfully in viticulture), the Netherlands, Italy, Germany, etc., Asia and the Pacific (24%), where China is the country that has the largest photovoltaic park located in the Gobi Desert and which it has a capacity of 1,000 MV being used in the cultivation of goji fruits, but also Japan where there are over 2,000 implemented projects.

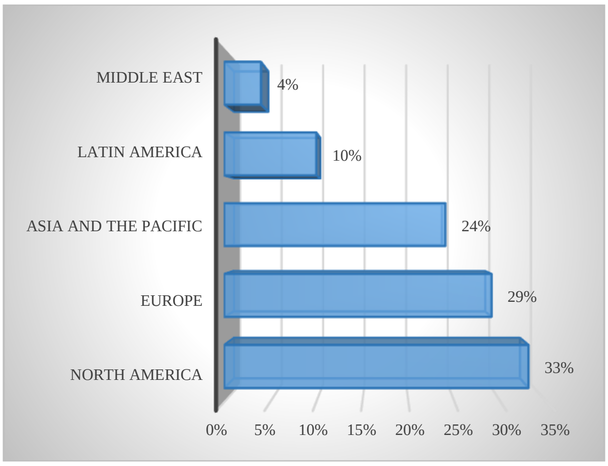


Fig. 2. The situation of the agrivoltaic systems market, by region, in 2021
Source: own processing [25].

If initially the approach to energy production and the use of agricultural land was thought of separately, raising the issue of the cost of decommissioning agricultural land for the purpose of installing photovoltaic panels and producing energy to be used both within the farm, as well as introduced in the centralized system, later Goetzeberg and Zastrow proposed a form of simultaneous use of agricultural land, at this time there were two systems, namely: the raising of fixed panels above the crops to allow either the work to be carried out in the case of vegetable crops, but also to ensure the natural conditions for their development (elevated to 4-5 meters), or to allow the passage of grazing animals under them, for example (elevated to 2 meters); the use of dynamic panels connected with trackers.

The height at which the photovoltaic panels can be mounted can vary depending on the culture, but they can also have a rotation system, depending on the position of the sun, so that both the capture efficiency and the plants' needs are ensured. What is important is that the panels use only the excess solar energy, and not the energy needed for crops.

The main parameters that must be taken into account when choosing agrivoltaic technology are presented in Table 1.

Table 1. The main development parameters of the agrivoltaic system

Indicator	Work	Recommendation
Shade Tolerance	The capacity of the plants regarding shade tolerance is important because this will influence the production obtained. The specialized works highlight the fact that the amount of light is important in the juvenile phase of crop development, and this can be compensated by the dynamic system of photovoltaic panels.	[2, 20, 26]
Water stress and irrigation	Since the shading system has a direct influence on the preservation of humidity, it is expected that the use of agrivoltaic technology will benefit crops that have higher water requirements or that do not have a high resistance to water stress.	[20, 33, 24]
Crop rotation	Crop rotation aims to preserve nutrients in the soil with the aim of increasing fertility, so that the crops can be as profitable as possible. The use of agrivoltaic technology must be done in accordance with crop rotation	[15, 29, 35]
Height	The height at which the photovoltaic panels can be mounted depends both on the culture or category of animals that ensure the symbiosis of the system's functioning, as well as on the applied technology. According to specialized literature, the heights at which photovoltaic panels can be mounted vary between 2-5 meters	[11, 28, 34]
Climate change resilience	Since climate changes are the ones that affect the obtaining of agricultural productions year after year, it follows that agrivoltaic systems can contribute to optimizing productions in the case of crops sensitive to these changes.	[16, 9, 27]
Lifetime	The lifetime of the photovoltaic panels must be adapted to the exploitation period of the crops. There are certain cultures, which have a long lifespan, such as fruit and wine plantations, therefore there must be a concordance between the two elements.	[1, 10, 3]

Source: own processing.

The main crops suitable for the use of agrivoltaic systems, as they resulted from the analysis of specialized works, are: cereals (wheat, corn, barley, oats, etc.), oilseeds (rapeseed, sunflower, etc.), vegetables (tomatoes, cucumbers, carrots, peppers, eggplant, salad, etc.), blackberry, raspberry, blueberry, etc., but also aromatic plants or pastures.

In Romania, the areas occupied by these crops are important. Thus, at the level of 2021, from a total area of 8,263.8 thousand cultivated hectares, the largest share is owned by cereals (65%), considering the specifics of production, but also the climate that favors obtaining high productions, oil plants (20 %) and perennial fodder (8%). There are also areas occupied by vegetables (2%), vines (2%) and leguminous plants (1%), which would make the adaptation of the agrivoltaic system at the level of agricultural farms suitable.

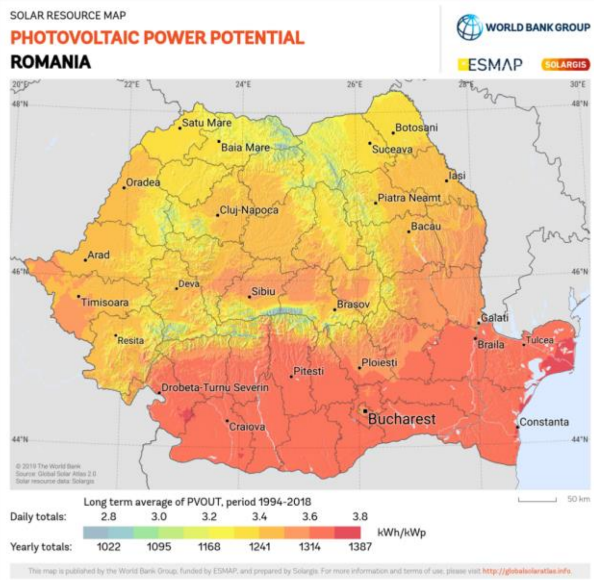
Table 2. Evolution of cultivated areas, which can be adapted to the agrivoltaic system in Romania (Thousand ha)

Culture	2020	2021	2022
Cereals - total	**5,338.1**	**5,351.5**	**5,190.0**
Wheat	2,155.3	2,175.1	2,144.0
Maize	2,537.1	2,549.3	2,472.0
Barley	442.0	449.4	415.0
Oat	101.3	87.0	80.0
Legumes - total	**107.4**	**84.9**	**77.0**
Beans	9.0	8.0	*
Green peas	98.1	76.6	*
Root	130.0	110.4	*
Potatoes	98.5	84.4	75.0
Oil plants - total	**1,678.8**	**1,715.4**	**1,687.0**
Sunflower	1,142.8	1,124.0	1,082.0
Rape	362.9	445.9	467.0
Vegetables - total	**200.5**	**197.7**	**172.0**
Tomato	34.1	34.7	*
Onion	29.2	29.3	*
Garlic	9.5	9.6	*
Cabbage	37.6	38.0	*
Pepper	17.2	18.3	*
Melons	13.8	13.1	*
Perennial fodder	**684.5**	**700.8**	*
Vineyard	**167.3**	**165.6**	**163.0**

Source: own processing [13, 14]
* lack of data

According to Romania's Energy Strategy 2022-2030, with the perspective of 2050, from the point of view of sunshine, it is in the European B zone (1,200-1,600 kWh/m^2 per year), due to the fact that it has approximately 210 sunny days/year, thus having the largest solar potential among the countries located in South-Eastern Europe. The lowest values are recorded at the level of the country in depression areas, and the highest values are recorded in the east of Bărăganu, in Dobrogea and in the south of Oltenia. This means that the solar technical potential registered at the level of Romania is 19.35 GW, i.e. 25.80TWh [23].

The photovoltaic power potential of Romania is presented in Map 1.



Map 1. Photovotaic Power Potential of Romania
Source: [7].

Capitalizing on this potential through the use of photovoltaic panels, with the aim of obtaining electricity, can be achieved by achieving a total capacity of 4,000 MW, which will annually produce energy with a value of 4.8 TWh.

Romanian legislation supported the installation of photovoltaic panels. Thus, Law 220/2008 established the support scheme for the period 2009-2016. On the other hand, there are also certain restrictions that result from the protection of some areas included in Natura 2000, but also from the restriction of the location of photovoltaic parks on agricultural land, these being limited to the location on unproductive or degraded land [17].

According to the data of the Statistical Yearbook, at the level of Romania, in 2022 the number of households that owned uncultivated agricultural land rose to 76,172 ha, which means that these surfaces could have such a destination.

In February 2022, the Land Fund Law no. 18/1991 was amended, adding an amendment whereby agricultural lands of the III, IV and V quality classes, which have the use category of arable land, pasture, vineyards and orchards, but also on those on which land improvement works are planned and which are located outside the village, different categories of production capacity can be located, including those for solar energy production, on the surface of a maximum of 50 ha. However, a building permit and a final removal approval are needed or Also, agricultural land areas located outside the village, with the exception of arable land, can be used in a dual system, being able to obtain both agricultural production and electricity. In these cases, however, removal from the agricultural circuit can be done only for the land surfaces occupied by the solar panels, the rest of the surface being integrated into the agricultural circuit. Therefore, although there is talk about this dual use, in Romania there is still no legal framework for the use of solar panels concomitant with the realization of agricultural production [18].

Under the conditions that, until 2030, from the total of 25,052 MW that Romania must ensure for its energy consumption, a share of 20.17% will come from solar energy sources, increasing compared to 2020 when it represented 7.18% and compared to 2025 when it is estimated that 3,393 MW from solar energy will be reached, i.e. 15.42% of the total, it follows that a development of agrivoltaic technologies is needed.

Table 3. Energy capacity of Romania (MW)

Source	2020	2025	2030
Solar energy	1,362	3,393	5,054
Total	18,968	22,003	25,052

Source: own processing [22].

Even if the legislation does not yet allow the full use of agrivoltaic technology in Romania, solar energy obtained within farms can contribute to providing the energy needed for irrigation systems, heating protected spaces, powering storage and refrigeration spaces, which can contribute to reducing electricity costs and increasing the profitability of agricultural activities

Studies show that according to Dupraz et al. an LER value of 1.7 means that a 100 ha farm with agrovoltaic panels can produce both electricity and agricultural production equivalent to a farm with an area of 170 ha [4].

Another study belonging to Valle highlighted the fact that in the case of the lettuce culture exploited in an agrivoltaic system, the LER index had a value greater than 1.5, which indicates the efficiency of the use of this technology [32]. In the case of the corn study, the LER index approached the value of 2 [2], and a study carried out in 2018 in Germany obtained an LER index with a value of 1.6 for an area of 2 ha cultivated with cereals and covered with photovoltaic panels in -a first variant, and 1.86 in variant 2 in which 1 ha was cultivated in an agrovoltaic system with potatoes [31].

CONCLUSIONS

The solution for the implementation of agrivoltaic systems was also supported by the fact that the land surfaces available to humanity are limited, which necessitated the finding of various combinations of electricity production, concomitant with the use of agricultural land. These systems not only revolutionize agriculture, but also contribute to obtaining non-polluting energy.

Among the disadvantages of photovoltaic systems are: the reduction of production due to the areas occupied by photovoltaic installations, the reduction of the possibilities of ensuring crop rotation, the still insufficient knowledge regarding the implementation of agrivoltaic systems, the costs still high at this moment for the installation of the systems, the lack of adapted legislative support the application of agrivoltaic systems.

The adoption of agrivoltaic systems could contribute to the transformation of agricultural farms from energy consumers to prosumers, thus reducing their expenses and contributing to increasing profits.

Among the advantages of photo-voltaic systems are: the reduction of pressure related to the use of agricultural land in conditions where there is no longer a need for these lands to change their destination, the protection of crops against weather phenomena (hail, heavy rains, frost, erosion, etc.), providing passive income to farmers that can contribute to their financial independence, etc.

In conclusion, agrivoltaic systems are a way of ensuring the synergy between food security, environmental security and energy security in the conditions of population growth and the continuous reduction of planetary resources.

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