Agrivoltaic systems: a contribution to sustainability*

Sistemas agrivoltaicos: una contribución a la sostenibilidad

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Abstract

In this scientometric article, an analysis was conducted to highlight how agrivoltaic systems represent an innovative solution to meet food and energy needs simultaneously. For the development of this study, two essential databases, Web of Science and Scopus, were utilized, both recognized for housing highly relevant and, often, novel research. These databases provided valuable information on how these systems improve food production and energy generation. The Tree of Science method was employed to filter the abundance of articles initially obtained from these databases, allowing their classification into root, trunk, and three main branches, each focused on key components of agrivoltaic systems. The findings were categorized into three main themes: advances in panel manufacturing, including improvements in their resistance to extreme conditions and the optimization of their orientation to better capture photons. These improvements also contribute to the increase in food and energy production. The second theme describes how innovation in agrivoltaic systems contributes to food and energy security, especially in regions with distinct climatic conditions and needs. Finally, the last theme describes how the use of algorithms and optimization technologies in the implementation of agrivoltaic systems contributes to maximizing both agricultural and energy production.

Keywords: Agrivoltaics, Renewable energies, Food production, Photovoltaic systems, Sustainability, Land use.

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Resumen

En este artículo cienciométrico, se realizó un análisis para resaltar cómo los sistemas agrivoltaicos representan una solución innovadora para satisfacer las necesidades alimentarias y energéticas simultáneamente. Para el desarrollo de este estudio se utilizaron dos bases de datos esenciales, Web of Science y Scopus, ambas reconocidas por albergar investigaciones altamente relevantes y, a menudo, novedosas. Estas bases de datos proporcionaron información valiosa sobre cómo estos sistemas mejoran la producción de alimentos y la generación de energía. Se empleó el método del Árbol de la Ciencia para filtrar la abundancia de artículos obtenidos inicialmente de estas bases de datos, permitiendo su clasificación en raíz, tronco y tres ramas principales, cada una centrada en componentes clave de los sistemas agrivoltaicos. Los hallazgos se clasificaron en tres temas principales: avances en la fabricación de paneles, incluidas mejoras en su resistencia a condiciones extremas y la optimización de su orientación para capturar mejor los fotones. Estas mejoras también contribuyen al aumento de la producción de alimentos y energía. El segundo tema describe cómo la innovación en los sistemas agrivoltaicos contribuye a la seguridad alimentaria y energética, especialmente en regiones con distintas condiciones y necesidades climáticas. Finalmente, el último tema describe cómo el uso de algoritmos y tecnologías de optimización en la implementación de sistemas agrivoltaicos contribuye a maximizar la producción tanto agrícola como energética.

Palabras clave: agrivoltaica, energías renovables, producción de alimentos, sistemas fotovoltaicos, sostenibilidad, uso del suelo.

1. Introduction

Over the last 10 years, population growth has increased by 10%, adding over 1 billion people, predominantly in Asia and Africa, as well as in countries like India, Pakistan, and Nigeria, which have incredibly high growth rates. This population surge generates significant demand for food and energy, which, in turn, exert tremendous pressure on natural resources. This situation highlights present challenges in achieving sustainable resource use. Consequently, the availability of land suitable for agriculture is shrinking as more space is allocated to urban and energy infrastructure, jeopardizing food security for the ever-growing population [1], [2].

Simultaneously, the transition to energy sources with a lower environmental impact presents a considerable challenge. One potential solution is energy production through solar panels[3], [4]. Meeting the energy demands of a city requires implementing solar farms; however, these facilities demand vast stretches of land with sunlight requirements that closely compete with agricultural needs.

In this context, agrivoltaic systems emerge as a highly promising alternative to address the increasing competition for land use effectively. These systems integrate solar energy generation with food production in the same space, enhancing both efficient land use and environmental sustainability [5], [6]. Various studies indicate that, in some regions, agrivoltaic systems improve land use by creating shade, which reduces water stress on crops and protects them from excessive solar radiation—a particularly useful feature in arid areas

[7]. Therefore, agrivoltaic systems not only optimize resource utilization but also represent a sustainable and viable option to tackle climate change challenges, contributing to a more adaptive and resilient development model [8].

The deployment of agrivoltaic installations is expanding, with examples worldwide demonstrating their agricultural and energy-related benefits. These systems significantly reduce the need for irrigation. In India, rural areas such as Maharashtra showcase farmers who supplement their income by simultaneously cultivating crops and producing solar energy. This approach helps supply food and clean energy as demand grows [9]. These projects illustrate that combining agriculture with solar energy can address local challenges such as water conservation, energy generation, and increasing rural income—critical in tackling issues related to agriculture and energy use [10].

Dupraz et al. [5] examine the potential of agrivoltaic systems but only briefly address recent technological advances or the optimization of bifacial panels for areas with diverse climatic patterns. It also explores new ideas and future possibilities. In contrast, the present article not only reviews research up to 2024 but also employs a scientometric methodology to identify impactful trends and classifies studies using the Tree of Science (ToS) model [11], encompassing recent innovations and future projections.

The objective of this article is to highlight the importance of agrivoltaic systems and their advantages as a sustainable method that integrates clean energy production through solar panels with agriculture. These systems are increasingly relevant in the context of energy and agricultural sustainability, offering a solution to land-use competition between clean energy production and agriculture. The main databases used in the exhaustive search for documents that strengthen this article are Web of Science (WoS) and Scopus. This strategy, which has been increasingly adopted in the academic environment, is among the most current in the system [12]and aims to be more efficient in identifying significant articles.

Current research is categorized into three branches. The first branch focuses on technology and innovation related to photovoltaic systems, aiming to optimize the conversion of sunlight into clean energy. The second branch addresses the geopositioning of systems, considering environmental factors to meet the demand for both food and clean energy. Lastly, the third branch emphasizes the market, using algorithms to enhance system availability and improve productivity.

This article provides a broad overview of the current benefits of agrivoltaics. Through a scientometric and bibliographic review, the article presents the key advancements, benefits, and challenges in this field, highlighting relevant research that addresses economic and environmental aspects as well as land-use efficiency. Additionally, the use of the ToS algorithm enables the classification of articles into roots, trunks, and branches, offering a theoretical framework to understand the development of academic contributions.

2. Methodology

In the preparation of this article, two databases were used, allowing us to gather significant and detailed information on agrivoltaic systems. The two databases utilized were Scopus and WoS. Subsequently, the ToS method was employed to filter the articles obtained from these databases, aiming to consolidate the information collected. The focus was on optimizing land use through agrivoltaic systems, which utilize the same space to implement two distinct systems: agriculture and photovoltaic systems. This approach addresses the increasing demand for food and energy caused by rapid population growth and urban expansion.

The search strategy included the use of key terms such as "agrivoltaics," "agriculture," and "renewable energy" in article titles (see Table I), which enabled the identification of a broad range of studies centered on the intersection of agriculture and renewable energy. The search spanned publications from 1971 to the present, aiming to capture the historical evolution and, where possible, identify current trends in this field, reflecting the increasing interest in agrivoltaic sustainability. This is according to the new trends in scientometric research [13], [14], [15], [16], [17].

Table I. Parameter

Parameter	Web of Science	Scopus
Range	1971	2024
Date	November 1, 2024	
Document Type	articles	
Words	"agrivoltaics" OR "agrovoltaic systems" OR "agro-photovoltaics" OR "agrivoltaic technology" OR "agricultural photovoltaics" OR "dual land use for agriculture and solar power" OR "solar energy in agriculture" OR "agricultural solar power"	
Results	208	428
Total (Wos+Scopus)	440	

As a result of this search, 208 articles were initially identified in the WoS database and 428 in Scopus. However, to enhance the precision of the dataset and ensure the relevance of the selected articles, the ToS tool was employed [18]. ToS facilitated the removal of duplicate articles and identified documents that appeared to be the most influential in the field, generating a consolidated Excel file. Following a thorough review, the dataset was refined to 441 unique articles. ToS algorithm is well-known and applied in academic research [19], [20], [21].

After conducting the search and selecting the relevant articles, comprehensive information about the documents was obtained. This information included the title, authors, abstract, keywords, references, cross-references, and DOI. Figure 1 illustrates the process of conducting a systematic literature review to apply the ToS algorithm.

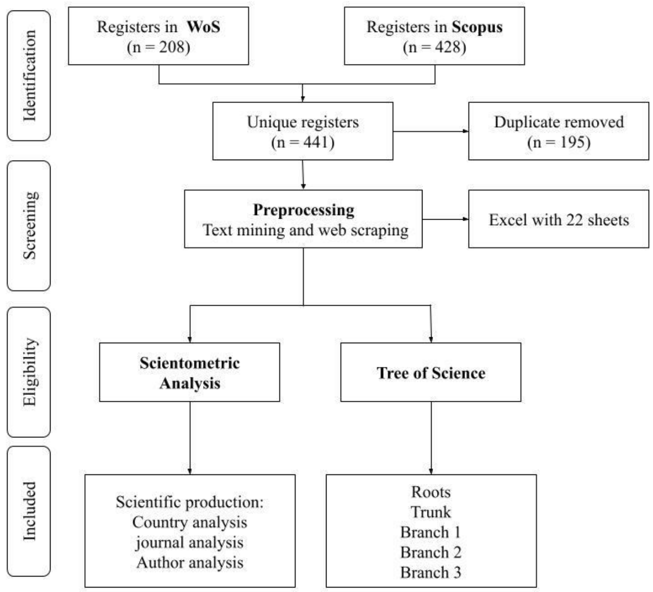

Figure 1. Detailed illustration of collected information.

Scientometric Analysis

➢ Scientific production

Figure 2 illustrates the total production of scientific articles published and cited on the topic of agrivoltaic systems from 2015 to 2024. This figure provides a detailed breakdown of the number of articles published during this period in both WoS and Scopus, as well as their corresponding citations. The purpose of this analysis is to present relevant insights into the trajectory of each published article. The figure also highlights the annual sum of published articles and provides important information regarding the variety and number of citations recorded each year. Specifically, the orange bars represent the number of articles published in WoS, while the green bars show publications in Scopus. The red line depicts the total sum of articles published per year, whereas the purple line indicates the annual citation count for these articles. The overall growth in publications and citations during this period is 61.20%, underscoring the increasing significance of agrivoltaic systems in scientific research.

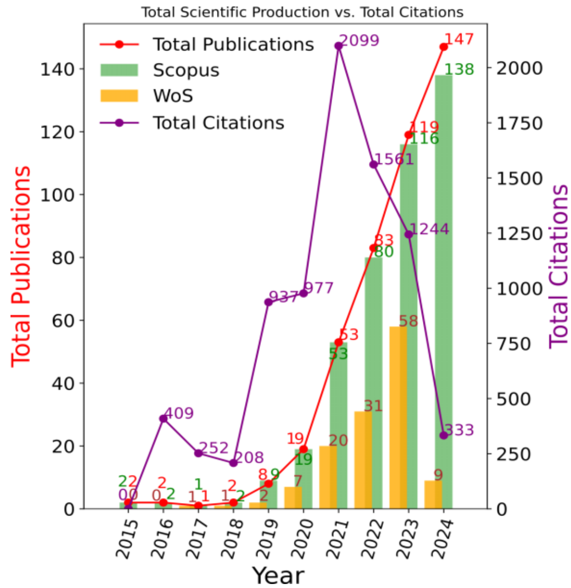

Figure 2: Scientific article and citation

Period 1: Start (2015-2020) 56.87%

This period, from 2015 to 2020, is characterized by a 56.87% growth in citations. It is notable that during this period, from the beginning of publications in Scopus (the only database with records dating back to 2015), scientific production was very scarce between 2015 and 2018. However, the research published during this time was highly relevant in terms of citations. Two of the most prominent contributors during this period are Dinesh & Pearce, whose study on agrivoltaic systems addressed the growing global demand for food. Their research demonstrated that lands equipped with these systems could increase their value by 30% without losing agricultural productivity. This was particularly evident in crops such as lettuce, which are tolerant to shade [18].

Period 2: Accelerated Growth (2021-2024) 40.50%

This second period, from 2021 to 2024, saw an accelerated peak in citations, reaching a 40.50% increase, the highest recorded in terms of citations received. The latest article by Barron-Gafford et al. discusses how agrivoltaic systems implemented in arid regions can maximize agricultural production, optimize land use, reduce water consumption, and enhance the efficiency of solar panels. The study found that agricultural productivity increased due to reduced water usage, with greater moisture retention promoting growth in crops such as cherry tomatoes and chiltepin peppers. Additionally, the operation of solar panels at lower temperatures further boosted their efficiency [22].

Country Analysis

Table 2 presents the scientific output of 10 countries on agrivoltaic systems, along with impact metrics (measured by citations) and quality (measured by Scimago quartiles). The country with the highest productivity is the USA, contributing 20.23% of the total output, followed by Germany with 8.14%. Notably, the USA's production surpasses Germany's by approximately 12.09%, establishing the USA as the leading contributor. In terms of impact, measured through citations, the USA also dominates, with a significantly larger margin of 29.42% over Germany, exceeding the difference observed in productivity. Regarding quality, in Q1 journals, the USA outperforms China with a ratio of approximately 2.26:1 and Germany with a ratio of 13:5. In Q2, Q3, and Q4 quartiles, the three countries share notable similarities, reflecting a more balanced contribution. The USA stands out prominently in quantity, quality, and impact, positioning itself as the principal research hub in this analysis. Germany and China also play significant roles, though with different focuses: Germany demonstrates strong influence in citations, while China shows notable growth in Q1 outputs. In Europe, there is a prominent presence of several countries—Germany, Spain, Italy, Belgium, and France—highlighting the region's inherent potential and interest in agrivoltaic systems. Similarly, Asia is notable for its expansion of high-quality research contributions. The high concentration of Q1 quality output among a few countries underscores their access to resources and top-tier journals. However, the diversity observed in lower quartiles suggests a growing global scientific ecosystem, reflecting broader engagement with agrivoltaic research worldwide.

Table II. Countries

Country	Production		Citation		Q1	Q2	Q3	Q4
Usa	87	20.23%	2122	39.46%	52	4	1	1
Germany	35	8.14%	540	10.04%	20	2	1	0
China	30	6.98%	168	3.12%	23	2	2	0
Spain	28	6.51%	192	3.57%	17	2	2	3
Italy	24	5.58%	297	5.52%	9	2	0	2
Canadá	18	4.19%	150	2.79%	8	3	0	0
India	14	3.26%	91	1.69%	4	2	2	0
Belgium	13	3.02%	100	1.86%	9	0	0	1
Japan	13	3.02%	89	1.66%	7	0	1	1
France	11	2.56%	87	1.62%	5	0	0	1

One of the most recent articles from the USA is by Professor Sturchio et al. [23], which analyzes how photovoltaic solar panel installations modify the environment in which plants grow, particularly in arid regions. The study highlights how shadow modifications affect water distribution in crops, a crucial factor for understanding these interactions when implementing agrivoltaic systems. From Germany, the most recent article explores how agrivoltaic technology can help address complex problems in developing countries. It emphasizes the potential contributions of these systems to achieving sustainable development goals, particularly in areas related to food security, climate change, and clean energy [24]. Meanwhile, the latest article from China examines how agrivoltaic systems impact small-scale farmers. It underscores their potential to increase energy production and promote efficient land use. However, the study also highlights significant challenges, such as adapting to this new technology, accessibility issues, and limited government support, which could hinder proper implementation in small or rural farming communities [25].

In the collaboration network, two major groups led by the USA and China can be observed, where studies in this area focus on creating an evaluation framework to locate electricity generation projects through solar panels, in order to reduce land-use conflicts in Taiwan. Geographic Information Systems (GIS) are implemented, along with local community participation through surveys and workshops to integrate concerns and perspectives based on the GIS data from local stakeholders, helping to achieve national energy goals without severely impacting the local environment [26]. France and Italy stand out in collaborations related to research on semi-transparent perovskite-based panel technologies. These studies focus on creating flexible cells, highlighting their potential applications due to their mechanical resistance [27].

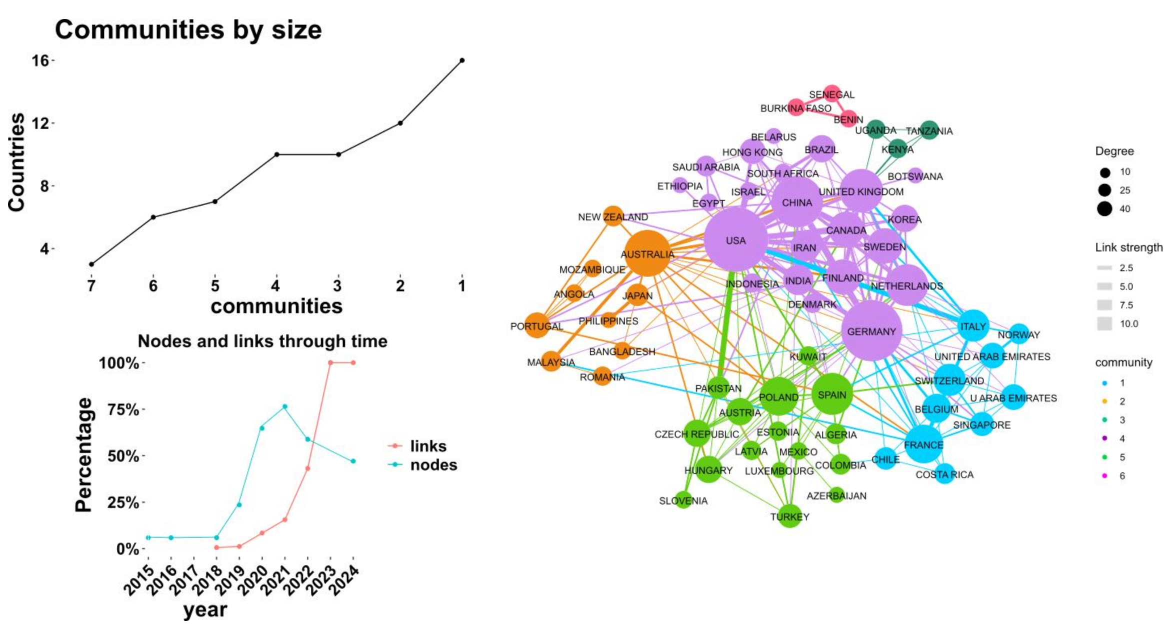

Figure 3: Scientific collaboration between countries

Journal Analysis

In Table III, the top 10 journals with the most publications on agrivoltaic system technology are shown, with Applied Energy leading in publications, having published around 63 articles, of which 31 were in WoS and 32 in Scopus. It has an impact factor of 2.82 and an h-index of 292, with all articles being Q1 publications. One of the articles published in this journal is [28], which provides information about the contribution to sustainability through agrivoltaic systems. Next is Renewable Energy, with a total of 29 articles published, 14 in WoS and 15 in Scopus, an impact factor of 1.923, and an h-index of 250, all Q1 articles. One of the articles emphasizes the importance of agrivoltaic systems due to their space utilization [29]. These important articles raise awareness about the importance of investing in sustainability due to the high population growth.

Tabla III. Journals

Journal	WoS	Scopus	Impact Factor	H Index	Quantile
Applied Energy	31	32	2.82	292	Q1
Aip Conference Proceedings	0	25	0.152	83	-
Renewable Energy	14	15	1.923	250	Q1
Conference Record Of The Ieee Photovoltaic Specialists Conference	0	14	0.294	66	-
Renewable And Sustainable Energy Reviews	0	14	3.596	421	Q1
Energies	9	12	0.651	152	Q1
Sustainability (Switzerland)	0	12	0.672	169	Q1
Agronomy	0	10	0.688	91	Q1
Journal Of Cleaner Production	10	10	2.058	309	Q1
Solar Energy	8	9	1.311	224	Q1

Figure 4 shows the citation network among journals, highlighting the three main groups. The first group stands out for studies related to clean production, sustainability, and agricultural systems, implementing agrivoltaic systems [30]; [31]. The second group emphasizes the connection closely linked to topics of sustainability, clean production, and agrivoltaic technologies, where high collaboration with the first group is notable [32];[33]. Lastly, the green group focuses on strengthening this community by addressing key issues related to energy transition and the implementation of dual land-use systems [34];[35].

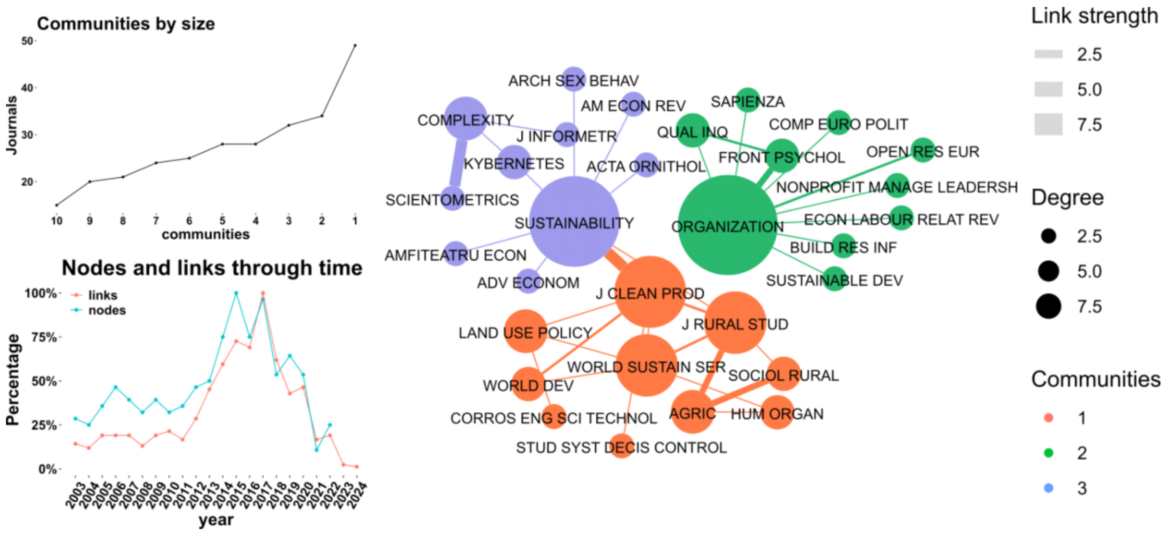

Figure 4. Red de citaciones de revistas.

Author Collaboration Network

In Table 4, the 20 most important researchers who have contributed and published articles on agrivoltaics are shown, providing solid information about these systems. The number of published articles, h-index in Scopus, and institutional affiliation are also included. One of the most prominent researchers in the field of agrivoltaics is Pearce, J., who has published a total of 20 articles related to agrivoltaics, with an h-index of 68. He is affiliated with Western University in London, Canada. In one of his articles, Pearce provides detailed information on the issues related to land use due to the growing expansion of photovoltaic systems [32]. Professor Stathatos, with 6 publications on agrivoltaic systems and an h-index of 39, presents one of the revolutionary panels for agrivoltaic systems [36], providing detailed information on the importance and quality of these semi-transparent panels for agrivoltaics.

Table IV. Production By Author

No	Researcher	Total Articles*	Scopus-Index	Affiliation
1	PEARCE J	20	68	Western University, London, Canada
2	WILLOCKX B	10	6	KU Leuven., Leuven, Belgium
3	CAPPELLE J	10	10	KU Leuven, Leuven, Belgium
4	TROMMSDORFF M	9	9	Fraunhofer Institute for Solar Energy Systems ISE, Freiburg im Breisgau, Germany
5	LIU W	9	20	University of Science and Technology of China, Hefei, China
6	MACKNICK J	8	29	National Renewable Energy Laboratory, Golden, United States
7	LAVAERT C	8	5	KU Leuven, Leuven, Belgium
8	ZHANG X	7	12	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
9	HIGGINS C	7	25	Oregon State University, Corvallis, United States
10	BUTT N	7	17	Lahore University of Management Sciences, Lahore, Pakistan
11	STATHATOS E	6	39	University of the Peloponnese, Tripolis, Greece
12	LÓPEZ-LUQUE R	6	24	Universidad de Córdoba , Córdoba, Spain
13	LIU Y	6	37	P.C. Rossin College of Engineering & Applied Science, Bethlehem, United States
14	JAMIL U	6	4	Western University, London, Canada
15	HAYIBO K	6	8	Western University, London, Canada
16	CHALKIAS D	6	12	University of the Peloponnese, Tripolis, Greece
27	BARRON-GAFFORD G	6	41	Info The University of Arizona, Tucson, United States
18	JORDAN M	5	41	U.S. Department of Veterans Affairs, Washington, D.C., United States
19	HÖGY P	5	35	Universität Hohenheim , Stuttgart, Germany
20	FEUERBACHER A	5	8	Universität Hohenheim , Stuttgart, Germany

Figgure 5 shows a series of nodes representing groups of authors, which in turn are part of a collaboration network among authors of articles published in the field of agrovoltaic systems. It can also be noted that these groups are quite divided and specifically small. However, it can be observed that among these small groups, two stand out due to their collaboration links: one is the violet group formed by Professor Ricard Espelt, and the other is the blue group formed by Professor Francisca Castilla-Polo, who exhibit greater collaboration richness.

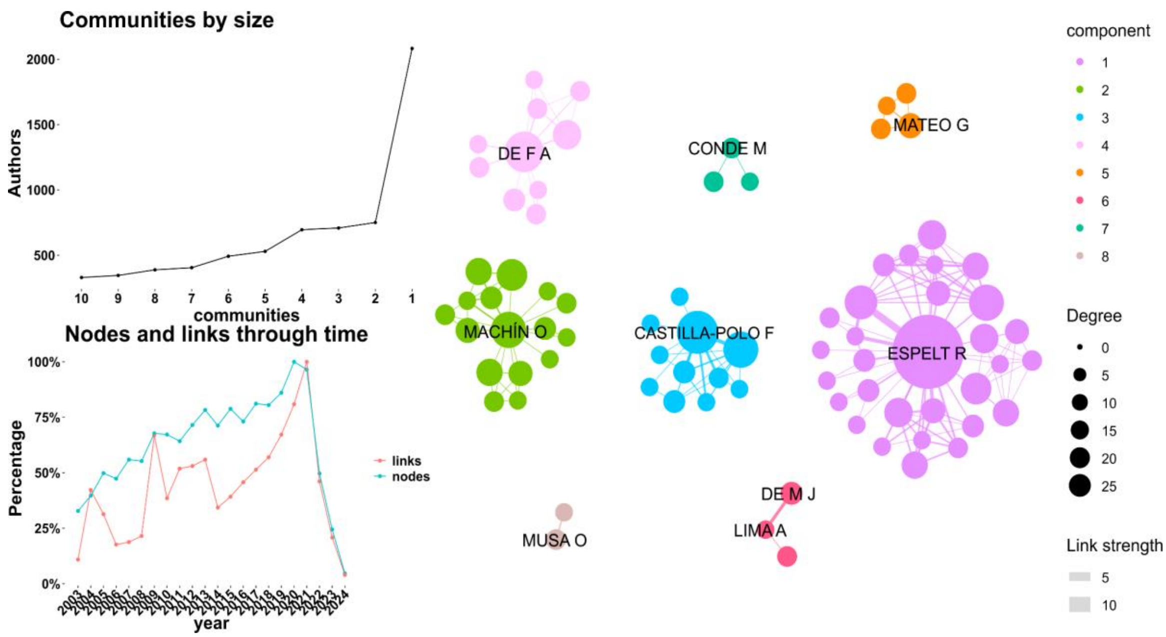

Figure 5. Groups of authors

Figure 6 illustrates the configuration of the referenced items sequentially, formatted into three main segments that constitute the central framework of the research. Each branch represents a specific proportion in the scope of the research: branch 1 covers 40.79%, branch 2 covers 37.75%, and branch 3 covers 21.46%. Additionally, a distinct terminology cloud was designed for each division, which facilitates the visualization of the main topics discussed within it.

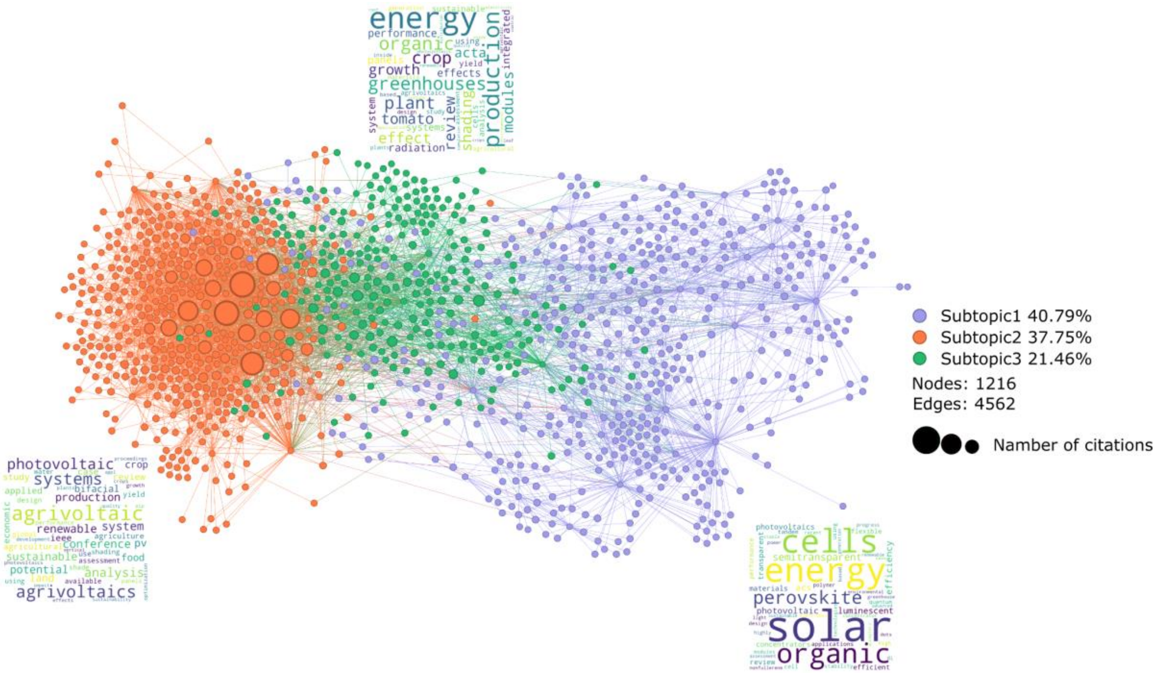

Figure 6: Citation network and word cloud analysis

3. Results

Tree of Science

Root

Agrivoltaic systems combine photovoltaic energy and agriculture in the same context, exploring strategies for efficient land use. [5]conducted studies where, in addition to the energy production from photovoltaic panels, they create a microclimate that helps reduce water stress in agricultural production. One example is the case of lettuce cultivation, where the microclimate generated by the photovoltaic panels results in a desirable outcome in more arid climates, such as the Mediterranean, where photovoltaic system production is abundant. Studies have shown that these systems not only optimize food and energy production but also help conserve water in dry environments [22]. This combination proves to be very effective in acting as a protective shade in areas of high solar radiation.

On the socioeconomic side, agrivoltaic systems contribute to improved crop production while also generating energy from solar radiation, a critical advantage in areas where access to energy is challenging. Additionally, these systems optimize land use by transforming it into dual-production zones, which is especially important in regions with limited space and resources [10]. Agrivoltaic systems emerge as a relevant option for mitigating the ecological impact of energy and agricultural production while helping regions conserve water through the creation of microclimates in the implementation areas [1].

Trunk

Currently, agrivoltaic generation systems are in a favorable spotlight, especially in areas with space limitations, as they enable the combination of electricity generation through sunlight, a source that is environmentally friendly [30].

The integration of technologies such as bifacial solar panels has also shown promising results. These are dual-sided solar cells that allow light absorption from both sides, which is highly useful for minimizing energy loss due to the sun's movement over time. Katsikogiannis et al. [37] demonstrated that these panels not only increase energy generation but also protect crops from excessive radiation, enhancing their growth.

In urban areas, [38]highlighted the potential of adapting rooftops and other infrastructures to implement agrivoltaics, benefiting densely populated cities like Mumbai and Beijing. Finally, Jones et al. [39]emphasized the need for public policies that promote their adoption, ensuring efficient resource use and a positive impact on vulnerable communities.

Branch 1 - Network

With the rapid advancement of semitransparent solar cells, new opportunities for use in agriculture are opening up. [18]highlights that the degree of transparency affects how light passes through. Perovskite-based cells are among the best materials for manufacturing and implementing these systems.

Eco-friendly technologies are increasingly gaining ground in agrovoltaic systems, envisioning a cleaner and more efficient future. Organic photovoltaic energy stands out for its versatility in sizes and shapes, but most importantly, it is made with environmentally friendly materials. This is crucial in residential and ecological areas. Additionally, being organic has its advantage: it absorbs less solar radiation, allowing the plants beneath to receive more light [40].

The diversity of designs in these systems is a major strength, as they can be adapted to the unique characteristics of the environment and focus on energy or food production as needed [41].

Branch 2 - Innovación

The efficient production of energy and food through agrivoltaic systems has already been implemented in various countries. [42]presents how these systems have been implemented in Jordan, primarily due to its water issues, as the climate is mostly arid, making agrivoltaics highly impactful and beneficial for the region. By creating a microclimate through agrivoltaic systems, water consumption reduction becomes more noticeable. [43]also shows that these systems enable balanced sustainability and production of clean energy and food.

In arid regions, there is a wide range of challenges when it comes to implementing the widespread use of these systems, especially in rural areas where access to water and energy is very difficult. Ideas have been proposed to achieve first-hand government participation to facilitate their implementation [44]. In Southeast Asia, it can be observed how the use of these systems, combined with agroforestry—a productive system that integrates trees, livestock, and pasture into a single productive unit—strengthens the agricultural and energy sustainability of the region of origin [45]

Also, a recent study by [46]demonstrates the reliability generated by the implementation of these systems in Bangladesh, highlighting the benefits in food production and clean energy generation. It also emphasizes how the use of new technologies helps optimize land use, while also addressing the financial and technical challenges faced when implementing agrovoltaic systems.

Branch 3 - Emerging Markets

Agroviltaics has the great potential to optimize both agriculture and photovoltaic energy production using the same land. The recent article by [47]provides a tool that models the shadow created by semi-transparent panels, allowing for a better understanding of where to position these panels to achieve the highest efficiency in both crop yields and energy production.

Additionally, [48]in their recent article presents that these panels not only allow for clean energy generation but, being translucent, they facilitate photon transfer, which enhances soybean crop growth and strengthens their stems without compromising the quality of their fruits. This suggests that for clean energy production, it is not necessary to sacrifice crop quality.

[49]discusses in its article the potential impact that the distribution of solar panels can have on certain crops, such as tomatoes. Asa'a et al. [50] further explore the optical properties of crystalline silicon panels, emphasizing the importance of their distribution for optimizing crop growth. It seems that the key lies in the design of these integrated systems.

Conclusions

The primary purpose of this article is to detail agrivoltaic systems through scientometric analysis, highlighting their importance in a growing population context. Agrivoltaic systems combine two distinct systems in the same space: photovoltaics and agriculture. This is a good practice to meet energy and food needs. In searching for documents to support this article, two of the most important current databases, Web of Science and Scopus, were used, as well as the Tree of Science technology to filter information. This system helps compile and organize the most important articles, eliminating duplicates and creating a single Excel file to facilitate the study and grouping of information.

A collection of articles was made that visually displays a timeline of references, helping to understand the significance of each article within the scope of solar agriculture. This illustrates the importance of agrivoltaic systems worldwide, showing how they are used in different countries and how they differ. These articles demonstrate that this technology helps farmers earn more money and make better use of their land. The dissemination of documents in the reference field allows us to detect patterns in the field. Some research aims to improve these systems to achieve the highest energy and food output, while others seek to adjust the technology to different climates and cultures.

Regarding emerging trends, the research on agrivoltaic systems analyzed through the ToS algorithms indicates that they are focusing on three main branches: technological innovation in photovoltaic materials, adaptation to different climatic and geographic contexts, and optimization of dual production (energy and agriculture). In the first branch, the research focuses on the development of transparent photovoltaic cells made from inorganic and organic materials that not only generate energy but also allow the proper passage of light for crops. In the second branch, studies emphasize the importance of adapting these systems to the climatic and cultural conditions of different regions, such as Africa and Asia, where efforts are being made to achieve a balance between agricultural production needs and clean energy generation. Finally, in the third and last branch of emerging markets, studies show a growing interest in applying algorithms to optimize the dispersion of solar panels and maximize dual production. These trends reflect the evolution of these systems towards more efficient and adaptable systems that can be effectively integrated into the various socio-economic and environmental realities of today’s society.

This study presents certain limitations that should be considered. First, the scope of the literary review of articles was based solely on articles obtained from the Scopus and WoS databases. While this allowed for extensive coverage, it also limits the inclusion of research that may be present in other databases or in non-indexed publications. Additionally, the methodology used, specifically the ToS algorithm, facilitated the filtering and organization of the selected articles, but this algorithmic approach may have excluded emerging studies or lower-impact articles that could offer innovative perspectives on agrivoltaic systems. Finally, the analysis did not consider in detail the impact of these systems across all geographic regions, so the results and conclusions may not be applicable to areas with significantly different agricultural or climatic characteristics.

Based on the identified limitations, several recommendations for future research in the field of agrivoltaic systems are suggested. First, it would be helpful to expand the reviewed database and include studies from diverse disciplines that could enrich the understanding of the topic from ecological, economic, and public policy perspectives. Furthermore, long-term experimental studies are recommended to assess the performance of different crop types under various solar panel configurations and in diverse climatic conditions, which would contribute to optimizing the design of these systems based on regional context. Finally, future studies should focus on the socio-economic impact of these systems in rural communities, considering factors such as social acceptance, implementation costs, and economic benefits for local populations, key aspects to ensure the feasibility and success of agrivoltaic systems in different contexts.

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