horticulturae

Article

Research Trends on Greenhouse Engineering Using a Science Mapping Approach

Ileana Blanco [1,*], Andrea Luvisi [1], Luigi De Bellis [1], Evelia Schettini [2], Giuliano Vox [2] and Giacomo Scarascia Mugnozza [3]

1 Department of Biological and Environmental Sciences and Technologies, University of Salento, 73100 Lecce, Italy
2 Department of Agricultural and Environmental Science, University of Bari, 70126 Bari, Italy
3 Department of Civil, Environmental, Land, Building Engineering and Chemistry, Polytechnic University of Bari, 70125 Bari, Italy
* Correspondence: ileana.blanco@unisalento.it; Tel.: +39-0832-297038

Abstract: Horticultural protected cultivation has spread throughout the world as it has proven to be extremely effective. In recent years, the greenhouse engineering research field has become one of the main research topics within greenhouse farming. The main objectives of the current study were to identify the major research topics and their trends during the last four decades by analyzing the co-occurrence network of keywords associated with greenhouse engineering publications. A total of 3804 pertinent documents published, in 1981–2021, were analyzed and discussed. China, the United States, Spain, Italy and the Netherlands have been the most active countries with more than 36% of the relevant literature. The keyword cluster analysis suggested the presence of five principal research topics: energy management and storage; monitoring and control of greenhouse climate parameters; automation of greenhouse operations through the internet of things (IoT) and wireless sensor network (WSN) applications; greenhouse covering materials and microclimate optimization in relation to plant growth; structural and functional design for improving greenhouse stability, ventilation and microclimate. Recent research trends are focused on real-time monitoring and automatic control systems based on the IoT and WSN technologies, multi-objective optimization approaches for greenhouse climate control, efficient artificial lighting and sustainable greenhouse crop cultivation using renewable energy.

Keywords: automation; bibliometric analysis; energy efficiency; greenhouse heating; horticulture; monitoring and control systems; protected agriculture; renewable energy; sustainability

check for updates

Citation: Blanco, I.; Luvisi, A.; De Bellis, L.; Schettini, E.; Vox, G.; Scarascia Mugnozza, G. Research Trends on Greenhouse Engineering Using a Science Mapping Approach. *Horticulturae* **2022**, *8*, 833. https://doi.org/10.3390/horticulturae8090833

Academic Editor: László Sipos

Received: 11 July 2022
Accepted: 6 September 2022
Published: 9 September 2022

1. Introduction

The need to increase a sustainable food production for a predicted world population of 9 billion by 2050 represents a priority for all countries [1]. Protected agriculture has enabled us to extend the food production capability in many developed countries and, recently, to less prosperous regions of the world. Greenhouses represent a symbol of modern agriculture and can have several relevant effects on the economy, society, and on agro-ecosystems [2]. The worldwide protected agriculture area (including greenhouse and any crop "under cover" production systems) was estimated to be 5.6 million ha [3]. Globally, the greenhouse area is estimated to have expand multifold in the last decades, comparing the 200,000 ha in 1980 to the 2 million ha in 2010, particularly in Asia and the Mediterranean basin [4]. More than 60% of the total area of greenhouses in the Mediterranean region was concentrated in three countries: Spain (53,843 ha), Italy (42,800 ha) and Turkey (30,669 ha) [5]. In Asia, large greenhouse areas were recorded in China (3.4 million ha in 2010) and Japan (46,000 ha in 2012) [4,6]. In particular, the greenhouse area in China underwent a rapid expansion from 1982 to 2010 [6].

Greenhouse systems represent a defense measure against unfavorable climatic conditions as well as pests and diseases. Furthermore, greenhouses have the great advantage of remarkably increasing off-season products, thus satisfying the demand for quality fresh products throughout the year by the large-scale retail chains. Greenhouse farming is mainly involved in vegetable crops (tomato, pepper, eggplant, zucchini, cucumber, melon, squash and lettuce), and to a lesser extent of other commodities, like flowers, ornamentals and fruits (mainly strawberries). Tomato, cucumber and sweet pepper are the dominant crops [7].

In countries with a mild and warm climate, the greenhouse systems are characterized by low technology and a low use of energy inputs, which are characteristics that have created, however, some critical issues. The low night-time temperatures in winter, and the excessively high day-time temperatures in warm periods require proper solutions. These issues are related to the strong and direct dependence of the internal microclimate on the external climatic conditions [8]. The dominant trend in these areas is the minimal control of the greenhouse microclimate that is often limited to natural ventilation, shading techniques and emergency heating [9]. In the warmest Mediterranean areas, the greenhouse technology is generally based on the principle of minimizing capital investments, running costs and energy consumption, thus greenhouses are commonly characterized by lightweight structures without artificial heating systems [9,10]. In Northern Europe, there is a clear trend to optimize the greenhouse environment in order to obtain the maximum crop production potential [8,11]. Greenhouse farming in North-Western Europe has evolved in parallel with the emergence of advanced engineering technologies, including computerized climate control, soilless cultivation systems and agro-robot systems [12,13].

In Mexico and Colombia, naturally ventilated structures are mainly used, and greenhouse climate dynamics are primarily affected by the local weather conditions because greenhouses are not equipped with heating and cooling systems [14,15]. Computational fluid dynamic (CFD) studies were applied to greenhouses in order to evaluate the inside air flow patterns and temperature distribution as affected by the slope of the terrain [16] and by the height and ventilation configuration in a Colombian greenhouse [17], the airflow and ventilation rates as affected by the greenhouse orientation and roof vent and screen characteristics [18].

The great diffusion of greenhouses, however, has been criticized for its associated environmental impact due to energy use, plastic waste generation, soil pollution, biodiversity degradation, local runoff alteration [19,20], as well as for their impact on the visual quality of the surrounding rural landscape [21–23]. The major environmental burden in high-tech greenhouses is represented by the high fossil fuel-based energy use; the soilless cultivation with the recirculation of drain water allows for achieving a high resource and water use efficiency and low N emissions [24]. The greenhouse structure, fertilizers and auxiliary equipment were found to be the major environmental burdens in unheated, plastic covered multi-tunnels [25]. The necessary frequent replacement of plastic covering films generates huge quantities of post-consumer materials that are often improperly disposed of, causing environmental and economic problems [26]. Studies on greenhouse engineering have been previously reviewed by Hanan [27], Critten and Bailey [28], Montero et al. [29], Shamshiri et al. [30], Syed and Hachem [31] and Achour et al. [32].

The bibliometric analysis approach, including the performance analysis and science mapping techniques, has been used to analyze the quantity and quality of the scientific production and to graphically represent the structure of scientific activity within a discipline, a research field or a topic area, by applying mathematical and statistical methods and data mapping techniques [33–35]. This methodology is a useful and powerful tool to analyze publishing activities at the level of countries, institutions or research groups for comparative analyses of productivity, cooperation between universities and research centers, for the description, evaluation and monitoring of scientific and technological activities and projects and to identify research trends and areas that are developing or regressing [36]. A bibliometric analysis can facilitate the development of science-based strategies including private and public research management, the development of science and technology programs and policies and research strategic decision making [34,37]. HistCite [38], CiteSpace [39] and VOSviewer [40] are freely available software widely used to create networks of publications, journals, researchers, research institutions, countries, keywords or terms [41].

The science mapping approach has been widely used in several research areas [42]. In agricultural sciences, this methodology has been employed to analyze research trends into various research fields, such as global biodiversity [43], structure and evolution of the Mediterranean forest [44], plant phenotyping [45], precision agriculture [46], unmanned aerial vehicles in agricultural and forestry [47], soil remediation [48], greenhouse farming [49], durum wheat and pasta quality [50], agricultural pollution [51], mapping of agricultural greenhouses and plastic-mulched crops by remote sensing approach [52] and in the study of natural ventilation in protected agricultural structures in tropical and subtropical climatic regions using CFD [15].

Considering that the several studies published on greenhouse engineering cover a wide range of scientific areas, an advanced visualization methodology, such as science mapping, could provide a useful alternative tool to analyze the pertinent literature and reveal the structure and the evolution of the research activity.

The objective of the current work was to analyze the global research trends on greenhouse engineering in the last four decades through a bibliometric mapping approach. Particularly, our aims were: (1) examining the number of publications per journal, country and research institutions and the trends in scientific publication outputs; (2) identifying and visualizing the main research topics and their relations; and (3) providing a general overview of the main topics and their trends over time. To our knowledge, there are no studies that have applied this method to analyze the research on such a wide topic in the last four decades. This work will provide a general comprehensive knowledge on the structure and progress of research in this scientific field. Such knowledge could be beneficial to research project funding and to university curricula as well as to young researchers, research managers and policy makers who may be interested in knowing where, by whom research is being carried out and what are the main recent directions of the research progress in greenhouse engineering, a field that is undergoing increasing technological and sustainable improvement and application.

2. Materials and Methods

2.1. Data Collection

The Elsevier's Scopus database was chosen as one of the most widely used data sources for bibliometric analyses. It is one of the largest abstract and citation repositories of peer-reviewed literature, covering scientific journals, books, conference proceedings, etc. [53].

T bibliographical records related to greenhouse engineering research were retrieved using the Scopus database. The relevant scientific documents were identified using appropriate keywords in the combined fields of title, abstract and keywords; the search terms always included "greenhouse" and the terms related to the principal topics of the research in greenhouse engineering. Some terms were used with an asterisk in order to retrieve documents associated with the derived words. The following search equation was typed into Scopus to collect relevant publications: (TITLE-ABS-KEY ((greenhouse) AND ("environment monitoring" OR "environment control" OR "wind load*" OR "snow load*" OR "construction element" OR "structural element" OR "shading net*" OR "insect screen*" OR "covering material" OR "CFD" OR "computational fluid dynamic" OR "internet of things" OR "thermal* control*" OR "pest protection" OR "ventilation system" OR "cooling system" OR "heating system")) OR TITLE-ABS-KEY ("greenhouse energy" OR "intelligent greenhouse" OR "intelligent agricultural greenhouse" OR "greenhouse automation" OR "greenhouse cover*" OR "greenhouse cladding" OR "greenhouse climate control" OR "greenhouse conditioning" OR "greenhouse heating" OR "greenhouse cooling" OR "greenhouse dehumidification" OR "greenhouse glazing" OR "greenhouse lighting" OR "greenhouse microclimate" OR "greenhouse monitoring" OR "greenhouse shading" OR "greenhouse structure" OR "greenhouse design" OR "greenhouse engineering" OR "sustainable greenhouse" OR "photovoltaic greenhouse" OR "smart greenhouse" OR "greenhouse film")).

The document search was carried out in April 2022 by restricting the research to original publications written in English (article, book chapter, book, reviews and conference papers) and published in the last four decades (1981–2021) in order to capture the evolution dynamics of the research field over a long period. Regional research published in other languages was therefore not included in the current bibliometric analysis. Although the initial number of documents retrieved was high, the number was reduced after conducting a search refinement based on the application of filters for terms included in the title, abstract or keywords, based on the abstract reading and keywords analysis in order to get a more detailed view on greenhouse engineering for crop production. Some keywords such as "global warming", "greenhouse warming", "greenhouse gas", "greenhouse effect", "paleo*", "cretace*", "icehouse", "thermosphere*", "ionosphere*" were excluded to prevent the downloading of documents on climate change, climatology and related aspects, or on technologies based on the exploitation of the greenhouse effect.

2.2. Bibliometric Analysis and Clustering

The records were analyzed in order to obtain the number of publications per year in the examined period, the subject categories of each publication, the journals where the documents were published and their SCImago Journal Rank (SJR), their Scopus CiteScore (CS) and their highest CiteScore percentile (HP), as well as the articles with more citations. The SJR indicator is built on the Scopus database and considers the number of citations received by a given journal and the prestige of the journals where the citations are mentioned. It is defined as the average number of weighted citations received in a year per document published in a given journal in the previous three years. The SJR weighs each incoming citation of the journal by the SJR of the citing journal [54]. The CiteScore is calculated as the ratio of the number of citations received by articles, reviews, conference papers, book chapters and data papers of a given journal over four years and published in those same four years, over the number of the same documents [55]. The CS and HP are also calculated from the Scopus data.

The VOSviewer bibliometric mapping program version 1.6.16 (www.vosviewer.com, accessed on 1 June 2021), developed by Van Eck and Waltman [40], was used for the bibliometric analysis. We conducted a co-occurrence keyword analysis and a co-authorship analysis of the retrieved publications, and some bibliometric maps were built to represent, in two dimensions, the research area of greenhouse engineering and to identify the knowledge structure of the research topics.

The keywords network representing the different research themes on greenhouse engineering was built by assigning keywords to a cluster based on their co-occurrences in the publications. One cluster is represented by terms (in the same color) belonging to a general or specific research theme; one or more research topics can be identified in a cluster. The terms occurring at least five times were considered in the current study. Duplicated keywords as singular and plural of a term or synonymous terms were previously merged into a single keyword in order to conduct a more accurate assessment of the relative importance of specific keywords within the thematic clusters.

The co-operative network of key authors was used to identify the collaboration among contrasting key researchers. All co-authors of an article were considered, excluding papers with more than 25 authors. Authors with a minimum of 10 documents were considered in the current study. The different colors highlight the clusters of authors who usually collaborate with each other.

Figure 1 summarizes the methodology followed in the present study to carry out the bibliometric analysis and science mapping. More detailed explanations about the cluster analysis and the graphical map representation are available in the VOSviewer manual [56].

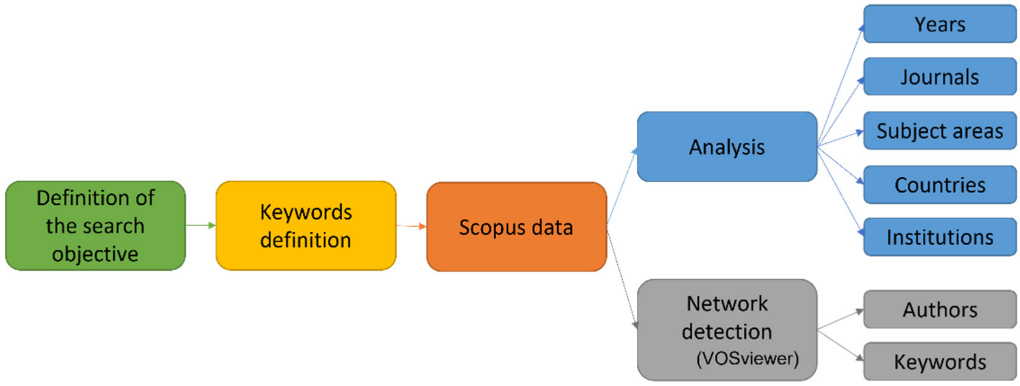

Figure 1. Workflow for the data screening and analysis.

3. Results and Discussion

3.1. Greenhouse Engineering Publication Trends

3.1.1. Annual Evolution of Published Papers

A total of 3804 scientific documents fitting the search on greenhouse engineering in the last 40 years (1981–2021) were retrieved from the Scopus database and analyzed. Only a few papers (n = 42) were present before 1981 with 0 to 14 articles/year. A percentage of 48.9% (n = 1861) of the 3804 documents were original research articles and 2.4% (n = 92) were reviews; 46.7% (n = 1778) of the documents were conference papers published in journals, conference proceedings or book series and 1.9% (n = 72) were book chapters or books. In the first 15 years of the considered period (1981–1995) few papers per year were present (n = 7–36, mean 21.2). In the following 15 years (1996–2010) the number per year significantly increased (n = 35–140, mean 66.1), and even more in the last period 2011–2021 (n = 170–365, mean 226.8), when the growth is most evident for articles published in journals than in conference proceedings (Figure 2).

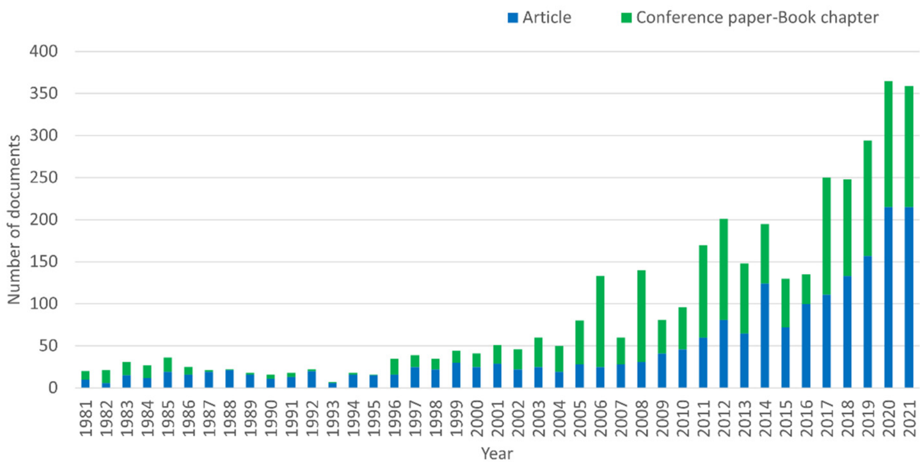

Figure 2. Trends in publications on greenhouse engineering from 1981 to 2021. The histogram represents the number of articles published in indexed journals with respect to other papers reported in conference proceedings and book chapters.

3.1.2. Journals of Publication

The documents were published in several journals and conference proceedings or book series. Ninety-seven sources published at least five documents. The leading 30 sources published more than 16 documents each. Table 1 shows their principal characteristics, such as the publisher, total number of publications, CS, SJR and HP within the Scopus categories. Overall, 1634 documents out of 3804 (43.0%) were published in these journals. Only three sources published more than 50 documents. Most of the documents are present in *Acta Horticulturae*: 812 (21.3%). *Acta Horticulturae* is a Belgian peer reviewed series (publisher: International Society for Horticultural Science, ISHS) that mainly publishes the proceedings of the ISHS Symposia and of the International Horticultural Congresses. Some ISHS symposia focus specifically on advanced technologies and innovative greenhouse management, and over time have become an important opportunity for researchers to discuss the state of the art and future perspectives within these research topics. *Biosystems Engineering* is the second top journal in relation to the number of papers (n = 86) published on the subject. It is a monthly peer reviewed scientific journal, owned by The Institution of Agricultural Engineers (IAgrE) and published by Elsevier; it is also the official scientific journal of the European Society of Agricultural Engineers (EurAgEng). Its topic reflects the interdisciplinary nature of research in biological systems engineering. *Computers and Electronics in Agriculture*, the third journal with 53 papers, focuses on developments and applications of computers or electronics in plant or animal agricultural production, including agronomy, horticulture, forestry, aquaculture and animal/livestock farming; it also includes the technological aspects of artificial intelligence, sensors and robotics.

Table 1. Publisher, number of documents, Scopus CiteScore (CS), Scimago Journal Rank (SJR) and highest CiteScore percentile (HP) of the top journals publishing studies on greenhouse engineering.

Journal [a]	Publisher	N. [b]	CS [c]	SJR [d]	HP [e]
Acta Horticulturae	Inter. Soc. Hort. Science (ISHS)	812	0.5	0.181	12
Biosystems Engineering	Elsevier	86	7.2	0.894	93
Computers and Electronics in Agriculture	Elsevier	53	8.6	1.208	99
Solar Energy	Elsevier	39	8.9	1.337	87
Journal of Agricultural Meteorology	Society of Agricultural Meteorology of Japan	37	2.6	0.472	65
Agricultural and Forest Meteorology	Elsevier	36	8.9	1.837	97
Energies	MDPI	34	4.7	0.598	85
Transactions of the American Society of Agricultural Engineers	American Society of Agricultural Engineers	34	na	na	na
Advanced Materials Research	Trans Tech Publications Ltd.	32	na	na	na
Applied Mechanics and Materials	Scitec Publications Ltd.	31	na	na	na
Journal of Agricultural and Engineering Research	Scitec Publications Ltd.	31	na	na	na
Journal of Physics: Conference Series	IOP Publishing Ltd.	30	0.7	0.210	18
Renewable Energy	Elsevier	28	10.8	1.825	88
Scientia Horticulturae	Elsevier	28	5	0.906	93
Paper-American Society of Agricultural Engineers	American Society of Agricultural Engineers	26	na	na	na
Journal of Agricultural Engineering Research	Elsevier	24	na	na	na
Applied Engineering in Agriculture	American Society of Agricultural Engineers	22	1.9	0.276	57
IOP Conference Series Earth and Environmental Science	IOP Publishing	22	0.5	0.179	17
Renewable and Sustainable Energy Reviews	Elsevier	22	30.5	3.522	97
Energy and Buildings	Elsevier	21	10.9	1.737	97
International Journal of Agricultural and Biological Engineering	IJABE	21	3.8	0.570	83
Sensors (Switzerland)	MDPI	21	5.8	0.636	90
Applied Energy	Elsevier	20	17.6	3.035	99
Energy	Elsevier	18	11.5	1.961	98
Energy Conversion and Management	Elsevier	18	15.9	2.743	97
Hortscience	American Society for Horticultural Science	18	2.1	0.518	63
Journal of Agricultural Engineering	PagePress	18	2.8	0.300	61
Sustainability (Switzerland)	MDPI	18	3.9	0.612	84
IFAC-PapersOnLine	IFAC Secretariat	17	2.1	0.308	43
Transactions of the ASABE	ASABE	17	2.6	0.396	67

[a] Top 30 journals; [b] N.: number of documents; [c] CS: CiteScore 2020; [d] SJR: SCImago Journal Rank 2020; [e] HP: highest CiteScore percentile 2020; n.a. = not available.

The top five journals with the highest SJR were *Renewable and Sustainable Energy Reviews* (3.522), *Applied Energy* (3.035), *Energy Conversion and Management* (2.743), *Energy* (1.961) and *Agricultural and Forest Meteorology* (1.837). These five journals, along with *Renewable Energy*, *Energy and Buildings* and *Solar Energy*, also showed a high CiteScore (higher than 8.8) and ranked in the 87th–99th CS percentile.

Renewable and Sustainable Energy Reviews mainly publishes studies that have a significant review element on renewable and sustainable energy resources and related systems, applications, utilizations and techno-socio-economic aspects. *Applied Energy* focuses on the research on energy conversion/conservation, the optimization of energy resource uses and energy processes and sustainable energy systems. *Energy Conversion and Management* is principally focused on energy production, use, conversion, storage, transmission, management and sustainability and also includes renewable energy resources. *Energy* covers research on energy analysis, modelling, prediction, conservation, efficiency, planning and management, supply and demand, storage, renewable energy and integrated energy systems. *Agricultural and Forest Meteorology* mainly focuses on the inter-relationship between agriculture, meteorology, natural ecosystems and forestry.

3.1.3. Subject Area

The publications on greenhouse engineering overall fall mainly under the subject areas of agricultural and biological Sciences (28%) and engineering (21%), and to a minor extent into other subject areas such as computer science (11%), energy (8%) and environmental science (6%) (Figure 3). It should be noted that papers, particularly those that are multidisciplinary or dealing with different aspects of greenhouse engineering, are classified simultaneously in several subject areas. Overall, the documents were classified into more than 12 different Scopus subject areas, which may suggest the broad interest that this research field has generated in the scientific community. Figure 4 shows the trend of the principal subject areas into which Scopus has classified the documents related to greenhouse engineering in more recent years (1991–2021). The growing trend of publications in the areas of engineering, computer science, energy and mathematics, at the expense of agricultural and biological sciences, emerges. This may be due to the increase of complex interdisciplinary studies on greenhouses and their automation stimulated by advances in technology, modelling and simulation techniques, artificial intelligence, as well as to the increasing demand for environmentally sound greenhouse productions and for using renewable energy sources.

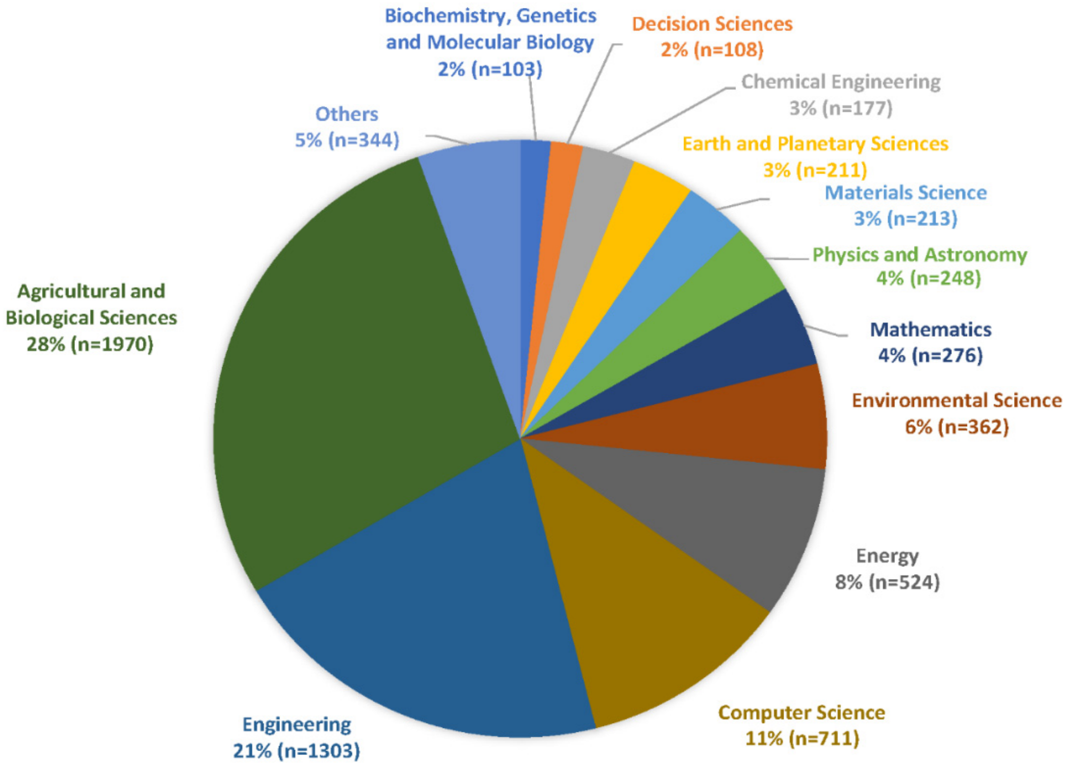

Figure 3. Subject areas of the publications on greenhouse engineering.

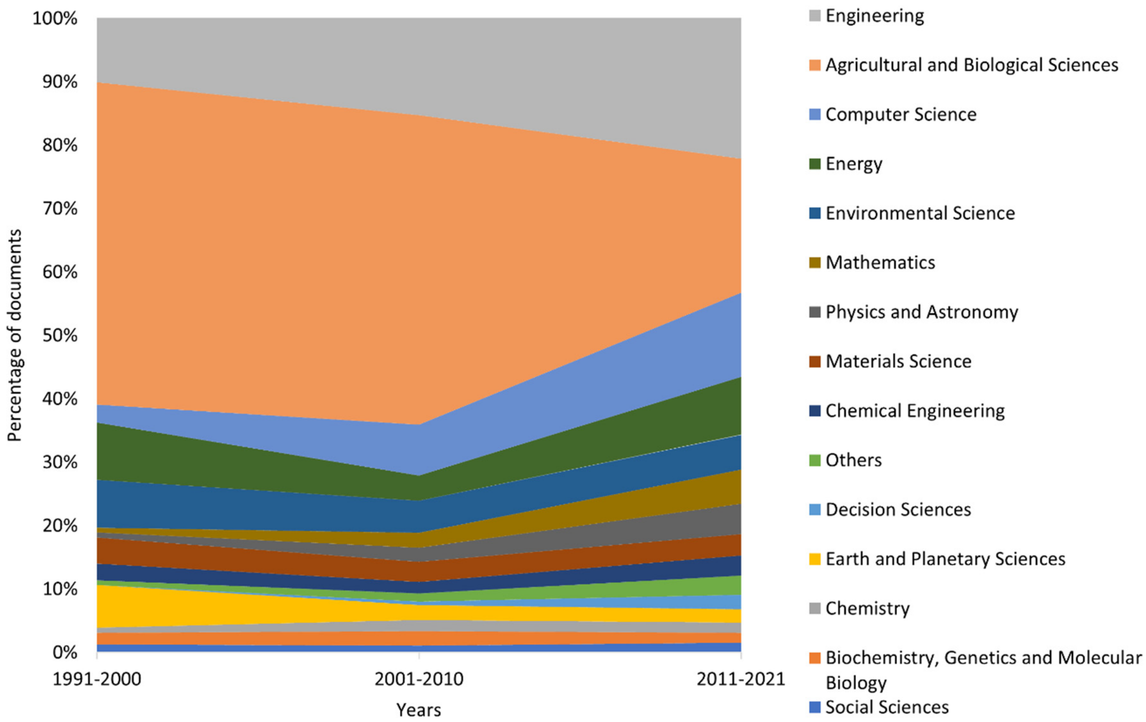

Figure 4. Trend of the distribution of the publications by Scopus category in 1991–2021.

3.1.4. Most Relevant Countries

The countries to which the authors' affiliations belong were analyzed. At least one hundred and six countries were identified as publishing on greenhouse engineering during the period 1981–2021, and 70 countries participated in at least five papers. These numbers point to the great interest that greenhouse engineering has captured worldwide. In this analysis, more than one country can be assigned to the same document in cases of international collaborations. Figure 5 shows the most active countries identified as those having participated in more than 50 papers. The countries with higher paper productivity were China (n = 593; 15.6%), the United States (n = 356; 9.4%), Spain (n = 260; 6.8%), Italy (n = 235; 6.2%) and the Netherlands (n = 209; 5.5%). However, the analysis of the scientific productivity of the countries in relation to the year of publication allows to highlight that 88% of the Chinese documents were published in the last decade, and this is reflected in the main themes addressed in the research. In effect, the cluster analysis on the keywords of the Chinese publications highlighted that the research focused mainly on the following topics: greenhouse automation; climate monitoring and control systems; design of wireless sensor networks; greenhouse heating systems performances. Research groups from the United States mostly focused on: microclimate and crop growth in photovoltaic (PV) greenhouses; energy efficiency of artificial lighting systems; optimal design of lighting systems in relation to plant response; CFD greenhouse modelling for climate uniformity; cooling systems performance. The prominent topics in Spanish research were the following: ventilators configurations and evaporative cooling systems performances; light transmission properties and the effect on the greenhouse microclimate of insect-proof screens; pest control by using plastic films. Italian research has principally focused on: radiometric and mechanical properties of greenhouse plastic covering films and shading nets; energy saving strategies in greenhouses; integrated use of several renewable energy sources for greenhouse heating and cooling; light distribution modelling and analysis in PV greenhouses; ventilation efficiency evaluation by means of CFD modeling. The dominant topics of the research carried out in the Netherlands were: greenhouse climate and crop growth modeling; lighting technologies and strategies for ventilation efficiency optimization; interaction of technology and plants. Up until 2010, France, Japan, Israel and Greece also had a significant role among the authors' affiliated countries on greenhouse engineering.

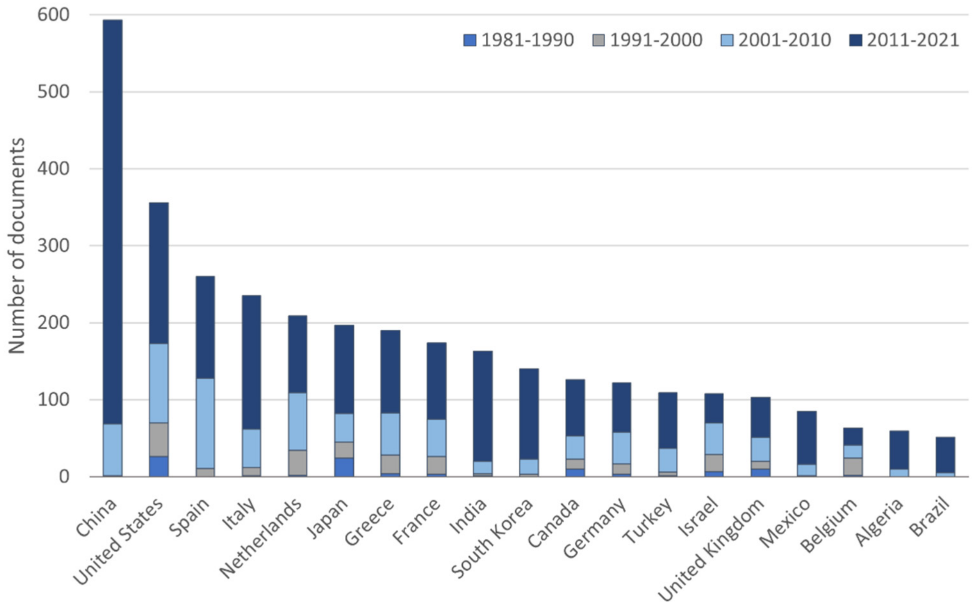

Figure 5. Countries publishing more than 50 articles related to greenhouse engineering from 1981 to 2021 (countries are related to the authors' affiliations).

3.1.5. Most Relevant Research Institutions

The paper productivity of the most active institutions on greenhouse engineering is reported in Table 2. While China leads the country distribution of research output in this field, the distribution by institution is dominated by non-Chinese research institutions. Emerging as the leader in this field is Wageningen University and Research, Netherlands (n = 183; 4.8%) followed by the University of Almeria, Spain (n = 95; 2.5%), the University of Thessaly, Greece (n = 90; 2.4%), the INRAE Provence-Alpes-Côte d'Azur Research Centre, France (n = 84; 2.2%), the Agricultural Research Organization (Volcani Center), Israel (n = 78, 2.1%) and the University of Bari Aldo Moro, Italy (n = 62; 1.6%). The total number of papers published by these institutions, along with the Agricultural University of Athens, Greece, and the Institute of Agriculture and Food Research and Technology (IRTA), Spain, received more than 1000 citations and achieved a higher h-index. However, considering the average number of citations (total number of citations divided by number of articles), the following institutions published articles with an average of at least 20 citations per article: the INRAE Provence-Alpes-Côte d´Azur Research Centre, France (33.1), the Agricultural University of Athens, Greece (28.4), Leibniz University of Hannover, Germany (25.1), the Institute of Agriculture and Food Research and Technology (IRTA), Spain (24.5), the University of Bari Aldo Moro, Italy (23.6).

3.1.6. Co-Operative Network of Authors

The co-operative network of key authors based on the number of documents on greenhouse engineering is reported in Figure 6. It indicates the collaborations between the authors interconnected in terms of the number of articles co-authored. The node size indicates the number of published articles. The connecting links indicate the co-authorship between a given author and other researchers and the strength of a link indicates the intensity of the cooperation. The collaboration clusters are represented by different colors. The red cluster emerges as the largest one and is represented mainly by Chinese authors. The dark green cluster highlights a close collaboration between authors from the Netherlands, Germany and Greece. The dark blue cluster is mainly composed of researchers from the United States and Japan. It also emerges that some clusters are located particularly close together, namely the dark blue and the pink clusters, which indicates the strong collaboration among research groups from the United States, Japan and Israel, and the pale blue, yellow, orange and green clusters, which indicates the extensive collaboration among researchers from Greece, Spain, Portugal, Malaysia, the Netherlands and Germany.

Table 2. The most productive institutions publishing at least 30 articles on greenhouse engineering from 1981 to 2021.

Institution	Country	N. of Documents			Total Number of Citations	Average Number of Citations *	Documents h-Index
		Total	Journal	Book Chapter-Conference Paper			
Wageningen University and Research	The Netherlands	183	70	113	3463	18.9	33
University of Almería	Spain	95	42	53	1400	14.7	21
University of Thessaly	Greece	90	53	37	1641	18.2	18
INRAE Provence-Alpes-Côte d´Azur Research Centre	France	84	36	48	2778	33.1	28
Agricultural Research Organization – Volcani Center	Israel	78	39	38	1421	18.2	21
University of Bari Aldo Moro	Italy	62	37	25	1463	23.6	22
China Agricultural University	China	54	23	31	455	8.4	10
Agricultural University of Athens	Greece	50	31	19	1421	28.4	20
Israel Ministry of Agriculture and Rural Development	Israel	47	25	22	764	16.3	16
Institute of Agriculture and Food Research and Technology (IRTA)	Spain	46	24	32	1127	24.5	19
The University of Arizona	USA	45	21	24	722	16.0	26
Cajamar Las Palmerillas Research Station	Spain	40	14	26	669	16.7	15
Seoul National University	South Korea	40	30	10	382	9.6	10
Leibniz University Hannover	Germany	36	23	13	902	25.1	15
Ghent University	Belgium	32	21	11	345	10.8	12
Tongji University	China	32	19	13	444	13.9	12
The Ohio State University	USA	31	15	16	548	17.7	11
Agriculture and Agri-food Canada	Canada	30	16	14	381	12.7	9
Ministry of Agriculture of the People's Republic of China	China	30	22	8	296	9.9	9

* Number of citations divided by the number of articles.

3.2. Principal Topics and Trends of Greenhouse Engineering Research in the World

The results of the cluster analysis on the keywords of the 3804 documents related to the greenhouse engineering research field are shown in Figure 7. Each keyword is represented by a circle in the map. The circles diameter and the size of the keyword labels are correlated to the keyword frequency. The distance between two circles indicates the relatedness of the two keywords (the smaller the distance between two keywords the larger the number of papers in which those two keywords were found). The lines connecting the circles represent the co-occurrence of the two keywords, while their thickness is related to their frequency (the thicker the line, the more frequently those two keywords are found together). A total of 768 keywords with a minimum number of occurrences of eight are grouped in five hot themes highlighted by different colors: (1) climate modification and energy resources; (2) covering materials and plant growth; (3) automation and smart technology; (4) structural and functional design; (5) climate monitoring and control. While the first three research themes are clearly defined and do not overlap each other, the "structural and functional design" theme overlaps to those of "climate modification and energy resources" and "covering materials and plant growth", and the "climate monitoring and control" overlaps with "automation and smart technology", because of their closer relationships. However, it should be noted that the five clusters are tightly interconnected and that some aspects of greenhouse research can be included in more than one cluster.

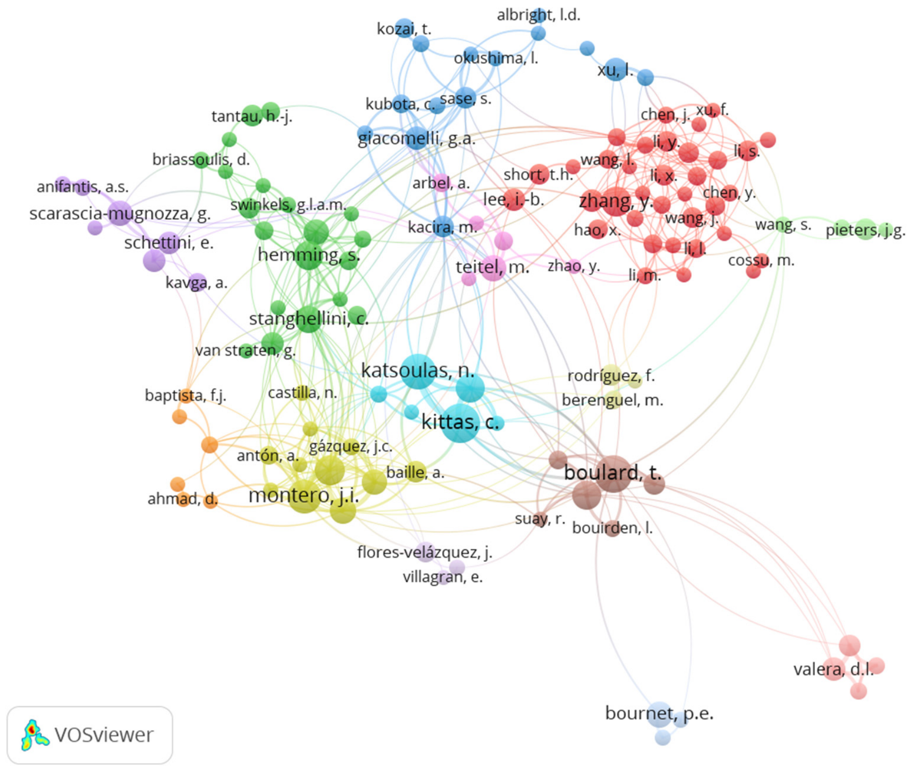

Figure 6. Co-operative network of the key authors.

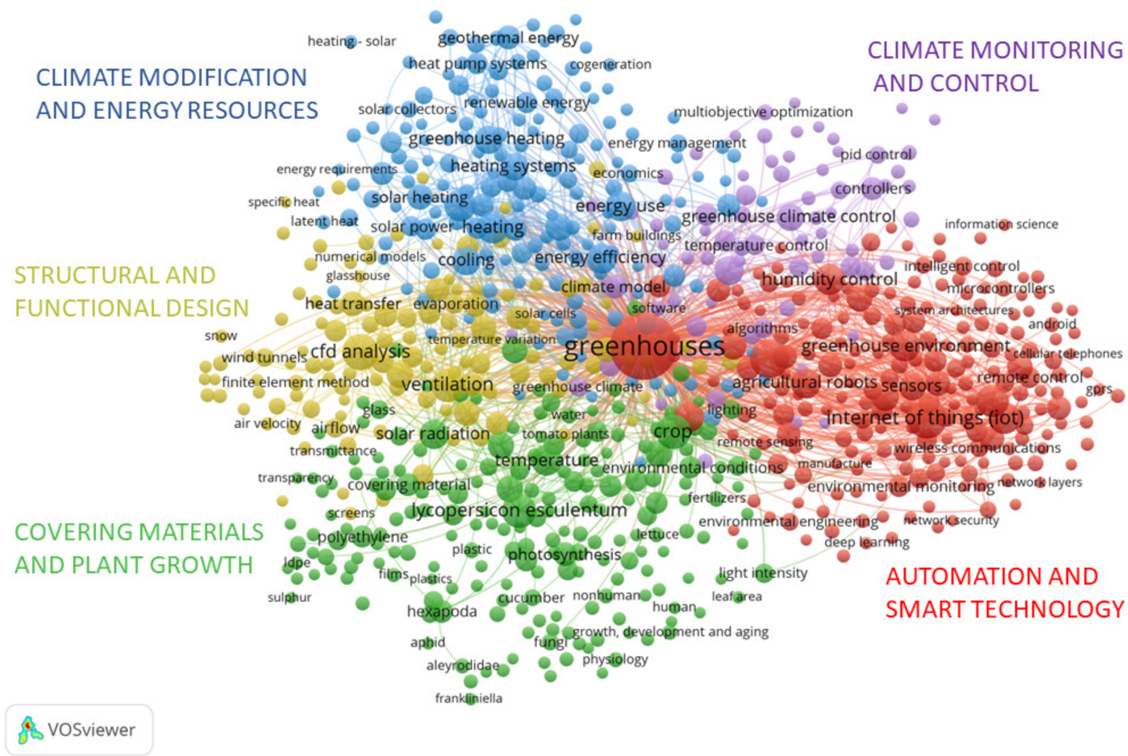

Figure 7. Keywords network based on the greenhouse engineering publications from 1981 to 2021.

3.2.1. Climate Modification and Energy Resources

The climate modification and energy resources cluster (in blue in Figure 7) consists of 170 keywords. The high frequency keywords are: "solar energy", "renewable energy", "geothermal energy", "energy use", "heating systems", "cooling", "heat storage", "photovoltaic systems", "solar heating" and "economic analysis". This research theme mainly focuses on energy efficiency and the use of climate control systems based on the exploitation of different renewable energy resources. Studies on passive solar greenhouses, energy collection, storage and production systems, cogeneration plants, industrial waste heat recovery systems and energy efficient equipment are also included. The reduction of greenhouse heating demand and costs within temperate and cold climate regions has been one of the major research topics in the last two decades [57], as heating and to a lesser extent cooling costs can be about 70–85% of the total operating costs, in northern latitudes, and about 50% or less in warmer areas [58]. The share of heating and cooling in the total operating cost varies widely depending also on the technology level used in the greenhouse and on the needs of the different cultivated crops: vegetables, flowers and ornamentals. Passive greenhouses were designed as solar collectors in order to make maximum solar heat gains by using the appropriate coatings and structural materials, thereby allowing energy savings of about 40% [59]. Several strategies have been studied to minimize heating, cooling, air-conditioning, lighting and ventilation demands of conventional greenhouses in order to reduce operational costs, the dependency on fossil fuels and ultimately the emissions of harmful gases into the atmosphere. These strategies include: the design of energy efficient greenhouses based on the local climate and some relevant parameters such as shape and orientation [60]; the use of energy-efficient covering materials [61,62]; the utilization of thermal screens [63]; the optimal control of indoor microclimates [64]; and the use of sustainable and renewable energy based systems such as PV modules, solar thermal and photovoltaic-thermal (PV/T) collectors, heat pumps, cogeneration systems, solar cooling systems, thermal energy storage technologies, ventilation technologies, and efficient lighting systems [57,65–67]. Different thermal energy storage techniques were investigated in order to reduce the greenhouse energy consumption for heating and to improve the solar energy utilization. The use of thermal energy storage has the benefit of providing less fluctuation of the solar greenhouse temperatures [68]. The underground thermal energy storage systems, such as thermal storage with boreholes and aquifers, can be used in greenhouses for seasonal storage [68]. The optimal control of an energy system including both short term buffers and aquifer long term energy storage was addressed and the high potential of the system for cost savings (29%) was demonstrated [69].

The most important drivers of the environmental impacts were identified by a combined greenhouse energy demand-yield simulation tool and a life cycle assessment in the five main climate world regions and future climate scenarios. The energy systems, inside air temperature, covering materials and crop growth features were identified as the most affecting factors on climate change impacts, with a different ranking according to the climate zone of the greenhouse [19]. The life cycle assessment was frequently used as a tool to evaluate or compare the potential environmental impacts of several greenhouse typologies and structures [70,71], heating systems [72], renewable energy sources implementation in greenhouses [73,74], lighting technologies [75], greenhouse production versus open field [76] and integrated rooftop greenhouse versus conventional [77,78].

Energy Sources

Mathematical models were developed to minimize energy inputs, and several researchers focused on finding innovative energy sources such as solar and wind power, industrial waste heat, geothermal energy and wood biomass [79–81].

The impacts of various PV module arrangements on the greenhouse roof on the shading effect and energy efficiency [82,83], or the dynamic PV systems allowing variable shading that are able to balance the interior irradiance and the PV energy generation [84,85], were investigated. The use of concentrating PV modules allows for the reduction of the dimensions of the PV system and of its capital cost for the same power output [66]. An alternative solution for roof applications could be the semi-transparent PV modules that can allow for the reconciling of energy generation and agricultural activities [86,87]. The application of the concentrating photovoltaic/thermal (CPV/T) modules permits for the lighting and temperature control of the greenhouse environment while delivering enough energy to cover the heating demand of a greenhouse in Northern Europe [88]. The flat-plate solar thermal collectors are considered in various applications because of their modest cost and their ability to alleviate the greenhouse heating loads. When considering concentrating solar thermal collectors, the Fresnel lens system is considered to be the best solution due to its higher amount of available energy per unit aperture area in comparison with the parabolic trough collector [66].

A wood biomass can be considered a viable option as an alternative fuel for greenhouse heating [89]. A techno-economic analysis on wood biomass boilers showed that providing 40% of the annual heat demand through a wood biomass boiler and the remaining 60% with a natural gas boiler was more economical than using only natural gas [90]. However, the economic feasibility of using a wood biomass should be evaluated considering the technical and market changes such as wood pellets or natural gas prices and greenhouse sizes [91]. Research efforts were spent on the improvement of technologies and management strategies for using renewable energy for the CO_2 enrichment of the greenhouse air, which is useful for improving the photosynthetic efficiency and, consequently, the crop yield. Pure CO_2 in bulk or in hydrocarbon fuel combustion, such as propane or natural gas, are commonly used for CO_2 supplementing. Using exhaust gases taken from biomass heating systems for CO_2 enrichment provides several benefits including the recovery of a waste product, the reduction of the environmental footprint of the greenhouse production and its dependency on fossil fuels [92]. Wood biomass boilers produce a larger amount of particulate matters and ash emissions than other fossil fuels, thus the CO_2 enrichment from biomass boiler flue gases is still both challenging and costly [93].

The use of industrial waste heat could be a potential solution to lower the heating costs of greenhouses as in the case of low-temperature industrial wastewater [94], low-temperature waste heat [95] and the waste heat from biogas driven power plants [96]. The technical, economic and environmental performance of hybrid systems for heating and cooling was investigated with the aim of enhancing the utilization of renewable energy resources in the greenhouse sector; this is the case of: solar photovoltaic system assisted earth-to-air heat exchangers consisting of underground air tunnels [97]; solar assisted water-to-water heat pumps [98]; air-to-water heat pumps using underground air [99]; PV assisted ground source heat pumps [100]; and heating systems based on solar-hydrogen energy and biomass or geothermal energy [79,101].

3.2.2. Climate Monitoring and Control

The climate monitoring and control cluster (in violet in Figure 7) consists of 73 terms. The crucial terms are: "climate control", "controllers", "temperature control", "PID control", "climate model" and "fuzzy control". Greenhouse climate monitoring and control has been one of the main objectives of agricultural engineering publications because of the direct relationship between the environmental conditions and crop yield and quality. During the last three decades many studies have examined different technologies and strategies for controlling the main inside environmental factors (temperature, relative humidity, CO_2 concentration and solar radiation intensity) [102,103].

Researchers were interested in building reliable and accurate mathematical models that describe the greenhouse environmental dynamics, since most control theories rely on the mathematical model of the system to fine-tune the proposed algorithms, and on discussing the efficiency of different microclimate control theories (reviewed by Duarte-Galvan et al. [104]). Research on greenhouse climatic models also received notable attention in order to develop and validate methods for greenhouse design in the context of different climatic and economic conditions [105,106]. Some publications focused on traditional greenhouse climate models based on energy and mass balances, also involving many factors influencing the greenhouse behavior for temperature prediction [107–109]. Extensive models that even predict the temperature of the greenhouse air, cover, plants, and soil [110], crop response to environmental conditions such as photosynthesis or transpiration processes [111] and air relative humidity [112] have further been developed.

Time and effort were dedicated to the optimal climate control to maximize growers' profits [113] or to minimize energy consumption by exploiting the dynamic ambient conditions [114]. The optimal control approach requires that the models describe both the dynamic behavior of the greenhouse climate and crop, and reliable forecasts of the weather conditions [115]. Many researchers considered only one objective in the greenhouse crop optimization [116–118]. Other researchers combined more objectives (fruit quality, water-use efficiency, energy saving and profits) by using multi-objective techniques embedded within a hierarchical control scheme [119].

Different types of control algorithms have been applied to the management of greenhouse systems such as the Proportional-Integral-Derivative (PID), non-linear, robust, fuzzy logic, neural network and hybrid control algorithms [120]. The focus of the research has shifted from classical (feedback controllers) and artificial intelligence controllers to modern ones such as model predictive, robust and adaptive controllers, due to advancement of the wireless sensor network (WSN) technological field. Modern control systems allow for both more precise management of the microclimate parameters and energy consumption reduction by considering the uncertainties arising from the weather conditions, energy production and storage and the operating mode of physical devices [32].

3.2.3. Smart Technology and Automation

The smart technology and automation cluster (in red in Figure 7) consists of 204 words and phrases. The crucial terms are: "sensors", "wireless sensor networks", "internet of things", "greenhouse environment", "greenhouse monitoring", "precision agriculture", "digital storage", "computer software", "intelligent greenhouse" and "irrigation". The application of the internet of things (IoT) technology has been recently investigated for the model-based evaluation of the microclimate parameters and to develop optimization algorithms for the microclimate control and for the energy efficient crop production [121–123]. The high costs of greenhouse structures, equipment and energy, and the need of an efficient, sustainable, high quality and quantity crop production, has incited several researchers to study and apply the WSN and IoT technologies to the greenhouse automation [124–126]. Recent trends in research and technology development on the greenhouse environmental monitoring show the shift from offline systems to wireless and cloud-based data collection [127,128]. The research on the continuous and remote monitoring and collection of data about air temperature and humidity, CO_2, solar radiation, growing medium moisture and mineral nutrients content (mainly nitrogen, phosphorous and potassium) by the WSN and IoT provided useful information for understanding the effects of each factor on plant growth, in order to maximize plant productivity, to achieve significant energy savings and to ensure an efficient greenhouse automation system without the use of several manual inspections [128–132]. Automated systems were developed on mobile cloud connected robots for climate and irrigation control in greenhouses; in addition to air temperature and relative humidity, substrate moisture and pH data, images for detecting unhealthy plants were also collected [133]. The automatic feature extraction provided by the deep learning techniques allows for achieving a human-level accuracy in several crop operations [134]. Deep learning was applied to plant disease detection and classification [135,136], fruit recognition/counting and harvesting [137] and plants/leaves recognition and classification [138].

3.2.4. Structural and Functional Design

The structural and functional design cluster (in yellow in Figure 7) consists of 121 terms. The important keywords of this cluster are: "ventilation", "wind effects", "airflow", "air temperature", "CFD analysis", "fluid dynamics", "evaporative cooling system", "heat transfer", "temperature gradient", "structural design", "finite element method" and "transpiration". This research theme mainly focused on the influence of the design parameters on greenhouse ventilation and microclimate, and on the design of structures capable of resisting to all types of loads due to extreme conditions such as significant snow/ice loads and strong winds. Many studies all over the world concerned the effects of different greenhouse parameters on energy conservation, and various options (greenhouse orientation, shape, north wall insulation, double wall glazing, thermal screens and cladding materials) were investigated to reduce heat losses and for the design of energy efficient greenhouses [139–141]. Climate is the principal determinant of greenhouse design and several studies focused on optimizing the structure of a greenhouse with respect to the local climatic conditions, which poses a challenge both technologically and financially. However, the spread of some types of greenhouses also depends on the local economic, technical and legal frameworks [142]. Glass and rigid plastic greenhouses are classified into wide-span and Venlo-type greenhouses, in relation to the roof design. Plastic film greenhouses range from the simplest tunnel greenhouses to the more complex pitched roof and arch-shaped roof greenhouses [142]. Several types of shapes, such as the gothic arch, vinery, Quonset, even-span and uneven-span, were investigated in relation to the solar gain [143] and the heating requirement [144,145]. Depending on the specific local climate conditions and the greenhouse dimensions, different shapes have emerged as energy efficient.

The climatic control equipment, physical data and plant physiological processes were studied in order to formulate models and for their application on the design, operational control and the evaluation of energy conservative systems [146]. The researchers were interested in proposing climate models of greenhouses equipped with evaporative cooling systems in order to improve their design and management; the effect on greenhouse air temperature and on crop transpiration of different outside climate conditions, ventilation and shading strategies were also evaluated [147,148].

Modern greenhouses are characterized by lightweight structures with a low rigidity, which are particularly vulnerable to wind loads. Several researchers were interested in estimating the wind pressures on the structure by carrying out numerical simulations, wind tunnel experiments and full-scale field experiments, which are useful for the structural design [149–152]. Despite providing a lot of quantitative data, the full-scale field experiments involve the use of expensive instruments and long test cycles, and the related results are strictly related to the test surrounding environment; in order to overcome the limitations of the field tests, wind tunnel tests were widely carried out on scaled models [153]. The research has shown that the CFD models can successfully reproduce experimental results. The CFD models were developed to estimate the wind pressure coefficient of various kind of greenhouses, such as large multi-span greenhouses for which wind tunnel tests are difficult to perform [154] and of greenhouses covered with plastic films whose shape may undergo instantaneous distortion due to the wind action [155]. The research results were also compared with the greenhouse design standards to ensure its structural safety by compensating for the insufficient detail in the greenhouse design standards [149,150].

The CFD was also used to study greenhouse ventilation (natural and mechanical) that is one of the key factors for controlling the greenhouse climate. Since ventilation is complex to characterize, the CFD procedures were conveniently used to predict the ventilation rate, airflow, temperature and humidity patterns inside the greenhouse, to compare several scenarios such as the greenhouse geometries and meteorological conditions, and to perform sensitivity studies to improve the microclimate [156–158]. The research mainly focused on: the effect of the ventilation arrangement of a greenhouse on the airflow and temperature trends [159]; the effect of the presence of insect screens on the natural ventilation in greenhouses [160]; evaluating the fluid-dynamic properties of greenhouse shading screens [161]; the effect of the neighboring buildings on the thermal performance of naturally ventilated greenhouses [162]; the influence of wind direction on the airflow and air temperature patterns in the roof openings and inside a naturally ventilated greenhouse [163] and the influence of the orientation of crops rows on the inside air temperature and humidity conditions [156].

3.2.5. Covering Materials and Plant Growth

The covering materials and plant growth cluster includes studies on the greenhouse covering materials and on the plant growth in relation to the inside greenhouse microclimate. The cluster consists of 200 terms and short phrases (in green in Figure 7). The crucial terms are: "solar radiation", "covering material", "plastic films", "polyethylene", "light transmission", "photosynthesis", "transparency", "microclimate", "temperature", "light", "humidity", "crop yield", "plant growth", "physiology", "hexapoda", "fungi", "vegetable", "*Lycopersicon esculentum*" and "Cucumis".

Covering Materials

The cover of a greenhouse has the main functions of protecting the crop from the external unfavorable climate and of promoting the greenhouse effect in order to provide the favorable microclimatic conditions for the crops. The main research topics within this theme were focused on the radiometric and mechanical properties, the chemical composition of the covering materials, and particularly for the plastic materials, in order to deliver solar radiation spectral modifying capabilities and energy-saving abilities. The radiometric properties of the cover are fundamental in affecting the intensity and the spectral and physical distribution of the solar radiation wavelengths entering and leaving the greenhouse. The radiometric properties of the cover, along with the thermal properties, are the key factors in determining the greenhouse microclimate in order to maximize the yield and quality of the crop production by making very efficient use of the incoming solar radiation and minimizing the demand for external resources such as energy and water. The covering materials should be characterized by a high transmittance to photosynthetically active radiation (PAR, 400–700 nm). The PAR fraction of the incoming radiation is absorbed by plants and is significant for their growth and yield. The transmissivity of the solar radiation outside the PAR, such as ultraviolet (UV, 280–400 nm) and near infrared (NIR, 700–2500 nm), should be considered in relation to the desired inside climatic conditions and external weather conditions, and to the needs of the crops grown inside the greenhouse. A low transmissivity of the long wave infrared (LWIR, 2500–25,000 nm, with the maximum radiation emitted by the bodies at the ambient temperature centered on 7500–12,500 nm) radiation results in lower radiative losses during the night [62]. The thermo-mechanical performance, the radiometric properties and the impacts of a wide range of covering materials on the incoming solar radiation, also in relation to the different climatic regions [164–168], as well as the proper testing methods of the radiometric and thermal properties [62] were investigated. The effect of water condensate on the inside surface of the greenhouse cladding, on the transmittance and the forward diffusion pattern of the plastic and glass claddings, was evaluated and analyzed in numerous studies [169–171]. Several researchers were interested in studying the effects on their mechanical and physical properties due to the exposure of plastic films to weathering conditions, agrochemicals and to dust accumulation [172–175]. Greenhouse climate models were used to study the impact of whitening and dust accumulation on the optical properties of the covering materials, on canopy parameters and greenhouse microclimate [176,177]. Recent studies are focusing on the development and the performance evaluation of advanced optical materials and of greenhouse covering systems able to adapt their properties by themselves to the dynamic sunlight conditions [178–180]. The topic of the reduction of the impact of plastic coverings on the environmental sustainability in greenhouse production was addressed by considering the carbon emissions in the production phase, their durability and the related amount of waste generated during their use in greenhouses [181]. The technical design of the plastic coverings was also considered in relation to the improved suitability of the material for further recycling [182].

Microclimate and Plant Growth

Within the microclimate and plant growth theme, the important aspects are the optimal microclimate and the effects of the greenhouse microclimate on plant growth. Several publications focused on the physiology of the greenhouse crops and on the optimal values of the microclimate parameters (air and root-zone temperature, relative humidity, vapor pressure deficit, lighting condition, intensity of solar radiation and CO_2 concentration) with the goal of increasing both the yield and crop quality [183–186]. Most papers considered the tomato (*Lycopersicon esculentum*) as being one of the most cultivated vegetables in greenhouses as well as being a consumer demand throughout the year. Plant requirements at different growth stages were studied in order to design adaptive control strategies for a sustainable greenhouse production [187–190]. Many papers published the investigations on the relations among plant physiology, yield and fruit quality with the greenhouse environmental factors in order to achieve a sustainable crop production [189,191,192]. The effects of the main microclimate parameters on tomato growth and the effects of the suboptimal values on the fruit quality and yield were reviewed by Katsoulas and Kittas [193] and Shamshiri et al. [194]. Numerous studies have been carried out on the effect of shading due to the integration with greenhouse structures of PV modules on greenhouse microclimate and crop productivity [68,195,196] and several approaches were proposed for improving the energy generation and crop production. These strategies include the partial roof covering with opaque PV modules [197] and the replacement of the entire roof with semi-transparent modules [198]. The introduction of light-emitting diode (LED) lighting systems was recently evaluated with respect to the potential for achievable electricity savings and an improved greenhouse crop production, by the optimized supplemental lighting regimens [199,200]. It has been found that switching from high-pressure sodium lighting to LED lighting can result in total energy savings of 10–25% [201]. By using LED panels, plants can be supplied with an optimal light spectrum with the proper intensity for their growth and a low power consumption [202]. LED lighting offers significant opportunities to produce energy savings and provide benefits by leveraging the rich knowledge of photobiology. The proper manipulation of the lighting, made possible by using LED lamps, can enhance production yield, plant quality, crop morphology, nutritional value, flavor, as well as can be used as part of an integrated disease management system [199]. Through the LEDs' use as a supplementary lighting technology, more food can be produced while preserving the high quality production [203]. In the context of more sustainable alternative pest management solutions to insecticides, several studies have been conducted to demonstrate the potential of using UV-absorbing plastic cover films and nets. These have shown that they can be effectively used as photoselective barriers to control various pests and the related viral diseases in greenhouse environments without compromising the crop yield and quality and even increasing the percentage of marketable plants [204–206].

Several research studies were focused on improving the water use in irrigation and on the development of irrigation methods and control systems for the greenhouse irrigation process based on growing medium monitoring, crop evapotranspiration (which is directly affected by greenhouse microclimate conditions) and phyto-sensing [207,208]. The semi-closed soilless cultivation systems were studied in order to enhance the efficiency in the use of water and nutrients and to reduce the fertilizer run-off and thus pollution of aquifers by nitrate contamination, while preserving the crop production yield and quality [209]. A machine learning model was developed to analyze the hyperspectral sensor data in order to automatically detect plant water and nitrogen deficit stress [210].

3.3. Research Trends

The publications that have received more than 130 citations and at least an average value of five citations per year are reported on Table 3. The analysis of these publications allows for the identification of the following key research topics that has considerably attracted the attention of researchers: photovoltaic and solar energy for heating the greenhouses, renewable and sustainable energy saving strategies for greenhouse systems, energy efficient greenhouse lighting, applications of the CFD in the modelling and design of ventilation systems, radiometric and thermal properties of greenhouse covering materials, crop transpiration in plastic tunnels and greenhouse monitor systems based on WSNs and on IOT technologies.

Three articles received more than 250 citations. The paper with most citations (n = 564) was published in *Energy and Buildings* in 2013 by two researchers working at Firat University, Elazig, and Cumhuriyet University, Sivas, Turkey [80]. This study experimentally investigated a hybrid heating system of a ground source heat pump, solar collectors and a biogas production plant with the objective to evaluate the technical feasibility of using various renewable energy sources (biogas, soil and sun) for the sustainable greenhouse heating. The performance of the different combinations of these three systems to meet the heating demands of a small-scale greenhouse was evaluated in different climatic conditions and operating parameters. The proposed system was considered adequate to heat greenhouses located in the eastern and southeastern regions of Turkey, especially due to the presence of livestock production. In fact, the proposed hybrid system could use biogas from livestock production, so considerably reducing the primary energy use for greenhouse heating. This could be an economic alternative over other conventional heating methods.

The second most cited article (n = 289) was published in the *Journal of Cleaner Production* in 2014 by two Macedonian research teams belonging to Ss. Cyril and Methodius University, Skopje, Macedonia [211]. In order to monitor and control some environmental parameters (temperature, humidity and radiation) that are important for greenhouse crop production and quality, the authors designed a low-cost, efficient and easy to use monitoring system based on the WSN technology. They tested, by simulation and measurements, the performance of several wireless network topologies and communication algorithms. The proposed architecture would be useful to farmers wishing to optimize their crop production and quality in a greenhouse environment while decreasing the farming and management costs.

Table 3. Published papers that received more than a total of 130 citations and at least an average value of five citations per year (30 December 2021).

Year	Authors	Countries [a]	Title	Journal	TC	Avg. C
2013	Esen M., Yuksel T. [80]	Turkey	Experimental evaluation of using various renewable energy sources for heating a greenhouse	*Energy and Buildings*	564	62.7
2015	Srbinovska M., Gavrovski C., Dimcev V., Krkoleva A., Borozan V. [211]	North Macedonia	Environmental parameters monitoring in precision agriculture using wireless sensor networks	*Journal of Cleaner Production*	289	41.3
2007	Norton T., Sun D.-W., Grant J., Fallon R., Dodd V. [212]	Ireland	Applications of computational fluid dynamics (CFD) in the modelling and design of ventilation systems in the agricultural industry: A review	*Bioresource Technology*	264	17.6
2015	Singh D., Basu C., Meinhardt-Wollweber M., Roth B. [213]	Germany, Switzerland	LEDs for energy efficient greenhouse lighting	*Renewable and Sustainable Energy Reviews*	204	29.1
2004	Bartzanas T., Boulard T., Kittas C. [159]	France, Greece	Effect of vent arrangement on windward ventilation of a tunnel greenhouse	*Biosystems Engineering*	203	11.3
2013	Kozai T. [214]	Japan	Resource use efficiency of closed plant production system with artificial light: Concept, estimation and application to plant factory	*Proceedings of the Japan Academy Series B: Physical and Biological Sciences*	191	21.2
1991	Jones J.W., Dayan E., Allen L.H., Van Keulen H., Challa H. [215]	United States	Dynamic tomato growth and yield model (TOMGRO)	*Transactions of the American Society of Agricultural Engineers*	189	6.1

Table 3. *Cont.*

Year	Authors	Countries [a]	Title	Journal	TC	Avg. C
2008	Sethi V.P., Sharma S.K. [67]	India	Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications	*Solar Energy*	185	13.2
2014	Nelson J.A., Bugbee B. [216]	United States	Economic analysis of greenhouse lighting: Light emitting diodes vs. high intensity discharge fixtures	*PLoS ONE*	175	21.9
1995	Boulard T., Baille A. [217]	France	Modelling of Air Exchange Rate in a Greenhouse Equipped with Continuous Roof Vents	*Journal of Agricultural Engineering Research*	171	6.3
2002	Boulard T., Wang S. [218]	France, United States	Experimental and numerical studies on the heterogeneity of crop transpiration in a plastic tunnel	*Computers and Electronics in Agriculture*	169	8.5
2010	Zhao J.C., Zhang J.F., Feng Y., Guo J.X. [219]	China	The study and application of the IOT technology in agriculture	*Proc. 3rd IEEE Int. Conference on Computer Science and Information Technology*	162	13.5
2016	Hassanien R.H.E., Li M., Dong Lin W. [220]	China, Egypt	Advanced applications of solar energy in agricultural greenhouses	*Renewable and Sustainable Energy Reviews*	157	26.2
2019	Zamora-Izquierdo M.A., Santa J., Martínez J.A., Martínez V., Skarmeta A.F. [221]	Spain	Smart farming IoT platform based on edge and cloud computing	*Biosystems Engineering*	148	49.3
2012	Stoessel F., Juraske R., Pfister S., Hellweg S. [222]	Switzerland	Life cycle inventory and carbon and water foodprint of fruits and vegetables: Application to a swiss retailer	*Environmental Science and Technology*	148	14.8
1997	Mistriotis A., Bot G.P.A., Picuno P., Scarascia-Mugnozza G. [158]	Italy, Netherlands	Analysis of the efficiency of greenhouse ventilation using computational fluid dynamics	*Agricultural and Forest Meteorology*	147	5.9
2017	Ebrahimi M.A., Khoshtaghaza M.H., Minaei S., Jamshidi B. [223]	Iran	Vision-based pest detection based on SVM classification method	*Computers and Electronics in Agriculture*	141	28.2
2015	Emmott C.J.M., Röhr J.A., Campoy-Quiles M., Kirchartz T., Urbina A., Ekins-Daukes N.J., Nelson J. [224]	Germany, Spain, United Kingdom	Organic photovoltaic greenhouses: A unique application for semi-transparent PV?	*Energy and Environmental Science*	140	20.0
2000	Papadakis G., Briassoulis D., Scarascia Mugnozza G., Vox G., Feuilloley P., Stoffers J.A. [62]	France, Italy, Greece, Netherlands	Radiometric and thermal properties of, and testing methods for, greenhouse covering materials	*Journal of Agricultural and Engineering Research*	139	6.3
2010	Bournet P.E., Boulard T. [157]	France	Effect of ventilator configuration on the distributed climate of greenhouses: A review of experimental and CFD studies	*Computers and Electronics in Agriculture*	137	11.4
2016	Cuce E., Harjunowibowo D., Cuce P.M. [66]	Indonesia, Turkey, United Kingdom	Renewable and sustainable energy saving strategies for greenhouse systems: A comprehensive review	*Renewable and Sustainable Energy Reviews*	134	22.3
2014	Cossu M., Murgia L., Ledda L., Deligios P.A., Sirigu A., Chessa F., Pazzona A. [195]	Italy	Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity	*Applied Energy*	132	16.5

[a] Countries of the authors' institutions; TC: total number of citations; Avg. C: average number of citations per year.

The third most cited paper, with 264 citations, was published in *Bioresource Technology* in 2007 by three Irish research groups working at the University College Dublin and at Teagasc Agricultural Research Centre, Ireland [212]. This paper presents a state-of-the-art of the application of the CFD in the modelling and design of ventilation systems in agricultural buildings and describes the CFD studies on the developments of greenhouse technology and different technical aspects for the optimal greenhouse climate management in order to achieve higher crop yields. The greenhouse CFD modelling that takes into consideration the responses of plant physiology, according to the environmental conditions, was found to be of a superior standard than the animal housing CFD applications.

The keyword year map is reported in Figure 8. It is based on the keywords' occurrence and average year of publication. Blue and dark green colored circles represent terms with a higher frequency in early publications. Terms such as "climate control", "ventilation", "greenhouse heating", "heat transfer", "plastic films" and "geothermal energy" are related to the "conventional" themes of greenhouse engineering research. Early studies mainly focused on the design of greenhouses in relation to different loads such as significant snow and wind, the study of the characteristics and effects of the use of different roofing materials and the improvement of the ventilation efficiency. The yellow and light green terms are more frequently represented in the more recent publications, which are related to the themes of "greenhouse monitoring", "wireless sensor network", "internet of things", "agricultural robots", "smart greenhouse", "photovoltaic panels" and "light emitting diodes".

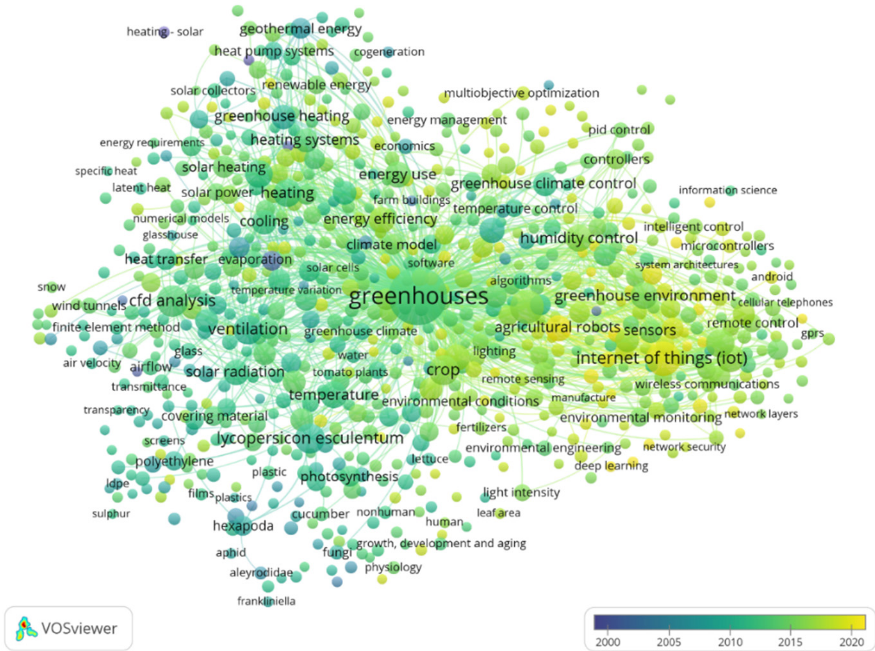

Figure 8. Keywords year map based on the greenhouse engineering publications (the blue, green and yellow colors represent earlier, recent, and most recent terms, respectively).

Future Developments of Research

Recent research trends, that provide a context for future studies, are centered on: the development of smart monitoring and automatic control systems of greenhouse operations including climate control, transplanting, harvesting, soilless culture and fertigation, based on the exploitation of wireless sensor networks and the internet of things; the use of agricultural robots equipped with sensors for monitoring plants abnormalities, disease or insects; the application of multi-objective optimization approaches for greenhouse climate control systems; the implementation of energy sustainable greenhouse crop cultivation using renewable energies and efficient energy storage systems, energy efficient lighting and photovoltaic technologies.

Research studies on the optimal and autonomous control of greenhouse operations have recently been further promoted by the advancement of the WSN field. Research efforts are needed to develop low-cost technology and methods and mathematical models for accurately simulating the complex microclimate and energy dynamics in greenhouses. In addition, research efforts are needed to develop a global greenhouse control that takes into account the different active systems that can be part of a greenhouse in order to implement the correct control means for an overall improvement of its function [32]. The technical performance and proper control strategies for the integrated use of the different renewable energies in order to reduce heating costs in greenhouse production and to support a sustainable growth of the greenhouse industry should be further studied, considering also the financial aspects [32]. Further studies are needed to prove the feasibility of self-sufficient, fossil fuel-independent integrated generation plants based on the synergistic operation of solar panels, wind turbines, gasifiers, digesters, etc. to meet the heating, cooling, electricity and CO_2 demand of a greenhouse [9]. Research efforts are needed to explore the methods and technologies for the biomass post-combustion CO_2 capture, on strategies for improving the overall efficiency of the systems for greenhouse heating and CO_2 enrichment by using an excess heat storage [225].

The optimization of the lighting systems design and control will be required in the near future with the improvement of LED systems and with the advancement of knowledge on pest, pathogens and different plants responses to LED lighting [57,199]. Modeling approaches will be of growing importance in order to avoid costly and time-consuming experimental testing of new approaches to lighting crops with LEDs [199]. Supplemental lighting can also contribute to significantly heating the greenhouse, according to the different types of lamps used. The expected important transition from the widely used high-pressure sodium (HPS) lamps to the more efficient LED lamps will therefore require further studies on the greenhouse operation that consider the effect of LEDs on the greenhouse energy budget and consider the various climates and greenhouse settings [201]. Furthermore, the experimental comparison between the HPS and LED lamp effect on plants should consider that HPS lamps can raise leaf temperature, and this can influence plant growth rates [199]. Tomato plants under LED exhibited a higher photosynthetic capacity and gas exchange in comparison with the HPS lamps, which may be related to the lower leaf temperature under LED [226].

4. Conclusions

Research and studies on greenhouse engineering over the past decades have addressed the issues surrounding and the need for reducing the environmental and landscape impacts, lowering production costs and satisfying the requirements of consumers of large-scale retail chains. Research is constantly applied to: (a) explore strategies in order to balance the production and environmental impacts in a socially acceptable and economically feasible way through an optimal use of natural resources, and an efficient integrated use of the different renewable energies; (b) the greenhouse design optimization and the improvement of energy saving techniques for reducing the heating and cooling energy demands and costs; (c) the development of innovative and efficient greenhouse covering materials; (d) the microclimate control optimization according to specific crops, crop growth stage, agro-techniques and climate circumstances; (e) an enhanced incorporation of rooftop greenhouses, vertical farms and plant factories in buildings and in cities; (f) the exploitation of wireless sensor networks and internet of things technologies for greenhouse monitoring and control; g) the automation of crop operations using deep learning.

The greenhouse design represents a complex task for the relevant interactions among the several factors affecting the production processes, for the large variety of greenhouse types, level of technology and control and the external climatic conditions. The current bibliometric analysis on greenhouse engineering, carried out on 3804 publications, highlighted that the number of articles per year increased considerably in the last decade and showed a growing trend towards publish in indexed journals rather than in conference proceedings or book series. About 61.1% of articles were published after 2010, and of these more than 53.4% were in indexed journals. The search for renewable and sustainable energy sources, the environmental impact of greenhouse farming and the complex interdisciplinary research on greenhouse engineering has led to an increase in publications in journals falling into the engineering, computer science, energy and mathematics subject areas.

The leading countries are China, the United States, Spain, Italy and the Netherlands that published over 36% of the relevant literature on greenhouse engineering. The cluster analysis identified five main research themes related to: climate modification and energy resources; climate monitoring and control; automation and smart technology; covering materials and plant growth; structural and functional design. Recent research trends are focused on finding innovative solutions for replacing the fossil-fuel energy with alternative energy resources exploiting the benefits of their integrated use, natural resources conservation, greenhouse gas emissions reduction, integrating precision agriculture technologies and improving smart monitoring and automatic control systems, automation of crop operations and a sustainable growth of the greenhouse production sector.

Author Contributions: Conceptualization, I.B., L.D.B., A.L., G.V., E.S. and G.S.M.; methodology, I.B., A.L., G.V. and E.S.; software, I.B.; validation, I.B., L.D.B., A.L., G.V., E.S. and G.S.M.; investigation, I.B., A.L., G.V. and E.S.; writing—original draft preparation, I.B.; writing—review and editing, I.B., L.D.B., A.L., G.V., E.S. and G.S.M.; supervision, I.B., L.D.B., A.L., G.V., E.S. and G.S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global Food Demand and the Sustainable Intensification of Agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20260–20264. [CrossRef] [PubMed]
2. Jensen, M.H.; Malter, A.J. *Protected Agriculture: A Global Review*; World Bank Technical Paper 253; World Bank Publications: Washington, DC, USA, 1995.
3. Hickman, G. *International Greenhouse Vegetable Production—Statistics (2019 Edition)*; Cuesta Roble Greenhouse Vegetable Consulting: Mariposa, CA, USA, 2019.
4. Takeshima, H.; Joshi, P.K. *Protected Agriculture, Precision Agriculture, and Vertical Farming: Brief Reviews of Issues in the Literature Focusing on the Developing Region in Asia*; IFPRI Discussion Paper 1814; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2019. [CrossRef]
5. Castilla, N. *Greenhouse Technology and Management*, 2nd ed.; CABI Publishing: Oxfordshire, UK, 2013.
6. Ma, X.; Liu, S.; Li, Y.; Gao, Q. Effectiveness of Gaseous CO_2 Fertilizer Application in China's Greenhouses between 1982 and 2010. *J. CO2 Util.* **2015**, *11*, 63–66. [CrossRef]
7. Lamont, W.J. Overview of the Use of High Tunnels Worldwide. *Horttechnology* **2009**, *19*, 25–29. [CrossRef]
8. Baille, A. Trends in Greenhouse Technology for Improved Climate Control in Mild Winter Climates. *Acta Hortic.* **2001**, *559*, 161–168. [CrossRef]
9. Giacomelli, G.A.; Sase, S.; Cramer, R.; Hoogeboom, J.; MacKenzie, A.; Parbst, K.; Scarascia-Mugnozza, G.; Selina, P.; Sharp, D.A.; Voogt, J.O.; et al. Greenhouse Production Systems for People. *Acta Hortic.* **2012**, *927*, 23–38. [CrossRef]
10. Castilla, N.; Montero, J.I. Environmental Control and Crop Production in Mediterranean Greenhouses. *Acta Hortic.* **2008**, *797*, 25–36. [CrossRef]
11. Castilla, N.; Hernández, J.; Abou-Hadid, A.F. Strategic Crop and Greenhouse Management in Mild Winter Climate Areas. *Acta Hortic.* **2004**, *633*, 183–196. [CrossRef]
12. Stanghellini, C.; Kempkes, F.L.K.; Knies, P. Enhancing Environmental Quality in Agricultural Systems. *Acta Hortic.* **2003**, *609*, 277–283. [CrossRef]
13. De Pascale, S.; Maggio, A. Sustainable Protected Cultivation at a Mediterranean Climate. Perspectives and Challenges. *Acta Hortic.* **2005**, *691*, 29–42. [CrossRef]
14. Rojano, F.; Flores-Velázquez, J.; Villarreal-Guerrero, F.; Rojano, A. Dynamics of Climatic Conditions in a Greenhouse: Two Locations in Mexico. *Acta Hortic.* **2014**, *1037*, 955–962. [CrossRef]
15. Rocha, G.A.; Pichimata, M.A.; Villagran, E. Research on the Microclimate of Protected Agriculture Structures Using Numerical Simulation Tools: A Technical and Bibliometric Analysis as a Contribution to the Sustainability of Under-Cover Cropping in Tropical and Subtropical Countries. *Sustainability* **2021**, *13*, 10433. [CrossRef]
16. Villagran, E.; Bojacá, C.; Akrami, M. Contribution to the Sustainability of Agricultural Production in Greenhouses Built on Slope Soils: A Numerical Study of the Microclimatic Behavior of a Typical Colombian Structure. *Sustainability* **2021**, *13*, 4748. [CrossRef]

17. Villagrán, E.; Flores-Velazquez, J.; Akrami, M.; Bojacá, C. Influence of the Height in a Colombian Multi-Tunnel Greenhouse on Natural Ventilation and Thermal Behavior: Modeling Approach. *Sustainability* **2021**, *13*, 13631. [CrossRef]
18. Romero-Gómez, P.; Choi, C.Y.; Lopez-Cruz, I.L. Enhancement of the Greenhouse Air Ventilation Rate under Climate Conditions of Central México. *Agrociencia* **2010**, *44*, 1–15.
19. Golzar, F.; Heeren, N.; Hellweg, S.; Roshandel, R. A Comparative Study on the Environmental Impact of Greenhouses: A Probabilistic Approach. *Sci. Total Environ.* **2019**, *675*, 560–569. [CrossRef]
20. Castro, A.J.; López-Rodríguez, M.D.; Giagnocavo, C.; Gimenez, M.; Céspedes, L.; La Calle, A.; Gallardo, M.; Pumares, P.; Cabello, J.; Rodríguez, E.; et al. Six Collective Challenges for Sustainability of Almería Greenhouse Horticulture. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4097. [CrossRef]
21. Picuno, P.; Tortora, A.; Capobianco, R.L. Analysis of Plasticulture Landscapes in Southern Italy through Remote Sensing and Solid Modelling Techniques. *Landsc. Urban Plan.* **2011**, *100*, 45–56. [CrossRef]
22. Rogge, E.; Nevens, F.; Gulinck, H. Reducing the Visual Impact of "greenhouse Parks" in Rural Landscapes. *Landsc. Urban Plan.* **2008**, *87*, 76–83. [CrossRef]
23. Tomaselli, G.; Russo, P.; Riguccio, L.; Quattrone, M.; D'Emilio, A. Assessment of Landscape Regeneration of a Natura 2000 Site Hosting Greenhouse Farming by Using a Dashboard of Indicators. A Case in Sicily through the Territorial Implementation of a "Pilot Project" at Farm Level. *Land Use Policy* **2020**, *92*, 104444. [CrossRef]
24. Zhou, D.; Meinke, H.; Wilson, M.; Marcelis, L.F.M.; Heuvelink, E. Towards Delivering on the Sustainable Development Goals in Greenhouse Production Systems. *Resour. Conserv. Recycl.* **2021**, *169*, 105379. [CrossRef]
25. Torrellas, M.; Antón, A.; Montero, J.I. An Environmental Impact Calculator for Greenhouse Production Systems. *J. Environ. Manag.* **2013**, *118*, 186–195. [CrossRef] [PubMed]
26. Blanco, I.; Loisi, R.V.; Sica, C.; Schettini, E.; Vox, G. Agricultural Plastic Waste Mapping Using GIS. A Case Study in Italy. *Resour. Conserv. Recycl.* **2018**, *137*, 229–242. [CrossRef]
27. Hanan, J.J. (Ed.) *Greenhouses: Advanced Technology for Protected Horticulture*; CRC Press: Boca Raton, FL, USA, 2017. [CrossRef]
28. Critten, D.L.; Bailey, B.J. A Review of Greenhouse Engineering Developments during the 1990s. *Agric. For. Meteorol.* **2002**, *112*, 1–22. [CrossRef]
29. Montero, J.I.; Van Henten, E.J.; Son, J.E.; Castilla, N. Greenhouse Engineering: New Technologies and Approaches. *Acta Hortic.* **2011**, *893*, 51–64. [CrossRef]
30. Shamshiri, R.R.; Kalantari, F.; Ting, K.C.; Thorp, K.R.; Hameed, I.A.; Weltzien, C.; Ahmad, D.; Shad, Z. Advances in Greenhouse Automation and Controlled Environment Agriculture: A Transition to Plant Factories and Urban Agriculture. *Int. J. Agric. Biol. Eng.* **2018**, *11*, 1–22. [CrossRef]
31. Syed, A.M.; Hachem, C. Review of Design Trends in Lighting, Environmental Controls, Carbon Dioxide Supplementation, Passive Design, and Renewable Energy Systems for Agricultural Greenhouses. *J. Biosyst. Eng.* **2019**, *44*, 28–36. [CrossRef]
32. Achour, Y.; Ouammi, A.; Zejli, D. Technological Progresses in Modern Sustainable Greenhouses Cultivation as the Path towards Precision Agriculture. *Renew. Sustain. Energy Rev.* **2021**, *147*, 111251. [CrossRef]
33. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to Conduct a Bibliometric Analysis: An Overview and Guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
34. Noyons, E. Bibliometric Mapping of Science in a Science Policy Context. *Scientometrics* **2001**, *50*, 83–98. [CrossRef]
35. Noyons, E.C.M.; Moed, H.F.; Luwel, M. Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes: A Bibliometric Study. *J. Am. Soc. Inf. Sci.* **1999**, *50*, 115–131. [CrossRef]
36. Verbeek, A.; Debackere, K.; Luwel, M.; Zimmermann, E. Measuring Progress and Evolution in Science and Technology—I: The Multiple Uses of Bibliometric Indicators. *Int. J. Manag. Rev.* **2002**, *4*, 179–211. [CrossRef]
37. Gauthier, É. *Bibliometric Analysis of Scientific and Technological Research: A User's Guide to the Methodology*; Science and Technology Redesign Project Statistics; Observatoire des Sciences et des Technologies: Ottawa, ON, Canada, 1998.
38. Garfield, E.; Pudovkin, A.I.; Istomin, V.S. Why Do We Need Algorithmic Historiography? *J. Am. Soc. Inf. Sci. Technol.* **2003**, *54*, 400–412. [CrossRef]
39. Chen, C. CiteSpace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]
40. Van Eck, N.J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
41. Cobo, M.J.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. Science Mapping Software Tools: Review, Analysis, and Cooperative Study among Tools. *J. Am. Soc. Inf. Sci. Technol.* **2011**, *62*, 1382–1402. [CrossRef]
42. Chen, C. Science Mapping: A Systematic Review of the Literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [CrossRef]
43. Liu, X.; Zhang, L.; Hong, S. Global Biodiversity Research during 1900–2009: A Bibliometric Analysis. *Biodivers. Conserv.* **2011**, *20*, 807–826. [CrossRef]
44. Nardi, P.; Di Matteo, G.; Palahi, M.; Scarascia Mugnozza, G. Structure and Evolution of Mediterranean Forest Research: A Science Mapping Approach. *PLoS ONE* **2016**, *11*, e0155016. [CrossRef]
45. Costa, C.; Schurr, U.; Loreto, F.; Menesatti, P.; Carpentier, S. Plant Phenotyping Research Trends, a Science Mapping Approach. *Front. Plant Sci.* **2019**, *9*, 1933. [CrossRef]

46. Pallottino, F.; Biocca, M.; Nardi, P.; Figorilli, S.; Menesatti, P.; Costa, C. Science Mapping Approach to Analyze the Research Evolution on Precision Agriculture: World, EU and Italian Situation. *Precis. Agric.* **2018**, *19*, 1011–1026. [CrossRef]
47. Raparelli, E.; Bajocco, S. A Bibliometric Analysis on the Use of Unmanned Aerial Vehicles in Agricultural and Forestry Studies. *Int. J. Remote Sens.* **2019**, *40*, 9070–9083. [CrossRef]
48. Hu, Y.; Sun, Z.; Wu, D. Analysis of Hot Topics in Soil Remediation Research Based on VOSviewer. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *300*, 032098. [CrossRef]
49. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; López-Felices, B.; Román-Sánchez, I.M. An Analysis of Global Research Trends on Greenhouse Technology: Towards a Sustainable Agriculture. *Int. J. Environ. Res. Public Health* **2020**, *17*, 664. [CrossRef] [PubMed]
50. Cecchini, C.; Menesatti, P.; Antonucci, F.; Costa, C. Trends in Research on Durum Wheat and Pasta, a Bibliometric Mapping Approach. *Cereal Chem.* **2020**, *97*, 581–588. [CrossRef]
51. Xin, Z.; Keyu, Z.; Lin, P. Analysis of Domestic and Foreign Research Status of Agricultural Pollution Control Based on VOSviewer. In Proceedings of the 2020 International Conference on Energy Big Data and Low-Carbon Development Management (EBLDM 2020), Nanjin, China, 18–20 December 2020; Volume 214, p. 03026. [CrossRef]
52. Jiménez-Lao, R.; Aguilar, F.J.; Nemmaoui, A.; Aguilar, M.A. Remote Sensing of Agricultural Greenhouses and Plastic-Mulched Farmland: An Analysis of Worldwide Research. *Remote Sens.* **2020**, *12*, 2649. [CrossRef]
53. Singh, V.K.; Singh, P.; Karmakar, M.; Leta, J.; Mayr, P. The Journal Coverage of Web of Science, Scopus and Dimensions: A Comparative Analysis. *Scientometrics* **2021**, *126*, 5113–5142. [CrossRef]
54. González-Pereira, B.; Guerrero-Bote, V.P.; Moya-Anegón, F. A New Approach to the Metric of Journals Scientific Prestige: The SJR Indicator. *J. Informetr.* **2010**, *4*, 379–391. [CrossRef]
55. How Are CiteScore Metrics Used in Scopus? Available online: https://service.elsevier.com/app/answers/detail/a_id/14880/supporthub/scopus/ (accessed on 31 August 2021).
56. Van Eck, N.J.; Waltman, L. VOSviewer Manual. Available online: https://www.vosviewer.com (accessed on 21 April 2021).
57. Ahamed, M.S.; Guo, H.; Tanino, K. Energy Saving Techniques for Reducing the Heating Cost of Conventional Greenhouses. *Biosyst. Eng.* **2019**, *178*, 9–33. [CrossRef]
58. Rorabaugh, P.; Jensen, M.; Giacomelli, G. *Introduction to Controlled Environment Agriculture and Hydroponics*; Controlled Environment Agriculture Center, University of Arizona: Tucson, AZ, USA, 2002; pp. 1–130.
59. Bot, G.; van de Braak, N.; Challa, H.; Hemming, S.; Rieswijk, T.H.; van Straten, G.; Verlodt, I. The Solar Greenhouse: State of the Art in Energy Saving and Sustainable Energy Supply. *Acta Hortic.* **2005**, *691*, 501–508. [CrossRef]
60. Mobtaker, H.G.; Ajabshirchi, Y.; Ranjbar, S.F.; Matloobi, M. Solar Energy Conservation in Greenhouse: Thermal Analysis and Experimental Validation. *Renew. Energy* **2016**, *96*, 509–519. [CrossRef]
61. Papadopoulos, A.P.; Hao, X. Effects of Greenhouse Covers on Seedless Cucumber Growth, Productivity, and Energy Use. *Sci. Hortic.* **1997**, *68*, 113–123. [CrossRef]
62. Papadakis, G.; Briassoulis, D.; Scarascia Mugnozza, G.; Vox, G.; Feuilloley, P.; Stoffers, J.A. Radiometric and Thermal Properties of, and Testing Methods for, Greenhouse Covering Materials. *J. Agric. Eng. Res.* **2000**, *77*, 7–38. [CrossRef]
63. Andersson, N.E. Properties of Thermal Screens Used for Energy Saving in Greenhouses. In Proceedings of the International Conference on Agricultural Engineering-AgEng 2010: Towards Environmental Technologies, Clermont-Ferrand, France, 6–8 September 2010; Cemagref: Aubiere, France, 2010; pp. 1–6.
64. Sethi, V.P.; Sumathy, K.; Lee, C.; Pal, D.S. Thermal Modeling Aspects of Solar Greenhouse Microclimate Control: A Review on Heating Technologies. *Sol. Energy* **2013**, *96*, 56–82. [CrossRef]
65. Blanco, I.; Scarascia Mugnozza, G.; Schettini, E.; Puglisi, G.; Campiotti, C.A.; Vox, G. Design of a Solar Cooling System for Greenhouse Conditioning in a Mediterranean Area. *Acta Hortic.* **2017**, *1170*, 485–491. [CrossRef]
66. Cuce, E.; Harjunowibowo, D.; Cuce, P.M. Renewable and Sustainable Energy Saving Strategies for Greenhouse Systems: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2016**, *64*, 34–59. [CrossRef]
67. Sethi, V.P.; Sharma, S.K. Survey and Evaluation of Heating Technologies for Worldwide Agricultural Greenhouse Applications. *Sol. Energy* **2008**, *82*, 832–859. [CrossRef]
68. Gorjian, S.; Calise, F.; Kant, K.; Ahamed, M.S.; Copertaro, B.; Najafi, G.; Zhang, X.; Aghaei, M.; Shamshiri, R.R. A Review on Opportunities for Implementation of Solar Energy Technologies in Agricultural Greenhouses. *J. Clean. Prod.* **2021**, *285*, 124807. [CrossRef]
69. Van Beveren, P.J.M.; Bontsema, J.; van't Ooster, A.; van Straten, G.; van Henten, E.J. Optimal Utilization of Energy Equipment in a Semi-Closed Greenhouse. *Comput. Electron. Agric.* **2020**, *179*, 105800. [CrossRef]
70. Boulard, T.; Raeppel, C.; Brun, R.; Lecompte, F.; Hayer, F.; Carmassi, G.; Gaillard, G. Environmental Impact of Greenhouse Tomato Production in France. *Agron. Sustain. Dev.* **2011**, *31*, 757. [CrossRef]
71. Cellura, M.; Longo, S.; Mistretta, M. Life Cycle Assessment (LCA) of Protected Crops: An Italian Case Study. *J. Clean. Prod.* **2012**, *28*, 56–62. [CrossRef]
72. Heuts, R.F.; Van Loon, J.; Schrevens, E. Life Cycle Assessment of Different Heating Systems for Glasshouse Tomato Production in Flanders, Belgium. *Acta Hortic.* **2012**, *957*, 107–114. [CrossRef]
73. Hollingsworth, J.A.; Ravishankar, E.; O'Connor, B.; Johnson, J.X.; DeCarolis, J.F. Environmental and Economic Impacts of Solar-powered Integrated Greenhouses. *J. Ind. Ecol.* **2020**, *24*, 234–247. [CrossRef]

74. Russo, G.; Anifantis, A.S.; Verdiani, G.; Scarascia Mugnozza, G. Environmental Analysis of Geothermal Heat Pump and LPG Greenhouse Heating Systems. *Biosyst. Eng.* **2014**, *127*, 11–23. [CrossRef]
75. Zhang, H.; Burr, J.; Zhao, F. A Comparative Life Cycle Assessment (LCA) of Lighting Technologies for Greenhouse Crop Production. *J. Clean. Prod.* **2017**, *140*, 705–713. [CrossRef]
76. Martínez-Blanco, J.; Muñoz, P.; Antón, A.; Rieradevall, J. Assessment of Tomato Mediterranean Production in Open-Field and Standard Multi-Tunnel Greenhouse, with Compost or Mineral Fertilizers, from an Agricultural and Environmental Standpoint. *J. Clean. Prod.* **2011**, *19*, 985–997. [CrossRef]
77. Sanyé-Mengual, E.; Oliver-Solà, J.; Montero, J.I.; Rieradevall, J. An Environmental and Economic Life Cycle Assessment of Rooftop Greenhouse (RTG) Implementation in Barcelona, Spain. Assessing New Forms of Urban Agriculture from the Greenhouse Structure to the Final Product Level. *Int. J. Life Cycle Assess.* **2015**, *20*, 350–366. [CrossRef]
78. Sanjuan-Delmás, D.; Llorach-Massana, P.; Nadal, A.; Ercilla-Montserrat, M.; Muñoz, P.; Montero, J.I.; Josa, A.; Gabarrell, X.; Rieradevall, J. Environmental Assessment of an Integrated Rooftop Greenhouse for Food Production in Cities. *J. Clean. Prod.* **2018**, *177*, 326–337. [CrossRef]
79. Aschilean, I.; Rasoi, G.; Raboaca, M.S.; Filote, C.; Culcer, M. Design and Concept of an Energy System Based on Renewable Sources for Greenhouse Sustainable Agriculture. *Energies* **2018**, *11*, 1201. [CrossRef]
80. Esen, M.; Yuksel, T. Experimental Evaluation of Using Various Renewable Energy Sources for Heating a Greenhouse. *Energy Build.* **2013**, *65*, 340–351. [CrossRef]
81. García, J.L.; De La Plaza, S.; Navas, L.M.; Benavente, R.M.; Luna, L. Evaluation of the Feasibility of Alternative Energy Sources for Greenhouse Heating. *J. Agric. Eng. Res.* **1998**, *69*, 107–114. [CrossRef]
82. Yano, A.; Kadowaki, M.; Furue, A.; Tamaki, N.; Tanaka, T.; Hiraki, E.; Kato, Y.; Ishizu, F.; Noda, S. Shading and Electrical Features of a Photovoltaic Array Mounted inside the Roof of an East-West Oriented Greenhouse. *Biosyst. Eng.* **2010**, *106*, 367–377. [CrossRef]
83. Castellano, S. Photovoltaic Greenhouses: Evaluation of Shading Effect and Its Influence on Agricultural Performances. *J. Agric. Eng.* **2014**, *45*, 168–175. [CrossRef]
84. Marucci, A.; Cappuccini, A. Dynamic Photovoltaic Greenhouse: Energy Efficiency in Clear Sky Conditions. *Appl. Energy* **2016**, *170*, 362–376. [CrossRef]
85. Gao, Y.; Dong, J.; Isabella, O.; Santbergen, R.; Tan, H.; Zeman, M.; Zhang, G. Modeling and Analyses of Energy Performances of Photovoltaic Greenhouses with Sun-Tracking Functionality. *Appl. Energy* **2019**, *233–234*, 424–442. [CrossRef]
86. Roslan, N.; Ya'acob, M.E.; Jamaludin, D.; Hashimoto, Y.; Othman, M.H.; Iskandar, A.N.; Ariffin, M.R.; Ibrahim, M.H.; Mailan, J.; Jamaluddin, A.H.; et al. Dye-Sensitized Solar Cell (DSSC): Effects on Light Quality, Microclimate, and Growth of Orthosiphon Stamineus in Tropical Climatic Condition. *Agronomy* **2021**, *11*, 631. [CrossRef]
87. Buttaro, D.; Renna, M.; Gerardi, C.; Blando, F.; Santamaria, P.; Serio, F. Soilless Production of Wild Rocket as Affected by Greenhouse Coverage with Photovoltaic Modules. *Acta Sci. Pol. Hortorum Cultus* **2016**, *15*, 129–142.
88. Sonneveld, P.J.; Swinkels, G.L.A.M.; van Tuijl, B.A.J.; Janssen, H.J.J.; Campen, J.; Bot, G.P.A. Performance of a Concentrated Photovoltaic Energy System with Static Linear Fresnel Lenses. *Sol. Energy* **2011**, *85*, 432–442. [CrossRef]
89. Hepbasli, A. A Comparative Investigation of Various Greenhouse Heating Options Using Exergy Analysis Method. *Appl. Energy* **2011**, *88*, 4411–4423. [CrossRef]
90. Chau, J.; Sowlati, T.; Sokhansanj, S.; Preto, F.; Melin, S.; Bi, X. Techno-Economic Analysis of Wood Biomass Boilers for the Greenhouse Industry. *Appl. Energy* **2009**, *86*, 364–371. [CrossRef]
91. Chau, J.; Sowlati, T.; Sokhansanj, S.; Preto, F.; Melin, S.; Bi, X. Economic Sensitivity of Wood Biomass Utilization for Greenhouse Heating Application. *Appl. Energy* **2009**, *86*, 616–621. [CrossRef]
92. Roy, Y.; Lefsrud, M.; Orsat, V.; Filion, F.; Bouchard, J.; Nguyen, Q.; Dion, L.-M.; Glover, A.; Madadian, E.; Lee, C.P. Biomass Combustion for Greenhouse Carbon Dioxide Enrichment. *Biomass Bioenergy* **2014**, *66*, 186–196. [CrossRef]
93. Bibbiani, C.; Fantozzi, F.; Gargari, C.; Campiotti, C.A.; Schettini, E.; Vox, G. Wood Biomass as Sustainable Energy for Greenhouses Heating in Italy. *Agric. Agric. Sci. Procedia* **2016**, *8*, 637–645. [CrossRef]
94. Başak, M.Z.; Sevilgen, S.H. A Techno-Economic Model for Heating of a Greenhouse Site Using Waste Heat. *Arab. J. Sci. Eng.* **2016**, *41*, 1895–1905. [CrossRef]
95. Chinese, D.; Meneghetti, A.; Nardin, G. Waste-to-Energy Based Greenhouse Heating: Exploring Viability Conditions through Optimisation Models. *Renew. Energy* **2005**, *30*, 1573–1586. [CrossRef]
96. Pietzsch, M.; Meyer, J. Use of Reject Heat from Biogas Power Plants for Greenhouse Heating. *Acta Hortic.* **2008**, *801 Pt. 1*, 719–724. [CrossRef]
97. Yildiz, A.; Ozgener, O.; Ozgener, L. Energetic Performance Analysis of a Solar Photovoltaic Cell (PV) Assisted Closed Loop Earth-to-Air Heat Exchanger for Solar Greenhouse Cooling: An Experimental Study for Low Energy Architecture in Aegean Region. *Renew. Energy* **2012**, *44*, 281–287. [CrossRef]
98. Agrebi, S.; Chargui, R.; Tashtoush, B.; Guizani, A. Comparative Performance Analysis of a Solar Assisted Heat Pump for Greenhouse Heating in Tunisia. *Int. J. Refrig.* **2021**, *131*, 547–558. [CrossRef]
99. Lim, T.; Baik, Y.-K.; Kim, D.D. Heating Performance Analysis of an Air-to-Water Heat Pump Using Underground Air for Greenhouse Farming. *Energies* **2020**, *13*, 3863. [CrossRef]

100. Yildirim, N.; Bilir, L. Evaluation of a Hybrid System for a Nearly Zero Energy Greenhouse. *Energy Convers. Manag.* **2017**, *148*, 1278–1290. [CrossRef]
101. Pascuzzi, S.; Anifantis, A.S.; Blanco, I.; Scarascia Mugnozza, G. Electrolyzer Performance Analysis of an Integrated Hydrogen Power System for Greenhouse Heating a Case Study. *Sustainability* **2016**, *8*, 629. [CrossRef]
102. Bakker, J.C.; Bot, G.P.A.; Challa, H.; Van de Braak, N.J. *Greenhouse Climate Control: An Integrated Approach*; Wageningen Press: Wageningen, The Netherlands, 1995.
103. Rodríguez, F.; Berenguel, M.; Guzmán, J.L.; Ramírez-Arias, A. Climate and Irrigation Control. In *Modeling and Control of Greenhouse Crop Growth. Advances in Industrial Control*; Springer: Cham, Switzerland, 2015; pp. 99–196. [CrossRef]
104. Duarte-Galvan, C.; Torres-Pacheco, I.; Guevara-Gonzalez, R.G.; Romero-Troncoso, R.J.; Contreras-Medina, L.M.; Rios-Alcaraz, M.A.; Millan-Almaraz, J.R. Review. Advantages and Disadvantages of Control Theories Applied in Greenhouse Climate Control Systems. *Span. J. Agric. Res.* **2012**, *10*, 926–938. [CrossRef]
105. Vanthoor, B.H.E.; Stanghellini, C.; Van Henten, E.J.; De Visser, P.H.B. A Methodology for Model-Based Greenhouse Design: Part 1, a Greenhouse Climate Model for a Broad Range of Designs and Climates. *Biosyst. Eng.* **2011**, *110*, 363–377. [CrossRef]
106. Vanthoor, B.H.E.; Gázquez, J.C.; Magán, J.J.; Ruijs, M.N.A.; Baeza, E.; Stanghellini, C.; van Henten, E.J.; de Visser, P.H.B. A Methodology for Model-Based Greenhouse Design: Part 4, Economic Evaluation of Different Greenhouse Designs: A Spanish Case. *Biosyst. Eng.* **2012**, *111*, 336–349. [CrossRef]
107. Setiawan, A.; Albright, L.D.; Phelan, R.M. Application of Pseudo-Derivative-Feedback Algorithm in Greenhouse Air Temperature Control. *Comput. Electron. Agric.* **2000**, *26*, 283–302. [CrossRef]
108. Arvanitis, K.G.; Paraskevopoulos, P.N.; Vernardos, A.A. Multirate Adaptive Temperature Control of Greenhouses. *Comput. Electron. Agric.* **2000**, *26*, 303–320. [CrossRef]
109. Castañeda-Miranda, R.; Ventura-Ramos, E.; del Rocío Peniche-Vera, R.; Herrera-Ruiz, G. Fuzzy Greenhouse Climate Control System Based on a Field Programmable Gate Array. *Biosyst. Eng.* **2006**, *94*, 165–177. [CrossRef]
110. Reyes-Rosas, A.; Molina-Aiz, F.D.; Valera, D.L.; López, A.; Khamkure, S. Development of a Single Energy Balance Model for Prediction of Temperatures inside a Naturally Ventilated Greenhouse with Polypropylene Soil Mulch. *Comput. Electron. Agric.* **2017**, *142*, 9–28. [CrossRef]
111. Van Straten, G.; Challa, H.; Buwalda, F. Towards User Accepted Optimal Control of Greenhouse Climate. *Comput. Electron. Agric.* **2000**, *26*, 221–238. [CrossRef]
112. Ben Ali, R.; Aridhi, E.; Mami, A. Dynamic Model of an Agricultural Greenhouse Using Matlab-Simulink Environment. In Proceedings of the 16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering, STA 2015, Monastir, Tunisia, 21–23 December 2015; IEEE: New York, NY, USA, 2016; pp. 346–350. [CrossRef]
113. Ioslovich, I.; Gutman, P.-O.; Linker, R. Hamilton-Jacobi-Bellman Formalism for Optimal Climate Control of Greenhouse Crop. *Automatica* **2009**, *45*, 1227–1231. [CrossRef]
114. Van Beveren, P.J.M.; Bontsema, J.; van Straten, G.; van Henten, E.J. Optimal Control of Greenhouse Climate Using Minimal Energy and Grower Defined Bounds. *Appl. Energy* **2015**, *159*, 509–519. [CrossRef]
115. Dong, Q.; Yang, W.; Yang, L.; Chen, Y.; Du, S.; Feng, L.; Shi, Q.; Xu, Y. Crop Model-Based Greenhouse Optimal Control System: Survey and Perspectives. In *Computer and Computing Technologies in Agriculture VI, Proceedings of the 6th IFIP WG 5.14 International Conference, CCTA 2012, Zhangjiajie, China, 19–21 October 2012*; Li, D., Chen, Y., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; Volume 392, pp. 216–224. [CrossRef]
116. Körner, O.; Van Straten, G. Decision Support for Dynamic Greenhouse Climate Control Strategies. *Comput. Electron. Agric.* **2008**, *60*, 18–30. [CrossRef]
117. Rodríguez, F.; Guzmán, J.L.; Berenguel, M.; Arahal, M.R. Adaptive Hierarchical Control of Greenhouse Crop Production. *Int. J. Adapt. Control Signal Process.* **2008**, *22*, 180–197. [CrossRef]
118. Van 't Ooster, A.; Bontsema, J.; Van Henten, E.J.; Hemming, S. GWorkS—A Discrete Event Simulation Model on Crop Handling Processes in a Mobile Rose Cultivation System. *Biosyst. Eng.* **2012**, *112*, 108–120. [CrossRef]
119. Ramírez-Arias, A.; Rodríguez, F.; Guzmán, J.L.; Berenguel, M. Multiobjective Hierarchical Control Architecture for Greenhouse Crop Growth. *Automatica* **2012**, *48*, 490–498. [CrossRef]
120. López-Cruz, I.L.; Fitz-Rodríguez, E.; Torres-Monsivais, J.C.; Trejo-Zúñiga, E.C.; Ruíz-García, A.; Ramírez-Arias, A. Control Strategies of Greenhouse Climate for Vegetables Production. In *Biosystems Engineering: Biofactories for Food Production in the Century XXI*; Guevara-Gonzalez, R., Torres-Pacheco, I., Eds.; Springer: Cham, Switzerland, 2014; pp. 401–421. [CrossRef]
121. Ojha, T.; Misra, S.; Raghuwanshi, N.S. Wireless Sensor Networks for Agriculture: The State-of-the-Art in Practice and Future Challenges. *Comput. Electron. Agric.* **2015**, *118*, 66–84. [CrossRef]
122. Guzmán, C.H.; Carrera, J.L.; Durán, H.A.; Berumen, J.; Ortiz, A.A.; Guirette, O.A.; Arroyo, A.; Brizuela, J.A.; Gómez, F.; Blanco, A.; et al. Implementation of Virtual Sensors for Monitoring Temperature in Greenhouses Using CFD and Control. *Sensors* **2019**, *19*, 60. [CrossRef]
123. Shamshiri, R.R.; Bojic, I.; van Henten, E.; Balasundram, S.K.; Dworak, V.; Sultan, M.; Weltzien, C. Model-Based Evaluation of Greenhouse Microclimate Using IoT-Sensor Data Fusion for Energy Efficient Crop Production. *J. Clean. Prod.* **2020**, *263*, 121303. [CrossRef]
124. Kodali, R.K.; Jain, V.; Karagwal, S. IoT Based Smart Greenhouse. In Proceedings of the 2016 IEEE Region 10 Humanitarian Technology Conference, R10-HTC 2016, Agra, India, 21–23 December 2016; IEEE: New York, NY, USA, 2016; pp. 1–6. [CrossRef]

125. Liu, D.; Cao, X.; Huang, C.; Ji, L. Intelligent Agriculture Greenhouse Environment Monitoring System Based on IOT Technology. In Proceedings of the International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2015, Halong Bay, Vietnam, 19–20 December 2015; IEEE: New York, NY, USA, 2016; pp. 487–490. [CrossRef]
126. Raj, J.S.; Ananthi, J.V. Automation Using IoT in Greenhouse Environment. *J. Inf. Technol. Digit. World* **2019**, *1*, 38–47. [CrossRef]
127. Xiaoyan, Z.; Xiangyang, Z.; Chen, D.; Zhaohui, C.; Shangming, S.; Zhaohui, Z. The Design and Implementation of the Greenhouse Monitoring System Based on GSM and RF Technologies. In Proceedings of the International Conference on Computational Problem-solving (ICCP), Jiuzhai, China, 26–28 October 2013; IEEE: New York, NY, USA, 2013; pp. 32–35. [CrossRef]
128. Pallavi, K.; Mallapur, J.D.; Bendigeri, K.Y. Remote Sensing and Controlling of Greenhouse Agriculture Parameters Based on IoT. In Proceedings of the 2017 International Conference on Big Data, IoT and Data Science, BID 2017, Pune, India, 20–22 December 2017; IEEE: New York, NY, USA, 2018; pp. 44–48. [CrossRef]
129. Munoz, M.; Guzman, J.L.; Sanchez-Molina, J.A.; Rodríguez, F.; Torres, M.; Berenguel, M. A New IoT-Based Platform for Greenhouse Crop Production. *IEEE Internet Things J.* **2022**, *9*, 6325–6334. [CrossRef]
130. Liao, M.-S.; Chen, S.-F.; Chou, C.-Y.; Chen, H.-Y.; Yeh, S.-H.; Chang, Y.-C.; Jiang, J.-A. On Precisely Relating the Growth of Phalaenopsis Leaves to Greenhouse Environmental Factors by Using an IoT-Based Monitoring System. *Comput. Electron. Agric.* **2017**, *136*, 125–139. [CrossRef]
131. Akkaş, M.A.; Sokullu, R. An IoT-Based Greenhouse Monitoring System with Micaz Motes. *Procedia Comput. Sci.* **2017**, *113*, 603–608. [CrossRef]
132. Sun, J.; Abdulghani, A.M.; Imran, M.A.; Abbasi, Q.H. IoT Enabled Smart Fertilization and Irrigation Aid for Agricultural Purposes. In Proceedings of the 2020 International Conference on Computing, Networks and Internet of Things (CNIOT2020), Sanya China, 24–26 April 2020; Association for Computing Machinery: New York, NY, USA, 2020; pp. 71–75. [CrossRef]
133. Dharmasena, T.; de Silva, R.; Abhayasingha, N.; Abeygunawardhana, P. Autonomous Cloud Robotic System for Smart Agriculture. In Proceedings of the 2019 Moratuwa Engineering Research Conference (MERCon), Moratuwa, Sri Lanka, 3–5 July 2019; IEEE: New York, NY, USA, 2019; pp. 388–393. [CrossRef]
134. Saleem, M.H.; Potgieter, J.; Arif, K.M. Automation in Agriculture by Machine and Deep Learning Techniques: A Review of Recent Developments. *Precis. Agric.* **2021**, *22*, 2053–2091. [CrossRef]
135. Pothuganti, K.; Sridevi, B.; Seshabattar, P. IoT and Deep Learning Based Smart Greenhouse Disease Prediction. In Proceedings of the 6th International Conference on Recent Trends on Electronics, Information, Communication and Technology, RTEICT 2021, Bangalore, India, 27–28 August 2021; IEEE: New York, NY, USA, 2021; pp. 793–799. [CrossRef]
136. Kumar, V.; Arora, H.; Sisodia, J. ResNet-Based Approach for Detection and Classification of Plant Leaf Diseases. In Proceedings of the 2020 International Conference on Electronics and Sustainable Communication Systems, ICESC 2020, Coimbatore, India, 2–4 July 2020; IEEE: New York, NY, USA, 2020; pp. 495–502. [CrossRef]
137. Kitpo, N.; Kugai, Y.; Inoue, M.; Yokemura, T.; Satomura, S. Internet of Things for Greenhouse Monitoring System Using Deep Learning and Bot Notification Services. In Proceedings of the 2019 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, USA, 11–13 January 2019; IEEE: New York, NY, USA, 2019; pp. 1–4. [CrossRef]
138. Zheng, Y.-Y.; Kong, J.-L.; Jin, X.-B.; Wang, X.-Y.; Su, T.-L.; Zuo, M. Cropdeep: The Crop Vision Dataset for Deep-Learning-Based Classification and Detection in Precision Agriculture. *Sensors* **2019**, *19*, 1058. [CrossRef] [PubMed]
139. Gupta, M.J.; Chandra, P. Effect of Greenhouse Design Parameters on Conservation of Energy for Greenhouse Environmental Control. *Energy* **2002**, *27*, 777–794. [CrossRef]
140. Chou, S.K.; Chua, K.J.; Ho, J.C.; Ooi, C.L. On the Study of an Energy-Efficient Greenhouse for Heating, Cooling and Dehumidification Applications. *Appl. Energy* **2004**, *77*, 355–373. [CrossRef]
141. Waaijenberg, D. Design, Construction and Maintenance of Greenhouse Structures. *Acta Hortic.* **2006**, *710*, 31–42. [CrossRef]
142. Von Elsner, B.; Briassoulis, D.; Waaijenberg, D.; Mistriotis, A.; von Zabeltitz, C.; Gratraud, J.; Russo, G.; Suay-Cortes, R. Review of Structural and Functional Characteristics of Greenhouses in European Union Countries, Part II: Typical Designs. *J. Agric. Eng. Res.* **2000**, *75*, 111–126. [CrossRef]
143. Çakır, U.; Şahin, E. Using Solar Greenhouses in Cold Climates and Evaluating Optimum Type According to Sizing, Position and Location: A Case Study. *Comput. Electron. Agric.* **2015**, *117*, 245–257. [CrossRef]
144. Singh, R.D.; Tiwari, G.N. Energy Conservation in the Greenhouse System: A Steady State Analysis. *Energy* **2010**, *35*, 2367–2373. [CrossRef]
145. Ahamed, M.S.; Guo, H.; Tanino, K. Energy-Efficient Design of Greenhouse for Canadian Prairies Using a Heating Simulation Model. *Int. J. Energy Res.* **2018**, *42*, 2263–2272. [CrossRef]
146. Bakker, J.C. Model Application for Energy Efficient Greenhouses in The Netherlands: Greenhouse Design, Operational Control and Decision Support Systems. *Acta Hortic.* **2006**, *718*, 191–202. [CrossRef]
147. Villarreal-Guerrero, F.; Kacira, M.; Fitz-Rodríguez, E.; Linker, R.; Kubota, C.; Giacomelli, G.A.; Arbel, A. Simulated Performance of a Greenhouse Cooling Control Strategy with Natural Ventilation and Fog Cooling. *Biosyst. Eng.* **2012**, *111*, 217–228. [CrossRef]
148. Kittas, C.; Bartzanas, T.; Jaffrin, A. Temperature Gradients in a Partially Shaded Large Greenhouse Equipped with Evaporative Cooling Pads. *Biosyst. Eng.* **2003**, *85*, 87–94. [CrossRef]
149. Kwon, K.-S.; Kim, D.-W.; Kim, R.-W.; Ha, T.; Lee, I.-B. Evaluation of Wind Pressure Coefficients of Single-Span Greenhouses Built on Reclaimed Coastal Land Using a Large-Sized Wind Tunnel. *Biosyst. Eng.* **2016**, *141*, 58–81. [CrossRef]

150. Mistriotis, A.; Briassoulis, D. Numerical Estimation of the Internal and External Aerodynamic Coefficients of a Tunnel Greenhouse Structure with Openings. *Comput. Electron. Agric.* **2002**, *34*, 191–205. [CrossRef]
151. Richardson, G.M.; Westgate, G.R. Full-Scale Measurements of the Wind Loads on Film Plastic Clad Greenhouses: A Comparison of Measured and Calculated Strains on the Supporting Hoops of a Tunnel Greenhouse. *J. Agric. Eng. Res.* **1986**, *33*, 101–110. [CrossRef]
152. Robertson, A.P.; Roux, P.; Gratraud, J.; Scarascia, G.; Castellano, S.; Dufresne de Virel, M.; Palier, P. Wind Pressures on Permeably and Impermeably-Clad Structures. *J. Wind Eng. Ind. Aerodyn.* **2002**, *90*, 461–474. [CrossRef]
153. Wang, C.; Nan, B.; Wang, T.; Bai, Y.; Li, Y. Wind Pressure Acting on Greenhouses: A Review. *Int. J. Agric. Biol. Eng.* **2021**, *14*, 1–8. [CrossRef]
154. Kim, R.-W.; Lee, I.-B.; Yeo, U.-H.; Lee, S.-Y. Estimating the Wind Pressure Coefficient for Single-Span Greenhouses Using an Large Eddy Simulation Turbulence Model. *Biosyst. Eng.* **2019**, *188*, 114–135. [CrossRef]
155. Vieira Neto, J.G.; Soriano, J. Computational Modelling Applied to Predict the Pressure Coefficients in Deformed Single Arch-Shape Greenhouses. *Biosyst. Eng.* **2020**, *200*, 231–245. [CrossRef]
156. Majdoubi, H.; Boulard, T.; Fatnassi, H.; Bouirden, L. Airflow and Microclimate Patterns in a One-Hectare Canary Type Greenhouse: An Experimental and CFD Assisted Study. *Agric. For. Meteorol.* **2009**, *149*, 1050–1062. [CrossRef]
157. Bournet, P.-E.; Boulard, T. Effect of Ventilator Configuration on the Distributed Climate of Greenhouses: A Review of Experimental and CFD Studies. *Comput. Electron. Agric.* **2010**, *74*, 195–217. [CrossRef]
158. Mistriotis, A.; Bot, G.P.A.; Picuno, P.; Scarascia-Mugnozza, G. Analysis of the Efficiency of Greenhouse Ventilation Using Computational Fluid Dynamics. *Agric. For. Meteorol.* **1997**, *85*, 217–228. [CrossRef]
159. Bartzanas, T.; Boulard, T.; Kittas, C. Effect of Vent Arrangement on Windward Ventilation of a Tunnel Greenhouse. *Biosyst. Eng.* **2004**, *88*, 479–490. [CrossRef]
160. Baeza, E.J.; Pérez-Parra, J.J.; Montero, J.I.; Bailey, B.J.; López, J.C.; Gázquez, J.C. Analysis of the Role of Sidewall Vents on Buoyancy-Driven Natural Ventilation in Parral-Type Greenhouses with and without Insect Screens Using Computational Fluid Dynamics. *Biosyst. Eng.* **2009**, *104*, 86–96. [CrossRef]
161. Santolini, E.; Pulvirenti, B.; Torreggiani, D.; Tassinari, P. Novel Methodologies for the Characterization of Airflow Properties of Shading Screens by Means of Wind-Tunnel Experiments and CFD Numerical Modeling. *Comput. Electron. Agric.* **2019**, *163*, 104800. [CrossRef]
162. Villagrán, E.A.; Bojacá, C.R. Effects of Surrounding Objects on the Thermal Performance of Passively Ventilated Greenhouses. *J. Agric. Eng.* **2019**, *50*, 20–27. [CrossRef]
163. Teitel, M.; Ziskind, G.; Liran, O.; Dubovsky, V.; Letan, R. Effect of Wind Direction on Greenhouse Ventilation Rate, Airflow Patterns and Temperature Distributions. *Biosyst. Eng.* **2008**, *101*, 351–369. [CrossRef]
164. Fuina, S.; Marano, G.C.; Scarascia-Mugnozza, G. Polycarbonate Laminates Thermo-Mechanical Behaviour under Different Operating Temperatures. *Polym. Test.* **2019**, *76*, 344–349. [CrossRef]
165. Al-Mahdouri, A.; Baneshi, M.; Gonome, H.; Okajima, J.; Maruyama, S. Evaluation of Optical Properties and Thermal Performances of Different Greenhouse Covering Materials. *Sol. Energy* **2013**, *96*, 21–32. [CrossRef]
166. Hemming, S.; Mohammadkhani, V.; Dueck, T. Diffuse Greenhouse Covering Materials—Material Technology, Measurements and Evaluation of Optical Properties. *Acta Hortic.* **2008**, *797*, 469–476. [CrossRef]
167. De Salvador, F.R.; Scarascia Mugnozza, G.; Vox, G.; Schettini, E.; Mastrorilli, M.; Bou Jaoudé, M. Innovative Photoselective and Photoluminescent Plastic Films for Protected Cultivation. *Acta Hortic.* **2008**, *801*, 115–122. [CrossRef]
168. Cabrera, F.J.; Baille, A.; López, J.C.; González-Real, M.M.; Pérez-Parra, J. Effects of Cover Diffusive Properties on the Components of Greenhouse Solar Radiation. *Biosyst. Eng.* **2009**, *103*, 344–356. [CrossRef]
169. Pollet, I.V.; Pieters, J.G. PAR Transmittances of Dry and Condensate Covered Glass and Plastic Greenhouse Cladding. *Agric. For. Meteorol.* **2002**, *110*, 285–298. [CrossRef]
170. Pollet, I.V.; Pieters, J.G.; Deltour, J.; Verschoore, R. Diffusion of Radiation Transmitted through Dry and Condensate Covered Transmitting Materials. *Sol. Energy Mater. Sol. Cells* **2005**, *86*, 177–196. [CrossRef]
171. Stanghellini, C.; Bruins, M.; Mohammadkhani, V.; Swinkels, G.J.; Sonneveld, P.J. Effect of Condensation on Light Transmission and Energy Budget of Seven Greenhouse Cover Materials. *Acta Hortic.* **2012**, *952*, 249–254. [CrossRef]
172. Teitel, M.; Vitoshkin, H.; Geoola, F.; Karlsson, S.; Stahl, N. Greenhouse and Screenhouse Cover Materials: Literature Review and Industry Perspective. *Acta Hortic.* **2018**, *1227*, 31–44. [CrossRef]
173. Djakhdane, K.; Dehbi, A.; Mourad, A.-H.I.; Zaoui, A.; Picuno, P. The Effect of Sand Wind, Temperature and Exposure Time on Tri-Layer Polyethylene Film Used as Greenhouse Roof. *Plast. Rubber Compos.* **2016**, *45*, 6. [CrossRef]
174. Briassoulis, D.; Aristopoulou, A.; Bonora, M.; Verlodt, I. Degradation Characterisation of Agricultural Low-Density Polyethylene Films. *Biosyst. Eng.* **2004**, *88*, 131–143. [CrossRef]
175. Schettini, E.; Vox, G.; Stefani, L. Interaction between Agrochemical Contaminants and Uv Stabilizers for Greenhouse Eva Plastic Films. *Appl. Eng. Agric.* **2014**, *30*, 229–239. [CrossRef]
176. Mashonjowa, E.; Ronsse, F.; Mhizha, T.; Milford, J.R.; Lemeur, R.; Pieters, J.G. The Effects of Whitening and Dust Accumulation on the Microclimate and Canopy Behaviour of Rose Plants (*Rosa hybrida*) in a Greenhouse in Zimbabwe. *Sol. Energy* **2010**, *84*, 10–23. [CrossRef]

177. Graefe, J.; Sandmann, M. Shortwave Radiation Transfer through a Plant Canopy Covered by Single and Double Layers of Plastic. *Agric. For. Meteorol.* **2015**, *201*, 196–208. [CrossRef]
178. Hu, J.; Yu, X. Adaptive Greenhouse with Thermochromic Material: Performance Evaluation in Cold Regions. *J. Energy Eng.* **2020**, *146*, 4020032. [CrossRef]
179. Baeza, E.J.; van Breugel, A.J.B.; Hemming, S.; Stanghellini, C. Smart Greenhouse Covers: A Look into the Future. *Acta Hortic.* **2020**, *1268*, 213–224. [CrossRef]
180. Timmermans, G.H.; Hemming, S.; Baeza, E.; van Thoor, E.A.J.; Schenning, A.P.H.J.; Debije, M.G. Advanced Optical Materials for Sunlight Control in Greenhouses. *Adv. Opt. Mater.* **2020**, *8*, 2000738. [CrossRef]
181. Stefani, L.; Zanon, M.; Modesti, M.; Ugel, E.; Vox, G.; Schettini, E. Reduction of the Environmental Impact of Plastic Films for Greenhouse Covering by Using Fluoropolymeric Materials. *Acta Hortic.* **2008**, *801*, 131–137. [CrossRef]
182. Picuno, P.; Sica, C.; Laviano, R.; Dimitrijević, A.; Scarascia-Mugnozza, G. Experimental Tests and Technical Characteristics of Regenerated Films from Agricultural Plastics. *Polym. Degrad. Stab.* **2012**, *97*, 1654–1661. [CrossRef]
183. Harel, D.; Fadida, H.; Slepoy, A.; Gantz, S.; Shilo, K. The Effect of Mean Daily Temperature and Relative Humidity on Pollen, Fruit Set and Yield of Tomato Grown in Commercial Protected Cultivation. *Agronomy* **2014**, *4*, 167–177. [CrossRef]
184. Lu, N.; Nukaya, T.; Kamimura, T.; Zhang, D.; Kurimoto, I.; Takagaki, M.; Maruo, T.; Kozai, T.; Yamori, W. Control of Vapor Pressure Deficit (VPD) in Greenhouse Enhanced Tomato Growth and Productivity during the Winter Season. *Sci. Hortic.* **2015**, *197*, 17–23. [CrossRef]
185. Olle, M.; Viršile, A. The Effects of Light-Emitting Diode Lighting on Greenhouse Plant Growth and Quality. *Agric. Food Sci.* **2013**, *22*, 223–234. [CrossRef]
186. Chen, R.; Kang, S.; Hao, X.; Li, F.; Du, T.; Qiu, R.; Chen, J. Variations in Tomato Yield and Quality in Relation to Soil Properties and Evapotranspiration under Greenhouse Condition. *Sci. Hortic.* **2015**, *197*, 318–328. [CrossRef]
187. Montero, J.I. Evaporative Cooling in Greenhouses: Effect on Microclimate, Water Use Efficiency and Plant Respons. *Acta Hortic.* **2006**, *719*, 373–383. [CrossRef]
188. Gázquez, J.C.; López, J.C.; Baeza, E.; Pérez-Parra, J.J.; Fernández, M.D.; Baille, A.; González-Real, M. Effects of Vapour Pressure Deficit and Radiation on the Transpiration Rate of a Greenhouse Sweet Pepper Crop. *Acta Hortic.* **2008**, *797*, 259–265. [CrossRef]
189. Dannehl, D.; Josuttis, M.; Ulrichs, C.; Schmidt, U. The Potential of a Confined Closed Greenhouse in Terms of Sustainable Production, Crop Growth, Yield and Valuable Plant Compounds of Tomatoes. *J. Appl. Bot. Food Qual.* **2014**, *87*, 210–219. [CrossRef]
190. Demrati, H.; Boulard, T.; Fatnassi, H.; Bekkaoui, A.; Majdoubi, H.; Elattir, H.; Bouirden, L. Microclimate and Transpiration of a Greenhouse Banana Crop. *Biosyst. Eng.* **2007**, *98*, 66–78. [CrossRef]
191. Heuvelink, E.; Bakker, M.; Marcelis, L.F.M.; Raaphorst, M. Climate and Yield in a Closed Greenhouse. *Acta Hortic.* **2008**, *801*, 1083–1092. [CrossRef]
192. Qian, T.; Dieleman, J.A.; Elings, A.; Marcelis, L.F.M. Leaf Photosynthetic and Morphological Responses to Elevated CO_2 Concentration and Altered Fruit Number in the Semi-Closed Greenhouse. *Sci. Hortic.* **2012**, *145*, 1–9. [CrossRef]
193. Katsoulas, N.; Kittas, C. Impact of Greenhouse Microclimate on Plant Growth and Development with Special Reference to the Solanaceae. *Eur. J. Plant Sci. Biotechnol.* **2008**, *2*, 31–44.
194. Shamshiri, R.R.; Jones, J.W.; Thorp, K.R.; Ahmad, D.; Man, H.C.; Taheri, S. Review of Optimum Temperature, Humidity, and Vapour Pressure Deficit for Microclimate Evaluation and Control in Greenhouse Cultivation of Tomato: A Review. *Int. Agrophys.* **2018**, *32*, 287–302. [CrossRef]
195. Cossu, M.; Murgia, L.; Ledda, L.; Deligios, P.A.; Sirigu, A.; Chessa, F.; Pazzona, A. Solar Radiation Distribution inside a Greenhouse with South-Oriented Photovoltaic Roofs and Effects on Crop Productivity. *Appl. Energy* **2014**, *133*, 89–100. [CrossRef]
196. Ntinas, G.K.; Kadoglidou, K.; Tsivelika, N.; Krommydas, K.; Kalivas, A.; Ralli, P.; Irakli, M. Performance and Hydroponic Tomato Crop Quality Characteristics in a Novel Greenhouse Using Dye-Sensitized Solar Cell Technology for Covering Material. *Horticulturae* **2019**, *5*, 42. [CrossRef]
197. Marrou, H.; Wery, J.; Dufour, L.; Dupraz, C. Productivity and Radiation Use Efficiency of Lettuces Grown in the Partial Shade of Photovoltaic Panels. *Eur. J. Agron.* **2013**, *44*, 54–66. [CrossRef]
198. Hassanien, R.H.E.; Li, M. Influences of Greenhouse-Integrated Semi-Transparent Photovoltaics on Microclimate and Lettuce Growth. *Int. J. Agric. Biol. Eng.* **2017**, *10*, 11–22. [CrossRef]
199. Davis, P.A.; Burns, C. Photobiology in Protected Horticulture. *Food Energy Secur.* **2016**, *5*, 223–238. [CrossRef]
200. Weaver, G.M.; van Iersel, M.W.; Mohammadpour Velni, J. A Photochemistry-Based Method for Optimising Greenhouse Supplemental Light Intensity. *Biosyst. Eng.* **2019**, *182*, 123–137. [CrossRef]
201. Katzin, D.; Marcelis, L.F.M.; van Mourik, S. Energy Savings in Greenhouses by Transition from High-Pressure Sodium to LED Lighting. *Appl. Energy* **2021**, *281*, 116019. [CrossRef]
202. Niangoran, N.U.; Canale, L.; Tian, F.; Haba, T.C.; Zissis, G. Optimal Spectrum Modeling Calculation with Light Emitting Diodes Set Based on Relative Quantum Efficiency. *Acta Hortic.* **2019**, *1242*, 815–822. [CrossRef]
203. Palmitessa, O.D.; Durante, M.; Caretto, S.; Milano, F.; D'imperio, M.; Serio, F.; Santamaria, P. Supplementary Light Differently Influences Physico-Chemical Parameters and Antioxidant Compounds of Tomato Fruits Hybrids. *Antioxidants* **2021**, *10*, 687. [CrossRef]

204. Díaz, B.M.; Biurrún, R.; Moreno, A.; Nebreda, M.; Fereres, A. Impact of Ultraviolet-Blocking Plastic Films on Insect Vectors of Virus Diseases Infecting Crisp Lettuce. *HortScience* **2006**, *41*, 711–716. [CrossRef]
205. Kumar, P.; Poehling, H.-M. UV-Blocking Plastic Films and Nets Influence Vectors and Virus Transmission on Greenhouse Tomatoes in the Humid Tropics. *Environ. Entomol.* **2006**, *35*, 1069–1082. [CrossRef]
206. Papaioannou, C.; Katsoulas, N.; Maletsika, P.; Siomos, A.; Kittas, C. Effects of a UV-Absorbing Greenhouse Covering Film on Tomato Yield and Quality. *Span. J. Agric. Res.* **2012**, *10*, 959–966. [CrossRef]
207. Pawlowski, A.; Sánchez-Molina, J.A.; Guzmán, J.L.; Rodríguez, F.; Dormido, S. Evaluation of Event-Based Irrigation System Control Scheme for Tomato Crops in Greenhouses. *Agric. Water Manag.* **2017**, *183*, 16–25. [CrossRef]
208. Nikolaou, G.; Neocleous, D.; Katsoulas, N.; Kittas, C. Irrigation of Greenhouse Crops. *Horticulturae* **2019**, *5*, 7. [CrossRef]
209. Massa, D.; Incrocci, L.; Maggini, R.; Carmassi, G.; Campiotti, C.A.; Pardossi, A. Strategies to Decrease Water Drainage and Nitrate Emission from Soilless Cultures of Greenhouse Tomato. *Agric. Water Manag.* **2010**, *97*, 971–980. [CrossRef]
210. Elvanidi, A.; Katsoulas, N.; Kittas, C. Automation for Water and Nitrogen Deficit Stress Detection in Soilless Tomato Crops Based on Spectral Indices. *Horticulturae* **2018**, *4*, 47. [CrossRef]
211. Srbinovska, M.; Gavrovski, C.; Dimcev, V.; Krkoleva, A.; Borozan, V. Environmental Parameters Monitoring in Precision Agriculture Using Wireless Sensor Networks. *J. Clean. Prod.* **2015**, *88*, 297–307. [CrossRef]
212. Norton, T.; Sun, D.-W.; Grant, J.; Fallon, R.; Dodd, V. Applications of Computational Fluid Dynamics (CFD) in the Modelling and Design of Ventilation Systems in the Agricultural Industry: A Review. *Bioresour. Technol.* **2007**, *98*, 2386–2414. [CrossRef]
213. Singh, D.; Basu, C.; Meinhardt-Wollweber, M.; Roth, B. LEDs for Energy Efficient Greenhouse Lighting. *Renew. Sustain. Energy Rev.* **2015**, *49*, 139–147. [CrossRef]
214. Kozai, T. Resource Use Efficiency of Closed Plant Production System with Artificial Light: Concept, Estimation and Application to Plant Factory. *Proc. Jpn. Acad. Ser. B Phys. Biol. Sci.* **2013**, *89*, 447–461. [CrossRef]
215. Jones, J.W.; Dayan, E.; Allen, L.H.; Van Keulen, H.; Challa, H. Dynamic Tomato Growth and Yield Model (TOMGRO). *Trans. Am. Soc. Agric. Eng.* **1991**, *34*, 663–672. [CrossRef]
216. Nelson, J.A.; Bugbee, B. Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures. *PLoS ONE* **2014**, *9*, e99010. [CrossRef] [PubMed]
217. Boulard, T.; Baille, A. Modelling of Air Exchange Rate in a Greenhouse Equipped with Continuous Roof Vents. *J. Agric. Eng. Res.* **1995**, *61*, 37–47. [CrossRef]
218. Boulard, T.; Wang, S. Experimental and Numerical Studies on the Heterogeneity of Crop Transpiration in a Plastic Tunnel. *Comput. Electron. Agric.* **2002**, *34*, 173–190. [CrossRef]
219. Zhao, J.-C.; Zhang, J.-F.; Feng, Y.; Guo, J.-X. The Study and Application of the IOT Technology in Agriculture. In Proceedings of the 2010 3rd IEEE International Conference on Computer Science and Information Technology, ICCSIT 2010, Chengdu, China, 9–11 July 2010; IEEE: New York, NY, USA, 2010; Volume 2, pp. 462–465. [CrossRef]
220. Hassanien, R.H.E.; Li, M.; Dong Lin, W. Advanced Applications of Solar Energy in Agricultural Greenhouses. *Renew. Sustain. Energy Rev.* **2016**, *54*, 989–1001. [CrossRef]
221. Zamora-Izquierdo, M.A.; Santa, J.; Martínez, J.A.; Martínez, V.; Skarmeta, A.F. Smart Farming IoT Platform Based on Edge and Cloud Computing. *Biosyst. Eng.* **2019**, *177*, 4–17. [CrossRef]
222. Stoessel, F.; Juraske, R.; Pfister, S.; Hellweg, S. Life Cycle Inventory and Carbon and Water Foodprint of Fruits and Vegetables: Application to a Swiss Retailer. *Environ. Sci. Technol.* **2012**, *46*, 3253–3262. [CrossRef]
223. Ebrahimi, M.A.; Khoshtaghaza, M.H.; Minaei, S.; Jamshidi, B. Vision-Based Pest Detection Based on SVM Classification Method. *Comput. Electron. Agric.* **2017**, *137*, 52–58. [CrossRef]
224. Emmott, C.J.M.; Röhr, J.A.; Campoy-Quiles, M.; Kirchartz, T.; Urbina, A.; Ekins-Daukes, N.J.; Nelson, J. Organic Photovoltaic Greenhouses: A Unique Application for Semi-Transparent PV? *Energy Environ. Sci.* **2015**, *8*, 1317–1328. [CrossRef]
225. Dion, L.-M.; Lefsrud, M.; Orsat, V. Review of CO_2 Recovery Methods from the Exhaust Gas of Biomass Heating Systems for Safe Enrichment in Greenhouses. *Biomass Bioenergy* **2011**, *35*, 3422–3432. [CrossRef]
226. Palmitessa, O.D.; Prinzenberg, A.E.; Kaiser, E.; Heuvelink, E. Led and Hps Supplementary Light Differentially Affect Gas Exchange in Tomato Leaves. *Plants* **2021**, *10*, 810. [CrossRef]