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Article

Agriculture 5.0: A New Strategic Management Mode for a Cut Cost and an Energy Efficient Agriculture Sector

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Abstract: The farmers' welfare and its interlinkages to energy efficiency and farm sustainability has attracted global scientific interest within the last few decades. This study examines the contribution of Agriculture 5.0 to the prosperity of the farmers in the post-pandemic era and the gradual transition to an energy-smart farm. To obtain an insight into the attributes of Agriculture 5.0 and the emerging technologies in the field, Bibliometrix analysis with the use of an R package was conducted based on 2000 data consisting of peer-reviewed articles. The data were retrieved from the Scopus database. A bibliometric approach was employed to analyze the data for a comprehensive overview of the trend, thematic focus, and scientific production in the field of Agriculture 5.0 and energy-smart farming. Emerging technologies that are part of Agriculture 5.0 in combination with alternative energy sources can provide cost-effective access to finance, weather updates, remotely monitoring, and future energy solutions for the establishment of smart farms. Keywords such as "renewable energy," "Internet of Things," and "emission control" remain the trending keywords. Moreover, thematic analysis shows that "economic and social effects", "energy efficiency", "remote sensing", and "Artificial Intelligence" with their associated components such as "anaerobic digestion", "wireless sensor network," "agricultural robots", and "smart agriculture" are the niche themes of Agriculture 5.0 in combination with green energy sources, which can lead to the cut cost, energy-efficient, and sustainable energy-smart farms.

Keywords: Agriculture 5.0; anaerobic digestion; artificial intelligence; bibliometric; cost-efficient; energy efficiency; renewable energy; strategy

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1. Introduction

In contemporary times, applications of artificial intelligence (AI) related to machine learning (ML) have been growing rapidly, while the COVID-19 pandemic has pushed these emerging technologies to the top of the business agenda [1,2]. The field of ML includes these methods of AI that enable machines to perform specific processes and solve problems without having been specially programmed for this purpose [1,3]. Essentially, these methods allow computer systems to be "trained" using existing data correlations of the problem to be solved. The increasing power in computing observed within the last decade, and the availability of large volumes of data in an abundance of scientific fields has led to the introduction of methods and models being part and parcel of a new category of ML, that of deep learning (DL), where more complex models that previously could not be implemented by existing computers are now realistic and functional [4,5]. The results of DL applications have revolutionized areas such as object recognition, voice recognition, and other correspondingly complex processes associated with large-volume data analysis [6–8]. The performance of computer systems in these applications has reached very high levels, making them capable in certain cases, if not to completely replace the human factor, at least to help it successfully to a great extent. Developments in AI, DL, the Internet of Things (IoT), blockchain, and other digital technologies are now being used in both crop and livestock agricultural production and transitioned sectors in the new age of "smart farming" [9,10].

The goal of smart farming is twofold: (i) to support the decision-making process when managing a crop or a herd, as well as to increase the number of correct decisions made per unit of cultivated area or per animal, considering the available time and (ii) to integrate the green energy sources into smart farms in order to achieve a sustainable agriculture sector (Figure 1) [11]. As for the first goal, this can be achieved by facilitating the collection of required data from the field, as well as their fast and reliable processing, so that it is possible to adapt the applied agricultural practices. Respectively, these procedures are carried out with the combined use of ICT, such as precision equipment, Internet of Things (IoT), big data, geolocation systems (GPS), non-GPS manned vehicles, robotics, sensors, 3D printing, agricultural automation, and management information systems [11,12].

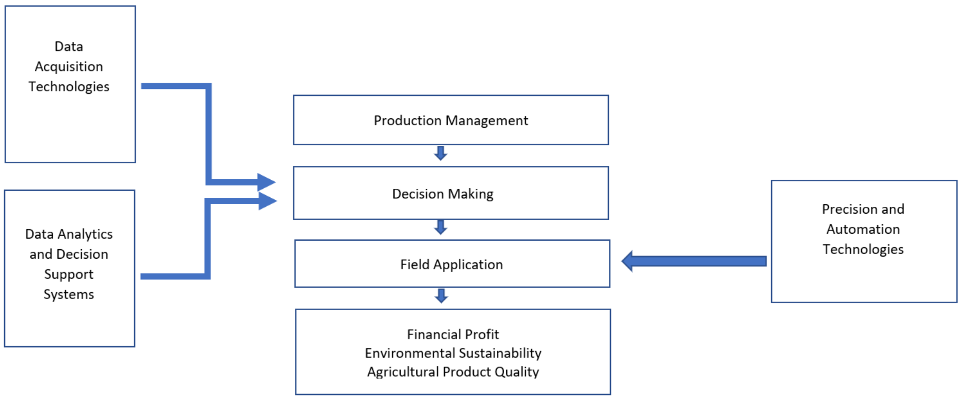

Figure 1. The smart farming processes.

However, most of the studies that refer to the field of smart farming focus only on a certain perspective [13,14]. Almost none has highlighted the impact of COVID-19 in the market and the new trends that the pandemic emerged, while overall visual bibliometric analysis is still very rare on the issue [15,16]. Precisely, field mapping is among the most used way of smart farming during the pandemic period and let farmers remotely monitor their farms with different tools such as satellite imaging [17]. The aim of this article is threefold. Firstly, the paper focus on the analysis of the impact of smart farming on the agriculture industry from 2017 to 2021. Promoting a path on smart farming can help practitioners in agriculture, as well as regions globally, to reduce their ecological footprint and improve their productivity and competitiveness. Secondly, this manuscript aims to highlight the new trends in smart farming that emerged during the COVID-19 pandemic. Lastly, this study contributes to the continuation and the modernization of the discussion of the strategies that practitioners in agriculture should develop oriented to the key trends of AI technology in the post-pandemic world.

The second goal of smart farming involves the corporation of new forms of energy in a smart farm, which will lead to a sustainable agriculture sector. Most of the agricultural machinery operates using fossil fuels, which contribute positively to greenhouse gas emissions while further enhancing climate change. However, renewable energy sources can reduce the above issues. These renewable resources have enormous potential for the agricultural sector. The adoption of emerging technologies and the transition of a traditional farm to a smart one can encourage more farmers to use green energy sources. The use of renewable energy sources offers farms in addition to reducing the environmental footprint and other additional benefits. These alternative energy sources can contribute to the sustainable and efficient use of agricultural resources and to the production of energy that meets local needs. Furthermore, the combination of the use of emerging technologies and green forms of energy can create new employment opportunities for the locals of each rural area. For example, young people, by using new forms of energy, will give locals the chance to improve their income and standard of living by recycling agricultural waste and reducing the use of chemical fertilizers. These improvements can strengthen and make more dynamic rural areas.

The importance of this study concerns the first macroscopic overview of the main characteristics of publications in the AI and agriculture industry in times of the COVID-19 pandemic [18]. Moreover, the study highlights the strong connection between smart farming and green energy sources, which lead to a new version of a smart farm, namely an "energy smart farm". Bibliometric analysis with the use of an R package is considered the main methodological tool of this study [19,20]. Moreover, clear, informative pictures are presented in this paper to demonstrate the research achievements in the domain of smart farming and green energy sources, which could help researchers and practitioners identify the underlying impacts from authors, journals, countries, institutions, references, and research topics.

The manuscript is organized as follows; Section 2 discusses the contribution of smart farming to the sustainability and efficiency of the agricultural sector, as well as the transition from a "smart farm" to an "energy smart farm". Section 3 presents and discusses the materials and methods used in highlighting the key factors and the trends of Agriculture 5.0. Section 4 discusses the key findings of our study. Section 5 summarizes the findings, outlines the research gaps, and suggests potential subjects for future surveys. Section 6 concludes.

2. Literature Review

Smart farming represents the implementation and integration of emerging technologies in agriculture, which drives the sector to the Third Green Revolution [21]. Technologies such as the Internet of Things (IoT), sensors, big data, Unmanned Aerial Vehicles (UAVs), drones, and robotics are only some of the most used in smart farming [19]. Smart farming has a real potential to provide more productive and sustainable agricultural production, which will be based on more accurate and efficient use of resources approach [13].

Agriculture 5.0: The New Path for an "Energy Smart Farm"

Smart farming is an integrated production system that utilizes the achievements of technology as well as specific decision-making processes, combines all factors of production, and integrates knowledge and agricultural research in order to optimize the agricultural sector [22,23]. Smart farming is related to three interconnected areas of technology as analyzed below:

Management Information Systems: Programmed systems for the collection, processing, storage, and dissemination of data in the format required to perform the tasks and functions of an agricultural enterprise [24].

Precision Agriculture: Managing spatial and temporal change to improve economic performance combined with reducing inputs and environmental impact. Includes Decision Support Systems (DSS) for the entire management of agricultural holdings in order to optimize yields on inputs while conserving resources, which are characterized by the widespread use of geolocation systems (GPS, GNSS), aerial photographs from UAVs, and the latest generation of supernatural images provided by Sentinel satellites, resulting in the creation of spatial variability maps of various measurable variables (e.g., crop yield, soil characteristics/topography, organic matter, moisture levels, nitrogen levels, etc.) [25–27].

Agricultural Automation and Robotics: The process of applying robotics, automated control, and artificial intelligence techniques to all levels of agricultural production, including farmbots and farmdrones [28].

The main goal of smart farming or precision farming is to optimize the yields of agricultural businesses with the best choice of agricultural practices, to enhance the environmental protection by reducing the use of chemicals and the proper use of agricultural machinery, to optimize the working conditions for staff combined with increased profit for the producer, and finally to optimize the greatest possible protection of the environment and the production of healthy products [22,27].

However, today we are at the dawn of a new era, that of Agriculture 5.0 (Figure 2) [29]. The concept of Agriculture 5.0 indicates the trend that the agricultural sector will face in the coming years. It includes the focus of agriculture on emerging technologies, such as the Internet of Things (IoT), artificial intelligence, machine learning, and the use of large volumes of data to increase the efficiency of agricultural enterprises [9,30]. However, it is not limited to that.

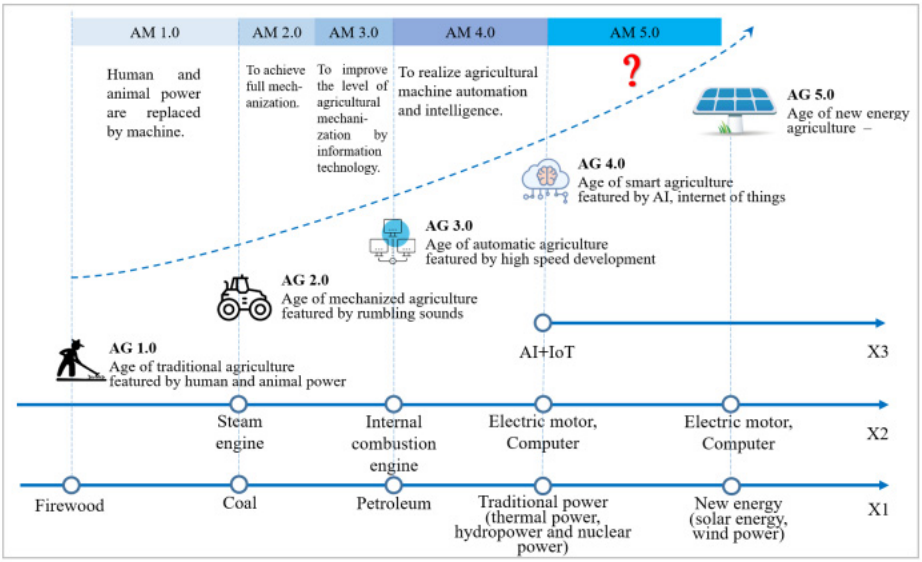

Figure 2. The trend of agriculture development. Source: Huang et al. (2017).

The above technological breakthroughs, in combination with the use of green energy sources, can serve as important milestones and lead to change as well as greater efficiency for the agriculture sector. Combining green energy sources, such as renewable energy sources with emerging technologies in agriculture, can be particularly profitable for the sector. The availability of wind, solar, and biomass energy is not limited. Thus, farmers, by using this kind of energy, can have a long-term source of income while achieving a decrease in their environmental footprint and becoming more efficient. However, which are the most used green energy sources for a smart farm? Biomass energy is one of the most used energy sources by smart farmers, and it can be produced from plants and organic waste [31]. Although corn is the most widely used energy crop, native prairie grasses or fast-growing trees such as switchgrass and poplar, respectively, are likely to become more popular in the future as energy sources [32]. These perennial crops require less maintenance and less care than annual crop series while they are cheaper and more sustainable for producing energy. Waste that comes from these crops can be converted into energy which can be used by smart farmers in different ways to heat their buildings, power their smart devices, or use them as transportation fuels for their smart vehicles [33,34].

Moreover, the role of solar power in smart farming is important too. The amount of energy from the sun that reaches the earth every day is unlimited. All the energy stored in the earth's coal, oil and gas reserves is equal to the energy of just 20 days of the sun. Solar energy can be used in smart agriculture in a variety of ways and can lead to saving money, increasing self-sufficiency, and reducing pollution [31]. However, one of the biggest benefits that solar power can offer to a smart farm is the ability to monitor farms and fields remotely. By collecting data under different circumstances and conditions, such as temperature or high levels of humidity, farmers can take good care of their yields. Furthermore, as farmers and their fields are often located in marginalized rural areas, this means that powering their smart monitoring devices can be very difficult [10]. However, solar power can provide an ideal solution to this weakness due to the capability of this type of green energy to provide power to smart devices such as sensors and other monitoring devices without the need for cables or any electrical sources. Thus, even in geographically challenging environments such as remote farms, farmers can reap the benefits of real-time monitoring [35].

Therefore, Agriculture 5.0 is more than just a new trend in the agricultural sector. The concept of Agriculture 5.0, in combination with the use of green energy sources, highlights the next step of agriculture towards the future, making the industry smarter and, by far, energy efficient.

3. Materials and Methods

Bibliometric analysis is a popular and rigorous method that can be used as a statistical evaluation for exploring and analyzing large volumes of scientific data. The aim of the bibliometric analysis is fourfold: (i) to detect the state of the art for a particular field, (ii) to highlight the most cited articles and examine their impact on the subsequent research by others, (iii) to show what journals, organizations, and even countries have high impact in different fields of research and (iv) to make comparisons [19,36,37]. Basically, the most commonly used bibliometric methods are citation or co-citation and content analysis. Regardless of the method to be used by the researcher, bibliometric analysis presents a comprehensive map of the structure of knowledge, its evaluation, and measurement that focuses on the bibliographic analysis of scientific publications collected in a database [20].

3.1. Data Sources and Collection

Scopus database was selected as the main data source of the current research. Scopus is Elsevier's bibliography and citation search services, which is provided through the SciVerse platform. It is the largest database in the world of references and summaries from reputable international literature with smart tools that help researchers globally to retrieve, analyze and visualize parts of the information that they are interested in [38]. It includes over 20,500 titles from 5000 publishers worldwide, 49 million subscriptions (78% with abstracts), over 5.3 million conference papers, and 100% Medline coverage [39]. The data collection was carried out in January 2022 with the entered search terms to be the following: [("Smart farming" OR "precision farming" OR "smart agriculture") AND ("green energy" OR "renewable energy")]. The search was carried out in English language, and the search of the keywords was made in the titles, abstracts, the main text, and authors' keywords of the published work in the research field. The Scopus bibliographic citation database includes various types of documents, but only original articles, book chapters, and conference proceedings were considered in the present analysis. A sum of 2000 documents was selected for this analysis. The records for each publication retrieved during the search were converted as a Scopus BibTex file and imported into Biblioshiny and VOSviewer [38].

3.2. Research Method

Both the use of Bibliometrix and Biblioshiny packages allows the current research to demonstrate bibliometric indicators for smart farming as well as Agriculture 5.0 and the integration of green technologies in farming, such as the volume of publications in number of research or original articles, the number of citations and keywords. Moreover, the article presents diagrams and maps, such as thematic map, country collaboration map, network visualization, which illustrate the research situation, MCA factorial analysis, and the dynamics of the smart farming frontiers in different periods (Figure 3).

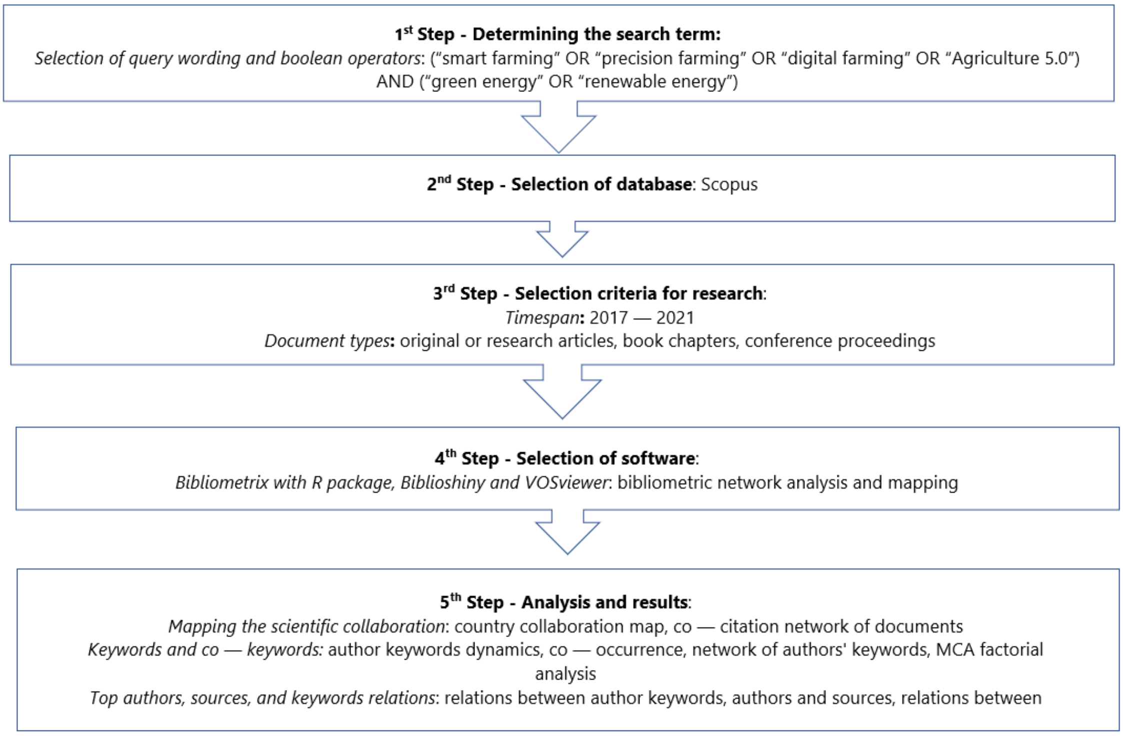

Figure 3. Methodological design for bibliometric process.

4. Results

4.1. Evolution of the Number of Articles

In the current study, a total of 2000 published journals, book chapters, and proceeding papers from 2017 to 2021 were analyzed. As presented in Figure 4, there has been a great evolution in publications on smart farming or precision farming, with over 70% of publications being originated between 2020–2021. The graph shows an escalation in smart farming publications from 52 documents in 2017 to 827 in 2021, characterized as the peak of publication.

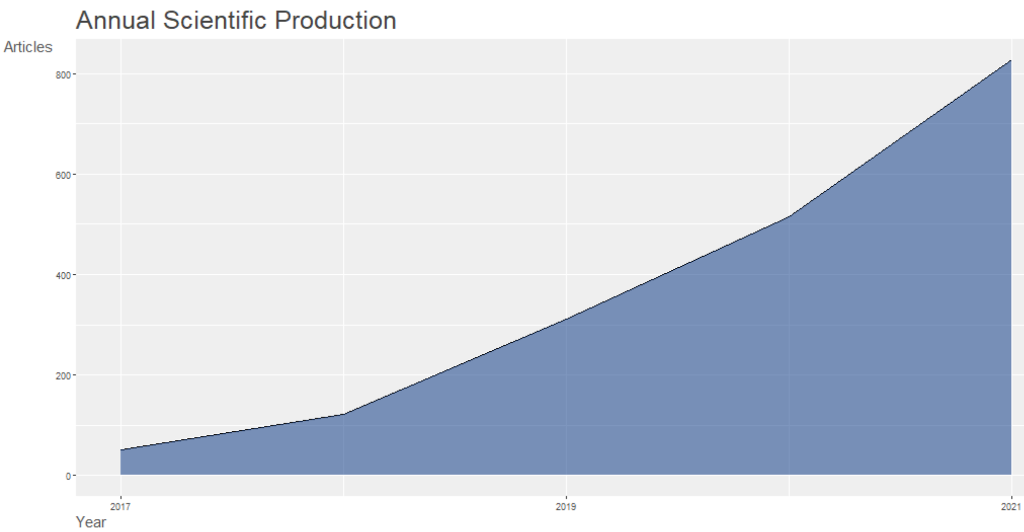

Figure 4. Annual scientific production of publications in smart farming. Source: Scopus-Biblioshiny.

This sharp increase is based on the strategies that many countries globally have adopted over the last two years, which are aimed at ensuring a satisfactory economic performance in the agriculture sector. For example, the main goal of the European Union's

(EU's) "farm to fork" strategy, which is at the heart of the Green Deal, is oriented to producers to enjoy a satisfactory income for their employment from agricultural activity [40]. This is a particularly important parameter, as according to surveys conducted, an average producer in the EU currently earns about half of the average worker in the economy [41]. However, for producers to be able to benefit financially, they will have to adopt more environmentally friendly production management models, such as practices that have been shown to capture carbon dioxide [42]. As this strategy states, strict certification rules for carbon dioxide absorption in the agriculture sector are the first step in enabling farmers to pay for their carbon sequestration. Among the measures proposed by the strategy are quantitative targets for the rational use of chemical pesticides and fertilizers, integrated plant protection, and the management of excess fertilizers in the soil, as well as the reduction of greenhouse gas emissions [41]. However, smart farming has been proven to help achieve these goals in a simple and economical way. Moreover, in the context of the development of smart farming applications in the agricultural sector, the EU has set the goal of the direct financing of producers through specially designed programs. The aim of these programs is to contribute to the immediate digital transformation of Europe's agricultural sector through the rapid adoption of emerging technologies, thus ensuring the long-term viability of the industry [40–42]. The above can be ensured by Figure 5 too, which illustrates the average article citations per year.

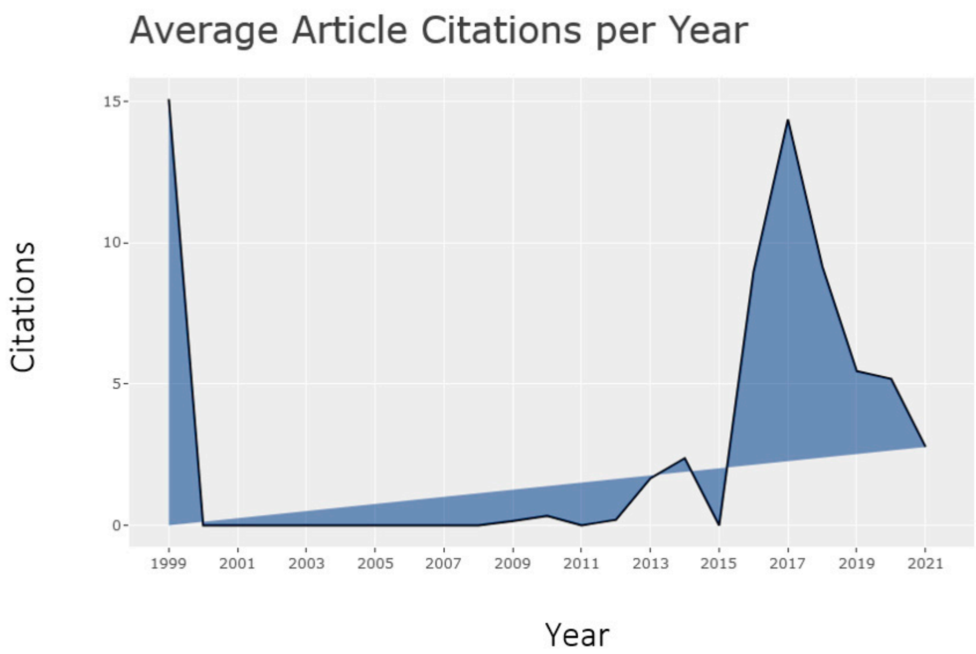

Figure 5. Average article citations per year. Source: Scopus-Biblioshiny.

The journals with the most published articles in the field of smart farming or precision farming for the years 2017–2021 are presented in Table 1. "Sustainability" was the journal with the highest number of published articles on smart farming and precision farming (48) during the period 2017–2021. "IEEE Access" ranked second with 46 articles found on smart farming. The journal "Sensors" published 42 articles, while the journal "Computers and Electronics in Agriculture" published 39 articles. In addition, many of the most-cited journals in the field of smart farming are indexed by Scopus and Scimago Journal and Country Rank.

Table 1. Most relevant resources in the field of smart and precision farming.

Sources	Articles	Ranking Quartiles	h-Index	Subject Area
Sustainability (Switzerland)	48	Q1	85	Energy and Environemental Engineering
Ieee Access	46	Q1	127	
Sensors (Switzerland)	42	Q2	172	Computer Science and Engineering
Computers and Electronics in Agriculture	39	Q1	115	Agricultural and Computer Science
Agronomy	35	Q1	30	Agricultural and Biological Sciences
Remote Sensing	30	Q1	124	Earth and Planetary Sciences
Advances in Intelligent Systems and Computing	27		41	Computer Science and Engineering
Agriculture (Switzerland)	18	Q3	10	Agricultural and Biological Sciences
Applied Sciences (Switzerland)	18	Q2	18	Computer Science and Engineering
Journal of Rural Studies	18	Q1	104	Agricultural and Social Sciences
Precision Agriculture	17	Q1	63	Agricultural and Biological Sciences
Communications in Computer and Information Science	14	Q4	51	Computer Science and Engineering
International Journal of Innovative Technology and Exploring Engineering	14		40	Computer Science and Engineering
Journal of Physics: Conference Series	13	Q4	85	Physics
Agricultural Systems	12	Q1	107	Agricultural and Biological Sciences
Electronics (Switzerland)	12	Q2	36	Computer Science and Engineering
International Journal of Advanced Computer Science And Applications	11	Q3	18	Computer Science
International Journal of Recent Technology and Engineering	10		20	Management of Technology and Innovation and Engineering
Journal of Cleaner Production	10	Q1	200	Energy
Animals	9	Q1	34	Agricultural and Biological Sciences
Ieee Sensors Journal	9	Q1	121	Engineering

Source: Scopus/Biblioshiny.

4.2. Geographical Collaboration Analysis

Table 2 illustrates the countries with the highest production of scientific papers in the field of smart and precision farming for the timespan 2017–2021. Total citations denotes the average article citations per annum. Both developed and developing countries present a strong research impact in the research field of smart agriculture. From the side of developed countries, the Netherlands has been observed as the most cited country, as Dutch papers have been cited 60,846 times. In recent years, the Netherlands has emerged as the country with the highest productivity in the agricultural sector even though it is a small country and has ten times fewer farmers and two and a half times less agricultural land than other European countries such as Greece [34,43]. However, the country is the EU's first food exporter as well as the second globally. This achievement is due to the particularly high degree of innovation that pervades the entire agri-food chain, as to the public authorities of the country too. In parallel with the United States of America and Spain, therefore the Netherlands is one of the three leading countries in the world in the production of fruits and vegetables [44]. A quarter of all European vegetable exports to third countries come from the Netherlands. With a view to 2030, the new Dutch vision for achieving a sustainable agricultural sector is governed by two key principles: (i) the integration of innovative crop improvement methods and (ii) the development of smart agriculture [45]. The agricultural sector has already begun to follow this "digital path" by adopting technologies from Agriculture 5.0, such as the integration of robotics. Robotics plays an important role in the agricultural sector in the Netherlands. At present, the annual income received by the agricultural robot amounts to about 700 million euros. However, the robotics sector is projected to triple this revenue over the next ten years due to the staff shortages, the transition to sustainable production and a lack of farmland. Most robots in agriculture are used to control weeds, such as mechanical hoe robots and chemical spray robots [46]. In addition to real robots, the Dutch agricultural sector will make more use of autonomous vehicles (tractors) in the coming years.

Table 2. Scientific production of the main countries related to the smart and precision farming.

Country	Total Citations (per Year)	Average Article Citations
Netherlands	1582	60,846
India	1525	7126
Usa	1180	18,730
China	942	8971
Spain	870	17,400
Italy	816	8870
Malaysia	766	14,185
Greece	703	16,349
Switzerland	669	37,167
Korea	590	14,390
France	564	26,857
Germany	548	8839
Australia	450	11,250
Brazil	421	13,581
United Kingdom	368	12,267
Iraq	309	44,143
Pakistan	272	14,316
Saudi Arabia	232	11,600
Canada	211	8440
New Zealand	174	19,333

Source: Scopus-Biblioshiny.

India holds the second position globally, with a total of 1525 published articles. Even though Indian papers have fewer citations (7126), which reveals the lack of digital monitoring of the agriculture farms, this is based on the refusion of small and medium-sized farmers, who are well known as Kisans [47]. In 2021, Kisans had been protesting masse and vigorously for many months against the government's promoted plan for the "modernization" of the agricultural sector [48]. The Indian government continues to try to convince farmers that the transition from the conventional agricultural sector to the digital one will allow farmers to increase their productivity and ensure better selling prices for their products [47,49]. However, discussions around this issue are still on the table. The rest of the top five with the highest number of publications is constituted by the USA (1180), China (942), and Spain (870). In early 2022, China's Ministry of Agriculture and Rural Affairs published its official five-year agricultural plan, which brings the revolution in the global agriculture sector. For the first time, China has included cultivated meat and other kinds of foods, such as eggs based on plants, as part of its strategy for future food security [50]. Cultivating meat in a bioreactor from stem cells and being fed with nutrient broth is a new technology adopted by the Chinese market, which promises to overthrow traditional livestock by replacing slaughterhouses with laboratories [51,52].

Figure 6 presents the geographical collaboration of the authors in the field of smart and precision farming. The visualization of this scientific collaboration was actualized by using the tool of Bibliometrix denoted as Biblioshiny. The aim of this geographical collaboration analysis is to highlight the social structure of the research community in the field of smart farming. The nodes in the graph represent the authors, while links represent the co-authorship. It is obvious from the map that the USA is the origin of most of the scientific collaborations in the field, as well as the strongest scientific channel, is between USA and China.

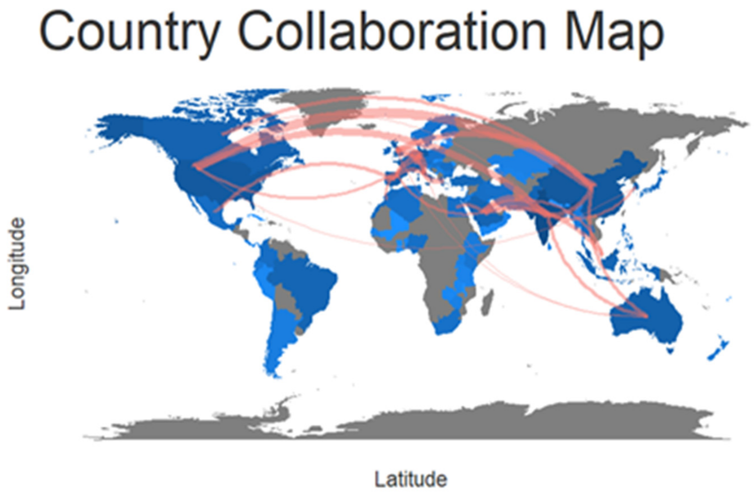

Figure 6. Country collaborations map. Source: Scopus-Biblioshiny.

4.3. Key Word Analysis

The aim of the keyword analysis is to highlight the direction and the key trends of the research. Figure 6 presents the network visualization based on the co-occurrence of the authors' keywords. To visualize the co-occurrence of authors' keywords VOSviewer tool was used [19,53]. VOSviewer is software that helps to build a bibliometric network, as well as visualize the information of this network. In Figure 6, each of the circles illustrates the occurrence. The bigger the size of the circle, the stronger the is the co-occurrence of authors' keywords. The similar color of the circles indicates the cluster of the keywords, and the lines between the circles show the link between the keywords [54]. A total of 241 words were selected and divided into nine clusters, and each cluster has a different color. Figure 7 illustrates the relationship between sources (left), authors' keywords (middle), and authors (right). The analysis presents the main research topics of smart farming that have been analyzed mostly by the authors in the field. The research topics are represented in the graph through the authors' keywords. The analysis of the keywords, authors, and sources highlighted that the three mentioned as top journals in Section 4.1 of this paper were closely linked to the research topic of smart or precision farming. Moreover, both Figures 7 and 8 indicate the transition of smart farming to the new era of Agriculture 5.0 [30]. This is observed by the keywords that dominate in the co-occurrence and three-field plot analysis. Concepts such as Internet of Things, deep learning, big data analytics, sensors, fog computing, artificial intelligence, and machine learning are the main characteristics of Agriculture 5.0, which lead to an overview of the latest development in the domain of smart farming [21,43].

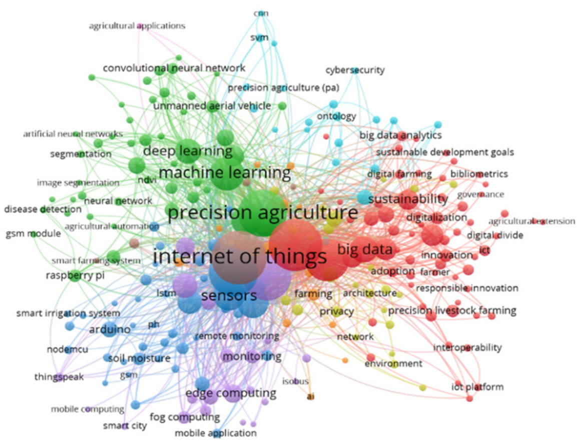

Figure 7. Network visualization–co-occurrence of author keywords. Source: Scopus-VOSviewer.

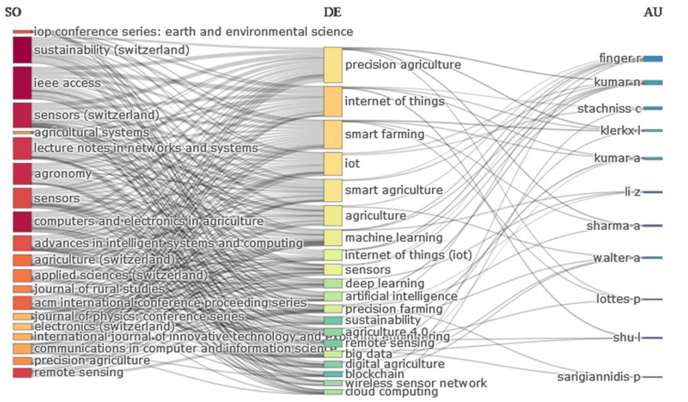

Figure 8. Relationships between sources (**left**), authors' keywords (**middle**), and authors (**right**). Source: Scopus-Biblioshiny.

Figure 9 presents the authors' keywords in the hierarchical arrangement of topics in smart farming, which have been discussed by scholars per year. The bigger the circle in the lines, the higher the number of references for the concept that is represented by the circle. These topics could relate to the field of smart agriculture, such as the IoT and the agricultural robots, but are not limited to that. Since 2016, researchers have started their discussion regards the integration of green energy sources into smart farms' daily operations. Despite the use of renewable energy sources, researchers highlighted alternative energy sources such as anaerobic digestion as a source with plenty of benefits for an energy-smart farm. Anaerobic digestion is a biological process that involves the breakdown of organic matter into simpler components with the help of microorganisms under anaerobic conditions. The process of anaerobic digestion is very complex and consists of numerous physical and biochemical reactions that lead to the production of biogas consisting mainly of methane (50–75%), carbon dioxide, and traces of other gases, as well as the production of stabilized fertilizer. Anaerobic digestion, depending on the operating temperature, is divided into two main categories: (i) mesophilic and (ii) thermophilic. In mesophilic anaerobic digestion, which is the most common category among the two, the temperature ranges between 20–45 °C. The thermophilic in which higher temperatures are developed in the digester is selected when additional disinfection of the materials is required so that they can be used for the benefit of agriculture. However, independently of each of the above types, anaerobic digestion can be characterized as an extremely flexible technology that can be used for a wide range of agricultural operations such as crops, residues, animal wastes, and imported food wastes into usable energy.

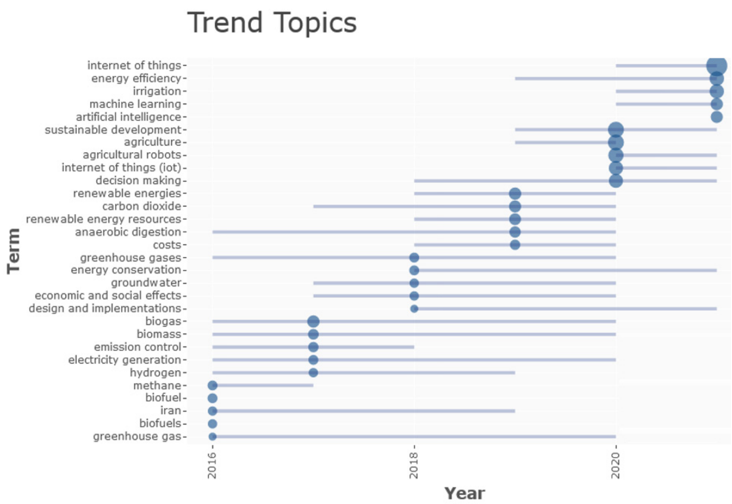

Figure 9. Trend topics of authors' keywords. Source: Scopus-Biblioshiny.

The above can be illustrated in Figure 10, too. This figure describes the research themes which are obtained from the conceptual structure of the documents included in the Bibliometric analysis. The clusters in the graph indicate the themes of the research, while the size of the clusters highlights the proportional to the number of the keywords. In the figure, each quadrant represents a different theme. The quadrant in the upper-right position of the figure illustrates the motor themes, which are characterized by both high centrality and density. Niche themes are represented by the quadrant in the upper-left position of the thematic map, and this typology is characterized by low centrality and high density. Moreover, themes that are placed in the lower-right position of the thematic map are known as basic themes, while lower-left quadrants represent the emerging themes which are defined by low centrality and density. Decreases in greenhouse gases, as well as carbon dioxide, are the niche themes of an energy-smart farm by adopting green energy sources such as anaerobic digestion. One more energy source that is emerged in the niche trends of green energy sources and is strongly related to the anaerobic digestion process is biogas [37]. Biogas is usually referred to as a different mixture of gases that are produced by the decomposition of organic matter in the absence of oxygen. Biogas can be characterized as a renewable energy source with a low carbon footprint. This energy release allows biogas to be used as fuel; it can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert energy in the gas into electricity and heat. Thus, in the case of a smart farm, that kind of green energy source can provide renewable heat and power and clean transport [31].

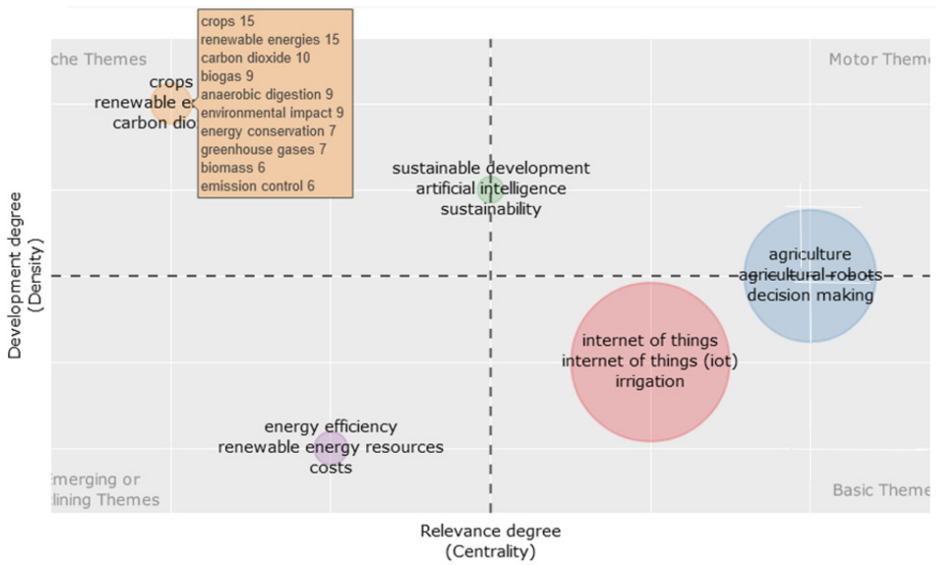

Figure 10. Thematic map of authors' keywords. Source: Scopus/Biblioshiny.

5. Discussion

The use of Bibliometrix analysis with an R package has contributed to mapping the evolution and the key themes that emerged within the research related to smart farming.

First and foremost, the findings note the increasing interest and scientific collaboration in smart farming and related to that field during the analyzed period 2017–2021. The USA is the origin of most of the scientific collaborations in the field of smart farming, as well as the strongest scientific channel between the USA and China [52]. Both developed economies have witnessed numerous revolutions over the last years. The biggest breakthrough is the integration of emerging technologies in the agriculture sector. This type of technology has led the agriculture sector into a "new age", which provides farmers with valuable insights to monitor the growth of their yield efficiently [9]. The incorporation of navigation systems into agricultural machinery and systems has led to the precise movement of farming equipment in the field. Regionally the market is dominated by the USA, which owns the highest market penetration of different technologically advanced solutions in the agriculture sector. However, it is time for other regions to be evolved in the market of smart farming. India can be one of these regions, as it is the second-largest country with the highest productivity of agricultural products. However, India's agriculture sector is in a mess [47,49]. Integration of technology will organize the sector and enhance its productivity.

The analysis of authors' keywords and co-occurrence can contribute to drawing useful conclusions about the field of smart farming. Likewise, the analysis of the authors' keywords indicates the transition from smart farming to Agriculture 5.0 [15]. As it is mentioned in Section 4.3, the population is growing rapidly, and the behavior of consumers has changed day by day. Thus, farmers are called to respond promptly to capture the needs of the consumers and mitigate the new challenges such as the effects caused by the pandemic of COVID-19. To achieve those goals, farmers should manage small-scale crops/farms, which, if integrated, will provide a solution for the management of larger agricultural ecosystems, which can contribute to maximizing agricultural production. At this point, the integration of emerging technologies is crucial. However, a smart and sustainable farm is not limited to the use of emerging technologies. Research directions highlight the integration of green energy sources into a smart farm as a highly important issue. Figure 11 illustrates the results from the factorial analysis of the documents with the assistance of Multiple Correspondence Analysis (MCA) [54]. MCA method is used to define, examine, and visualize the relationship among two or more categorical variables. The visualization of the results is presented in a conceptual structure map. In the current research, the map of the MCA method shows the clustering of documents and indicates the importance of a combination of alternative energy sources with emerging technologies. Thus, these findings imply that there is an essential space for future research to investigate more deeply the role and contribution of green energy sources such as anaerobic digestion and biogas. Moreover, the graph shows the contribution of emerging technologies as very important in making renewable energy sources smarter. This will help farmers to have a sustainable, energy-efficient, reduced-cost, and resilient smart farm.

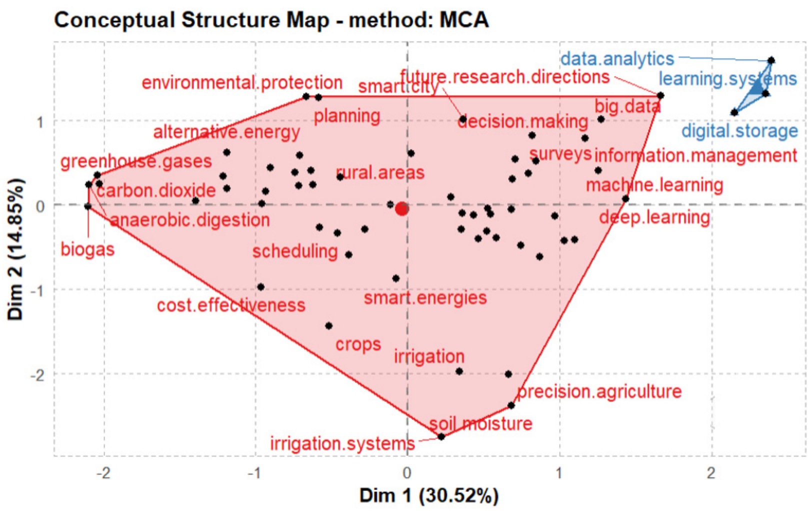

Figure 11. Factorial analysis based on MCA method. Source: Scopus-Biblioshiny.

Our research presents some limitations too. One of these limitations refers to the use of the Scopus database exclusively. Scopus offers the maximum coverage and the most accurate data compared to the rest available bases, but it would be desirable to integrate different databases such as Web of Science or Google Scholar. However, the analysis may have included some unnecessary research articles, as well as some that should have been omitted. This may be due to the restriction of the search based on specific keywords. It is also worth noting that some vital publications from the current year have not been included in this study. Lastly, another restriction has to do with the authors with the greatest influence. Influenced authors are organized according to the number of publications, so those with a single document but with plenty of citations may be misreported in the results.

The main purpose of this study was to highlight the contribution and the main trends in the field of smart agriculture. From the researchers' insight, this study provides a summary of the research being conducted in this area and suggests future directions, which will also contribute to the support of other studies. We expect that the thorough analysis that was carried out on the field of smart farming highlights the way to the new era of digital farming, that of Agriculture 5.0. However, Agriculture 5.0 is the next way for environmental, social, and governance (ESG) investors and can fight other challenges, too, such as climate change. The agricultural sector has not been on the "scanning system" of the three pillars of ESG practices (environmental, social, and governance). However, investors of ESG are now focusing their interest on fighting climate change. Thus, our proposal for future research is to examine the integration of ESG in the Agriculture 5.0 as a tool to mitigate agriculture's challenges, such as climate change.

6. Conclusions

Undoubtedly, we are going through an abundance of transformations in the production, distribution, and consumption of agricultural products. Within this regime, the pandemic of COVID-19 has become another major contemporary challenge to the agricultural sector. The concept of smart farming or precision farming is essential to address the current challenges in agriculture regarding productivity, climate change, food safety, and sustainability. This is luminous due to the continuous growth of the population, which leads to the rapid increase in food production, as well as the protection of natural ecosystems using sustainable agricultural processes. However, it is not enough just to increase the production process of agricultural products. It is also important to ensure and achieve high nutritional value in combination with the necessary safety. Thus, to address all the above issues, the development of agricultural ecosystems based on emerging technologies becomes important.

In the light of a sustainable and resilient agricultural ecosystem, this article highlighted the importance and contribution of smart farming. Moreover, the paper indicated the transition from smart farming to the new "digital era" of Agriculture 5.0, as well as the new model in farming, that of an energy-smart farm. The article described the evolution of the number of articles, the most relevant sources, the science of the countries and the collaboration between them, the co-citation and co-occurrence network, and the evolution of authors' keywords in the field of smart farming and related concepts. The Bibliometrix analysis with the R package examined the documents that are related to the field of smart farming. The data were collected from the Scopus database, while the language of the documents was English. The analysis revealed that the first records on smart farming appeared in 2017. However, it was only after 2020 that the concept attracted mostly researchers in the field since the publications were almost triplicated. The country that has published the most cited articles on smart farming is the Netherlands, whereas India, the USA, China, and Spain follow.

Moreover, keyword analysis, as well as factorial analysis, indicates the new age of smart farming, that of Agriculture 5.0. In a post-pandemic world, this new era will make a breakthrough in the agricultural sector. The period of agricultural production in the last two years due to the pandemic could be characterized as: (i) a period of maintaining food and nutritional adequacy and (ii) a transitional period towards the stage of verticalization of production and exploitation of new technologies. Thus, Agriculture 5.0, in combination with green energy sources and smart tools, is going in the right direction to move from a typical smart farm to an energy-smart farm. The main characteristic of Agriculture 5.0 is the need for remote sensing with the adoption of green energy sources such as anaerobic digestion and biogas. Thus, it can be achieved by using different smart devices such as Unmanned Aerial Vehicles, sensors, smart tractors, and much more that are based on the emerging technologies of artificial intelligence, machine learning, and big data analytics at a low cost and environmentally friendly use. The new age of Agriculture 5.0 is here to stay and address for a long time the needs of a post-pandemic world as well as climate change, the rapid growth of population, and environmental degradation.

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