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Review

Future Research Tendencies and Possibilities of Using Cogeneration Applications of Solar Air Heaters: A Bibliometric Analysis

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Abstract: Solar air heater systems are equipment that uses energy captured directly from the sun to heat an existing airflow through the module. The technology to operate these systems is based on clean, renewable and free energy. Solar air heaters absorb thermal energy from the sun using an ab-sorption surface and achieve a transfer of heat from the absorption surface to the air flow supplied by one or two fans. This type of equipment can be used for space heating, drying, or ventilation processes. In addition, the equipment is capable of operating in cogeneration with other systems, e.g., preheating the air used for drying wood, preheating the air used to heat industrial premises, or preheating the water used in different heating systems. This scientific work is meant to reveal the current research context and the future opportunities in the case of cogeneration applications of solar air heaters, which are analyzed in light of their actual evolving dynamics. On this basis, we highlight expectations regarding the main problems that the regenerable energy is currently facing in this specific research and development environment as well as focusing our direction on the eventual solutions that are considered in the present and on their shortcomings in the future with evolved necessities.

Keywords: research tendencies; cogeneration; optimization; bibliometric; solar air heater; SAHs; solar energy; VosViwer; bibliometrix

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1. Introduction

Bibliometrics involves achieving quantitative analyses in the field of academic literature and represents the statistical analysis of publications in different research fields. Bibliometric analyses are studies used to clarify the significance of different areas of research. The scope of this study is to perform a bibliographic analysis in the field of solar air heating systems (SAHs). The importance and usefulness of these systems is found in various applications where hot air is a necessity, due to the simplicity in operation and low costs of realization and operation.

Membrane distillation (MD) lags behind due to the relatively high energy consumption compared to other desalination processes, e.g., reverse osmosis. Membrane heating in distillation is the key and significant component of total energy consumption. To make membrane distillation competitive with existing technologies, research should turn to low-cost energy sources or alternative heating methods. The development of alternative methods of heating is based on the direct heating of the supply water. Direct heating of the water supply near the surface of the membrane by means of solar air heating systems can improve the thermal efficiency and economy of the distillation process [1].

A desalination system with humidification and dehumidification (HDH) requires heat to carry out the process of seawater desalination [2]. An effective and environmentally friendly approach to obtain heat energy is the use of solar energy using solar air heaters. Seawater, air, or both are usually preheated by desalination systems before they are entered into the humidifier. Compared to preheating only water or just air, preheating both is preferable, since this results in high performance and productivity. The most proposed desalination model is the one with a double preheating system that uses two separate solar systems for the simultaneous preheating of air and seawater. Simultaneous heating of sea water and air can also be carried out with a single solar air heating system. This type of system has at mass flow rates of 0.005, 0.010 and 0.020 kg/s the maximum air temperature values 66 °C, 62 °C and 57 °C, respectively, while the maximum values achieved for the seawater temperature were 83 °C, 78 °C and 73 °C, respectively. The maximum hourly productivity observed for the desalination system with humidification and dehumidification with a single SAH was 6.20 kg/h for an air mass flow of 0.005 kg/s. The highest values for the average monthly air temperature and for the sea water temperature were 60 °C and 69 °C, respectively.

The solar air heater is a device with huge potential for harnessing solar thermal energy [3]. The main advantages of this type of equipment are its simple technology and the abundance of solar energy. Globally recorded data show a huge consumption of energy used to heat spaces. This thus justifies the need for and usefulness of a SAH for space heating. The most common problem for this type of system, in some areas, is the day–night variation and the uncertainty of solar radiation, due to the seasons. For high thermal efficiency, modifications were made to the systems, especially the absorption surfaces, for the use of a longer period of a solar heating system with air at the day–night variation. Solar systems with thermal energy storage were proposed for a while. The question remains of the variation of the seasons that force the use of these systems in areas with solar radiation for a long time of the year.

For energy saving, solar air-heating systems are of high interest in the drying field of agri-food products. Among the dried products with such systems, we mention the following: figs [4], grapes [5], tapioca [6], medicinal herbs [7], red algae [8], black pepper [9], chili peppers [10], corn kernels [11], and bananas [12]. In addition, solar air heaters can be used in hybrid and cogeneration systems, such as a transpired solar air heater with a heat exchanger type capillary tube [13,14]; solar air heater, heat pump and ionic liquids; SAH and PV-T; SAH with thermochemical heat storage system; and solar air heater with a ventilation system [13].

The optimization of systems in this field is closely related to the type of application used or studied. The present study highlights the evolution of solar air heaters (SAHs) and the future trends of this field of study. The bibliometric study was conducted making use of the "Web of Science" database for the analysis of scientific articles published between 2017 and 2021 in the field of solar air-heater systems. The information used for the analysis was collected during February 2022 from 1355 articles constituting the total of articles published over the five-year period in the field of solar air-heating systems, wherein the words "solar air heater" was met at least once. From preliminary analyses of future trends in this area, important possibilities emerged. The scientific data were centralized and analyzed with the help of the following software: Microsoft Excel, VosViwer and Bibliometrix. The main recommendation of the study is to continue optimizing and improving solar air heaters applicable in other areas, not just in areas where air heating is required.

The bibliometric analysis was made out of the desire to better understand the scientific directions in the realm of solar air heater systems. Analyses of this type look for publications and their properties to expose them visually for a better understanding of the evolution in the studied field [15]. The quality of the results of a bibliometric study depends on the correctness of the information and the information entered. For a fair appreciation it is significant to approach the literature of solar air heating systems in an objective, unbiased manner.

Bibliometric analysis is an area that provides help in analyzing publications, delivers support in evaluating research and helps authors find new collaborators and possible topics with major impact. Bibliometric analysis is based on bibliographic information and can be a way to increase visibility into the specific field of research [16].

The use of bibliometric analysis helps to understand the structures and knowledge in a particular field of research, representing a start in the realization of a publication for researchers at the beginning of the road.

In the purpose of creating bibliometric networks with the help of bibliometric analyzers, the results are generated, mainly, starting from text-based data, which are saved in the form of an appropriate file (e.g., txt), after it is generated and downloaded directly from one of the online platforms that host databases of scientific papers (e.g., Web of Science) so that it includes complete data fields (e.g., title, authors, affiliation, and abstract) regarding a collection of scientific papers that are selected for analysis [17,18].

After they are gathered, a selected collection of data is imported into the analysis software and is further interpreted according to specific software configurations, which are slightly adjusted to provide improved readability after they are individually chosen and imposed for each generated result, as, in this manner, it is easy to obtain a bibliometric network that offers a raw and clear overview, while it highlights un-distorted ideas that address the proposed topic [17,19].

2. Scope

Bibliometric analysis is used to obtain quantitative analyses in the field of academic literature and represents the statistical analysis of publications in different research fields. Bibliometrics are used to determine the strength and weakness of a field of study from an objective point of view. At the moment, there are many bibliometric studies in the field of renewable sources, but very few are centered on the bibliometric inquiry of solar air heaters. Researcher A. Benhamza from the Faculty of Technology, Levres Laboratory, University of El Qued, Algeria, very briefly addressed the problem of bibliometrics in the field of SAHs, in the paper, "Multi-objective design optimization of solar air heater for food drying based on energy, exergy and improvement potential". The emphasis in the work is placed on the methods used to optimize the solar air heaters. Regarding the study and evaluation of the outcome of geometrical indexes on SAHs performance, the paper deals with the response surface methodology (RSM) alongside a numerical model [20].

The current paper presents the bibliometric study of SAHs in an attempt to discover and understand past, current and future trends in research on these systems. Therefore, using the "Web of Science" database, the scientific articles published between 2017 and 2021, in the area of solar air heaters, were analyzed. The articles analyzed represent all the publications where the words "solar air heater" are found at least once. The authors' keywords, the countries with the highest production of articles in the field and the main authors that dominate the area of these solar systems were analyzed. To ease the visualization and understanding of data, graphs were made with the help of the following software: Microsoft Excel 2019, version 2201, developed by Microsoft, Houston, TX, USA; Bibliometrix 3.1 R Package, developed by K-Synth Srl, Naples, Italy; and VosViwer 1.6.17, Centre for Science and Technology Studies, Leiden University, The Netherlands.

Mainly, the purpose of this study is to discover the topic trends and to determine the amount of literature published in the solar air heaters domain considering different solar equipment, different technologies, and different systems combinations, such as hybrid and cogeneration systems.

3. Methodology

For the bibliometric analysis, the steps suggested by two researchers, Zhao D. and Strotmann A., in the paper "Analysis and Visualization of Citation Networks", published in 2015, were followed. The four recommended steps are as follows: the first step (i) is to define the words needed for the search; the second step (ii) is to filter and format the information; in the third step (iii), the initial analysis is conducted; and in the fourth step (iv) the final analysis of the information is carried out. The search was implemented using the topic field which allows searches title, abstract, author keywords and Keywords Plus [21].

With regard to the first step (i) in this bibliographic analysis, the words selected for the search are "solar air heater". The word search was conducted using the data platform "Web of Science" in the title, summary and keywords of the authors.

The "Web of Science" database provides access to publications and their citations for different academic disciplines, for a total of 256 disciplines. The multidisciplinary platform connects data, regional, specialty and patent indices comprising 1.7 billion cited references, over 155 million records and over 34,000 journals [22].

In step two (ii), for the same criteria, 1355 articles were identified representing the total of publications, over the period 2017–2021, in the domain of solar air heating systems in which the words "solar air heater" are found at least once. In order to be uploaded and used in the VosViwer version 1.6.17, software developed by Centre for Science and Technology Studies, Leiden University, The Netherlands and in Bibliometrix program version 3.1 R Package software developed by K-Synth Srl, Naples, Italy, item data were filtered, standardized, and formatted in a text file.

The third step (iii) is to develop and analyze the temporal trends of publications and their citations, classify them by domains, identify terms with a major impact and establish the network of keywords.

Step four (iv) links meanings to filtered patterns and data. The interpretation of information helps to understand the evolution over time of research interests and indicates the future directions of trends in the field of solar air heater systems.

All of the information taken from the "Web of Science" database was previously used for an overview of solar air heating systems. Thus, the following are analyzed: the distribution by fields of SAHs articles, the classification of the main countries that have contributions in the field and the scientific production in the considered period, 2017–2021. The data were taken directly from the search made in the database, visually exposed with the help of Microsoft Excel 2019 and are analyzed in Section 4.2 (An Overview over SAH Research).

Uploading text files to VosViwer version 1.6.17 developed by Centre for Science and Technology Studies, Leiden University, The Netherlands and Bibliometrix 3.1 R Package version, developed by K-Synth Srl, Naples, Italy, making bibliometric maps and analyzing them are presented in Section 4 (Results and Discussions).

4. Results and Discussions

This section provides a concise and precise bibliographic analysis of the solar air heaters literature published during the considered period, as well as the emerged discussions and trends. In addition, the research evolution of renewable sources is also analyzed.

4.1. Renewable Sources Articles Evolution

Renewable energy sources are an alternative that meets energy standards and requirements for the sustainable and lasting development of the world [23,24]. Solar energy is taken into account as one of the best and most relevant alternatives to conventional systems for the production of heat and electricity.

This is due to the ability of solar systems to convert solar energy directly into electricity in the case of photovoltaic systems, and indirectly in thermal energy, as is the case with concentrating systems that convert solar energy into thermal energy and then heat into electricity [25,26]. Additionally, another way to transform solar energy into thermal energy is by using solar air heaters (SAHs), which converts solar energy into thermal energy through the greenhouse effect [27].

In order to expose and analyze the level of interest that researchers carry in the known types of solar systems, the articles analyzed and exposed by the graphs below are part of the most cited publications in which the words "photovoltaic system", "solar air heater system", "solar hybrid system", "solar thermal system" and "concentrated solar system" are encountered at least once.

The information was extracted out of the "Web of Science" database, for the analysis of scientific articles published between 2011 and 2021 and centralized with the help of Microsoft Excel 2019, version 2201.

From the graph of Figure 1, it can be noted that photovoltaic systems hold the highest percentage of published articles, with 47.0–55.71%, within the considered period. The share of scientific articles in the field of solar thermal systems is between 25.56% and 31.47%, occupying the second place after the percentage of articles published in the field of photovoltaic systems. In third and fourth places are the articles published in the fields of hybrid solar systems, with values between 10.35% and 15.92%, respectively, and concentrating solar systems with percentages between 6.01% and 7.65%. The articles published in the domain of solar air heater systems fills the last place, with the smallest share and values between 0.71% and 1.15%.

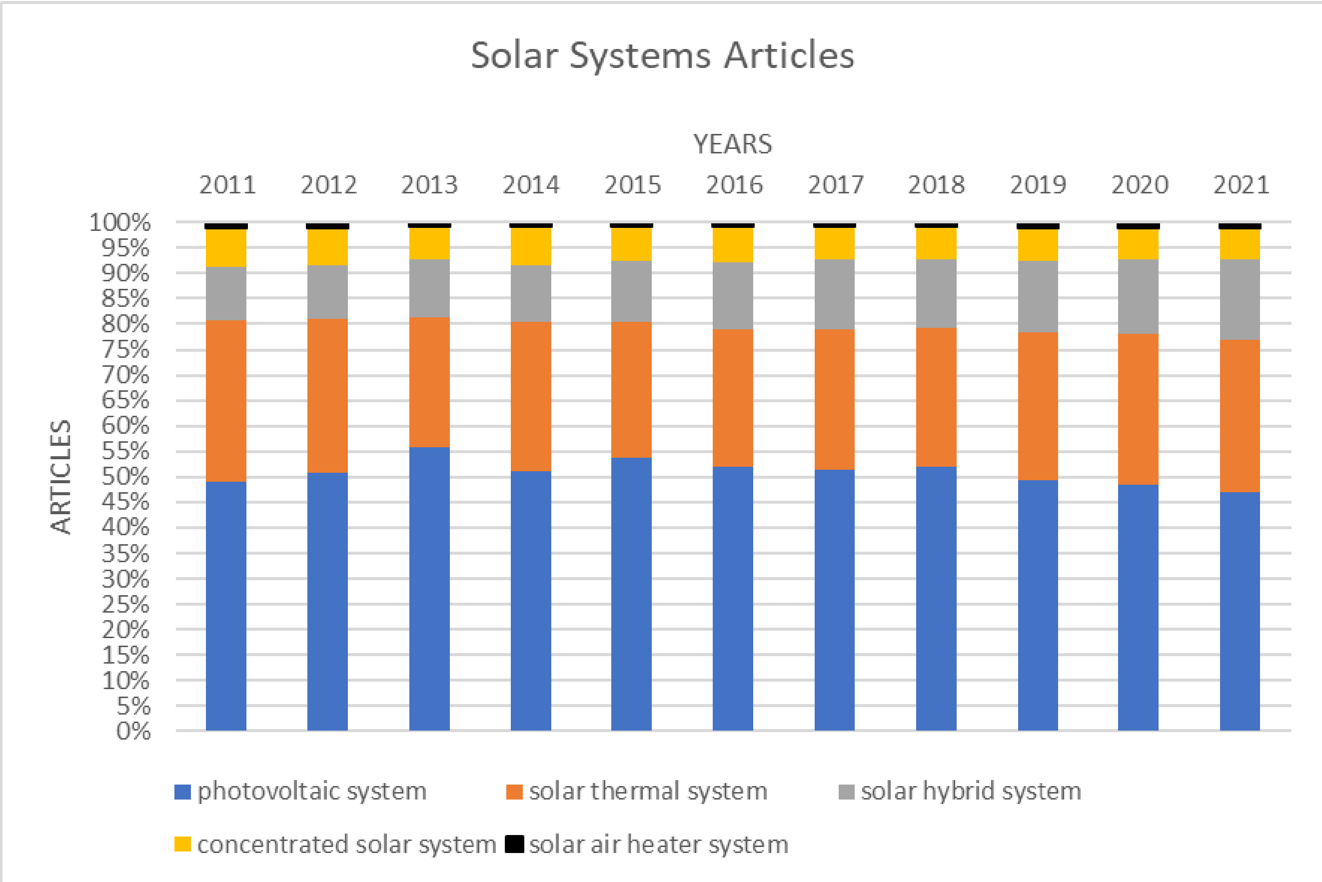

Figure 1. Articles percent for solar systems, period of 2011–2021.

In the graph shown in Figure 2, it can be analyzed the trend in which the researchers' attention turned during the period of time considered. The percentage of articles published in the fields of photovoltaic systems, respectively, of concentrating solar systems, is decreasing almost every year. Thus, photovoltaic systems are decreased in percentages in 2021 by 8.63% compared to the year with the largest share, 2013, and concentrating solar systems are decreased by 1.63% in 2021 compared to 2011, the year with the largest share. On the other hand, articles within the fields of solar thermal and hybrid solar systems are up by 4.27% and 5.57%, respectively, in 2021, compared to 2013 and 2012, respectively.

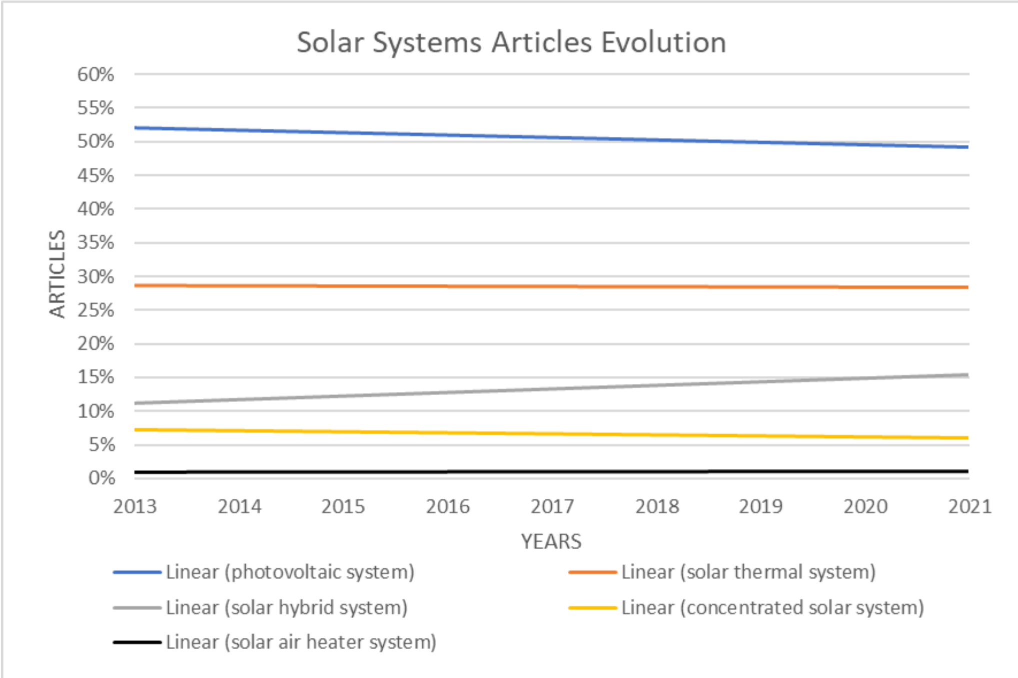

Figure 2. Articles evolution for solar systems, period of 2011–2021.

The percentage of articles published taking into consideration the domain of solar air heater systems is also increased by 0.44% in 2021 compared to 2015, the year with the lowest share. Solar air heaters are found to be useful in many processes where moderate or hot air temperatures are required due to energy availability and savings [28]. This type of system is mainly used to dry crops and to heat habitable spaces [20,29].

4.2. An Overview over SAH Research

With the help of the greenhouse effect, this solar air heating equipment manages, to a greater or lesser extent, to transfer the captured temperature to an air flow for different uses.

The graphs in this subchapter are made with the support of publications from the "Web of Science" database for the period considered. The literature in this field is not as vast as that in the field of photovoltaic systems, thus leaving room for optimization and continuous development. The evolution of articles in the area of solar air heating systems in the period 2017–2021 can be seen in Figure 3. Analyzing the chart over a period of five years, although 2021 is not as productive as the year 2020, it can be seen the upward slope of the number of articles, published in the field.

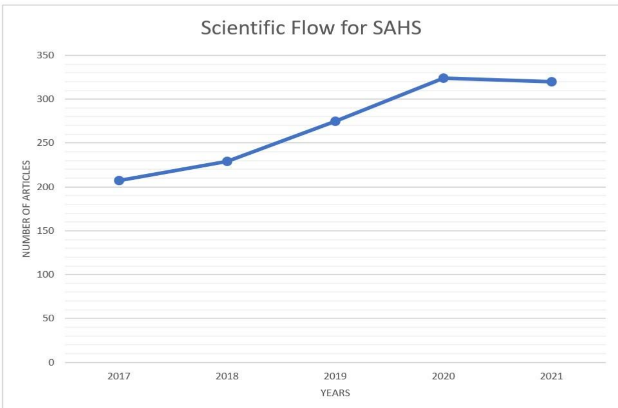

Figure 3. Number of articles published on SAHs.

The year 2020 was the most productive year of the considered period, with the most publications in the field of solar air heaters. It is meaningful to note that the number of items represented in the graph is the total of the articles in which the words "solar air heater" are found at least once.

The selected articles were published in a series of conferences and journals designated to one or more categories of topics. Figure 4 illustrates the main categories, based on the classification by category of subjects made using the "Web of Science" database, where articles based on solar air heating systems have been published.

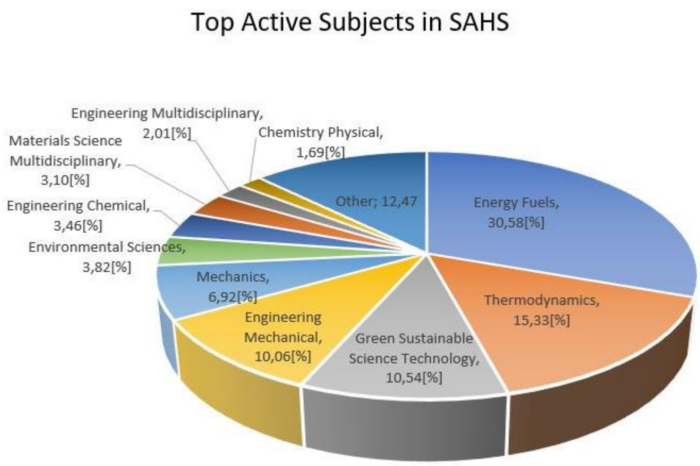

Figure 4. Top active categories in SAHs publication.

To be noted is the fact that the predominant area in which the problem of solar air heating systems has been addressed is the energy fuels domain, with 30.58 percent, followed by the thermodynamics domain, with a percentage of 15.33. The research carried out so far indicates that all the components of a solar air heater system, such as the material that absorbs and the material through which the solar radiation penetrates, the ducts, the insulation, the material of the enclosure, the air flow, and the angle of inclination, have a considerable impact on the thermal performance of the equipment. For superior performance, different methods are used, including optimizing the dimensions of the equipment, testing of solar radiation catchment surfaces with different shapes and sizes, using heat storage media, testing of solar radiation concentrators and the implementation of photovoltaic equipment in the capture room [30–32].

Additionally, the field of green sustainable science technology, with a percentage of 10.54, is very important because the equipment used must be suitable for the requirements dictated by the environment: safe, environmentally friendly and durable [33,34].

Regarding Figure 4, it is important to note that the percentages assigned to visible categories are percentages of the number of 2485 keywords that hold the percentage of one hundred percent. If we add up the percentages in the figure, we will have a total of 100%; the 12.47 percent assigned to other represents the categories in which the keywords were below two percent.

The categories with percentages between 1 and 2, which cannot be viewed, are physics applied, electrical engineering electronic, construction building technology, environmental engineering, chemistry analytical and civil engineering. The categories that are below one percent are water resources, multidisciplinary sciences, nuclear science technology, environmental studies, chemistry multidisciplinary, mathematics interdisciplinary applications, nanoscience nanotechnology, engineering manufacturing and optics.

The contributions made by different countries to the field of the analyzed systems are centralized, most often, using the location of the system investigated by the article. Thus, the most productive countries are those where the largest number of articles in the field of SAHs is identified.

The spatial distribution of the five most productive countries in the field of solar air heaters can be seen in Figure 5. The countries identified as the most productive in the field under review are India with 37.81%; China with 10.27%; Iran with 8.42%; Turkey with 5.98%; and Iraq with 4.14%. The countries listed together hold 66.62% of all publications made between 2017 and 2021.

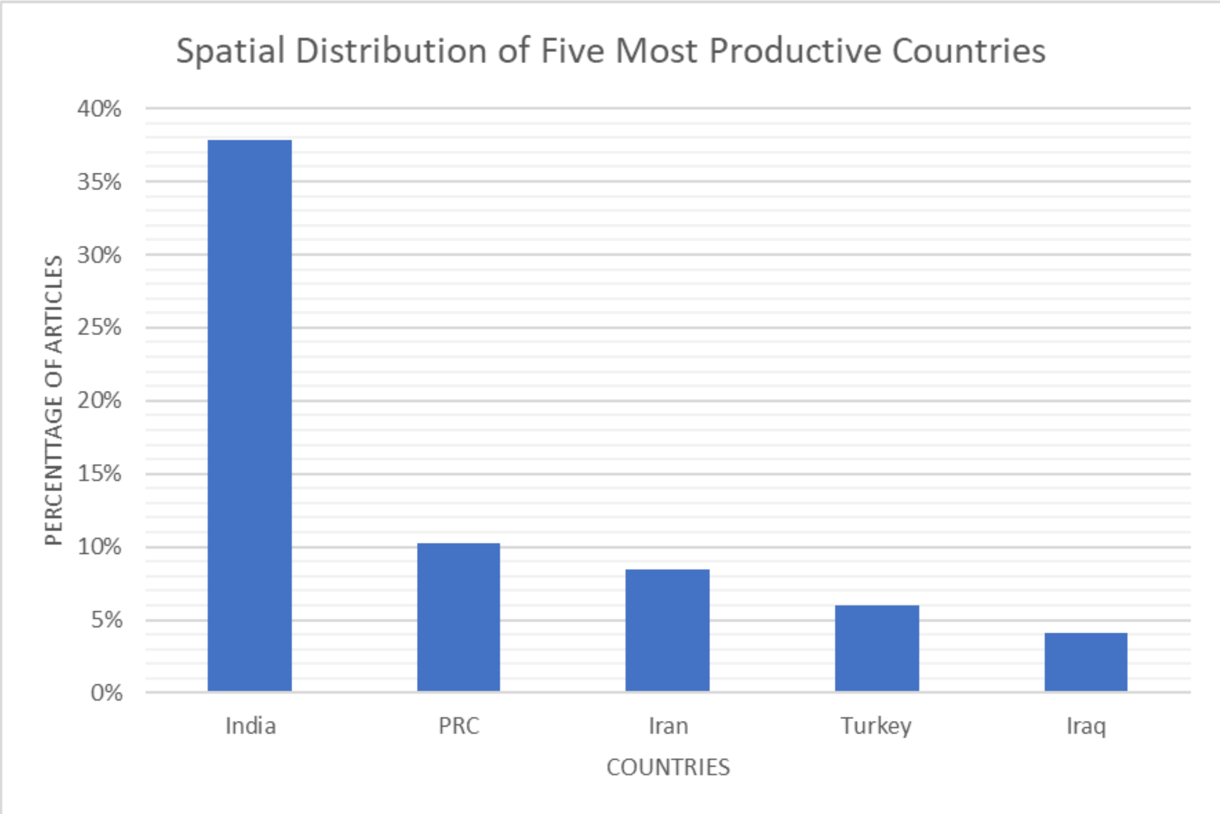

Figure 5. Spatial distribution of the most productive countries in SAHs.

India has a total of 512 published works, of which six works fall into the category of the most cited articles of the period considered. These papers address the following important topics for SAHs:

- Use of state change materials (PCM) in order to increase and enhance solar air heaters' performance [35];
- Study of state-changing nano compounds (nanoPCM) [36];
- Use of solar air heater systems for agricultural purposes, such as drying food products and drying wood [37];
- Protecting the environment and decreasing CO_2 [38];
- Study of thermal performance of a solar air heater with double porous bed in the form of serpentines [39];
- Investigation of different obstacles introduced in solar air-heater systems, such as helical inserts in the exhaust tube [40].

The time distribution of the five leading countries in the area of solar air-heater systems is visually represented in Figure 6. From 2017 to 2021, all the countries represented in the figure have an upward slope, with India being the country that leads detachedly in the field of SAHs.

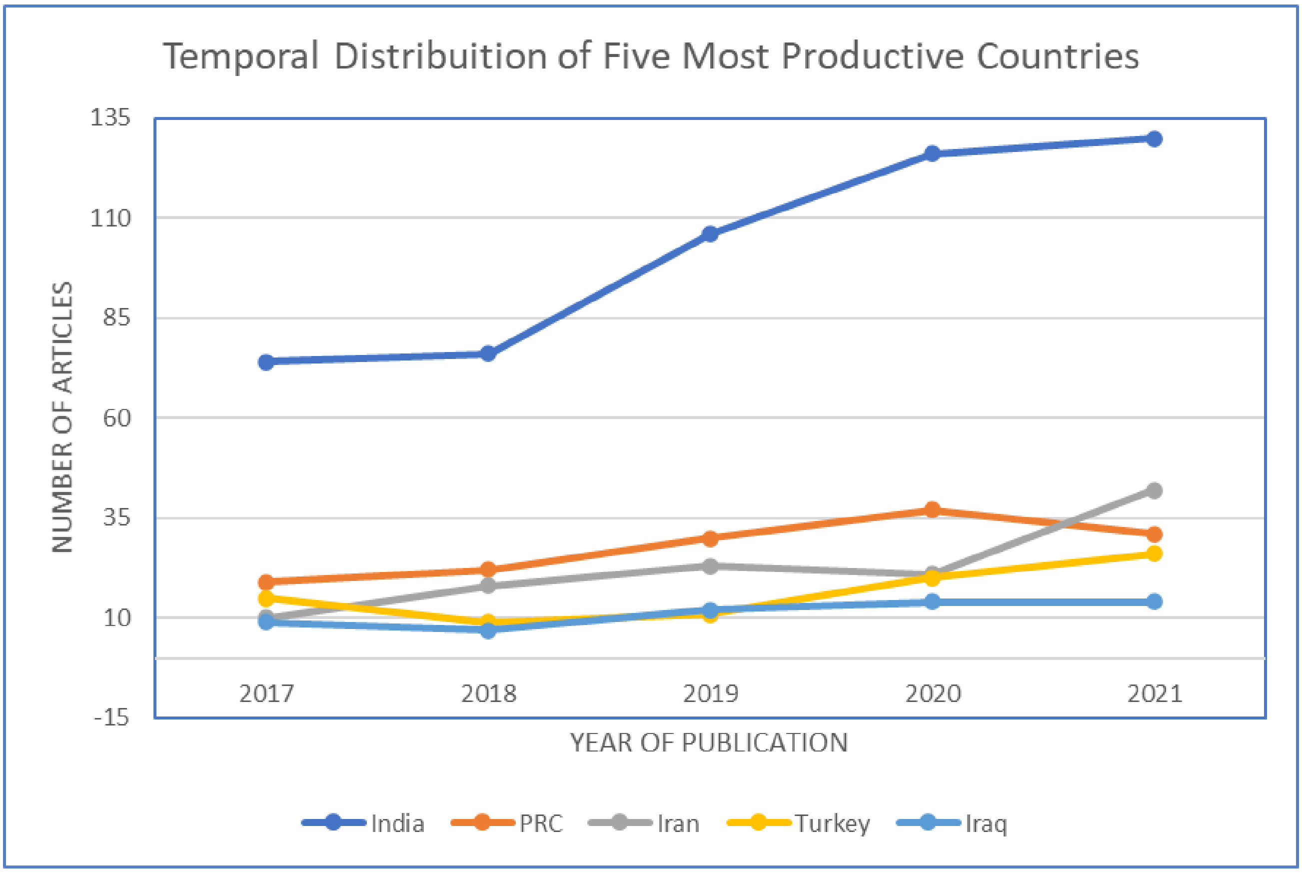

Figure 6. Temporal distribution of the most productive countries in SAHs.

Among the common interests of the main countries in the field of solar air heaters, it is worth mentioning the analysis through experiments and optimization through modeling and simulation with the support of programs specialized in computational fluid dynamics (CFD). In his work, Bezbaruah investigated by experimental method and numerical method SAHs with conical vortex generators modified in a staggered way. For the study of the characteristics of heat transfer and airflow, the results obtained numerically using a modeling program were validated using the physical model. Using the general evaluation criterion for optimization, the researcher managed to achieve a 257% improvement in the thermal performance of a modeled and physically realized system. The material used to capture solar radiation in the system developed and analyzed does not have energy storage capacity, but the author did not exclude the possibility of using such a material in a future study [41].

Aiming to improve the thermal performance of a solar air heater with a spiral labyrinth-shaped solar energy capture system, Jia Binguang developed four different three-dimensional mathematical models: spiral labyrinth pattern with arched corners (ARC-SSAH); pattern with a spiral labyrinth with rectangular corners (RA-SSAH); pattern with spiral labyrinth with arched corners and holes in the corners of the material (ARC-RH-SSAH); and pattern with spiral labyrinth with rectangular corners and holes in the corners of the material (RA-RH-SSAH). Patterns were developed for the study of the effect of deflector structures on the microscopic features of heat flux and transfer. Experimental data demonstrated the accuracy of the mathematical models. The model with the best results was the rectangular one with holes in the material of the spiral labyrinth [42]. We remain in the area of optimization of the airflow channels with the work conducted by Khosravi and Mortazavi. The authors proposed a number of 14 different models of disruptive channels of air flow through solar air heating systems. The proposed models were implemented on the solar radiation capture material to study flow behavior and thermal performance. The deflectors proposed for this work have simple forms, are easy to manufacture, and economical, gaining superior performance compared to previous models in the literature [43]. Abusca Mesut investigated the thermal performance of a SAHS with conical inserts on the surface of the material that absorbs solar radiation. By comparing the numerical results obtained by the CFD method with the experimental data, it resulted that the speed and temperature distributions are in harmony. Furthermore, it was discovered that conical inserts on the absorbent material are good for storing thermal energy [44]. The article by Al-Damook researches the impact of different airflow configurations on the thermal performance of SAHs. Three models were numerically analyzed: with inserts in the same orientation as the air flow, with inserts against the flow and a U-shaped model. Because the U-shaped model had higher thermal performance than the other models, experimentally, three different U-shaped models were made: without disruptive inserts, with straight inserts and with staggered disruptive inserts. The model with high thermal efficiency was U-shaped SAH with staggered inserts [45].

The works mentioned above are similar due to the fact that they deal with the same topic, optimization through CFD modeling and physical experiment, and are different because they have different authors, from five different countries, but in the top in the field of solar air heater systems.

4.3. Research Trend Topics

Identifying the trends prevailing during the analysis period presents a quick and efficient way to form an overview of solar air heating systems. The text files taken out of the "Web of Science" database for the analysis of scientific articles published during the years 2017–2022 in the field of SAHs were uploaded to the Bibliometrix 3.1 R Package software. Thus, a time map was made that presents the directions of the researchers in the publications recorded in the period 2017–2021. To highlight the main ideas, it is worth noting, in Figure 7, five trends for each year of the period under review.

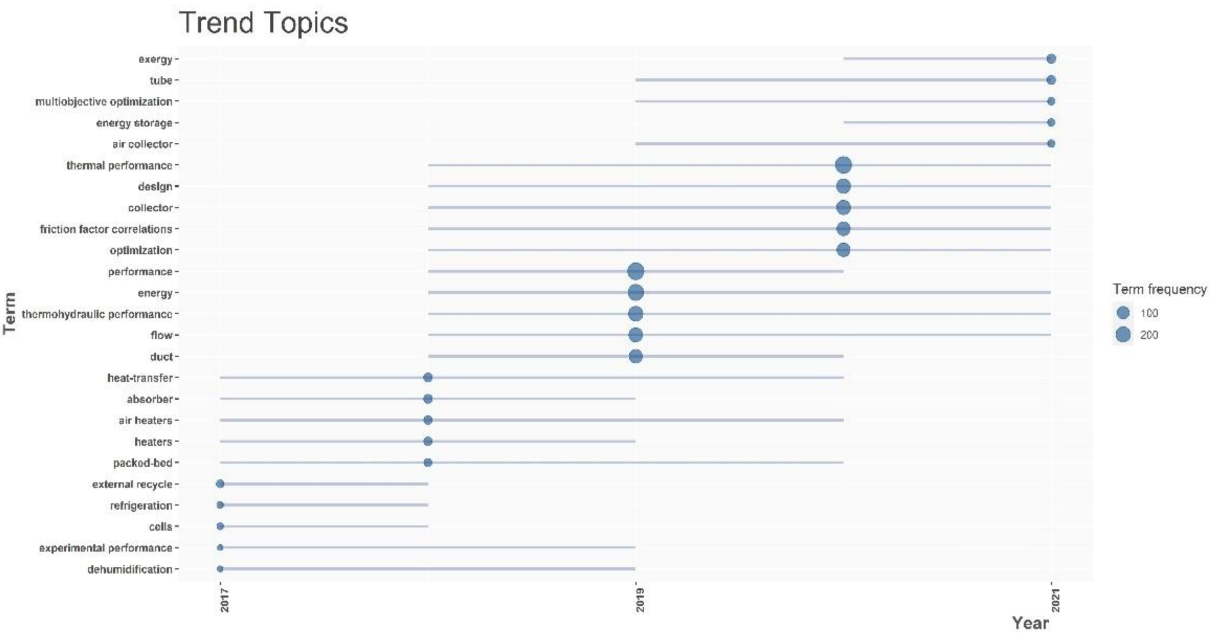

Figure 7. Research trend topics during 2017–2021 for solar air heater domain.

Studies on solar air heaters with packed bed predominate the year 2017. The author Chouksey made during this period a theoretical analysis of the performance of a solar air heater with a packed bed, made with a semitransparent optical material. Heat transfer equations were used to analyze thermal and exergy performances and to study operating parameters. The results obtained, the increase in thermal efficiency and temperature, were in line with the available results from the literature. There was also a considerable improvement in thermal efficiency [46]. Nems Magdalena of the University of Sciences and Technologies in Wroclaw, Poland, conducted a thermal analysis of a brick heat storage system. The project is part of a heating system assembled in a family home, integrated with a SAH adapted to the climatic conditions of Poland. The scope of the analysis was to verify the concept of energy storage within solar air heating systems, with the intention of achieving thermal self-sufficiency of a single-family building [47].

The studies conducted in 2018 are based on analytical, mathematical, numerical models and ANN (artificial neural network) models. Researcher Ghritlahre, from the National Institute of Technology, developed a neural network for the model of SAH with absorbent material, roughened with spring-shaped wire ribs. Statistical results indicated that the ANN model successfully predicted the exergy performance of the chosen solar air heater [48]. In 2019, researchers focused on the study and development of different types of surfaces with the ability to retain solar heat and succumb it to the flow of air that pervades the equipment. Experimentally, various tests were performed with the following materials: slag/chips of copper, iron, paraffin wax, cast iron and aluminum. Iron chips were distinguished in the study by the highest heat storage capacity [49]. Additionally, during this period, the thermal performance of SAH systems was studied. With the aim of improving these performances, various experiments were carried out, among which we mention artificial techniques using nanofluids, titanium dioxide nanoparticles (TiO2) in water [50,51] and the use of PCM macro capsules [52].

The articles published in 2020 addressed the issue of optimizing heat transfer by equipping SAHs with devices to change the direction of airflow [53], adding iron meshes to the airflow channel [54], using fluids with high thermal conductivity [55] and rough arc-shaped surfaces [56]. Exergy was the most in-depth topic in 2021 in the field of SAHs, centered on determining optimal geometry and operational parameters [28], the use of different air flows [57] and the design of new heat absorption surfaces [29]. The last paper listed examined experimentally from an energetic, ecological and exergy point of view the performance of a SAH designed with adjacent parallel tubes that absorb solar radiation. The outcomes were compared with the outcomes of a flat absorbent SAH system. The exergy efficiency proved to be higher in the tube system when passing an air flow equal to 0.025 kg/s, compared to the flat system. Additionally, when increasing the airflow for the tube model under analysis, it was observed to reduce the percent of the exergy efficiency and increase the thermal efficiency value [29].

4.4. Keywords Co-Occurrence Analysis

The network shown in Figure 8 resulted from the analysis of the frequency of occurrence of the keywords associated with SAHs in the titles and summaries present in the articles published in the period 2017–2021 in the area of SAHs on the "Web of Science" database.

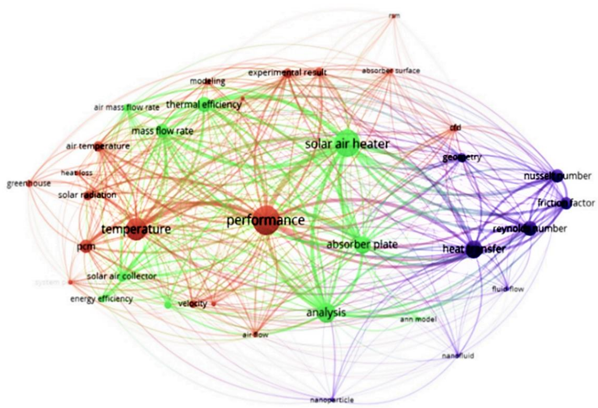

Figure 8. Solar air heaters keyword bibliometric overlap network.

Acquired data were introduced into the VosViwer software. For the generated map, the minimum occurrence of a keyword is 9. For better effective visualization and analysis, the keywords that appear are filtered so that Figure 8 can expose the most important and relevant keywords. The keyword creation network shown above in Figure 8 has three sets: the first set consists of 18 keywords, the second set consists of 10 keywords, and the third set contains 8 keywords.

Crowds, word counts, related colors, keywords, appearance number, links, and total link strength can be analyzed in Table 1.

Table 1. Solar air heaters keywords bibliometric network details.

Cluster Number	Items Amount	Keywords [1]	Cluster Color [2]	Occurrences	Links	Total Link Strength
1	18	Absorber surface		52	27	517
		Air flow		59	31	557
		Air temperature		203	35	1778
		CFD		80	31	857
		Experimental result		165	34	1592
		Glass cover		47	29	415
		Greenhouse		101	16	421
		Heat loss		50	32	383
		Modeling		74	33	621
		Optimization		149	32	1142
		PCM		340	31	2359
		Performance		1625	35	11399
		RSM		9	18	67
		Solar radiation		173	33	1328
		System performance		47	30	351
		Temperature		904	35	5579
		Temperature distribution		33	27	309
		Velocity		115	31	996
2	10	Absorber plate		52	27	517
		Air mass flow rate		59	31	557
		Analysis		203	35	1778
		Ann model		80	31	857
		Energy efficiency		165	34	1592
		Exergy analysis		47	29	415
		Mass flow rate		101	16	421
		Solar air collector		50	32	383
		Solar air heater		74	33	621
		Thermal efficiency		149	32	1142
3	8	Fluid flow		52	27	517
		Friction factor		59	31	557
		Geometry		203	35	1778
		Heat transfer		80	31	857
		Nanofluid		165	34	1592
		Nanoparticle		47	29	415
		Nusselt number		101	16	421
		Reynolds number		115	31	996

[1] Keywords presented are selected to better represent the analyzed domain. [2] The table colors represent the keyword creation networks shown above in Figure 8.

The visualization of bibliometric networks is carried out by means of overlapping networks, such as the network in Figure 8, or by means of density networks, seen in the figure below, Figure 9. The information used for the analysis was collected from 1355 articles signifying the total of publications in the domain of solar air heaters, extracted from the "Web of Science" database considering the interval of 2017–2021. The figure below represents the density network of the analysis of key terms. The terms that appear often are closely related to the color intensity of the nodes and the size of the writing. The most commonly used terms appear with a large writing size and pronounced color (e.g., "performance", and "temperature"), and the less used terms have a small writing size and fad color (e.g., "air flow", and "rsm").

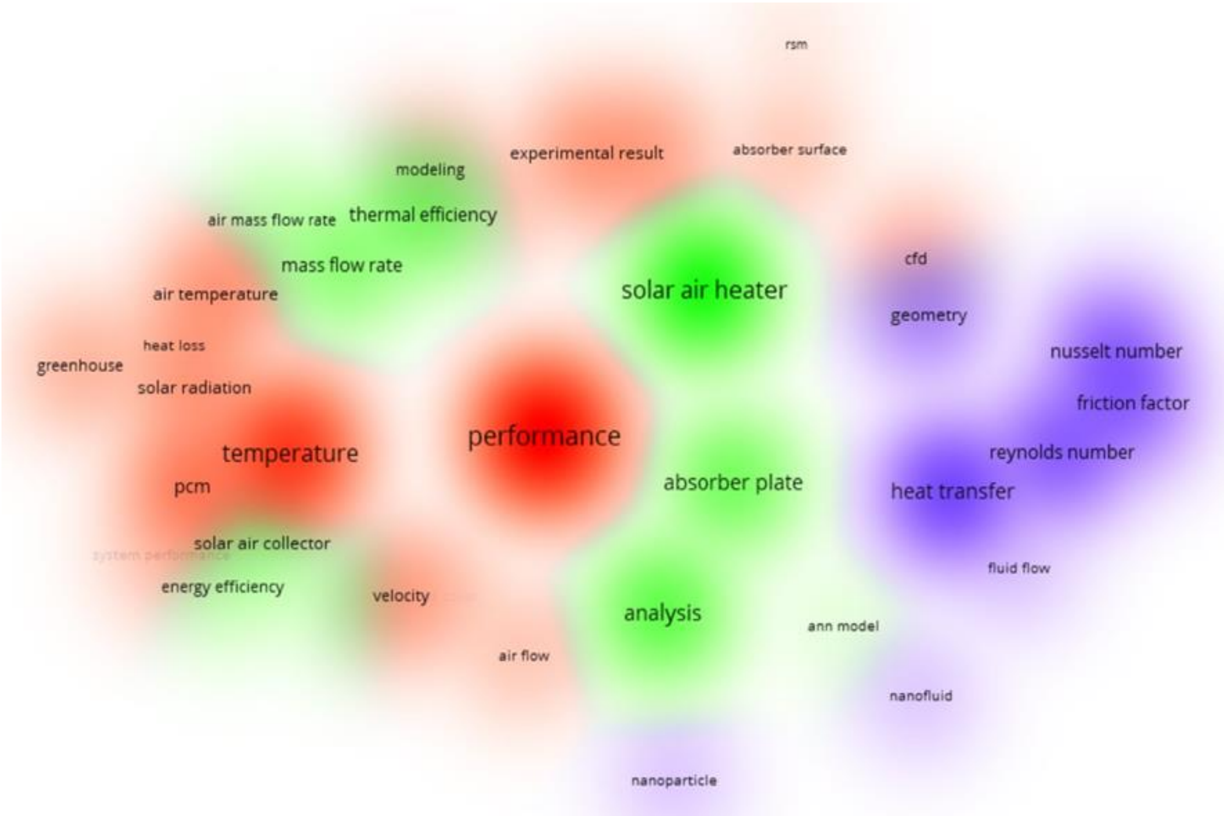

Figure 9. Solar air heaters keyword bibliometric density network.

Due to the minimum chosen in terms of the number of appearances of a keyword, although they will be of particular importance in the future, some keywords are not found in the occurrence maps generated in Figures 8 and 9. Among these words, the following are listed: hybrid, cogeneration, trigeneration, polygeneration and organic Rankine cycle (ORC).

Under natural meteorological conditions, the hybrid system realized by integrating a photovoltaic panel into a solar air heating panel was experimentally investigated. The manufactured PV/T system consists of a single-pass air channel with double flow. The absorption surface of the solar air heating panel was changed with an integrated photovoltaic panel. Ribs with uneven cross-section were attached to the module to augment the performance of heat transfer amongst the air flow and the photovoltaic module [13,58].

To cover the lack of cogeneration systems literature in solar air heaters domain, a system containing a transpired solar air heater with heat exchanger type capillary tube was experimentally realized. The system aims to preheat the air and improve the comfort of an industrial building used as a factory. The system allows the use of heated air based on solar radiation and a heat exchange system when solar energy is missing or does not provide enough thermal energy. The main components of the realized system are a transpired solar air heater, capillary tubes for heat exchange between cold air and hot water, and an integrated plate for the heat exchange between SAH and the compressor [13,14].

In order to recover and collect the thermal energy lost from the operation of solar-based ventilation equipment, a system was implemented that works on the organic Rankine cycle (ORC) principle. This system is an innovative method of producing electricity from thermal energy using the existing walls of a building. The method also contributes to the improvement and inward processing of solar air heaters in the field of ventilation with the help of solar energy. The use of the organic Rankine cycle in this system should produce electrical energy and construct buildings with a low carbon foot print. The optimal ventilation system with efficient organic Rankine cycle in hot air recovery, discovered by CFD simulation, has the air intake of 2–3 m/s, absorbing surface type rectangular tube with a cross section of 10 × 1 cm, air channel length of 4 m, and inactive air layer equal to 2 cm. The proposed method is suitable for heated air with solar air heaters and used for the production of electricity considering a system based on organic Rankine cycle [59]. Combining the hot air produced by solar air heaters with the heat recovered when producing cement and generate electricity using organic Rankine cycle-based systems is another important step in demonstrating the contribution that can be provided by the solar air heater systems. The study concluded that such systems could bring significant benefits to industry in terms of economic and environment advantages [60].

From the study carried out and the visualized analysis through the overlapping networks, respectively of density, in the domain of solar air heating systems, the following observations result for the analyzed time period:

1. Solar air heater systems (SAHS) are used for drying in agriculture of various crops and for heating habitable spaces [51,56];
2. The efficiency of SAH systems depends on the material used for the absorption of sunlight and the heat transfer achieved among the material and the air/fluid flow passing through [49,55];
3. Optimizing nanotechnology performance [50,51];
4. Use of solar air heaters in hybrid, cogeneration, trigeneration or polygeneration systems [13,14,58].
5. Recovery of thermal energy from ventilation systems and converting it to electrical energy considering systems based on the organic Rankine cycle (ORC) [59,60].
6. The exergy is widespread among researchers, but there are few publications in the field of SAHs dealing with this topic [29,61];
7. SAHs optimization procedures are based on the following methods: PCM method (phase change materials), RSM method (response surface methodology), DoE method (design of experiments), and the computational fluid dynamics (CFD) method. The RSM method was used intensively until 2017; the CFD method was used more after this year [28]. The latest research tries to combine methods with each other to improve system performance, for example, combinations of DoE and CFD [62], and RSM and CFD [63].

4.5. Countries Bibliometric Evolution

The network of cooperation between countries with researchers and publications in the domain of solar air heaters shown in Figure 10 was developed for the period 2017–2021 using the "Web of Science" database. The bibliometric network was developed in the VosViwer software. The information used for this analysis was gathered from 1355 articles representing the total of articles published in the field of solar air heating systems, extracted from the "Web of Science" database for the period considered. Each node in the graph represents a country. The size of the node constitutes the number of publications of each country, the lines in color express the collaborations between countries and the thickness of the line indicates how close the connection between them is. The network in Figure 10 consists of 25 countries, with 98 links, total bond power of 268 and three sets: the first set consists of 9 countries, and the second and third sets have 8 countries each. The minimum number of published documents in a country is 15. The sets, the number of terms, the countries, the associated colors, the number of documents, the links and the total strength of the links can be analyzed in Table 2.

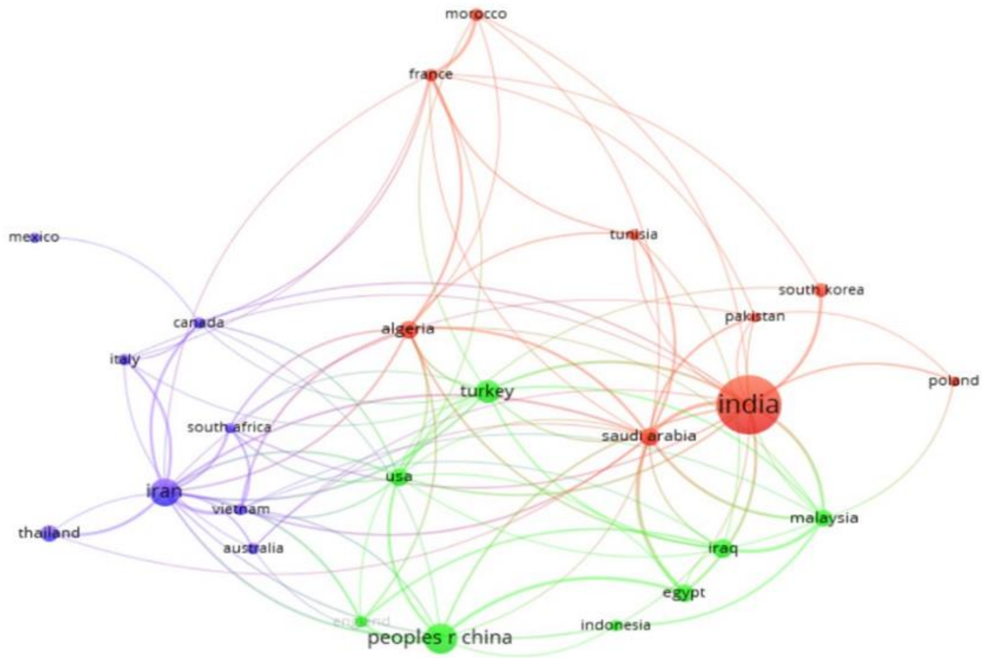

Figure 10. Solar air heaters countries cooperation network.

Table 2. Solar air heaters country bibliometric network details.

Cluster Number	Items Amount	Countries [1]	Cluster Color [2]	Article Amount	Links	Total Link Strength
1	9	Algeria		46	12	33
		France		25	10	22
		India		525	16	54
		Morocco		24	5	12
		Pakistan		16	6	9
		Poland		15	3	5
		Saudi Arabia		49	16	58
		South Korea		30	3	9
		Tunisia		19	5	10
2	8	Egypt		51	5	25
		England		19	5	14
		Indonesia		20	4	7
		Iraq		57	8	22
		Malaysia		40	10	32
		China		144	10	29
		Turkey		82	12	24
		United States of America		52	13	25
3	8	Australia		20	5	7
		Canada		22	8	16
		Iran		117	15	59
		Italy		20	6	11
		Mexico		15	1	1
		South Africa		17	6	17
		Thailand		40	3	8
		Vietnam		22	9	27

[1] Top listed country in the analyzed domain. [2] The table colors represent the networks of cooperation between countries shown above in Figure 10.

Looking at the cooperation network, we see three majority countries with significant impact: India, China and Iran. India has the largest node, which means it has the most partners and leads detached with the highest number of articles, 525, published in the field of SAHs. Next is China, with 144 articles and Iran with 117 articles published in the analyzed field. Although Iran is among the top three countries, there is no direct link between India and Iran; the link of cooperation is made indirectly through the countries China, Turkey, Saudi Arabia, the United States of America, Pakistan, Indonesia, South Africa, Australia, Canada and Italy. It is worth noting that although India has the highest number of publications compared to Saudi Arabia, both countries have developed the same number of ties with other countries. India and Saudi Arabia have a significant direct link between them. Mexico is the only country with a single cooperation direct link with Canada, through which several indirect links are made.

4.6. Authorship Bibliometric Evolution

Using the "Web of Science" database, the authors' bibliometric network was created for scientific articles from 2017 to 2021 with the help of the VosViwer program. The minimum of articles published by each author encountered on the network is 5. Although some authors have over 5 publications, they are not in the network listed in Figure 11 because the network only presents authors with links to each other.

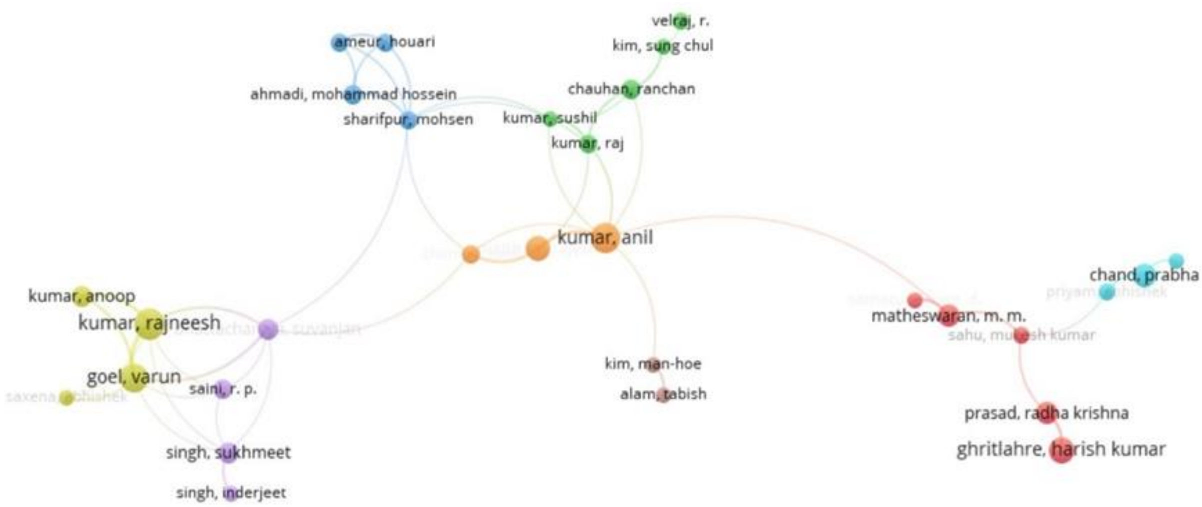

Figure 11. Solar air heaters authors' cooperation network.

Each node in the graph represents an author. The size of the node represents the number of publications of each author, the lines in color express the collaborations between them and the thickness of the line indicates how close the connection between them is. The network in Figure 11 consists of 30 authors, with 48 links, a total link power of 143 and 8 sets.

The table below shows the top five authors and the number of articles each published in the area of solar hot air heater systems.

The authors shown in Table 3, the number of publications and the links between them are taken from the network made with the VosViwer program, shown in Figure 11, and not from the filter for authors in the "Web of Science" database, since some authors have no links to each other although they have a large number of publications. Another thing to note is that on 12 February 2022, the database "Web of Science" associates the name Kumar A. with two different authors: Kumar Amit and Kumar Anil. The number of articles per author does not distinguish between one author and the other, associating all articles with the name Kumar A. for a total of 57 articles. This is another reason why we took the information for Table 3 from the VosViwer software and not from the site. The VosViwer software offers the possibility for the user to choose either an interconnected network or several networks without links to each other, depending on what is desired to be expressed through the network made.

Table 3. Solar air heaters authors' bibliometric network details.

Authors	Number of Publications	Number of Links
Kumar Rajneesh	21	6
Kumar Anil	19	7
Goel Varun	18	6
Ghritlahre H. Kumar	15	1
Maithani Rajesh	13	2

4.7. Sankey Diagram

Shortest way to view multiple attributes in the field of publications in SAHs at the same time is to plot a Sankey chart. The text files were taken out of the "Web of Science" database for the analysis of scientific articles.

The considered articles were published during the years 2017–2022 in the field of SAHs and were uploaded to the Bibliometrix 3.1 R Package software. Figure 12 listed below shows a graph with three fields that displays the following: on the left side of the graph are the main countries, in the middle of the graph, we have the keywords plus, and on the right side of the graph, we can analyze the keywords of the authors. The maximum number of terms for each field is 25.

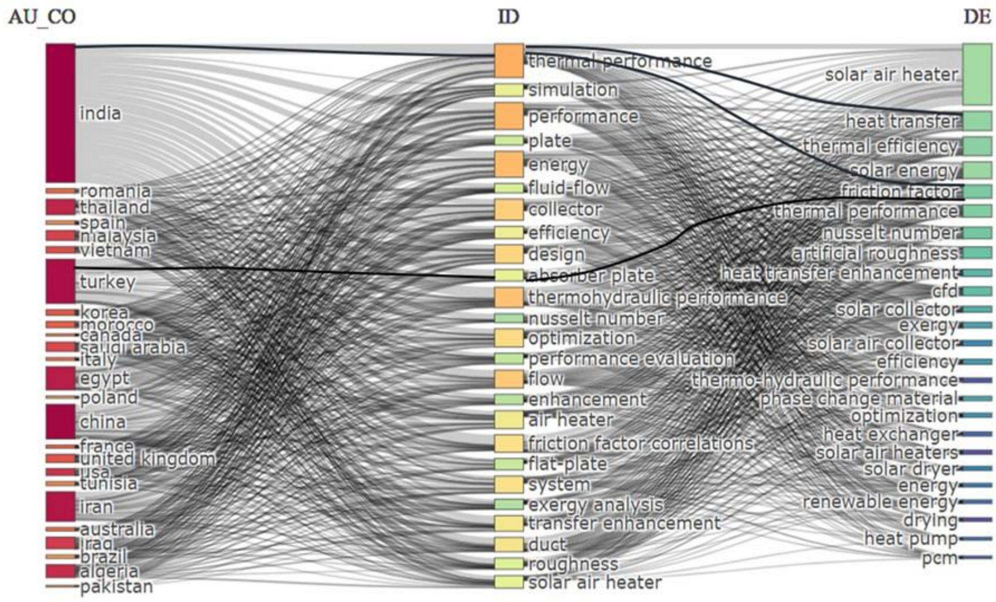

Figure 12. Sankey diagram for solar air heaters.

The keywords plus generated by the "Web of Science" database for the period considered and used for the study of publications are the index terms automatically generated from the titles of the cited articles. Regarding bibliometric analysis that analyzes the structure of knowledge in scientific fields, keywords plus are just as effective as the authors' keywords, but in representing the content of an article they are less comprehensive [64].

As an example, for a country like India, from the keywords plus for a published article the title refers to the thermal performance "thermal performance" of solar air heating systems and from the author's keywords one of the topics addressed in the text is heat transfer "heat transfer" and friction factor "factor friction" [65].

Another example would be to choose the country Turkey; from the keywords plus for a published article, the summary refers to the element that absorbs the solar radiation "solar absorber" of solar air heating systems, and from the author's keywords, one of the topics addressed in the text is the friction factor "friction factor" [66]. Figure 12 also shows the links made between the mentioned terms.

4.8. Future Research Tendencies

Aiming to get an idea of the future trends in the range of solar air heating systems, we will analyze the articles published in the period 1 January–6 February 2022 in which the words "solar air heater" are found at least once through the prism of the information provided by two databases "Web of Science" and "Scopus". The articles provided by the "Web of Science" database were 30 in number and the articles in the "Scopus" database were 49. Out of the total number of articles, 79 in total, 22 identical articles were found. For analysis, we selected and combined the items from the two databases by removing duplicates. We finally analyzed a number of 57 publications. The text files were retrieved on 6 February 2022 and uploaded to Bibliometrix 3.1 R Package for analysis. The trends for the period 1 January–6 February 2022 are shown in Figure 13.

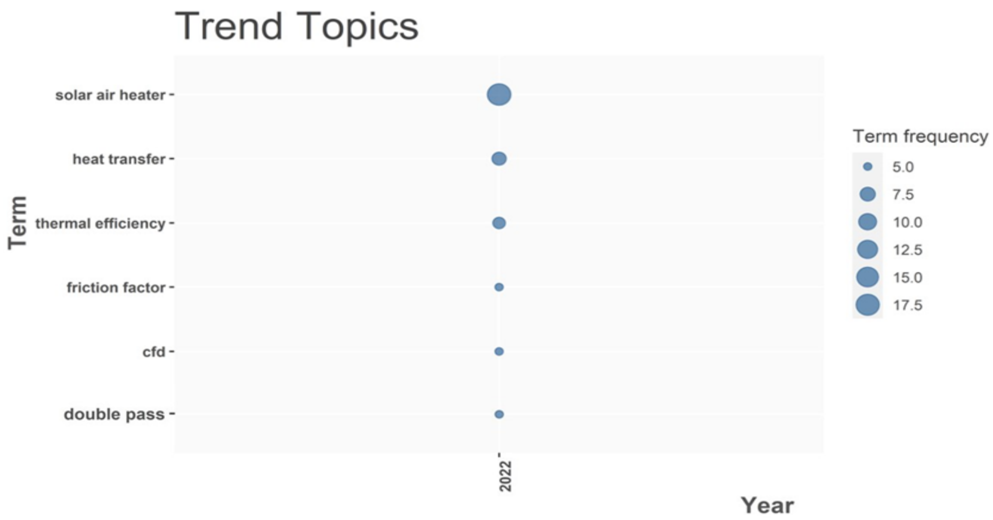

Figure 13. Solar air heaters trends during the period 1 January – 6 February 2022.

The publications of researchers in the realm of solar hot air heating systems for the period 1 January–6 February 2022 address the following issues:

- Improving heat transfer [67,68];
- Thermal performance analysis [69–71];
- Impact of friction on performance [67,72];
- Modeling and simulation using programs specialized in computational or numerical fluid dynamics (briefly called CFD—computational fluid dynamics) [73–75];
- Enhancing the performance of SAHs [76–78].

Researchers Kumar and Verma in the paper "Heat transfer and fluid flow analysis of sinusoidal protrusion rib in solar air heater" reviewed all types of shapes used on the absorbent plate and proposed a new model with sinusoidal protruding ribs with the aim of streamlining heat transfer in SAHs. The results obtained by analyzing the model made three-dimensionally with the help of a CFD program were validated with the results of a real model. The thermal efficiency of the analyzed model was 69% [68]. Another current work is "Experimental performance of a solar air heater using straight and spiral absorber tubes with thermal energy storage" by authors Muthukumaran and Senthil. The analyzed models had copper tubes as an absorbent material and as an energy storage system. For one model, a coiled spiral-shaped copper pipe was used, and for the other model, a straight copper pipe with uniform spaces. The models were filled with paraffin and glycerin, respectively. The most important conclusion is that the results of the enviro-economic study show that spiral structured heat storage is better than the horizontal parallel tube structure. In addition, the PCM integrated collector offers a lower energy payback period, carbon payback period, and simple payback period when compared to glycerol due to higher latent heat storage capacity. The experimental results concluded that SAH with paraffin-filled spiral copper pipe has higher thermal performance than the model of SAH with straight copper pipe filled with glycerin [76].

For a number of reasons, such as the growing number of articles published in the solar air-heater domain, viewing, analyzing and comparing the trends for different periods of the year 2022, with the mention that the first period is included in the second period, a trend analysis was also realized for the 1 January–1 August period of 2022. The trend topics presented in Figure 14 are based on the articles published in the period 1 January–1 August of the year 2022 in which the words "solar air heater" are found at least once, considering the information provided by the "Scopus" database. The reason for choosing the "Scopus" database over the "Web of Science" database is the higher number of articles returned by the "Scopus" database. The number of items displayed when searching for "solar air heater" keywords was equal to 181 for the "Web of Science" database and equal to 242 for the "Scopus" database. Additionally, the retrieved files on 01.08.2022 from "Scopus" database were uploaded to Bibliometrix 3.1 R Package for analysis.

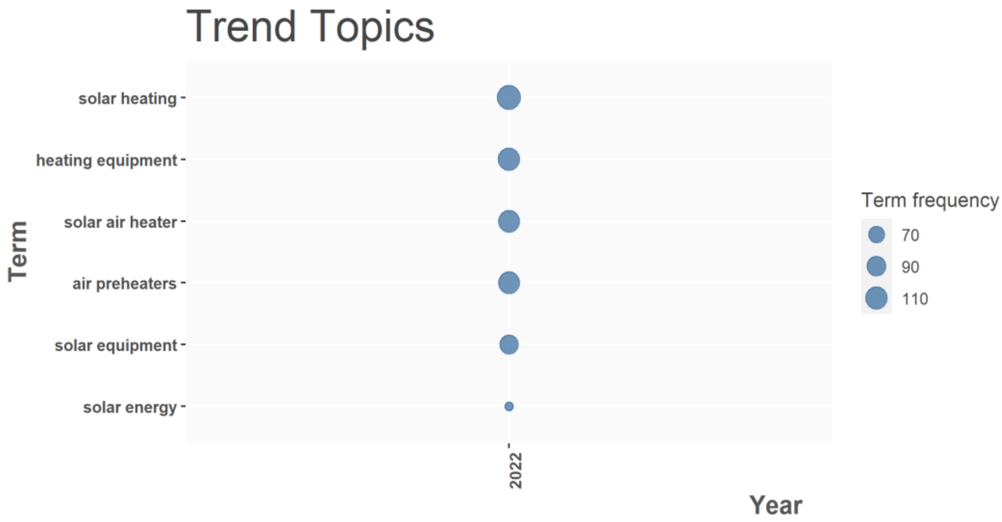

Figure 14. Solar air heaters trends during the period 1 January–1 August of 2022.

The presented trend topics in Figure 14 indicate, as the topics from Figure 13, the highest six words in terms of frequency occurrence.

Considering that the first analyzed period directed the trend of solar air heaters toward their performances, it is observed that the researcher's attention, in the second analyzed period, focused more on air-heating equipment technologies based on solar energy [79–81]. Of particular importance is shown toward systems that preheat air. Preheating air with solar air heaters automatically implies using these equipment in hybrid, cogeneration, trigeneration and polygeneration systems [82].

A combination between solar air heater and gas heater has been proposed to dry agricultural products. Depending on the consideration of each researcher, such a system can be analyzed from two points of view, namely a system in which the products are dried with the help of a solar air heater and the gas heater is used when the solar radiation is low or missing during the night, or a system in which the products are dried based on the gas heater and the solar air heater is used to preheat the air. The drawback of the system based mainly on the solar air heater sustained with the gas heater is the considerably higher amount of time needed to dry the products compared to the fully gas dryers. Preheating the air using solar air heaters for drying systems based on gas heaters represents a more feasible solution [83].

The system proposed by the researchers Pandey T. and Tejes P. can be used to enhance the conventional LDAC (liquid desiccant air conditioning) system performance, extract freshwater from the atmospheric air, dry agricultural/food products and room air conditioning. Additionally, the realized tests indicate a significant reduction in the energy consumption of the system [84].

5. Conclusions

The most in-depth studies in the field of solar air heater systems during the considered period are related to the optimization of solar energy capture and heat transfer through new absorbent surfaces, the testing of different air flows, experimentation, modeling and simulation. Energy, exergy and nanotechnology are less studied and experienced fields when talking about SAHs, with a high potential to provide major contributions in improving the performance and optimizing these systems. It was noted that maximizing the contact surface area amongst the PCM and the absorbing surface significantly augments the outlet temperatures.

The bibliometric analysis performed in the realm of solar air heaters provides the following information:

- Evolution or involution of publications in the field;
- The trend in which the attention of researchers has turned over a period of time considered;
- Broad vision on the study of the capabilities and performance of these equipment;
- Understanding the structure of basic knowledge in the field of SAHs;
- The researchers focused on the study and development of different types of surfaces with the ability to retain solar heat and release it to the airflow that pervades the equipment, improving heat transfer from the material to the air flow and optimizing performance;
- The trend in which most of the articles to be published will be directed.

Among the advantages of the solar air heaters, the following could be considered:

- Reducing energy consumption for drying agricultural products and heating spaces;
- Producing and using clean, renewable and sustainable energy;
- Zero CO_2 emissions during operation;
- Corrosion, leakage and freezing do not create any problems for solar air heaters;
- The possibility to use solar energy in countries with abundant solar climate but also in countries with different climates with the help of cogeneration systems;
- The use of solar air heaters in ventilation and cooling systems;
- Generating thermal energy without additional costs or electricity.

The results of the realized study are rather unsatisfactory because of the lack of articles published in the analyzed domain, yet somehow satisfying because they offer study opportunities to new researchers. In conclusion, the attention of researchers in the field of solar air heaters in the first half of 2022 is focused on increasing the performance of these equipment by modifying the component parts, improving the friction factor and enhancing heat transfer. It is also proposed and attempted to introduce solar air heaters in cogeneration systems, such as those for drying agricultural products, wood drying, space cooling or water heating.

The use of solar air heaters in cogeneration remains an unexplored field because existing studies are insufficient to determine the efficiency of this equipment in different combinations of systems. Considering this and the abundancy of solar energy, as future perspectives, the study of cogeneration systems, such as combinations of solar air heaters with photovoltaic panels, drying equipment, water desalination, cooling and preheating systems, is subject to be taken into consideration.

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