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Review

Worldwide Research Trends in Agrivoltaic Systems—A Bibliometric Review

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Abstract: An agrovoltaic system combines agricultural crop production and energy production in the same place, emphasizing the dual use of land. This article provides a bibliometric analysis of agrivoltaic topics based on publications indexed in SCOPUS, in which either economic assessments of agrivoltaics, agrivoltaic systems for crops and livestock animals, photovoltaic greenhouse and agrivoltaics with open field are discussed, or its ideas are used to analyze certain locations. A bibliometric analysis was conducted using the SCOPUS database. Multiple bibliometric tools, such as R Studio and Biblioshiny, were applied to analyze data for this study. Finally, 121 relevant articles were obtained and reviewed. The results show that the focus topic is a brand-new research area, with the majority of relevant scientific publications concentrated in the last three years, and with much ongoing research. This is why AV-specialized scientific conferences might be the best place to get relevant and up-to-date information, with the highest number being offered in the USA and China. A typical trend in recent years has been researched, focusing on different agricultural aspects. The research results show that scientific publications in recent years mainly focus on short-term predictions, there is no recognized evaluation standard for various prediction analyses, and it is difficult to evaluate various prediction methods so far.

Keywords: APV; agrophotovoltaics; trend; thematic map; correspondence analysis; solar farming; SLR

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1. Introduction

According to preliminary assessments of the United Nations Task Team for the Global Crisis Response Group14, two-plus years of the COVID-19 pandemic and the Ukrainian war's impact on food, energy, global commodity, inflation and financial markets have led to a sharp increase in food and energy prices. In addition, the unfolding impacts of climate change and resulting reduction in the yield of upcoming crops means consequently, a lack of food and energy insecurity are growing rapidly around the world [1,2]. Agrivoltaic (AV) systems can be a solution to the issues between food and energy with the category agricultural 5.0, as they apply power resources to provide agriculture production, including facility gardening, facility breeding and characteristic pastoral construction, making "farming + power generation + agricultural production activities" a new mode of production [3–7].

There has been discussion around the concept of agrivoltaic (AV) since 1980 [8,9], although this concept was rarely discussed until the beginning of the new millennium. In fact, as early as the 1960s, relevant research groups in Britain, France, India, Portugal and the United States carried out research on the application of solar energy in agriculture, including agricultural products and wood drying, air conditioning in breeding sheds, etc. [10]. With the emergence of photovoltaic technology, the application of agrivoltaic has gradually attracted attention. In 1975, the first photovoltaic water pump was launched, which opened the process of combining photovoltaic technology and agriculture [11]. After that, the applications of photovoltaics in agriculture have gradually shown a diversified trend, from the initial agricultural irrigation to the current lighting, ventilation, agricultural machinery, agricultural automation and agricultural robots [12,13].

Land use efficiency is a key factor restricting the coordinated development of the photovoltaic and agricultural industries [14,15]. Hassanpour Adeh et al. [16] quantified the effects of the presence of solar panels in AV systems on microclimatology, soil moisture, water use and biomass productivity in a given area. The researchers also observed significant differences in average air temperature, relative humidity, wind speed, wind direction and soil moisture. AV can realize the combination of some beneficial resources, promote the development of agriculture through various forces, and improve the utilization efficiency of various resources, e.g. by installing the PV panels to heights 2-5 m to allow agricultural activities underneath [17], as shown in Figure 1. In AV systems, crop and electricity production is located on the same land and can potentially facilitate competition for land [4]. A study conducted in India shows the importance of AV and the potential of this technology. According to [18], the results showed that for grape crops, food yields in India may be sustained while economic value of agriculture productions using proposed AVSs could increase more than 15 times annually, compared to traditional agriculture.

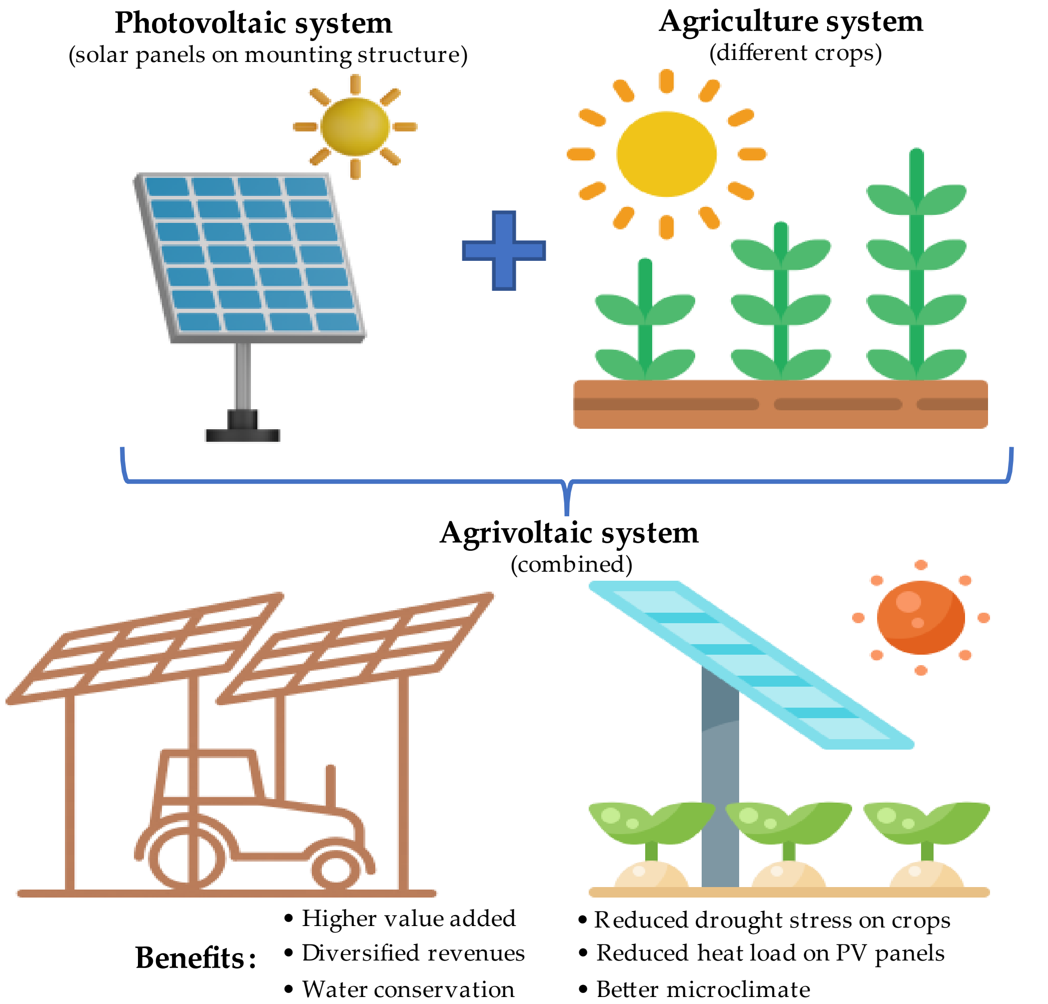

Figure 1. Comparison diagram of Agrivoltaic system and PV systems on the same agricultural land. Source: created by the authors.

Experiments on the technology are ongoing. Agrivoltaic system design began as a global project practice [19], and more than 2200 AV systems have been installed worldwide since 2014, resulting in a capacity of around 2.8 GW as of January 2020 [20]. Several years ago, the mainstream AV philosophy prioritized agricultural production. Studies dealing with AV systems are mainly focused on modelling [21–24], integration of energy and crop production [4,25], and the quantification of achievable results started after 2010 and accelerated since 2020. In recent years, assessments of the agricultural productivity of horticulture such as kiwifruit vines [26,27], apple [28,29], pear [30,31], wine grape [18,20] and other horticultural crops like tomato, cucumber, sweet pepper [32], chiltepin pepper and cherry tomato [33] in combination with AV have also been written, but data are quite limited. Additionally, several crops like potatoes, celeriac, winter wheat and grass clover [6,20,34,35], lettuce [25], and corn [36] have been evaluated for their suitability for growth under the AV system. These limited studies have shown inconsistent results induced by PV panel shading on yields of various crops. There may be a decrease in crop yields up to 20% [6,25] under unrestricted conditions, even with a slight increase of yield in hot and dry weather conditions, reduced soil and air temperature under AV. Zisis et al. [37] studied pepper plant (Capsicum annuum) cultivated under shading of the OPV panels with 2.1% efficiency and transparency of up to 19.4%; covering 22% of the Mediterranean greenhouse roof showed better performance than mass fruit. Moreda et al. [38] examined nine different vegetables in European conditions; however, it can be stated that weather in the given year significantly affected yields. Research on AV's effect on agricultural productivity has been conducted by [18,24,25,33,36,39–43]. Fu et al. [44] constructed an energy meteorology and agrometeorology model for the influences of weather and the means of safe and economic operation of park-level agricultural energy network, and used this model to calculate low temperatures and continuous cloudy days as well as causes of damage to agriculture productions and energy systems, reflecting the direct impacts of PV and weather conditions on the facility agricultural power load, and that both the facility agriculture environment and PV power are sensitive to weather conditions. Maia et al. [45] examined that land use for grazing livestock and electricity production under PV systems can be produced simultaneously from the same land. Their measurement also demonstrated that more than 70% of sheep's grazing activity took place in shade from photovoltaic panels when solar radiation was equal to or greater than 800 W/m^2. Consequently, electric power of 5.19 MWh was generated while reducing GHG emissions by 2.77 tons/year. In economic terms, this is equivalent to saving $740 (USD) per year. According to another study [46], comparable spring lamb growth and liveweight production per hectare were the same in both solar pastures and open pasture fields with no PV panels. Agrivoltaics (Agri-PV) in livestock grazing could provide 20% of total electricity generation in the United States. This percentage rose to 96% for its ruminating and idling activities [47]. Ma (2022) [48] improved agrivoltaics installations for greenhouses LCOE model by analyzing the carbon emission benefits in different regions (north Sweden, south Sweden and Spain). The sensitivity analysis and calculation of the influencing factors of LCOE showed that the power generation was most sensitive to the cost of electricity; the other influencing factors, ranked from high to low, were discount rate, unit cost, loan interest rate, component decay rate. In terms of carbon reduction, AV systems reduce CO_2 emissions by 20–55%, which reduces CO_2 emissions by 10–28 tones over a lifetime. High electricity prices in Spain increase the available LCOE for AV systems. Andalusia's thermal energy accounts for 45% of electricity, which leads to a high emission factor. Installing agrivoltaic systems in Almería can significantly reduce carbon emissions. In scenario 1, electricity is mainly generated from photovoltaic solar panels and batteries in north Sweden. It is found that the greater the solar energy production, the higher the emission, which the systems increase by 4–16%, rather than decrease. In addition to technical and economic considerations, the main problem is the negative reduction of carbon emissions. Taking electricity off the grid results in less CO_2 emissions than solar power. It is not practical to install AV systems at Hällnäs until the KPI targets are close to being achieved. Without limiting the available area for installation, installing PV panels and battery systems on the greenhouse roof and open field in south Sweden has better technical, economic and environmental performance than scenario 1. In scenario 2, solar fraction covers 19%, resulting in LCOE of 0.78 cents/kWh and 5% reduction in carbon emission, whereas for scenario 1, the optimal system has 13% of solar share, 0.78 cents/kWh of LCOE and 4% of carbon reduction. Fu et al. [49] proposed a new method for optimizing the interaction between photovoltaic load control systems in greenhouses and rural energy systems. The authors found that by using the proposed optimization method, 3996 m^2 greenhouse with PV coverage ratio of 25% can save 15% on electricity cost.

In their comprehensive research, Barron-Gafford et al. [33] cite agrivoltaic systems as one of the solutions to the vulnerability of food, energy and water systems, which could be of great importance in aligning renewable energy and food production, and building resilience in these areas. In this article, the authors have used an integrative approach to investigate microclimatic conditions in agrivoltaic systems, PV panel temperatures, soil moisture and irrigation water use, crop ecophysiology and crop biomass production compared to conventional PV installations and agricultural production. They found that shading PV panels has multiple additive and synergistic benefits, including reduced drought stress on crops, increased food production and reduced heat load on PV panels. All of these have the potential to contribute to increasing the resilience of food and energy systems in order to mitigate the effects of increasing environmental stress, temperatures and frequency of droughts.

Accordingly, review publications on the subject have also been published in the last ten years. In a study by Dinesh-Pearce [3], the authors reviewed the results of agrivoltaic experiments and developed a coupled simulation model for the integration of PV production and agricultural crop production to assess the technical feasibility of scaling up agrivoltaic systems. The results show that the value of solar energy production coupled with shade-tolerant crop production has led to an economic value increase of more than 30% on farms using agrivoltaic systems instead of conventional agriculture. The use of shade-tolerant crops makes it possible to minimize crop losses and, thus, the associated economic losses. In addition, the combined dual use of agricultural land can significantly impact photovoltaic energy production, even at the national level. At the same time, the authors emphasize that further work in this area is needed, both to evaluate the influence of climatic and other spatial conditions and to investigate the potential for cultivating different crop species. Mamun et al. [50] focus on international research on AV to date, including bibliometric data, and present the results of a systematic review of agrivoltaic research, including related analysis, discussion and directions for future research. Livestock such as spring lamb, sheep and goats under the small-scale agrivoltaic systems can be mobile and temporarily used for agriculture purposes due to their docile nature when compared to other livestock. Low-intensity rotation pastures may be viable, as sustainable grazing options on seasonally wet soils under panels [46,50,51].

The most common and objective parameter describing photovoltaic power generation technology is efficiency, as identified by the National Renewable Energy Laboratory (NREL). NREL of the United States has drawn an updated chart of the record value of the highest efficiency of photovoltaic devices in the development of photovoltaic power generation technology since 1975 (see Figure 2), which is typically marked as the best reference chart for studying power conversion efficiency. In the figure, different colours correspond to the power conversion efficiency of varying technology types: blue represents c-Si battery technology, green represents thin film battery technology, purple represents several compound semiconductor battery technologies, and orange represents emerging photovoltaic technologies such as quantum dots. In addition, grey represents the laboratory that provides the results [52,53]. The development of new transparent solar cells by using semi-transparent PVs as OPVs and DSSCs [54,55] also provides a new solution to the issue of cooling energy consumption and light competition in greenhouses. There is little published research work in the area of greenhouse-integrated semi-transparent photovoltaic systems. The paper [55] considered semi-transparent c-Si technology, based on opaque cells, due to its high efficiency and reliability and investigated the potential of agrivoltaic systems from greenhouse applications at a global scale for the first time. Agrivoltaic systems could produce up to 200 kWh/m^2 of energy per year with transparency of about 68% without significant impact on the crop yield.

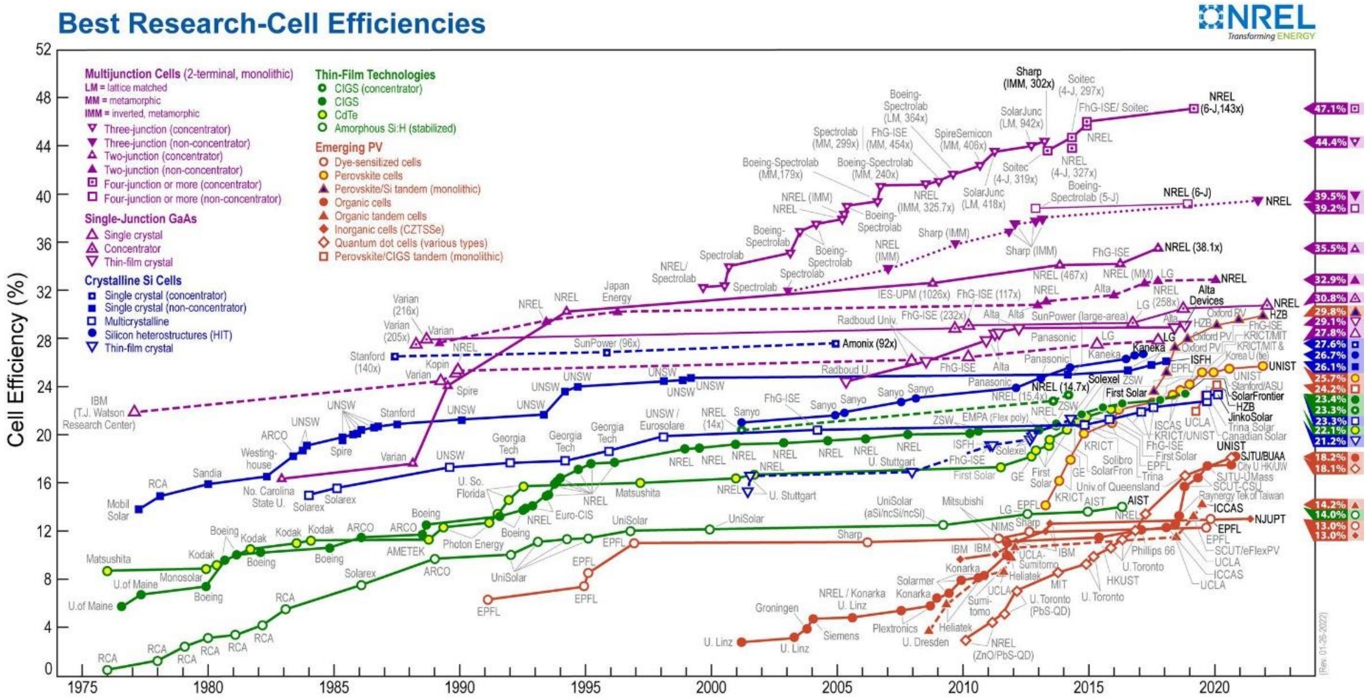

Figure 2. Development of solar cell efficiency based on various technologies. Source: [56].

AV technology includes not only PV equipment, but also the crop production underneath; therefore, its investment and operating costs far exceed both conventional PV and crop production separately. At the same time, revenues can be generated not only from electricity but also from crop production, so the key question in the economic assessment is whether the additional revenues will cover the additional investment and annual costs. Benchmark CAPEX showed a sharp decline in PV systems; they reduced from 3.5 to 0.3 USD/W between 2010 and 2020 [57], which provides a good basis for the spreading of AV systems, too. The role of size economy is significant in CAPEX; therefore, large-scale AV installations are expected to operate more profitably than small rooftop systems [58]. However, the installation of rooftop systems should enjoy priority, where possible, because of land use and landscape reasons [59]. Poonia et al. estimated economic analysis of the 105 kWp AVSs of AVS-1 (single raw PV array) design with the highest return per unit area compared with a reference ground-mounted photovoltaic (PV-GM) installation. The agrivoltaic system was established at ICAR-Central Arid Zone Research Institute and examined with several combinations of rainfed and irrigated crops. Average PV generation from the AVS-1 was 93.90 kWh/day, the highest LCOE (€0.041 kWh^{-1}) based on break even electricity tariff is evaluated in PV-GM and the lowest LCOE is calculated in AVS -1- Irrigated (€0.038 kWh^{-1}). Thus, it is concluded that the cultivation of crops, both rainfed and irrigated, can be very economical for the agrivoltaic system. This study found that a single raw PV array under the agriculture crop is the most suitable agrivoltaic design in terms of land use efficiency and economic parameters [60]. Agrivoltaic systems combined with shade-tolerant crop production increase economic value by more than 30% by using agrivoltaic systems instead of conventional agriculture [3]. In contrast, for the agrivoltaic system with a capacity of 520 kWh^{-1}, LCOE estimated €0.0828 kWh^{-1}, while for PV-GM was €0.0603 kWh^{-1}. Since the main product of both solar systems is green electricity, LCOE should be the most important indicator of competitiveness, which was 38% higher for AV, mainly due to the higher CAPEX and the additional costs of agricultural products. The higher investment cost of AV is due primarily to the costs of PV modules, mounting structure, site preparation and soil protection. However, the OPEX of AV systems was lower than typical PV installations, and the difference was 13%, according to Germanian experiences. The data show that operational costs are minimal (1.1% and 2.2%, respectively) compared to the investment costs in the case of solar installations. The difference in operation costs comes from the lower (dual) land cost per year, maintenance, mowing and surveillance costs; however, repair servicing costs were higher from the AV point of view [20]. An AV system and a PV-GM system were built in Italy to compare both systems. The LCOE of a 500 kWhm^{-2} agrivoltaic system was €0.0895 kWh^{-1}, while €0.0847 kWh^{-1} for the PV-GM system. This study assumed that 80% of the generated electricity is immediately consumed for its own needs and 20% is compensated by the national grid operator with the valuable cost to consider several factors, including annual average cost of the electricity, the cost of its transmission and other costs [61]. LCOE and CAPEX are far lower in developing countries compared to European standard costs (India: 0.02–0.07 and 492–588 €/kWp), respectively [62]. LCOE is estimated at three different locations. In Europe, CAPEX, OPEX and WACC are varied by 25%, LCOE in Northern Europe is much more dependent on the capital cost and the is reduced based on the shade tolerance of the crop [63]. According to Moreda et al.'s (2021) results, AV systems can be regarded as win-win options for both farmers and investors (IRR > 8% in baseline scenario), even if the yields of the considered vegetables show a 20% reduction. When considering more favorable geographical conditions and biomass productivity, competitiveness may be expected to be much better in tropical areas than in highly developed economies, which can make AV systems attractive for investors in these regions [38]. In the authors' opinion, the most exciting future research in the economics of AV is expected to seek the optimal cover, spacing and layout of solar panels, the ideal plants to be produced under different conditions and the effect on price changes in the related areas (markets of electricity, of solar panels, of agricultural inputs and outputs).

Bibliometrics help to depict the history and general contemporaneity of a specific research field or topic when considering written production as the main formal channel of communication between scholars [64,65]. The use of a bibliometric approach allows for providing more objective and reliable analyses based on statistical techniques [65,66], as it is possible to carry out both basic and advanced analyses of large volumes of documentation related to the field of interest. The key procedures commonly used in bibliometric studies are performance analysis [67] and scientific mapping [68]. The first is the evaluation of the productivity and popularity of the various actors based on bibliographic data. The second tries to highlight the structural and cognitive patterns of the domain and the main themes, from a synchronic [69] or diachronic [70] perspective.

To accomplish the objectives of this study, a bibliometric review method was employed to synthesize the possible benefits regarding the economic and environmental, infrastructure, technical and agricultural side of AV systems. This systematic review focused on the following categories:

1. Economic assessment of AVSs
2. Crop production under AVSs [4]
3. Livestock grazing under AVSs [71]
4. PV + greenhouse [72]

In this paper, we selected and detailed the most important relevant scientific literature, with special attention to the previous bibliometric results. The most important elements of the selection process, the eligibility criteria and the used evaluation tools are introduced. Then, our results related to the aforementioned aspects and the comparison with the previous results are presented. Finally, some conclusions and limitations are specified.

2. Materials and Methods

2.1. Research Strategy and Study Selection Criteria

This systematic literature review (SLR) follows the PRISMA guideline [73], which provides methods for identifying, selecting, evaluating and synthesizing studies in order to carry systematic review using the standard protocol. RStudio version 7.2.0 + Bibliometrix package is used to implement this protocol and find the results. All the scientific articles have designed and approved the methodology in accordance with PRISMA guidelines for this SLR. After fixing the topic, the inclusion and exclusion criteria were implemented according to the aims and objectives of the research.

We conducted literature searches from inception to 15 November 2022, using the SCOPUS database to query the metadata of documents related to the agrivoltaic system topic with no publication date restriction. SCOPUS was selected as the appropriate database for this paper because the majority of the articles related to the research field were found in this database. The full-text peer-review original research articles, including journals and conference papers, were selected for this systematic review, because these articles have undergone an evaluation process in which journal editors and academic experts critically evaluate the quality and have credibility as a result of the peer-reviewed process. In this systematic review, only English-written studies were identified because an analysis of SCOPUS data reveals an apparent bias toward the English language used in research and academic publishing, with 91.6% of the total academic articles published in English [74]. Table 1 contains the main information of our data (for full data see Supplementary Materials).

Table 1. Descriptive analysis: Main information regarding the collection.

Description	Results
Period	2011–2023
Documents	121
Sources (journals and conference papers)	59
Authors	382
References	5415
Author's keywords	363

Source: created by the authors.

The search strategy terms for the SCOPUS database are given in detail in Figure 3. The terms within each group were combined with 'OR'; the first group, KW1, only used synonyms of agri-PV, and sub-keywords for other groups were linked with 'AND'. Table A1 provides additional details for each of the included keywords.

A total of 532 articles were initially obtained for possible inclusion from the SCOPUS database. Accordingly, the SLR method included four steps, namely: (i) using a list of identified key words strings on the SCOPUS database search for peer-reviewed articles and conference papers; (ii) screening by titles, abstracts, and keywords and then by scrutinizing complete documents for inclusion in review; (iii) using the article's bibliography or references to find additional relevant articles. Study characteristics for the above studies were extracted from these SCOPUS sources using the BibTex format (*.bib), and the five keywords group were imported separately into Rstudio software, where 328 records were removed as duplicates before the screening. 204 records in the identification step were then exported from Rstudio and imported into MS Excel. Therefore, 151 records were assessed for eligibility by studying the full accessible text. At the stage of eligibility, 33 articles were excluded because the records did not have access to the full text. In the last step, three conference papers were included, after which a snowball search was undertaken in order to add more relevant articles. Finally, 121 full-text relevant articles were obtained and reviewed (see Supplementary Materials). An illustration flowchart of the review process is shown in Figure 3. The data were then proposed with Biblioshiny to perform relevant bibliometric and visual analyses on an interactive web interface and to graphically represent some of the potential outcomes. The paper used the co-occurrence of keyword trends, country scientific productions, most cited scientific paper, bibliographic linkage, thematic map, publication by year and analysis of co-authors by country. The results determined the major trends and status of development in terms of main countries, articles, authors, journals and topics.

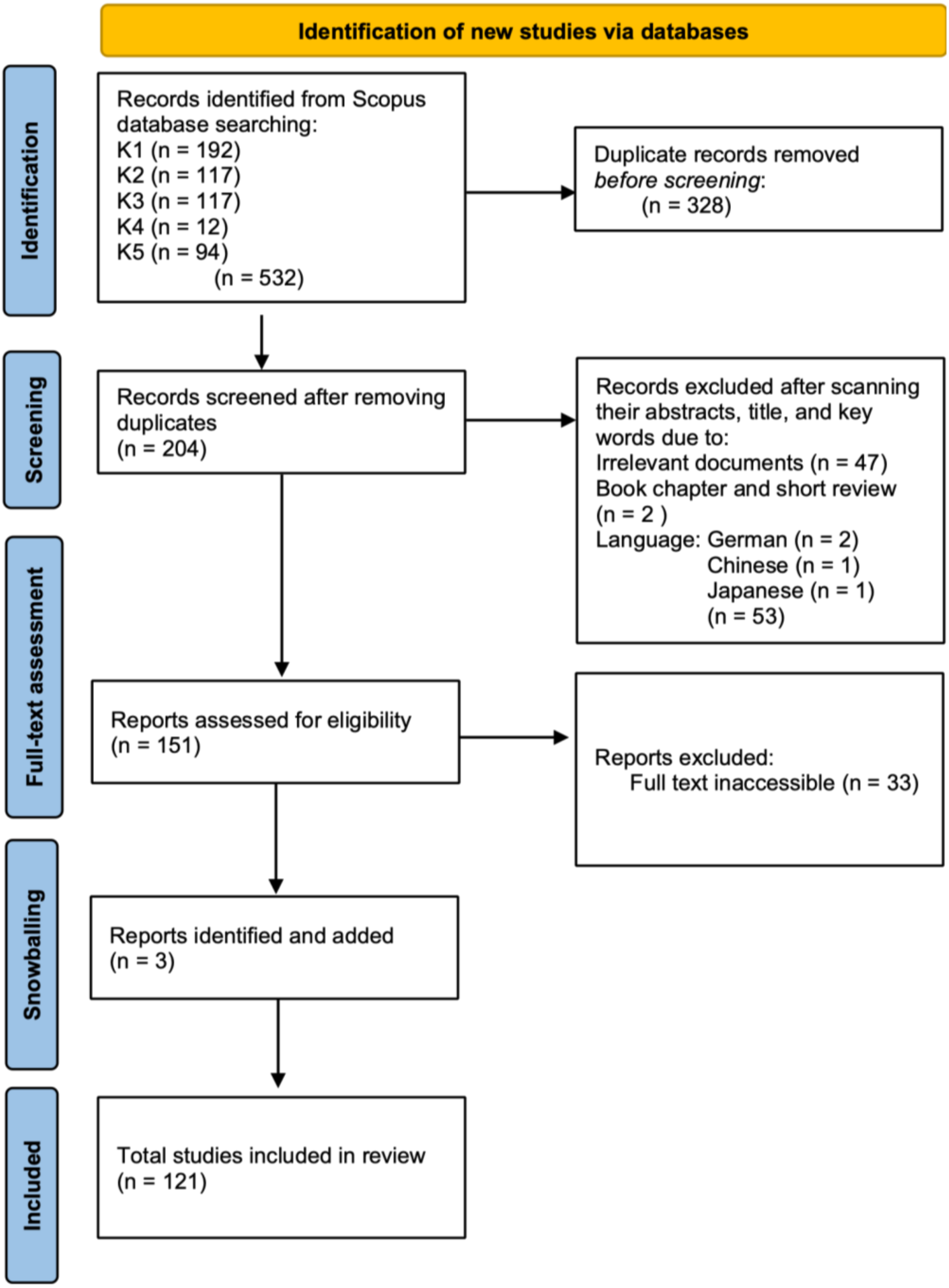

Figure 3. Flowchart illustrating the systematic review process. Source: created by the authors.

Eligibility Criteria

For the selection of articles, the following inclusion criteria were set: (1) studies should have a purpose of examining the economic, energy, technical, infrastructural, environmental, agricultural and benefits from the adaptation of agrivoltaic systems (AVS); (2) results of studies should relate to AVSs; (3) all scientific articles and conference papers should be published in peer-reviewed journals in English language. The following criteria were set for exclusion: (1) if the publication type was not a peer-reviewed academic report; (2) non-English articles; (3) book, book chapters, review or short survey.

2.2. Data Extraction

Data were extracted manually after reviewing each full text of the publication and recorded into Microsoft Excel for analysis. This study was focused on peer-reviewed articles in English. Study characteristics from the eligible records were extracted as follows: (1) non-scientific literature; (2) non-English language publication; (3) duplicate studies.

2.3. Bibliometric Analysis

Bibliometrics turns the main tool of science, quantitative analysis, on itself. Essentially, bibliometrics is the application of quantitative analysis and statistics to publications such as journal articles and their accompanying citation counts. Quantitative evaluation of publication and citation data is now used in almost all scientific fields to evaluate growth, maturity, leading authors, conceptual and intellectual maps and trends in the scientific community. Bibliometrix is an open-source tool for quantitative research in scientometrics and bibliometrics which includes all the main bibliometric methods of analysis. Bibliometrix package provides various routines for importing bibliographic data from different bibliographic databases, performing bibliometric analysis and building data matrices for co-citation, coupling, scientific collaboration analysis and co-word analysis. SCOPUS (https://www.scopus.com (accessed on 19 November 2022)), founded in 2004, offers great flexibility for the bibliometric user. It permits queries for different fields, such as titles, abstracts, keywords, references, etc. SCOPUS allows for relatively easy downloading of data queries.

3. Results

3.1. Descriptive Statistical Analysis of the Research Literature

3.1.1. Emerging Trends in the Literature on Agrivoltaic Systems

Figure 4 shows that there was no high-level scientific publication activity before 2011 related to AV. However, Prof. Dr. Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems (ISE), and Dr. Armin Zastrow were the pioneers in the establishment of Agrivoltaics in 1981, when it was aimed at optimizing the utilization of the land [75]. Since then, this technique has been considered a prototype until 2011, when it was first published as agrivoltaic (AV). All over the world, the method is known under different names. The authors propose different terminologies for the concept of an AV system. For instance, in the German research context, it is known as "agrophotovoltaics (APVs)", in French, Italian and American research contexts it is known as "agrovoltaics", and in the Asian research context, "photovoltaic agriculture" and "solar sharing" are mentioned [72]. Currently, "Agrivoltaic" is the internationally recognized term, as well as the well-established acronym for Agrivoltaics, "AV". Over the years, innovations have been used to supply the needed power for different agricultural applications such as crop drying, cultivation in a greenhouse, irrigation, desalination, etc. Moreover, it enables the production of food and energy, providing benefits for farmers.

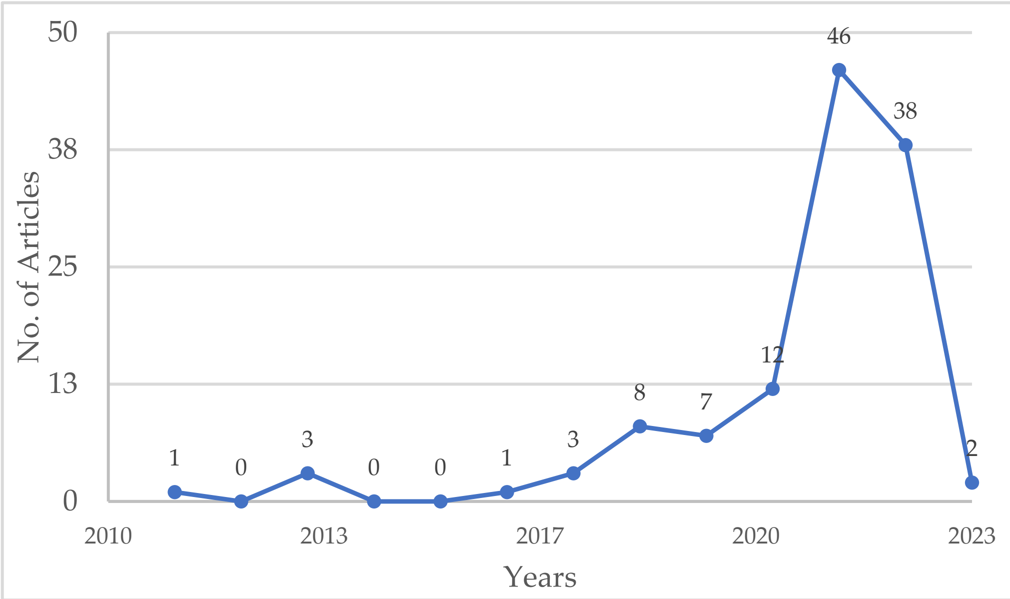

Figure 4. Annual scientific production. Source: created by the authors.

Attention to the implications of agrivoltaics in renewable energy has risen from 2011 (Figure 4). In the 2010s, the first agrivoltaic-pilot plants were built and researched in Japan and then in Germany and France [75]. Agri-PV is interdisciplinary, and as such, we expected to find a wide variety of disciplines represented in our study. Most studies are seeking to address questions such as the long-term impact of solar energy infrastructure on soil quality, suitable crops, etc. [76]. There is very little scientific research examining their agriculture parameters, such as crop performance, crop yields and quality of the harvestable products. Meanwhile, economic, social and political implementation of AV systems have also been researched since 2020 [20,77,78]. Nevertheless, agrivoltaic systems are gradually being installed around the world, and there is very little scientific research examining their local acceptance in society, the economic factors for the market launch of agrivoltaic systems and farmers' motivation for agrivoltaic systems. Figure 4 presents the annual scientific production of agrivoltaics research by year. After screening this research field, it can be stated that the research activity related to agrivoltaic systems emerged after 2011 and started to grow rapidly in 2021 and beyond. The number of articles published from 2011 to 2020 climbed very gradually, peaking in 2021 and dipping drastically in the following years. The difference in publication between 2020 and 2021 is 35.4%, and between 2021 and 2022, it is 8.3%. One of the reasons for this might be the topic under development and the experimental stage of APV, as well as little experience with other popular crops such as rapeseed, turnips and legumes [59], the high concentration of studies in specific regions and lower citation rate.

3.1.2. Top 10 Most Relevant Journals

One of the most interesting aspects of bibliometric analysis is the identification of journals that researchers most often use to disseminate their research work. Regarding the most relevant journals based on the number of publications, based on the H-index, Table 2 lists the top 10 journals that cover a wide range of research disciplines and shows that the three most relevant journals account for over 46.6% of publications. The articles were issued by seven different publishers, and the largest production of articles was found in the AIP conference proceedings journal, published by the American Institute of Physics, with 11 conference papers, followed by Applied Energy from Elsevier, with 9 articles. AIP conference proceedings journal and Applied Energy are considered the most influential sources of publication related to agrivoltaic systems in an emerging interdisciplinary research area, so we don't need to be limited to a specific area. Table 2 represents other sources with scores of 8 or less. It shows that AV-specialized scientific conferences are the best way to get relevant and up-to-date information about this research area. The majority of the journals in Table 2 have Q1 ranking, which means that the topic is interesting for the highest-level publishers. Sustainability and Energies are two of the few exceptions; they are also excellent sources of AV. This also indicates that there is a growing propensity for interdisciplinary research in agrivoltaic systems that could make agriculture more sustainable and use green energy in the future.

Table 2. Most productive scientific sources.

Journal/Proceedings	Publisher	Country	H Index	SJR	TP
AIP CONFERENCE PROCEEDINGS	American Institute of Physics	United States	75	0.19 (Not yet assigned quartile)	11
APPLIED ENERGY	Elsevier	United Kingdom	235	3.06 (Q1)	9
AGRONOMY	John Wiley & Sons.	United States	138	0.69 (Q1)	8
ENERGIES	MDPI	Switzerland	111	0.65 (Q1/Q2)	7
SUSTAINABILITY (SWITZERLAND)	MDPI	Switzerland	109	0.66 (Q1/Q2)	7
IOP CONFERENCE SERIES: EARTH AND ENVIRONMENTAL SCIENCE	IOP Publishing Ltd.	United Kingdom	34	0.2 (Not yet assigned quartile)	4
RENEWABLE ENERGY	Elsevier	United Kingdom	210	1.88 (Q1)	4
SCIENTIFIC REPORTS	Nature Publishing Group	United Kingdom	242	1.01 (Q1)	4
JOURNAL OF CLEANER PRODUCTION	Elsevier	United Kingdom	232	1.92 (Q1)	3
PLOS ONE	Public Library of Science	United States	367	0.85 (Q1)	3

TP: the number of total publications. Source: Created by the Authors.

3.1.3. Distribution of Production by Countries and Authors

In general, agrivoltaics publications related to agriculture activities and green electricity are written by authors representing 32 countries. Table 3 lists the ten most productive countries in terms of this indicator, along with such an indicator as the number of articles. This can partly be explained by the fact that SCOPUS primarily indexes publications published in English. The latter also explains the fact that most of the publications included in the study database (90%) are written in English.

Table 3. Top 20—Most productive countries (based on first author's affiliation).

Region	No. of Articles	Region	No. of Articles
USA	15	SPAIN	4
CHINA	11	AUSTRALIA	3
GERMANY	9	BELGIUM	3
FRANCE	8	FINLAND	3
SOUTH KOREA	8	PAKISTAN	3
JAPAN	7	NETHERLANDS	2
ITALY	6	SINGAPORE	2
CANADA	5	THAILAND	2
INDIA	5	TURKEY	2
MALAYSIA	5	UK	2

Source: created by the authors.

A country's scientific output (Table 3) shows the contributions of various countries to the agrivoltaic area. In terms of the geographical distribution of scientific research works, approximately 14.2% of publications are produced in the USA, which is not surprising since the USA is a leading country in renewable energy consumption [79]. In addition, US researchers are studying the potential of co-locating photovoltaic energy production with pasture production, cattle, lamb or sheep, crops, grazing behavior, soil rehabilitation and other ecosystem services [16,46,80,81]. A US study showed that the development of solar energy applications in agriculture function is important to multi-level and multi-sectoral policy integration [82]. China ranks second in the number of publications, with the continuous growth of China's demand for clean energy, such as solar power generation. Its high-level population demands a large amount of food, as well as the gradual improvement of the corresponding photovoltaic industry policy and photovoltaic industry service system; photovoltaic industry projects in various regions continue to be launched. The photovoltaic industry presents a thriving scene [5,83,84], which is reflected in the outstanding work related to photovoltaic agriculture. On the side of agrivoltaic system, in European countries, a few agrivoltaic system projects have also been implemented in Europe in recent years. France was the first country to implement the AV financial support scheme in September 2017. Between 2017 and 2019, 15 MW of AV capacity was auctioned, and Germany is also one of the countries considering AV implementation. A German study constructed a comparative scenario of the cost structure, including CAPEX and OPEX of the AV system and GM-PV system. The actual CAPEX (including commissioning) in Germany regarding AV was higher by 73% compared to the normal PV installations. In contrast to the higher CAPEX, the OPEX of AV systems was lower than normal PV installations; the difference was 13%, according to German experiences [20]. AV implementation also depends on the legislation of the country and geographical area, as well as on agrivoltaic objectives and crop selection.

Table 4 lists the most influential articles in the journal. Top 10 articles cited during the study period of 11—(2011–2022), including authors' initials, publication year, publication sources (journal), titles, digital object identifier (DOI), total citation and yearly citation. The analysis of the references cited is carried out in two stages. In Table 4, we show the article with the most citations and the average number of citations per year to give a meaningful assessment of the impact of this article on the research community. The research articles listed from the dataset using co-citation analysis have been cited in other pairs of articles in the sample, giving an idea of the contribution of major citations that have influenced the development of the field in recent years. It has been proven that citations are increasing year by year. This is probably due to the large interest in research in this field. Notably, old papers were favored in this analysis because the longer time allows them to accumulate more citations compared to recently published research work. Dupraz et al.(2020) [39] from INRA, UMR System, France, ranked at one. The article has 256 citations and 21.33 total citations per year. This paper becomes the most prolific and dominant paper in the field of agrivoltaic systems. Therefore, the total citation per year was also taken into account when assessing the new trends in this field. However, due to its significant contribution to the current discussion on the social, economic, and policy aspects of APV, Schindele et al.'s (2020) [20] paper titled "Implementation of agrophotovoltaics technoeconomic analysis of the price performance ratio and its policy implications" published in 2020 received an average of 25.67 citations each year.

The above table provides information at two levels, both in absolute and relative terms. Consequently, we have two metrics: total citation (TC) and total citation per year (TC per year). The most cited references in absolute terms are:

- Dupraz et al. (2011) [39], with 256 citations. The top-cited paper by Dupraz et al. [39] first proposed to designate the combination of solar panels and food crops in the same field as an agrovoltaic system. The researchers contrasted the relatively low intrinsic efficiency of the photosynthetic process (around 3%) with the average yield of commercially available monocrystalline photovoltaic (PV) solar cells (~15%) and estimated global land productivity increases of 35% and 73% for two different system designs. From an economic point of view, the authors predicted the land equivalent ratio (LER) of agrivoltaic systems, and the results were impressive. A value of 1.7 LER would mean the following, related to the productivity of land: a 100-ha farm would produce as much green energy and crops altogether as a 170-ha farm, when it is used independently for photovoltaic energy production and food crops.

- Marrou et al. (2013) [25] (with 143 citations) and Marrou et al. (2013) [85] (with 135 citations). Among the plant species studied, short-cycle crops such as various lettuce [25] and cucumber [85] appear, as well as long-cycle crops such as durum wheat [85].
- In relative terms (weighted citation of an article by the number of years), TC per year, the top three articles, with an average of over 20 citations, are:
- Among the publications, only the techno-economic side was researched by Schindele et al.(2020) [20], comparing the additional investment cost of agrivoltaic system and ground-mounted photovoltaic (PV-GM) system and both systems considered a reference to a land plot of two hectares. The total investment cost of AV amounts €1,343,846, and for PV-GM, €1,031,042. Cost factors that include PV models, installation, site preparation, and soil protection have relatively higher investment cost for AVSs. This is a very important study because APV represents a major source of economic analysis within agrivoltaic systems.
- Amaducci et al. (2018) [24] discovered that the productivity of land using agrivoltaic system can be doubled with APV over the separate production of maize and GM-PV modules. However, radiation available to the crop during APV is reduced by about 15–40%. These light conditions correspond to moderate shading which means that the amount of radiation available under an APV array depends more on the density of the panels than on the panel mobility. Authors found that growing corn under agrivoltaic systems in non-irrigated conditions can decrease soil evaporation, reduce crop losses in dry years and increase the average yield.
- Dupraz et al. (2011) [39] has an index of Total Citation per Year of around 21.33%.

3.1.4. Keywords Dynamics

Figure 5 presents the co-occurrence assessment and connection of keywords plus, which reflects the high frequency of matching keywords in research articles and conference papers; more than half of the author's keywords were mirrored in the keywords plus sets. Keywords plus covers most of the author's keywords, so we choose keyword plus methods.

Authors' keywords co-occurrence is following analysis prepared by Rstudio Biblioshiny, which was a way to comprehensively understand the leading keywords for agrivoltaic systems in agriculture activities, greenhouse and open fields. The size of the circle reflects the frequency of occurrence of the term, i.e., the larger its area, the more often this word or phrase occurs in the general list of an author's keywords. The distance between terms is a measure of their connection: a smaller distance represents a stronger connection. In contrast, the connection itself is determined by the frequency of the terms' joint occurrence. Colors, as already mentioned, are used to indicate clusters.

The concept map shows that the terms form a complex network in which three thematic clusters can be distinguished. The first (marked in red) is related to the crops of land use in the context of studying solar power generation, as well as the cultivation of crops in a typical agrivoltaic system. The second cluster (light blue) is closely related to the first and focuses on the concept of studying various types of fields, such as agricultural robots and carbon dioxide. At the same time, investment and economic analysis, cost-benefit analysis and agricultural land are studied separately. The third cluster (light green color) is associated with the study of photovoltaic systems with tracking systems placed crops in a microclimate where strips of shading are in any plant position several times a day.

Table 4. Most cited articles.

Paper	Titles	DOI	TC	TC Per Year
DUPRAZ C, 2011, [39], RENEW ENERGY	Combining solar photovoltaic panels and food crops for optimizing land use towards new agrivoltaic schemes	10.1016/j.renene.2011.03.005	256	21.33
MARROU H, 2013, [25], EUR J AGRON-a	Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels	10.1016/j.eja.2012.08.003	143	14.30
MARROU H, 2013, [85], AGRIC FOR METEROL	Microclimate under agrivoltaic systems is crop growth rate affected in the partial shade of solar panels	10.1016/j.agrformet.2013.04.012	135	13.50
AMADUCCI S, 2018, [24], APPL ENERGY	Agrivoltaic systems to optimize land use for electric energy production	10.1016/j.apenergy.2018.03.081	117	23.40
ADEH EH, 2018, [16], PLOS ONE	Remarkable agrivoltaic influence on soil moisture micrometeorology and wateruse efficiency	10.1371/journal.pone.0203256	86	17.20
MARROU H, 2013, [86], EUR J AGRON	How does a shelter of solar panels influence water flows in a soilcrop system	10.1016/j.eja.2013.05.004	80	8.00
SCHINDELE S, 2020, [20], APPL ENERGY	Implementation of agrophotovoltaics technoeconomic analysis of the priceperformance ratio and its policy implications	10.1016/j.apenergy.2020.114737	77	25.67
VALLE B, 2017, [15], APPL ENERGY	Increasing the total productivity of a land by combining mobile photovoltaic panels and food crops	10.1016/j.apenergy.2017.09.113	75	12.50
ADEH EH, 2019, [87], SCI REP	Solar PV power potential is greatest over croplands	10.1038/s41598-019-47803-3	75	18.75
MALU PR, 2017, [18], SUSTAINABLE ENERGY TECHNOL ASSESS	Agrivoltaic potential on grape farms in India	10.1016/j.seta.2017.08.004	71	11.83

TC: Total Citations. Source: created by the authors.

3.2. Thematic Analysis and Evolution

In the following section, we focus our attention on the conceptual structure of AV's publications. This type of analysis helps to understand the topics and define the most important and recent ones. Identifying the conceptual structure could also be useful for studying the research topic's evolution over time [88].

The basic idea is that terms (keywords, terms extracted from titles or abstracts) which appear together in a document can be represented as a term's co-occurrence network. We started from a co-occurrence matrix in which each cell outside the principal diagonal contains the similarity of two terms expressed as equivalence [89]. The co-occurrence matrices can be seen as adjacency matrices and graphically visualized as undirected weighted networks. On each subperiod co-occurrence matrix, we performed a community detection based on the simple center algorithm [90]. This analysis allows finding subgroups of strongly linked terms, where each subgroup corresponds to a center of interest or a given research theme/topic of the analyzed collection. Once the analysis is carried out, it is possible to plot the results in a so-called strategic or thematic diagram [91]. The graphical representation allows defining four typologies of themes [92], depending on the quadrant in which they are plotted:

- Themes in the upper-right quadrant are known as the motor themes, characterized by high centrality and high density, meaning that they are developed and important for the research field;
- Themes in the lower-right quadrant are known as basic and transversal themes, characterized by high centrality and low density, meaning that these themes are important

for a domain, and they concern general topics transversal to the different research areas of the field;

- Themes in the lower-left quadrant are known as emerging or declining themes, with low centrality and low density, meaning that they are weakly developed and marginal;
- Themes in the upper-left quadrant are known as the highly developed and isolated themes, with well-developed internal links (high density) but unimportant external links (low centrality), meaning that they are of limited importance for the field.

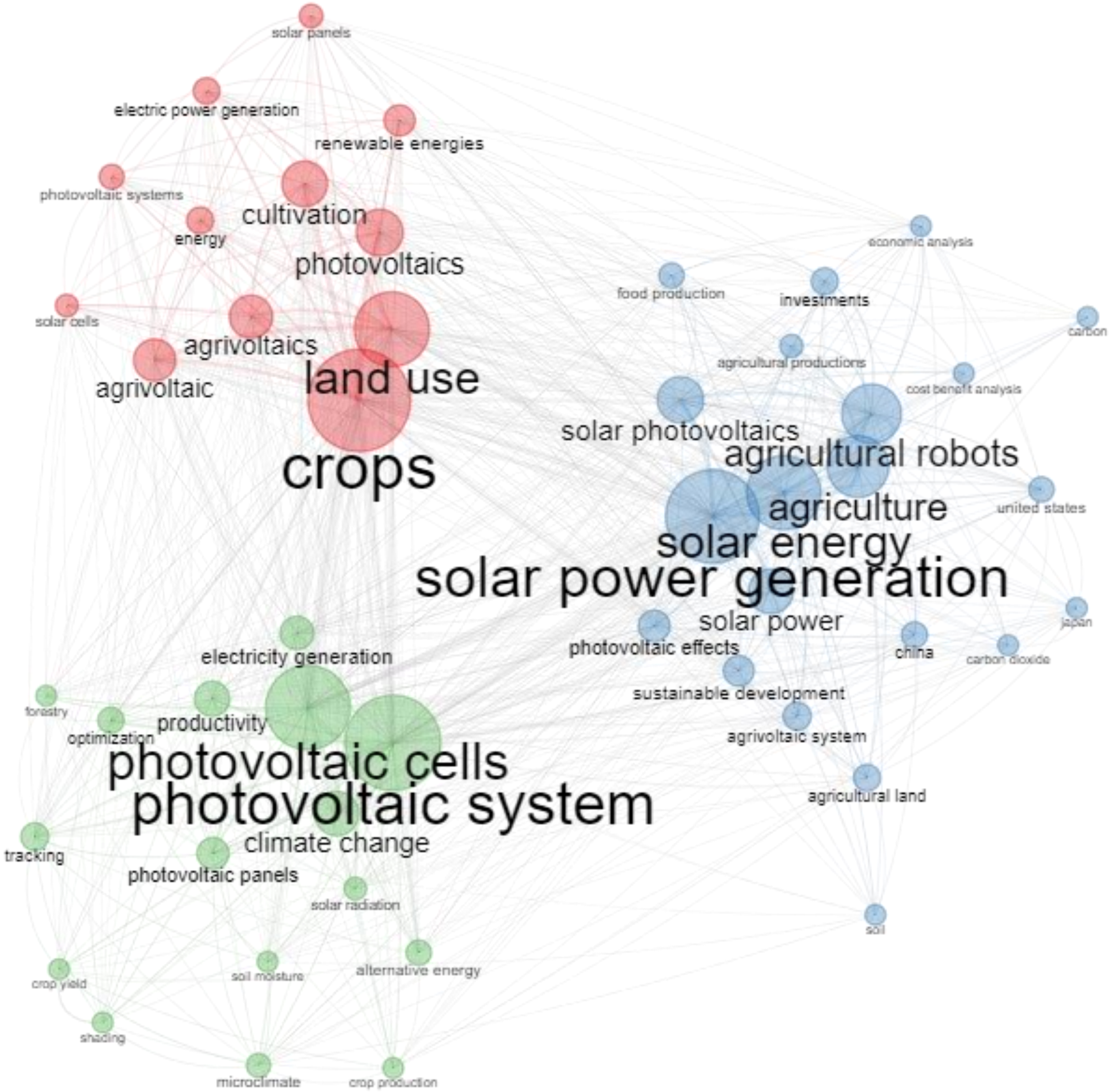

Figure 5. Keyword co-occurrence network. Source: created by the authors.

Figure 6 shows that five main topics emerged. The upper-right quadrant shows the motor themes. They are characterized by both high centrality and density. Among the motor themes that are the more developed in the literature, the main concern is crops. Highlighting how researchers have focused on this topic in the last few years is extremely important for structuring the field of study. The lower-right quadrant shows the themes that are basic and transversal. These themes concern general topics transversal to the different research areas of the field. In this area, 'solar power generation' appeared as a general theme and also included different applicative domains of the topic. In the lower-left quadrant are the emerging or declining themes. In this research, the theme of 'agriculture' emerges. In particular, 'agriculture' is a new topic in the field of agrivoltaics, where agriculture activities are emerging to explore new approaches related to agrivoltaic systems in agriculture production and green electricity on the same land and at the same period. The 'solar energy' and 'climate change' are in the upper-left quadrant as niche themes of the topic, with high density but low centrality, have a higher frequency, indicating that these research themes are considered very specialized in agrovoltaic research work.

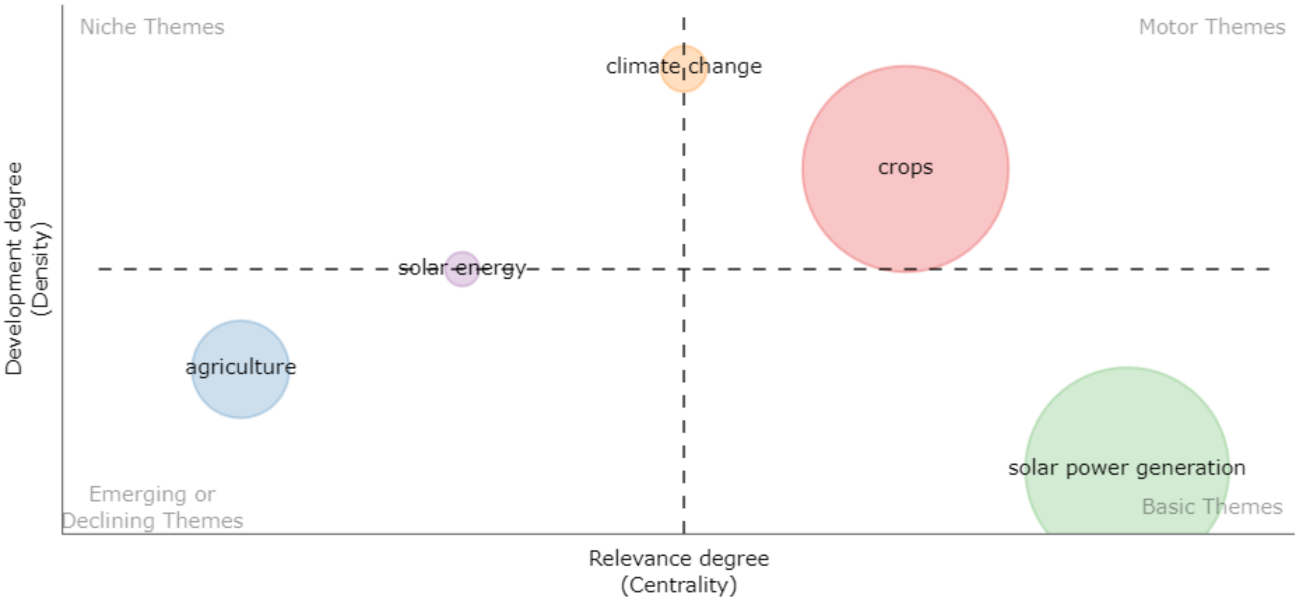

Figure 6. Thematic map. Source: created by the authors.

Figure 7 shows a co-word analysis, which aims to map the conceptual structure of a framework using the word co-occurrences in a bibliographic collection. The analysis was performed using Multiple Correspondence Analysis (MCA) as a dimensionality reduction technique. The conceptual structure includes natural language processing (NLP) routines to extract terms from titles and abstracts. It compresses extensive data with multiple variables into a low-dimensional space to form an intuitive two-dimensional graph that uses plane distance to reflect the similarity between the keywords. Keywords approaching the centre point indicate that they have received close attention over the years. The results are interpreted based on the relative positions of the points and their distribution along the dimensions; as words are more similar in distribution, the closer they are represented on the map. The red cluster is the most significant and consists of 42 keywords that focus on the documents related to 'agrivoltaic system', 'agrophotovoltaic', 'sustainable agriculture', 'energy' and 'photovoltaic panels'. The blue cluster of 5 keywords comprises papers regarding 'shading', 'organic agriculture', 'land productivity' and 'crop yield'. The green cluster consists of 5 keywords, focusing on the articles related to 'shade', 'lettuce', 'cucumber' and 'evapotranspiration'.

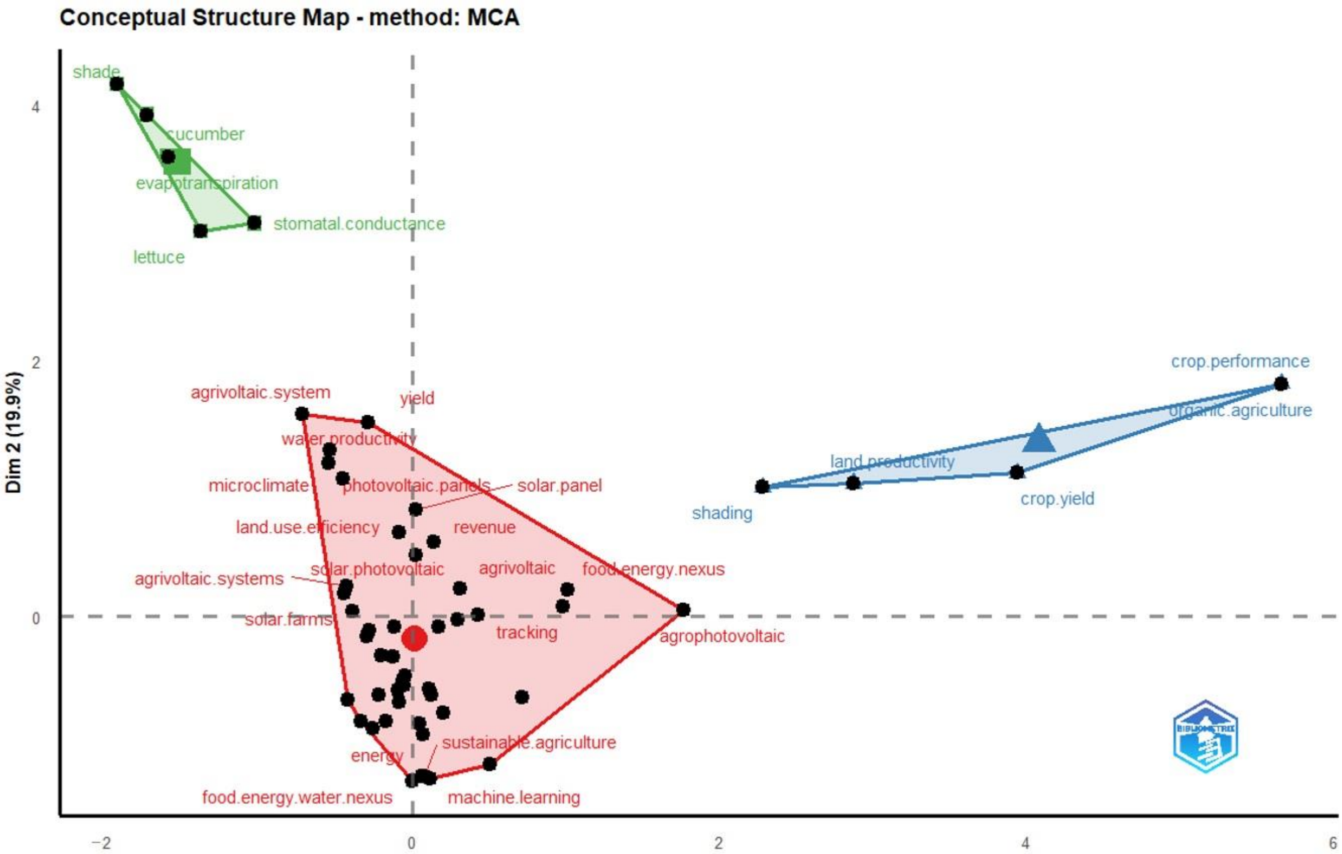

Figure 7. Multiple Correspondence Analysis of high-frequency keywords. Source: created by the authors.

4. Discussion

Previous research examined the efficiency of growing crops under solar panels. Over the past few years, the EU countries have seen a surge in agrivoltaic projects, many of which are still in the experimental stage. France has been one of the leading countries in Europe, having been successful in this form of agriculture [20].

In this study, it was found that there is an increasing trend in the field of agrivoltaic systems research. Significant growth has been observed since 2020, peaking in 2021, which is currently considered to be the most productive year in this field. This systematic review of 121 agrivoltaic systems in interdisciplinary studies focuses on economic feasibility, agriculture activities, AV design, performance of crops and soil with interactions with food and water aspects. The need for adaptation measures and the relevance of applying the accumulated experience of agrivoltaic systems to mitigate the consequences of climate change are discussed [25,85,93,94]. Management of the storage capacity of agrivoltaic systems is a key component of the proposed future solutions in the field of adaptation to climate change [22]. We found that virtually all of the studies reported agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency [16,85,87] and shading [15,24], while limiting the study of economic and financial implications in agrivoltaics on short-term outcomes [50]. However, we can see the tendency related to the economic research performance of agrivoltaics.

A systematic literature review in the field of agrivoltaic systems was performed by [50]. The authors reviewed 98 studies. Of these, 48 dealt with specific applications and 50 with the scale of PV production. Of the 50 studies, 14 investigated small-scale PV systems (<100 kW). The remaining 36 publications focused on medium- and large-scale installations (above 100 kW), and 26 on systems with more than 1 MW capacity. The results show that the research carried out so far has been mainly in the northern hemisphere and has typically focused on technical issues. Among these, configuration and factors influencing power output have been highlighted. This article draws attention to the research gap in the economic and financial areas of agrivoltaic systems. It also points out that relatively few studies have focused on large-scale (>1.0 MW) installations that integrate livestock grazing. These issues represent an important gap in current knowledge, as the regions of the world with the greatest potential for PV generation are typically those where grazing is prominent. The above-mentioned publication paid particular attention to the distribution of publications on agrivoltaic systems by year (2011–2022), the percentage distribution of publication types, the publication mapping based on six key features affecting agrivoltaic applications, the global horizontal irradiation map of agrivoltaic projects, the distribution of the studies' analytical approaches and benefits of and constraints to agrivoltaic development including water use efficiency, land use efficiency, income diversification, financial issues, as well as environmental outcomes and social benefits.

Our results are in line with a previous, similar review work [50]. This study also included a comprehensive review of agrivoltaic systems by identifying interdisciplinary research findings, showing similarity with our results. For instance, a review of information was about the impact of PV installation on cropping and livestock grazing, integration of agriculture and energy productions, land and water efficiency, as well as finance and economic concerns. When comparing our results to those of older studies, it must be pointed out that our paper synthesized the economic and environmental, infrastructure, technical and agricultural side of AV systems with the following categories: economic assessment of AVS, crop production under AVS, livestock grazing under AVS and photovoltaic greenhouse. In contrast, the research strategy tried to use all databases with a total of 98 publications; meanwhile, our review included the SCOPUS database, which helps to identify qualified research articles. Only nine similar articles were found based on the results of Mamun et al.'s [50] study. Additionally, the search criteria and protocol of the systematic literature review are quite different. Distribution of publications on agrivoltaic systems showed only three research papers in Mamun et al.'s manuscript in 2022. In our case, it showed 40 research articles in 2022, including two additional, very specific years (2023 with 2 articles). It means that we have considered the most significant trends in which areas are interested in agrivoltaics by research experts, as well as annual tendency covering recent years in our manuscript. Another possible difference, taking into account the identified themes, is that the current study presented the main research concepts and the subject of study with relationships between them, the most significant research questions and the results of SLR studies described in our results (keyword co-occurrence network in Figure 4, a thematic map in Figure 5 and a multiple correspondence analysis in Figure 6). Another review investigated the influence of the decision of energy management (solar PV architecture) and agronomic management in AV systems, but it showed solar radiation in terms of light density and stakeholder perspectives [95]. Contrary to our work, this review was limited to technical improvements and thus did not include other areas and components consumed by the target population. Among the review publications, Weselek et al. [4] discussed the potential of AV systems, as well as the microclimatic changes associated with AV and their impacts on crop production. A key finding of the research is that crop yields under AV may be reduced for several crops due to an expected reduction in solar radiation by about one-third. Still, AV can increase the productivity of a given land area by up to 70% by combining energy and crop production. As a result of the shading effect, potential benefits can also be envisaged: the negative effects of climate change can be mitigated using technology, and in a dry climate, the water balance and water retention capacity of the area can be expected to improve, which can be identified as a clear benefit if the proper plant species is selected. This article points out that there is still little information available on the shade-tolerant plant species that can be grown in PV shade and the yields that can be achieved, which certainly represents a research gap. In addition, AV can contribute to increasing added value and decentralized off-grid energy supply in developing and rural areas, thus further improving the productivity of agricultural activity. AV can thus be a promising and valuable technical approach for a more sustainable agriculture, contributing to meeting current and future demand for energy and food production, while at the same time conserving the Earth's resources.

All these factors are leading to increasing competition for limited arable land. Under the PV solar panels, soil moisture was higher throughout the observation period. At the same time, a significant increase in biomass (+90%) was observed in the late season, and areas under the PV panels were significantly (328%) more water efficient. A significant number of articles on this subject deal with the selection of the right plant species, the role of shade-tolerant plants and the impact of shading by PV panels on plant growth, which, in addition to reducing light intensity, affects air, plant and soil temperatures, contributes to improving water balance and supports water conservation efforts [16]. Agrivoltaic (AV) or agrovoltaic systems, which are a combination of photovoltaic energy production and crop production, can be identified as one of the ways to solve this contradiction [4]. In their publication, Weselek et al. [4,6] summarize the effects of shading on different crops, but point out that the specific expected effect depends on several factors other than the crop species used (e.g., climate, soil conditions, rainfall, system design, etc.). The system described in the later chapter also presents a technical perspective on the synergic combination of renewable energy and food production, which has been increasingly gaining attention in recent years, both in the field of scientific research and practical application.

Agrivoltaics research is in its early stages of maturity; researchers still study what configurations and crops to use in different climates for optimal yields, and most agrivoltaic sites are still providing new data. Based on the above, the international research activity regarding the economics of agrivoltaics and the relationships between them are under-researched and unexploited areas. Therefore, in the current study, the main focus is on the bibliographic analysis and illustration of related academic research work. The novelty of the proposed method lies in systematically reviewing the productivity of crops and photovoltaic systems in an integrated AVSs, determining structural, water efficiency, agricultural and electrical outcomes.

5. Conclusions

The SLR allows us to conclude that the current state of research and existing developments are able to form the framework priorities for the innovative development of agrivoltaics in the near and distant future: widespread use of an environmentally friendly resource-saving system of agriculture activities; the transition to green electricity; transition to multifunctional highly productive and environmentally friendly use of agrivoltaic system. Our study aimed to conduct a systematic review of bibliometric analysis on agrivoltaic systems. Out of the 121 sources included in the SLR, more than half of them were published in the last year, which indicates a significant increase in attention to agrivoltaic systems. Not many publications were found that offered the implementation of agrivoltaic systems. Nevertheless, the economic and financial implications of combining energy production and agriculture activities were observed among these publications, such as the cost of implementation, revenue, cost-benefit characteristics, NPV and LCOE related to AVS. Numerous publications indicate the design of AVSs, soil and climate factors.

The methodological advantages of the studies include the fact that the vast majority of them were based on technical, infrastructural, traditional outdoor agricultural planting and greenhouse agricultural cultivation, and were performed on large samples. Among shortcomings, the following can be noted: the studies used primary data, and data analysis was often limited to descriptive statistics. However, quality of research on agrivoltaic systems is steadily increasing, which includes comparing GM-PV and AV systems, more photovoltaic types of design are being used, and emphasis is on studying the current status of agrivoltaic systems and their potential economic benefits to energy and agriculture production. Our results highlight strategies that promote the understanding and implementation of agrivoltaic systems. Although the implementation of agrivoltaic systems has been identified in many kinds of crops, wheat, tomato, barley, soybean, and lettuce have notably been researched more often in literature. In the future, it is necessary to conduct comprehensive research and monitoring about the ecological effects of AV, selection crops, technical and social adaptation and its effects in different areas, and the long-term economic and financial consequences of AVSs. Additionally, another important aspect that future research should focus on is why farmers actually decide to implement agrivoltaic systems, since knowledge regarding AVSs becomes one of the major barriers to the implementation of AVSs on their land, and implementation of AVSs need valid business cases in order to get acceptance of farmers. Therefore, the future work of this study is consistent with the establishment of a recommendation system that, based on the information obtained through this systematic literature review, helps farmers and decision-makers to compare and select the agrivoltaic system implementation in their fields.

Supplementary Materials: An MS Excel spreadsheet contains a summary of the systematic literature review. The following supporting information can be downloaded at: https://unidebhu-my.sharepoint.com/:x:/g/personal/aidana_chalgynbayeva_econ_unideb_hu/EVq9btUf_cBAuDTAgKIHf1kB93QhtPtxELZ5aN_V3fhxwg?e=zoR6bN (accessed on 22 November 2022).

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

SLR	Systematic literature review
AV	Agrivoltaic
APV	Agrophotovoltaic
AVSs	Agrivoltaic systems
Agri-PV	agrivoltaics
PV	Photovoltaic
AVS-1	single raw PV array
GM-PV	Ground-mounted photovoltaic
NREL	National Renewable Energy Laboratory
LCOE	Levelized cost of electricity
NPV	Net present value
CAPEX	Capital expenditure
OPEX	Operating expenditure
OPV	Organic Photovoltaic
DSSC	Dye sensitized solar cell
c-Si	Crystalline Silicon

Appendix A

Academic Literature Search

A SCOPUS search was conducted to determine the required academic literature. The keywords selected for the search are those shown in Table A1. The results were refined using filters by agrivoltaic of economics, technical, infrastructure, environment, energy and agriculture-related areas and articles in English, as well as using articles all over the World.

Table A1. Selection Parameters used for peer-reviewed literature.

Number of Key Words	Keywords Selected
KW1	(TITLE-ABS-KEY (agrivoltaic) OR TITLE-ABS-KEY (agrovoltaic) OR TITLE-ABS-KEY (agrophotovoltaic) OR TITLE-ABS-KEY (agriphotovoltaic) OR TITLE-ABS-KEY ("agro-PV") OR TITLE-ABS-KEY ("agri-PV") OR TITLE-ABS-KEY ("Photovoltaic farming") OR TITLE-ABS-KEY ("Photovoltaic agriculture") OR TITLE-ABS-KEY ("Solar farming")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ch")) AND (EXCLUDE (DOCTYPE, "re") OR EXCLUDE (DOCTYPE, "ch"))
KW2	(TITLE-ABS-KEY (agrivoltaic) OR TITLE-ABS-KEY (agrovoltaic) OR TITLE-ABS-KEY (agrophotovoltaic) OR TITLE-ABS-KEY (agriphotovoltaic) AND ALL (technical) OR ALL (infrastructural) OR ALL (environmental)) AND (EXCLUDE (DOCTYPE, "re") OR EXCLUDE (DOCTYPE, "cr") OR EXCLUDE (DOCTYPE, "bk"))
KW3	(TITLE-ABS-KEY (agrivoltaic) OR TITLE-ABS-KEY (agrovoltaic) OR TITLE-ABS-KEY (agrophotovoltaic) OR TITLE-ABS-KEY (agriphotovoltaic) AND ALL (agriculture) OR ALL ("agriculture activity") OR ALL ("agriculture practice")) AND (EXCLUDE (DOCTYPE, "re") OR EXCLUDE (DOCTYPE, "bk") OR EXCLUDE (DOCTYPE, "ch"))
KW4	(TITLE-ABS-KEY (agrivoltaic) OR TITLE-ABS-KEY (agrovoltaic) OR TITLE-ABS-KEY (agrophotovoltaic) OR TITLE-ABS-KEY (agriphotovoltaic) AND ALL ("high mounted") OR ALL ("Dual-Axis Tracking") OR ALL ("Single-Axis Tracking") OR ALL ("Vertical PV")) AND (EXCLUDE (DOCTYPE, "re"))
KW5	(TITLE-ABS-KEY (agrivoltaic) OR TITLE-ABS-KEY (agrovoltaic) OR TITLE-ABS-KEY (agrophotovoltaic) OR TITLE-ABS-KEY (agriphotovoltaic) AND TITLE-ABS-KEY ("economic viability") OR TITLE-ABS-KEY (economic) OR ALL ("economic feasibility") OR ALL ("economic benefit") OR ALL (cost) OR ALL (investment)) AN (EXCLUDE (DOCTYPE, "cr") OR EXCLUDE (DOCTYPE, "bk") OR EXCLUDE (DOCTYPE, "ch") OR EXCLUDE (DOCTYPE, "sh"))
Filters	Language: English Sectors: agrivoltaic of economics, technical, infrastructure, environment, energy, and agriculture Country: All countries in the World Type: journal articles and conference paper

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