energies

MDPI

Review

Hydrogen as a Renewable Energy Carrier in a Hybrid Configuration of Distributed Energy Systems: Bibliometric Mapping of Current Knowledge and Strategies

Przemysław Ogarek [1,2], Michał Wojtoń [1,2] and Daniel Słyś [2,*]

[1] Department of Infrastructure and Water Management, Rzeszow University of Technology, al. Powstancow Warszawy 6, 35-959 Rzeszow, Poland; p.ogarek@prz.edu.pl (P.O.); m.wojton@prz.edu.pl (M.W.)
[2] Doctoral School, Rzeszow University of Technology, al. Powstancow Warszawy 12, 35-959 Rzeszow, Poland
* Correspondence: daniels@prz.edu.pl

Abstract: Storing energy in hydrogen deposits balances the operation of energy systems and is an effective tool in the process of energy transformation towards achieving Sustainable Development Goals. To assess the validity of its use as an alternative renewable energy carrier in dispersed energy systems of hybrid configuration, a comprehensive review of scientific literature was conducted in this study, based on bibliometric analysis. The bibliographic database used in the study was the international Web of Science database. This review contributes to a better understanding of the characteristics of the selected research area. The evolution of research trends implemented in the design of energy systems associated with hydrogen technologies is revealed, clearly indicating that it is a developing field. In recent years, there has been an increase in the number of publications, although the territorial range of research (mainly simulation) conducted in the domain does not include areas with the most favourable infrastructural conditions. The analysis reveals weak cooperation between South American, African, East Asian, and Oceanic countries. In the light of earlier, thematically similar literature reviews, several research gaps are also identified and proposals for future research are presented. They concern, in particular, the parallel implementation and optimization of the operation of hydrogen (HRES—Hybrid Renewable Energy System and HESS—Hybrid Energy Storage System) solutions in terms of economics, ecology, lifespan, and work efficiency, as well as their feasibility analysis. With the support of other researchers and those involved in the subject matter, this review may contribute to the further development of hybrid hydrogen systems in terms of increasing competitiveness and promoting the implementation of these technologies.

Keywords: bibliometric analysis; Bibliometrix; VOSviewer; hydrogen; distributed energy system; hybrid renewable energy system; hybrid energy storage system

Citation: Ogarek, P.; Wojtoń, M.; Słyś, D. Hydrogen as a Renewable Energy Carrier in a Hybrid Configuration of Distributed Energy Systems: Bibliometric Mapping of Current Knowledge and Strategies. *Energies* **2023**, *16*, 5495. https://doi.org/10.3390/en16145495

Academic Editor: Muhammad Aziz

Received: 19 June 2023
Revised: 11 July 2023
Accepted: 17 July 2023
Published: 20 July 2023

1. Introduction

The energy transformation holds paramount importance in mitigating the adverse impacts of climate change, which is one of the greatest challenges humanity is facing [1]. The global overhaul of the energy sector aims at consistently transitioning away from the exploitation of depleting fossil fuel reserves towards alternative energy production from renewable sources [2]. One of its intended outcomes is decoupling economic development from greenhouse gas emissions [3].

Contemporary strategies for the functioning of global economies are currently built upon the principles of sustainable development [4]. The fundamental determinant of this concept is meeting the needs of society without compromising the quality of life for future generations. In order to achieve the objectives of sustainable development, the United Nations (UN) has established a set of 17 Sustainable Development Goals (SDGs) [5]. The thematic considerations discussed in this paper have the potential to contribute to the

attainment of SDG 7, "Affordable and Clean Energy", and SDG 11, "Sustainable Cities and Communities".

As indicated in the latest report presented by the Intergovernmental Panel on Climate Change (IPCC) [6], the dominant conventional, highly centralized, unidirectional energy systems composed of isolated components are expected to decrease their share in energy mixes in favour of low-emission, decentralized, multidirectional energy markets with strongly integrated components (sector coupling).

In 2021, total global primary energy demand reached 595.15 EJ. A significant 82% of the utilized primary energy was generated from fossil fuels. However, this value has been declining annually (83% in 2019, 85% in 2016) due to the increasing share of alternative technologies. Renewable energy sources (excluding hydropower) contributed nearly 13% to global electricity production in 2021, demonstrating a rising trend primarily driven by significant advancements in solar and wind power. For comparison, coal accounted for 36% of the same sector in 2021, while gas and nuclear energy represented 23% and 9.8% of energy production, respectively [7].

According to forecasts by the International Renewable Energy Agency (IRENA), in order to limit global warming to 1.5 °C, the share of renewable energy sources in electricity production should reach 90% by 2050, with a total final energy consumption of 79% [8]. The growing renewable energy sector hypothetically promises sovereign supplies of clean and affordable energy. However, on the other hand, the dependence of renewable sources on stochastic weather conditions may lead to periodic shortages or excesses of electrical energy. The instability of the energy supply, coupled with the high costs of expanding local distribution networks, is noted in many analyses addressing the management of renewable energy mixes [9–12].

There are several solutions aimed at balancing fluctuations in energy production, both on a daily and seasonal basis, which are implemented on both the demand and supply sides [13,14]. In terms of energy consumers, demand-side management takes the lead, utilizing automation equipped with mechanisms and controllers implemented in smart grid networks [15,16]. There are also known solutions that reduce energy waste while simultaneously increasing its efficiency, such as waste energy recovery [17]. On the other hand, for energy producers, interregional connections are often established [18], and in economically justified cases, over-dimensioning of non-dispatchable energy sources is pursued [19,20], or complementarity in the operational characteristics of different renewable energy sources is sought [21]. In addition to stabilizing infrastructure design and management, the most popular solutions are associated with the periodic storage of energy excess. For this purpose, pumped storage hydroelectric plants, electric batteries, compressed air energy storage, large-scale flywheels, and "Power to X" technologies are mainly used [22,23].

Each energy storage system is diversified in terms of capacity, efficiency, cost-effectiveness, and longevity. The choice of the appropriate technology results from the selection of various variables, including the user's environmental characteristics and needs [24]. Therefore, analyzing the technologies explored so far and considering their storage capabilities and expected discharge times, it appears that in the face of seasonal variability in renewable energy production and the demand for a wide range of applications for stored energy, one of the most promising solutions could be the utilization of "Power to X" (P2X) technologies, with hydrogen as a commonly used energy carrier in the form of "Power to Hydrogen" (P2H) [25]. Hydrogen, a chemical element characterized by a wide range of production variants, high energy potential, and, most importantly, low or zero emissions in the context of climate change mitigation, holds great promise [26].

There are various methods of hydrogen production, with the most popular ones relying on fossil fuels. Hydrogen produced from natural gas, heavy oils and gasoline, as well as coal, accounts for over 96% of the world's production. However, due to the push for decarbonizing energy production, efforts are being made to reverse this dependence towards emission-free production technologies [27]. The potential for producing and utilizing renewable hydrogen and its derivatives is supported by the increasing number of

ongoing and planned investments. According to the International Energy Agency, in 2022, the production capacity of electrolyzers alone doubled within a year, reaching a capacity of nearly 8 GW. The implementation of all projects currently in preparation could lead to an installed electrolyzer capacity of 134–240 GW by 2030, which is twice as much as expected in 2021 [28].

The study takes into account the developments related to the production of exclusively renewable hydrogen (mainly through electrolysis) in hybrid installations (HES), where hybridity is understood as both integrated energy production (Hybrid Renewable Energy System, or HRES) and combined energy storage technologies (Hybrid Energy Storage System, or HESS). Due to the limitations associated with ensuring the continuous operation of renewable energy installations for electrolysis, the (P2H) technology should be supported by integrated auxiliary solutions.

One of the most commonly used methods for analyzing the latest research findings is a literature review. In recent years, several review papers have been published on the design, development, and implementation of hybrid hydrogen installations. The most important ones are presented in Table 1. These articles were published in scientific journals representing major publishers. However, none of the review articles presented so far directly address the utilization of HRES or HESS potential in distributed energy systems. Moreover, there is a lack of studies whose primary objective would be to conduct a bibliometric analysis of the subject matter. Such an approach enables the assessment of trends, identification of leaders in technology development, and exploration of the relationships between them, thereby facilitating knowledge transfer from researchers around the world.

Table 1. Review papers on the use of hydrogen in the distributed energy systems domain.

Authors	Article Title	Journal (Publisher)	Year	Citations *
Sgarbossa et al. [29]	Renewable hydrogen supply chains: A planning matrix and an agenda for future research	*International Journal of Production Economics* (Elsevier)	2023	3
Homa et al. [30]	Small-Scale Hybrid and Polygeneration Renewable Energy Systems: Energy Generation and Storage Technologies, Applications, and Analysis Methodology	*Energies* (MDPI)	2022	1
Ishaq et al. [31]	A review on hydrogen production and utilization: Challenges and opportunities	*International Journal of Hydrogen Energy* (Elsevier)	2022	81
Khan et al. [32]	Review on recent optimization strategies for hybrid renewable energy system with hydrogen technologies: State of the art, trends and future directions	*International Journal of Hydrogen Energy* (Elsevier)	2022	19
Sorrenti et al. [33]	The role of power-to-X in hybrid renewable energy systems: A comprehensive review	*Renewable & Sustainable Energy Reviews* (Elsevier)	2022	7
Ozturk and Dincer [34]	A comprehensive review on power-to-gas with hydrogen options for cleaner applications	*International Journal of Hydrogen Energy* (Elsevier)	2021	55
Mtolo and Saha [35]	A Review of the Optimization and Control Strategies for Fuel Cell Power Plants in a Microgrid Environment	*Institute of Electrical and Electronics Engineers* (IEEE)	2021	4
Fonseca et al. [36]	Trends in the design of distributed energy systems using hydrogen as energy vector: A systematic literature review	*International Journal of Hydrogen Energy* (Elsevier)	2019	76

* The number of citations in the Web of Science database as of 23 February 2023.

Taking into account the previously mentioned arguments, this study aims to present a bibliometric analysis of scientific literature concerning the exploitation of distributed energy systems balanced by hybrid installations that integrate renewable energy production with the storage of renewable hydrogen. This article presents publications on system design, simulation of their operation, their impact on external infrastructure and the environment, as well as the cost-effectiveness of the applications. It is divided into three main parts. The first part describes the methodology of the conducted analysis. The second part focuses on the topics presented in the literature related to hydrogen storage generated from renewable energy sources to ensure a stable energy supply for regional energy areas or individual applications, including the powering of households and autonomous off-grid devices. Finally, the third part presents the conclusions drawn from the conducted research. This study can serve as reference material for scientists, investors, and stakeholders interested in the application of these technologies, as well as regional energy distributors and institutions developing local energy strategies.

2. Materials and Methods

A literature review on the utilization of hydrogen in distributed energy systems was conducted based on the assumptions of bibliometric analysis. Bibliometric analysis is increasingly becoming a common method for determining future research directions in a given field [37]. The use of specialized software allows for the importation of extensive databases and their analysis, generating detailed graphs. The bibliometric analysis enables the identification of research directions that are gaining popularity and also helps determine research niches within the chosen topic [38,39].

Data Collection and Preparation

Web of Science (WoS) was utilized to gather bibliographic data. Web of Science is one of the largest databases, encompassing a wide range of scientific journals along with detailed information associated with each publication.

The process of searching and filtering publications was divided into four sequential stages. The first stage involved selecting a bibliographic database that allows for filtering, searching, and exporting results based on keywords. The next stage involved determining and appropriately editing the keywords. This stage focused on progressively narrowing the search range by adding additional keywords and their variants using conjunctions that define relationships between the keywords. Subsequently, through keyword query modifications, the number of results was reduced to several hundred positions. Ultimately, the sequence of keywords resulted in a database containing 684 publications. The third stage involved the analysis of the content, keywords, and abstracts of the publications to assess their alignment with the chosen topic. To classify the publication topics, five categories were selected: industry, electric power industry, energy storage, transport, and distributed hydrogen energy. Publications that did not fit into any of these categories were deemed irrelevant to the topic of interest. As a result of sorting, 332 publications were selected that corresponded to the assumptions of the conducted bibliometric analysis. The final stage involved exporting the collected publication database and analyzing it using software capable of processing bibliographic data.

The entire process is presented in detail in Figure 1. The data was retrieved from the Web of Science database on 23 February 2023, and the following analyses were based on the database acquired on that day.

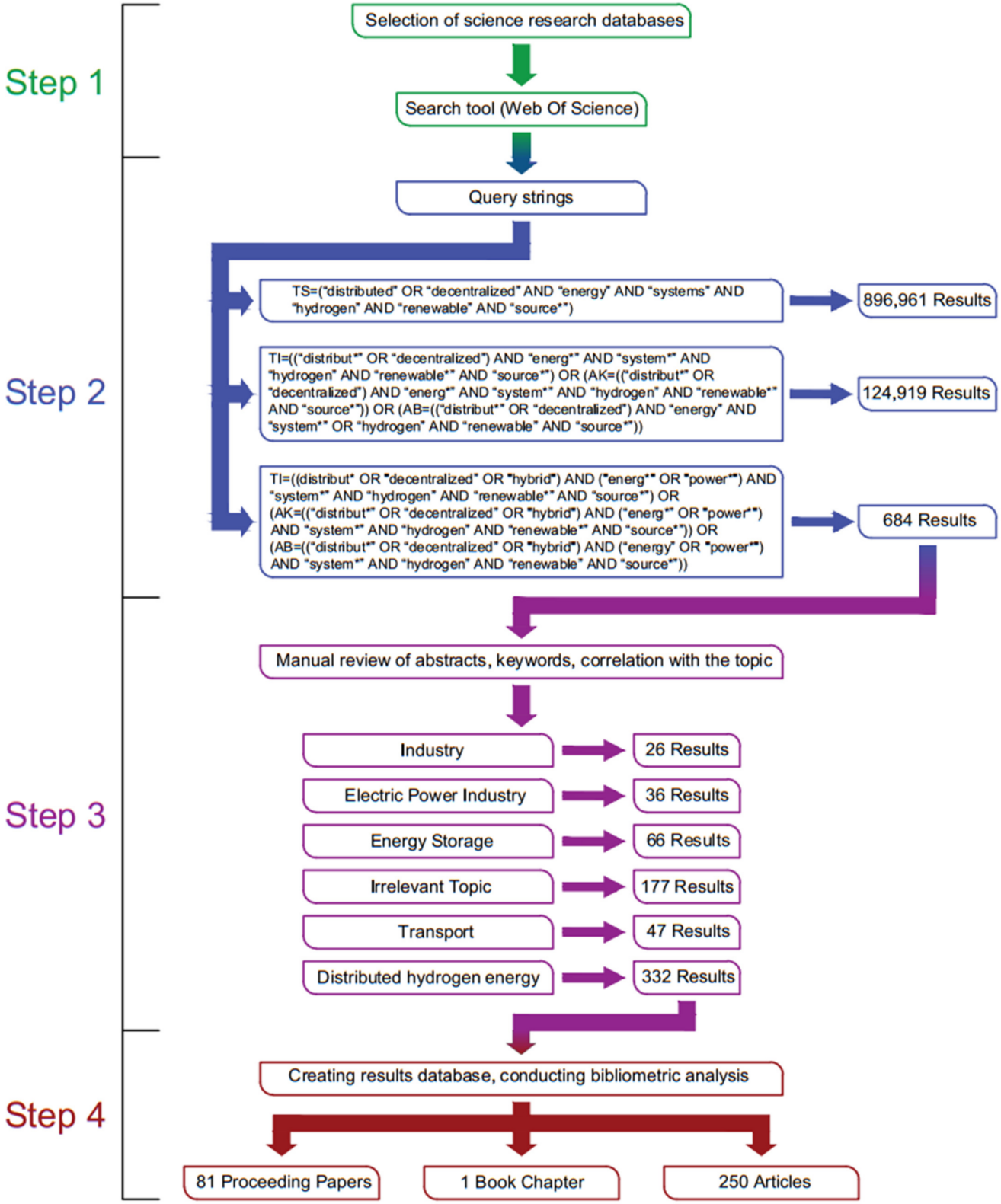

Figure 1. Indication of studies for bibliometric analysis. The asterisk (*) was used to find both plural and singular forms of the words.

Due to the application of a precise sequence of phrases together with conjunctions determining their occurrence in the area of the title, abstract, and keywords, it was possible to create a database that allows for a detailed bibliometric analysis while accurately defining

a unique subject. Detailed data regarding the developed database, on which further analyses were based, are presented in Figure 2.

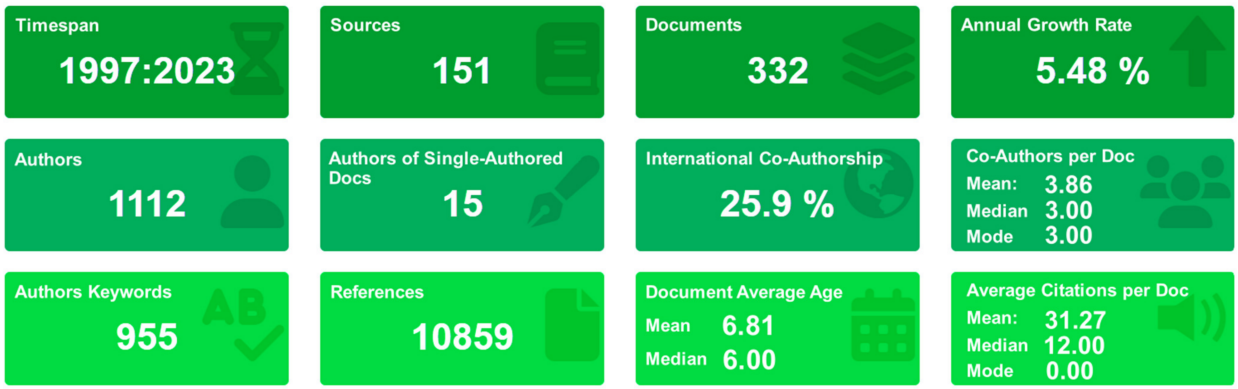

Figure 2. Main indicators obtained from the bibliographic analysis.

Bibliometric analysis involves studying the relationships between authors, publications, journals, or keywords [40]. Due to the complexity of the issue, this type of review mostly uses dedicated software. The software allows the assignment of a significant amount of data to each of the results and their analysis in a broader spectrum. These data may take into account the details of individual scientific publications, such as the exact publication date, used keywords, co-authorship, or the country of origin of the first author. Two of the most frequently used programs are VOSviewer [41] and Bibliometrix [42]. Due to universality and free access, this software is widely and commonly used in bibliometric analyses of scientific publications databases [43]. In this article, both VOSviewer and the Bibliometrix Biblioshiny App were used to carry out bibliometric analyses in the field of hydrogen use as a renewable energy carrier in a hybrid configuration of dispersed energy systems.

Bibliometrix software (ver. 4.1.1) was developed by Massimo Aria and Corrado Cuccurullo in 2017 [42]. Bibliometrix and based on the web browser app Biblioshiny, a plugin for RStudio, based on the R programming language. This language is simultaneously a computing environment and a graphic tool for programs mainly used in statistical research. The Biblioshiny application is a graphical interface of the Bibliometrix software that allows for the analysis and graphical presentation of bibliometric research results.

VOSviewer is one of the most popular programs used for bibliometric analyses. Generating bibliometric link maps in VOSviewer is based on an equation determining association strength [44]. The association strength s_{ij} is a measure of the proximity of elements appearing on the map and is calculated based on Equation (1):

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \quad (1)$$

where c_{ij} determines the number of occurrences of objects i and j, w_i and w_j determine the total number of occurrences of objects i and j or the total number of common occurrences of these objects.

3. Results and Discussion

Effective utilization of local energy resources through storing their excess in hydrogen deposits will contribute to an increase in energy supply security; moreover, it will reduce the carbon footprint of energy production, thus limiting the impact on the environment. In the long term, it may represent a cost-competitive solution compared to conventional power systems [45]. In this study, a retrospective analysis of selected publications concerning the issue of using renewable hydrogen as an energy carrier in distributed energy systems was carried out. Understanding the characteristics of the literature on the analyzed topic

of using renewable hydrogen will help identify weak points and possible means of their subsequent neutralization.

In recent years, interest in the subject of building dispersed energy systems, whose operation is balanced using hydrogen storage and its derivatives, is increasing. In the face of the current global energy crisis and rising energy prices, the diversification of energy production directions and sources of energy supply are becoming of greater importance [46,47]. Marocco et al. [25] point out that hybrid technologies for producing and storing excess energy using hydrogen are becoming key tools for effectively managing the variability in the operation of renewable sources and have considerable significance in striving for energy self-sufficiency. However, due to the diversified energy potential of selected regions and the complexity and multiplicity of factors determining the efficiency of the work of integrated HRES and HESS technologies, the clear demonstration of the profitability of such installations is a complex issue [48]. Therefore, it is necessary to search for methods of managing distributed energy systems based on hydrogen in the domain of generation, storage, and utilization of the obtained energy. This approach will enable stable and long-term operation which is technically and economically justified while maintaining environmental protection requirements and principles of sustainable development. Figure 3 presents the historical trend of the number of published papers in the domain of the use of hydrogen as a renewable energy carrier in distributed energy systems with a hybrid configuration, along with the average annual number of citations of these papers.

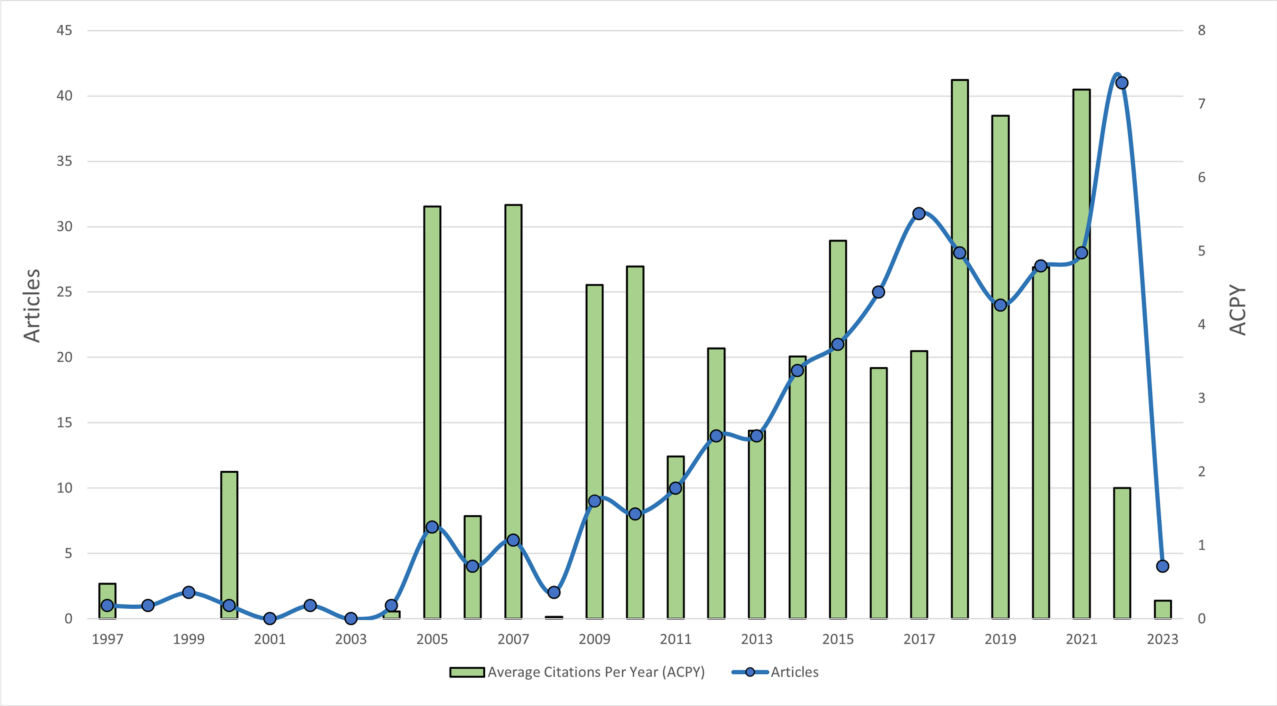

Figure 3. Publication and citation trends in hydrogen as a renewable energy carrier in distributed energy systems.

The first publications [49–52] concerning the issue of using hydrogen as an energy carrier in dispersed energy systems appeared at the end of the last decade of the 20th century. These were reports summarizing discussions held during international scientific conferences addressing the subject of future implementation of alternative sources of production, distribution, and energy storage, in which tighter requirements for flexibility, safety, and profitability of the energy infrastructure operation were predicted.

Following this line, in 2000, Isherwood et al. [53] presented a concept for the analytical optimization of a remote power system for a village located in Alaska. Their concept assumed the use of hydrogen storage and batteries integrated with a RES source and a

diesel engine. Researchers indicated that the expansion of the structure of devices with energy accumulation capabilities could effectively limit the demand for conventional fuels and lower the life costs of such an installation. In 2002, Glasanovic et al. [54] presented a project called the "Croatian Solar House", the aim of which was to create a demonstrative low-CO_2 emission single-family building. Among many proposed alternative energy technologies, fuel cells powered by electrolytic or reforming hydrogen were used in the building. With the increase in the level of technological readiness of hydrogen solutions, the number of publications grew. From 2004 to 2007, there was a clear increase in interest in the subject. In the published materials, the previously undertaken issues of using hydrogen for climate change mitigation were continued, but with a clear increase in interest in the construction of hybrid installations (HRES, HESS). For example, an analysis conducted by Chicco et al. [55] showed that significant benefits in the form of higher energy efficiency, economy, and CO_2 emission reduction in the light of autochthonous energy production are brought about by the integration of the concept of dispersed energy resources and combined production of various energy vectors. In 2008, there was a significant decrease in the number of publications, which might have been a consequence of the peak period of the global economic crisis prevailing at that time. However, from 2009 to 2017, an upward trend was noticeable. The total number of publications in the indicated period, comparing year by year, increased more than three times. The papers that were published during this time drew attention to the issue of the interaction of decentralized energy systems with power grids. The authors of the publications, pointing out the difficulties in achieving stable operation in off-grid mode, while taking into account profitability, scalability, efficiency, and resilience criteria, were looking for solutions integrating the capabilities of infrastructure dedicated to electrical energy and natural gas [56–58].

During this period, an increasing trend was also noticeable in the applications of computer numerical analyses, related to the intensification of the digitalization process in the design sector [59–63]. Subsequently, a slight decrease in the number of publications was noted over the next two years, perhaps due to the suspension of research work as a result of the SARS-CoV-2 global pandemic. However, the number of studies is currently continuing to increase. Articles addressing social issues related to feasibility analyses and the popularization of the use of these technologies are appearing more and more frequently, indicating the need to adapt regional policies and legal regulations to the requirements of innovative energy market operating models [64,65]. The technical issues in the articles do not significantly differ from the topics discussed in older publications. Currently, research work is mainly of a simulation nature and focuses particularly on optimizing the operation of hydrogen solutions HRES and HESS in terms of economics, ecology, longevity, and operational efficiency [66].

The most frequently used simulation software include HOMER Software, MATLAB/Simulink, and TRNSYS. To illustrate the characteristics of the research undertaken in recent years, Table 2 presents selected new research papers addressing the topic of dispersed hybrid installations based on local production, storage, and consumption of renewable hydrogen.

Below, Figure 4 presents a visualization of the co-occurrence of keywords used in the analyzed studies. Diagrams were generated using VOSviewer software (ver. 1.6.19). The study took into account both Author Keywords and Keywords Plus from Web of Science. These groups of keywords are useful for studying the structure of knowledge in a scientific field [76]. The size of the network nodes determines the prevalence of a given keyword. The distance between nodes indicates the frequency of co-occurrence of two keywords (the closer the nodes are to each other, the stronger the connection between them). Finally, the thickness of the lines connecting the nodes indicates the frequency of the occurrence of two keywords in publications.

Table 2. Most recent papers on the use of hydrogen in the distributed energy systems domain.

Authors	Purpose of the Paper	Journal (Publisher)	Year
Jasinski et al. [67]	Review and categorization of the use of mathematical optimization methods, including robust and hybrid techniques in the management and planning of multi-carrier energy systems.	*Institute of Electrical and Electronics Engineers* (IEEE)	2023
Islam et al. [68]	Review and assessment of renewable energy potential, including solar and wind power with hydrogen storage for remote communities in Far North Queensland, Australia, currently reliant on costly diesel generators.	*International Journal of Energy and Environmental Engineering* (Springer)	2022
Alzahrani et al. [69]	Study of a hybrid microgrid (HMG) system using hydrogen as a primary energy source alongside solar and wind energy, proposal of a control method for a bidirectional AC-DC converter.	*Energies* (MDPI)	2022
Wimalaratna et al. [70]	Review the integration of wind energy into hybrid renewable energy systems around the world, considering both economic and technical factors to optimize system efficiency, reduce costs, and enhance off-grid operation.	*Sustainable Energy Technologies and Assessments* (Elsevier)	2022
Pei et al. [71]	Comparison of different hydrogen production systems and analysis of the operational constraints and characteristics of a DC microgrid (MG) with an electric-hydrogen hybrid energy storage system (ESS).	*Journal of Power and Energy Systems* (CSEE)	2022
Ogbonnaya et al. [72]	Systematic update on the state-of-the-art of Integrated Photovoltaic-Fuel Cell (IPVFC) systems, an overview of the technical challenges that need to be overcome for IPVFC systems to reach full commercialization and widespread application.	*Energies* (MDPI)	2021
Herencic et al. [73]	Presentation of a unified model to assess the techno-economic performances of multi-vector energy communities (MECs), emphasizing their potential to provide flexibility and ability to enhance local renewable energy utilization.	*Energy Conversion and Management* (Elsevier)	2021
Naderipour et al. [74]	Comparative evaluation of optimal designs for hybrid renewable and clean energy systems, using a photovoltaic, wind turbine, tidal, and fuel cell energies with hydrogen storage in three regions of Iran.	*Journal of Cleaner Production* (Elsevier)	2021
Jahannoosh et al. [75]	Presentation of an optimal and cost-effective design for a hybrid renewable energy system using a photovoltaic, wind turbine, and fuel cells for residential-commercial centres in Iran.	*Journal of Cleaner Production* (Elsevier)	2021

The keywords were divided into 4 clusters (Figure 4a), and each cluster is marked with a different color on the graph. Due to the large number of keywords analyzed to create the co-occurrence network, only those that occurred in a minimum of 10 publications were selected. The individual clusters were created based on thematic coherence resulting from the number of connections between individual keywords. The largest of the clusters, marked on the co-occurrence network with the color red, is described in Table 3 as cluster 1; here the most common keyword was "renewable energy". The most common word for

clusters 2, 3, and 4 were "Optimization" (89 occurrences), "Performance" (68 occurrences), and "Demand Response" (57 occurrences), respectively.

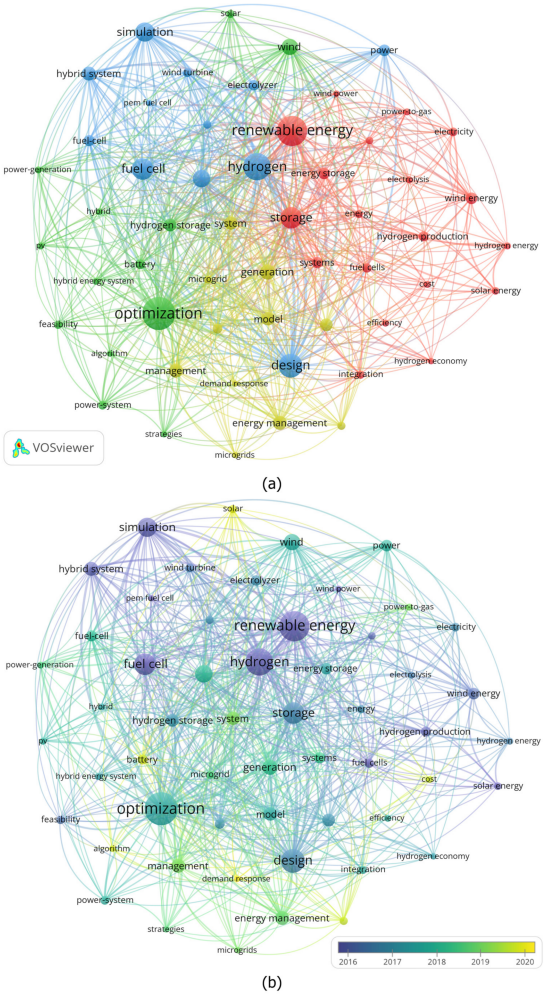

Figure 4. Publication trends in hydrogen as a renewable energy carrier in distributed energy systems: (**a**) Clusters distributions; (**b**) Timeline of occurrences.

Table 3. The most popular keywords in hydrogen as a renewable energy carrier in a hybrid configuration of distributed energy systems.

Keyword	Cluster	Links	Occurrences	Average Citations
renewable energy	1	53	79	44.34
storage	1	54	50	39.44
wind energy	1	43	23	63.09
energy storage	1	41	22	33.18
systems	1	37	21	21.90
hydrogen production	1	28	18	45.61
fuel cells	1	36	17	35.53
electricity	1	36	16	58.88
energy	1	31	14	25.93
integration	1	34	14	29.86

Table 3. *Cont.*

Keyword	Cluster	Links	Occurrences	Average Citations
hydrogen-production	1	31	13	45.92
solar energy	1	28	13	72.46
cost	1	31	12	31.17
efficiency	1	31	12	22.50
electrolysis	1	36	12	55.75
hydrogen energy	1	29	12	46.00
power-to-gas	1	28	12	54.58
hydrogen economy	1	31	10	25.10
wind power	1	27	10	51.40
optimization	2	54	89	42.30
wind	2	49	35	37.66
hydrogen storage	2	45	25	44.04
battery	2	41	19	31.95
power-system	2	32	16	41.56
feasibility	2	32	15	54.40
solar	2	34	15	25.87
hybrid	2	31	12	18.83
hybrid energy system	2	26	12	21.00
power-generation	2	31	12	26.17
pv	2	36	12	36.08
algorithm	2	31	11	25.45
strategies	2	27	10	13.50
hydrogen	3	53	68	30.29
design	3	51	57	31.46
fuel cell	3	42	50	28.90
simulation	3	49	43	32.81
performance	3	47	39	32.79
hybrid system	3	39	28	37.68
power	3	39	22	28.36
fuel-cell	3	36	21	36.48
electrolyzer	3	36	20	30.90
wind turbine	3	36	16	24.56
photovoltaic	3	34	14	22.50
pem fuel cell	3	27	11	33.27
generation	4	45	31	28.84
energy management	4	42	28	19.43
management	4	43	28	34.25
model	4	52	27	28.96
system	4	44	27	31.59
renewable energy sources	4	41	25	15.24

Table 3. *Cont.*

Keyword	Cluster	Links	Occurrences	Average Citations
operation	4	44	18	34.94
microgrid	4	25	14	12.79
technologies	4	38	14	36.07
demand response	4	32	10	12.30
Microgrids	4	27	10	32.20

On the other hand, (Figure 4b) shows the keywords co-occurrence network defining the average date of occurrence of keywords describing publications appearing in the analyzed database. There is a trend in which newer publications focus on optimizing the use of electricity, ensuring the continuity of its supply, the most efficient management of the operation of dispersed microgrids, and the use of batteries as additional energy storage. A total of 55 keywords were used to create this keywords co-occurrence network. The keywords used to create the network have been compiled in Table 3, including the frequency of occurrence, the number of links between keywords, and the average number of citations within the analyzed database.

The analyses also characterized the global geographical distribution of publications. The analysis revealed that the countries with the most publications were China (71), Iran (53), Italy (53), Spain (46), and the USA (42). The topic of using hydrogen in distributed energy systems was addressed by researchers from 64 countries, with the majority representing three continents: Europe, Asia, and North America. Interestingly, despite the fact that the analyzed articles indicate that distributed, hybrid energy systems are mainly installed in remote or peripheral regions with access to rich renewable resources, there was no significant interest in this topic in African countries, indicating a research gap. To date, only seven representatives from Africa have published studies in this domain, and most of these publications were from Algeria (31) and Egypt (21). The trends in cooperation between countries in relation to the total number of publications included in the analyzed database are presented in Figure 5. North America and Europe demonstrate a higher level of international collaboration than South America, Africa, East Asia, and Oceania.

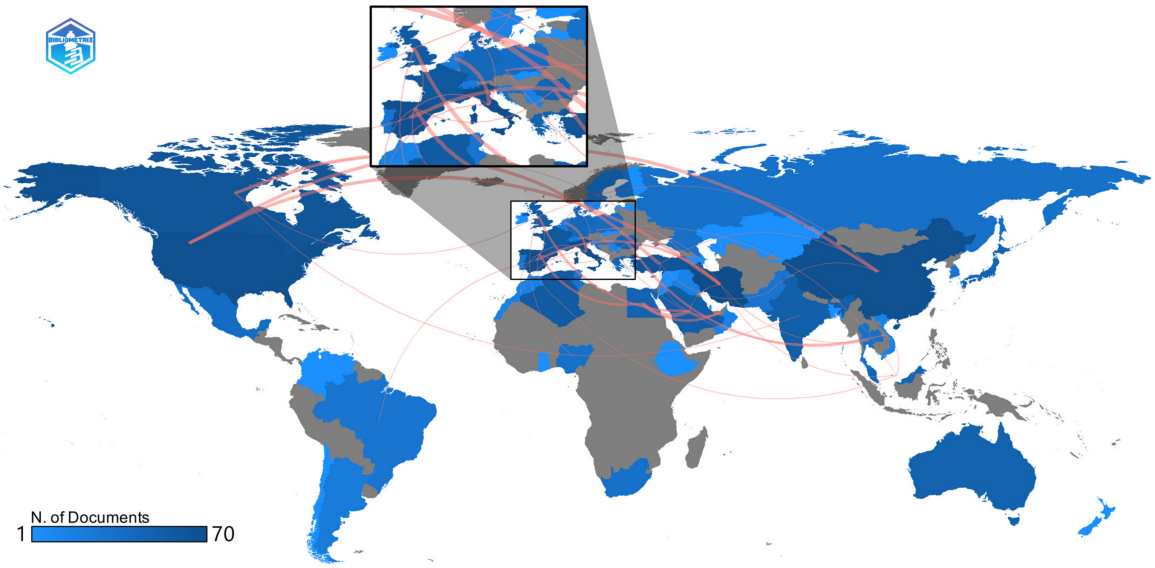

Figure 5. Global geographic distributions of publications in the hydrogen as a renewable energy carrier in distributed energy systems domain during the period from 1997 to 3 March 2023. Formatting by Mathematical Components. Pink lines indicate strength of cooperation between countries.

To improve cooperation between the mentioned countries, several parallel actions should be undertaken. These include the establishment of regional partnerships to enable knowledge exchange, joint research projects, and policy coordination within each region. Further strengthening communication channels such as regular conferences, workshops, trainings, and forums that bring together policymakers, researchers, and industry experts from these regions will facilitate dialogue, idea exchange, identification of common challenges and solutions, as well as sharing of best practices. Additionally, due to the high initial costs, it would be beneficial to explore possibilities of obtaining financial support or engaging in joint financing of renewable energy and hydrogen-related projects and investments, especially in countries with limited resources. This could involve collaboration with international financial institutions, development banks, and private sector entities. Considering the social and environmental aspects, it is also important to align the goals of implemented policies, encouraging the harmonization of strategies among countries within each region to create a favorable regulatory environment for the development of renewable energy and hydrogen.

The next step in the inquiry was an analysis of scientific journals addressing the topic of hybrid hydrogen systems. Figure 6 presents the number of publications in the 9 most productive scientific journals from 2004 to 2023. To date, most articles (71 articles) addressing the researched topic have been published in the *International Journal of Hydrogen Energy*. The first article from the analysed database appeared in this journal in 2008. By 2011, the journal had already taken the role of leader. Currently, in 2023, it still leads, surpassing the other publishers by nearly four times in terms of number of publications. Second place is held by the journal *Energy* (18 articles), one of the first to make its contribution to the literature on the topic, in 2004. The journals *Energy Conversion and Management* and *Energies* occupy third place with slightly fewer results (15 articles). It is worth noting that both these journals began their activity on this topic only in the second decade of this century, and despite this, they are currently assuming the role of leaders in promoting the use of hydrogen in dispersed energy systems. Journals not included in the figure published fewer than five articles on this topic.

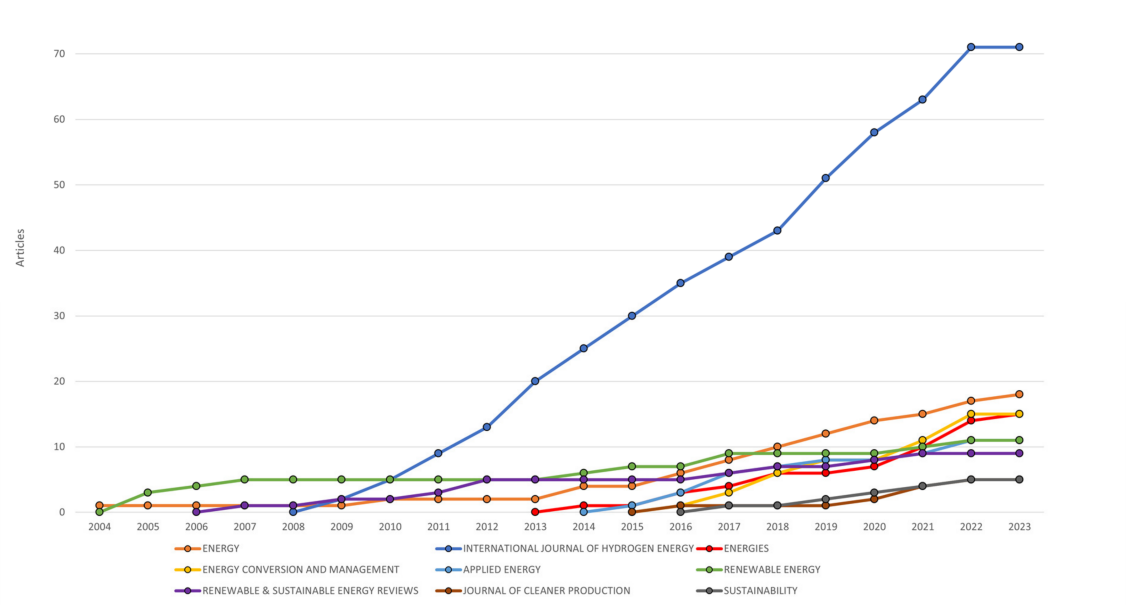

Figure 6. Publications in the hydrogen as a renewable energy carrier in distributed energy systems and individual autonomous applications domains in the top nine journals.

Using the Bibliometrix software (ver. 4.1.1), a Thematic Evolution plot was also developed, often used in bibliometric analyses. The diagram presented in Figure 7 illustrates the evolution of topics discussed over the years in the research field of applying hydro-

gen in the hybrid configuration of distributed energy systems. The characterized periods were determined based on the number of published articles, identifying four consecutive developmental stages. From 1997 to 2012, the discussions were primarily based on the theoretical concept of integrating hydrogen technologies with renewable energy sources, mainly wind energy and energy storage. In the period from 2013 to 2016, attempts were made to optimize the production process of renewable hydrogen on a microscale. Subsequently, from 2017 to 2019, there was a noticeable increase in the popularity of solar energy, energy management, and the utilization of broad automation (smart grids). Currently, from 2020 to 2023, the majority of ongoing considerations focus on adapting the operation of fuel cells to the characteristics of hybrid distributed installations, storing hydrogen surpluses, and assessing the potential of individual regions (HOMER Software) that plan to build emission-free hydrogen infrastructure.

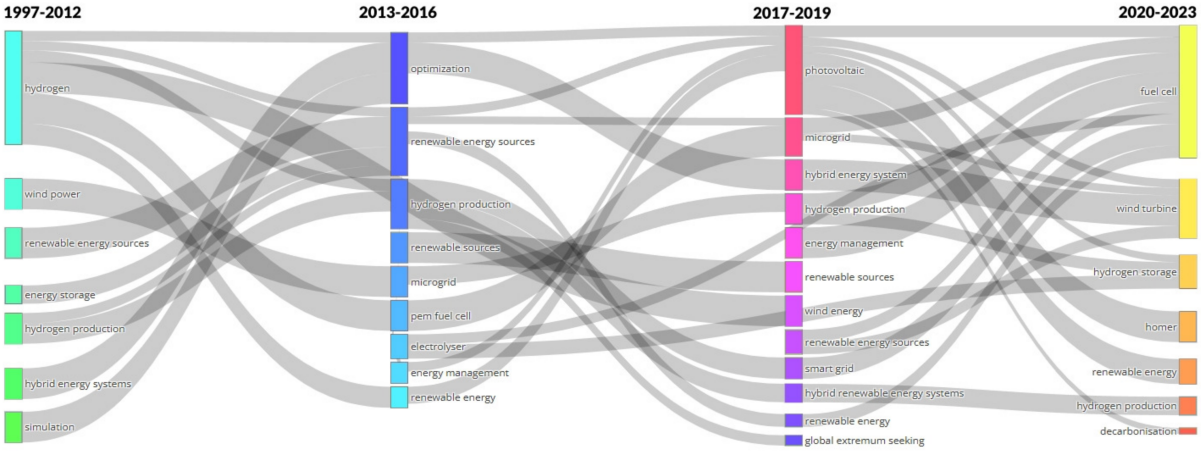

Figure 7. Thematic Evolution diagram for the hydrogen as a renewable energy carrier in distributed energy systems domain.

4. Conclusions

Hydrogen's potential as an energy carrier in distributed energy systems and autonomous applications is a forward-looking tool that could effectively support the realization of current sustainable development goals. The most popular hybrid installations for the production of renewable hydrogen in relation to the source of electric energy (HRES) are combined solar and wind power plants, whereas in relation to energy storage systems (HESS), compressed hydrogen tanks and battery storage are prevalent. This article presents the results of a retrospective analysis of selected publications addressing the implementation of hydrogen technologies in regional energy systems and individual applications. This analysis serves as a review of the literature published so far, creating the potential for conducting new research. The most important conclusions obtained are presented below.

In recent years, there has been a clear increase in interest in the topic of using hydrogen as a renewable energy carrier in the hybrid configuration of distributed energy systems. This is probably due to consistently tightened climate regulations, the occurrence of a global energy crisis, and the progressing decentralization of energy systems. The first articles on this topic were published at the end of the 20th century. Over the years, their number has grown, currently reaching several dozen publications annually.

The analysis of keywords indicates a trend of authors of newer publications focusing on optimizing the production and exploitation of renewable electrical energy, ensuring the continuity of high-quality energy supply, effective management of micro-grid operations, and the use of batteries as additional energy storage, which suggests that as technology progresses, increasing emphasis is placed on the efficiency, reliability, and ecology of energy system operation.

The territorial scope of publications on hybrid hydrogen installations in distributed energy systems mainly reaches researchers representing scientific centers from Europe, North and South America, Asia, and Oceania. Although dispersed hybrid energy systems are most often installed in remote or peripheral regions with access to rich renewable sources, African countries do not show much research activity in this area, which, considering the favourable environmental, social, and infrastructural conditions there, suggests the existence of a research gap that could be utilized in future studies.

In relation to the degree of cooperation between countries, the analysis also indicated that North American and European countries have a relatively higher level of international cooperation concerning hydrogen-based dispersed energy systems. South American, African, East Asian, and Oceanic countries appear to have a lower level of international cooperation. In order to enhance cooperation among the mentioned countries, the implementation of several concurrent actions is necessary. These steps include the establishment of regional partnerships, strengthening communication channels, exploring opportunities for financial support or joint funding of projects and investments, and promoting the harmonization of strategies among countries within each region.

The most influential scientific journal addressing the analyzed topic so far is the *International Journal of Hydrogen Energy*. A significant, albeit several times smaller, number of publications was noted in the journals *Energy*, *Energy Conversion and Management*, and *Energies*. All these journals belong to prestigious scientific publishers, and some of the materials gathered in them are published as open access, enabling access for a wide range of recipients (scientists, experts, decision-makers, designers, and most importantly, users).

Currently, research work is mainly simulation-based and focuses on multidimensional optimization of the operation of hybrid systems for generating and storing energy (including hydrogen technologies) in distributed energy systems in terms of their economics, ecology, and lifespan, along with focuses on increasing operational efficiency, feasibility studies, and promoting the implementation of these solutions.

Author Contributions: Conceptualization, P.O.; methodology, P.O. and M.W.; software, M.W.; validation, P.O., M.W. and D.S.; formal analysis, P.O. and M.W.; investigation, P.O., M.W. and D.S.; data curation, P.O., M.W. and D.S.; writing—original draft preparation, P.O. and M.W.; writing—review and editing, P.O.; visualization, M.W.; supervision, D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the reviewers for their feedback, which has helped improve the quality of the manuscript, as well as *Energies*' staff and editors for handling the paper.

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

References

1. International Energy Agency. *Net Zero by 2050—A Roadmap for the Global Energy Sector*; International Energy Agency: Paris, France, 2021.
2. Siddik, M.A.; Islam, M.T.; Mostafa Zaman, A.K.M.; Hasan, M.M. Current Status and Correlation of Fossil Fuels Consumption and Greenhouse Gas Emissions. *Int. J. Energy Environ. Econ.* **2021**, *28*, 103–119.
3. Hangun, B.; Eyecioglu, O.; Beken, M. Investigating the Energy Production Trends of Countries and Its Relationship Between Economic Development. In Proceedings of the 11th IEEE International Conference on Renewable Energy Research and Applications, ICRERA 2022, Istanbul, Turkey, 18–21 September 2022; pp. 597–600. [CrossRef]
4. Fujiwara, N. Increasing Synergies between Climate Change and Sustainable Development in Energy Policy. In *Exploring Synergies and Trade-offs between Climate Change and the Sustainable Development Goals*; Springer: Singapore, 2021; pp. 177–212. [CrossRef]
5. United Nations. *The Sustainable Development Goals Report*; United Nations: New York, NY, USA, 2021.
6. Intergovernmental Panel on Climate Change (IPCC). *AR6 Synthesis Report Climate Change 2023*; IPCC: Geneva, Switzerland, 2023.
7. BP. Statistical Review of World Energy 2022. 2022. Available online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf (accessed on 11 July 2023).

8. International Renewable Energy Agency. *World Energy Transitions Outlook 2022: 1.5 °C Pathway—Executive Summary*; International Renewable Energy Agency: Masdar City, United Arab Emirates, 2022; ISBN 9789292604295.
9. Ammari, C.; Belatrache, D.; Touhami, B.; Makhloufi, S. Sizing, Optimization, Control and Energy Management of Hybrid Renewable Energy System—A Review. *Energy Built Environ.* **2022**, *3*, 399–411. [CrossRef]
10. Casalicchio, V.; Manzolini, G.; Prina, M.G.; Moser, D. From Investment Optimization to Fair Benefit Distribution in Renewable Energy Community Modelling. *Appl. Energy* **2022**, *310*, 118447. [CrossRef]
11. Eghbali, N.; Hakimi, S.M.; Hasankhani, A.; Derakhshan, G.; Abdi, B. Stochastic Energy Management for a Renewable Energy Based Microgrid Considering Battery, Hydrogen Storage, and Demand Response. *Sustain. Energy Grids Netw.* **2022**, *30*, 100652. [CrossRef]
12. Vargas-Salgado, C.; Berna-Escriche, C.; Escrivá-Castells, A.; Díaz-Bello, D. Optimization of All-Renewable Generation Mix According to Different Demand Response Scenarios to Cover All the Electricity Demand Forecast by 2040: The Case of the Grand Canary Island. *Sustainability* **2022**, *14*, 1738. [CrossRef]
13. Vera, Y.E.G.; Dufo-López, R.; Bernal-Agustín, J.L. Energy Management in Microgrids with Renewable Energy Sources: A Literature Review. *Appl. Sci.* **2019**, *9*, 3854. [CrossRef]
14. Bukar, A.L.; Tan, C.W.; Said, D.M.; Dobi, A.M.; Ayop, R.; Alsharif, A. Energy Management Strategy and Capacity Planning of an Autonomous Microgrid: Performance Comparison of Metaheuristic Optimization Searching Techniques. *Renew. Energy Focus* **2022**, *40*, 48–66. [CrossRef]
15. Lamnatou, C.; Chemisana, D.; Cristofari, C. Smart Grids and Smart Technologies in Relation to Photovoltaics, Storage Systems, Buildings and the Environment. *Renew. Energy* **2022**, *185*, 1376–1391. [CrossRef]
16. Piotrowska, B.; Słyś, D. Variant Analysis of Financial and Energy Efficiency of the Heat Recovery System and Domestic Hot Water Preparation for a Single-Family Building: The Case of Poland. *J. Build. Eng.* **2023**, *65*, 105769. [CrossRef]
17. Kordana-Obuch, S.; Starzec, M. Horizontal Shower Heat Exchanger as an Effective Domestic Hot Water Heating Alternative. *Energies* **2022**, *15*, 4829. [CrossRef]
18. Putkonen, N.; Lindroos, T.J.; Neniškis, E.; Žalostība, D.; Norvaiša, E.; Galinis, A.; Teremranova, J.; Kiviluoma, J. Modeling the Baltic Countries' Green Transition and Desynchronization from the Russian Electricity Grid. *Int. J. Sustain. Energy Plan. Manag.* **2022**, *34*, 45–62. [CrossRef]
19. Anoune, K.; Bouya, M.; Astito, A.; Abdellah, A. Ben Sizing Methods and Optimization Techniques for PV-Wind Based Hybrid Renewable Energy System: A Review. *Renew. Sustain. Energy Rev.* **2018**, *93*, 652–673. [CrossRef]
20. Barhoumi, E.M.; Okonkwo, P.C.; Ben Belgacem, I.; Zghaibeh, M.; Tlili, I. Optimal Sizing of Photovoltaic Systems Based Green Hydrogen Refueling Stations Case Study Oman. *Int. J. Hydrogen Energy* **2022**, *47*, 31964–31973. [CrossRef]
21. Jurasz, J.; Canales, F.A.; Kies, A.; Guezgouz, M.; Beluco, A. A Review on the Complementarity of Renewable Energy Sources: Concept, Metrics, Application and Future Research Directions. *Sol. Energy* **2020**, *195*, 703–724. [CrossRef]
22. Rahman, M.M.; Oni, A.O.; Gemechu, E.; Kumar, A. Assessment of Energy Storage Technologies: A Review. *Energy Convers. Manag.* **2020**, *223*, 113295. [CrossRef]
23. Kebede, A.A.; Kalogiannis, T.; Van Mierlo, J.; Berecibar, M. A Comprehensive Review of Stationary Energy Storage Devices for Large Scale Renewable Energy Sources Grid Integration. *Renew. Sustain. Energy Rev.* **2022**, *159*, 112213. [CrossRef]
24. Choudhury, S. Review of Energy Storage System Technologies Integration to Microgrid: Types, Control Strategies, Issues, and Future Prospects. *J. Energy Storage* **2022**, *48*, 103966. [CrossRef]
25. Marocco, P.; Novo, R.; Lanzini, A.; Mattiazzo, G.; Santarelli, M. Towards 100% Renewable Energy Systems: The Role of Hydrogen and Batteries. *J. Energy Storage* **2023**, *57*, 106306. [CrossRef]
26. Dawood, F.; Anda, M.; Shafiullah, G.M. Hydrogen Production for Energy: An Overview. *Int. J. Hydrogen Energy* **2020**, *45*, 3847–3869. [CrossRef]
27. Nikolaidis, P.; Poullikkas, A. A Comparative Overview of Hydrogen Production Processes. *Renew. Sustain. Energy Rev.* **2017**, *67*, 597–611. [CrossRef]
28. International Energy Agency. *Hydrogen Energy System Overview*; International Energy Agency: Paris, France, 2022.
29. Sgarbossa, F.; Arena, S.; Tang, O.; Peron, M. Renewable Hydrogen Supply Chains: A Planning Matrix and an Agenda for Future Research. *Int. J. Prod. Econ.* **2023**, *255*, 108674. [CrossRef]
30. Homa, M.; Pałac, A.; Żołądek, M.; Figaj, R. Small-Scale Hybrid and Polygeneration Renewable Energy Systems: Energy Generation and Storage Technologies, Applications, and Analysis Methodology. *Energies* **2022**, *15*, 9152. [CrossRef]
31. Ishaq, H.; Dincer, I.; Crawford, C. A Review on Hydrogen Production and Utilization: Challenges and Opportunities. *Int. J. Hydrogen Energy* **2022**, *47*, 26238–26264. [CrossRef]
32. Khan, T.; Yu, M.; Waseem, M. Review on Recent Optimization Strategies for Hybrid Renewable Energy System with Hydrogen Technologies: State of the Art, Trends and Future Directions. *Int. J. Hydrogen Energy* **2022**, *47*, 25155–25201. [CrossRef]
33. Sorrenti, I.; Harild Rasmussen, T.B.; You, S.; Wu, Q. The Role of Power-to-X in Hybrid Renewable Energy Systems: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2022**, *165*, 112380. [CrossRef]
34. Ozturk, M.; Dincer, I. A Comprehensive Review on Power-to-Gas with Hydrogen Options for Cleaner Applications. *Int. J. Hydrogen Energy* **2021**, *46*, 31511–31522. [CrossRef]
35. Mtolo, S.N.; Saha, A.K. A Review of the Optimization and Control Strategies for Fuel Cell Power Plants in a Microgrid Environment. *IEEE Access* **2021**, *9*, 146900–146920. [CrossRef]

36. Fonseca, J.D.; Camargo, M.; Commenge, J.-M.; Falk, L.; Gil, I.D. Trends in Design of Distributed Energy Systems Using Hydrogen as Energy Vector: A Systematic Literature Review. *Int. J. Hydrogen Energy* **2019**, *44*, 9486–9504. [CrossRef]
37. Yap, J.; McLellan, B. A Historical Analysis of Hydrogen Economy Research, Development, and Expectations, 1972 to 2020. *Environments* **2023**, *10*, 11. [CrossRef]
38. Chen, M.; Zhou, Q.; Wu, F.; Sun, F.; Meng, Y.; Zhang, Y.; Zhao, M. Bibliometric Evaluation of 2011–2021 Publications on Hydrogen Sulfide in Heart Preservation Research. *Front. Cardiovasc. Med.* **2023**, *9*, 941374. [CrossRef]
39. Sharma, G.D.; Verma, M.; Taheri, B.; Chopra, R.; Parihar, J.S. Socio-Economic Aspects of Hydrogen Energy: An Integrative Review. *Technol. Forecast. Soc. Chang.* **2023**, *192*, 122574. [CrossRef]
40. Kordana-Obuch, S.; Starzec, M.; Wojtoń, M.; Słyś, D. Greywater as a Future Sustainable Energy and Water Source: Bibliometric Mapping of Current Knowledge and Strategies. *Energies* **2023**, *16*, 934. [CrossRef]
41. van Eck, N.J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef] [PubMed]
42. Aria, M.; Cuccurullo, C. Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis. *J. Inf.* **2017**, *11*, 959–975. [CrossRef]
43. Catumba, B.D.; Sales, M.B.; Borges, P.T.; Ribeiro Filho, M.N.; Lopes, A.A.S.; Sousa Rios, M.A.d.; Desai, A.S.; Bilal, M.; Santos, J.C.S. dos Sustainability and Challenges in Hydrogen Production: An Advanced Bibliometric Analysis. *Int. J. Hydrogen Energy* **2023**, *48*, 7975–7992. [CrossRef]
44. Waltman, L.; van Eck, N.J.; Noyons, E.C.M. A Unified Approach to Mapping and Clustering of Bibliometric Networks. *J. Inf.* **2010**, *4*, 629–635. [CrossRef]
45. Zoulias, E.I.; Lymberopoulos, N. *Hydrogen-Based Autonomous Power Systems: Techno-Economic Analysis of the Integration of Hydrogen in Autonomous Power Systems*; Power Systems; Springer: London, UK, 2008; p. 31. [CrossRef]
46. Liuhto, K. *The Future of Energy Consumption, Security and Natural Gas*; Palgrave Macmillan: Cham, Switzerland, 2022. [CrossRef]
47. Bichler, M.; Buhl, H.U.; Knörr, J.; Maldonado, F.; Schott, P.; Waldherr, S.; Weibelzahl, M. Electricity Markets in a Time of Change: A Call to Arms for Business Research. *Schmalenbach J. Bus. Res.* **2022**, *74*, 77–102. [CrossRef]
48. Keiner, D.; Thoma, C.; Bogdanov, D.; Breyer, C. Seasonal Hydrogen Storage for Residential On- and off-Grid Solar Photovoltaics Prosumer Applications: Revolutionary Solution or Niche Market for the Energy Transition until 2050? *Appl. Energy* **2023**, *340*, 121009. [CrossRef]
49. Sapru, K.; Stetson, N.T.; Ovshinsky, S.R.; Yang, J.; Fritz, G.; Fairlie, M.; Stuart, A.T. Development of a Small Scale Hydrogen Production-Storage System for Hydrogen Applications. In IECEC-97 Proceedings of the Thirty-Second Intersociety Energy Conversion Engineering Conference (Cat. No.97CH6203), Honolulu, HI, USA, 27 July–1 August 1997; IEEE: Honolulu, HI, USA, 1997.
50. Sato, T.; Hamada, A.; Kitamura, K. A Feasibility Study of Conceptual Design for International Clean Energy Network Using Hydrogen Conversion Technology. In Proceedings of the Hydrogen Energy Progress XII, Buenos Aires, Argentina, 21–26 June 1998; Volume 1–3, pp. 159–168.
51. Wokaun, A. Towards Sustainable Mobility. *Greenh. Gas Control Technol.* **1999**, *4*, 899–904. [CrossRef]
52. Mohamad, P.H.A.; Shamsuddin, A.H.; Sopian, K.; Abdul, M.A.; Yunus, M.N. Treatment of Toxic and Naturally Occurring Radioactive Material (NORM) in Oil Sludge and Scale from Malaysian Crude Oil Terminal Using Fluidized Bed Combustion Technology. In *Advances in Malaysian Energy Research 1998*; Universiti Kebangsaan Malaysia: Bangi, Malaysia, 1999; pp. 1–12.
53. Isherwood, W.; Smith, J.R.; Aceves, S.M.; Berry, G.; Clark, W.; Johnson, R.; Das, D.; Goering, D.; Seifert, R. Remote Power Systems with Advanced Storage Technologies for Alaskan Villages. *Energy* **2000**, *25*, 1005–1020. [CrossRef]
54. Glasnovic, Z.; Urli, N.; Desnica, U.; Etlinger, B.; Sesartic, M.; Miscevic, L.; Metikos, M.; Peric, N.; Galaso, I.; Firak, M.; et al. *Energy and the Environment 2002*; Croatian Solar House: Opatija, Croatia, 2002; pp. 215–225.
55. Chicco, G.; Mancarella, P. Distributed Multi-Generation: A Comprehensive View. *Renew. Sustain. Energy Rev.* **2009**, *13*, 535–551. [CrossRef]
56. Kotowicz, J.; Bartela, Ł.; Węcel, D.; Dubiel, K. Hydrogen Generator Characteristics for Storage of Renewably-Generated Energy. *Energy* **2017**, *118*, 156–171. [CrossRef]
57. Al Rafea, K.; Elsholkami, M.; Elkamel, A.; Fowler, M. Integration of Decentralized Energy Systems with Utility-Scale Energy Storage through Underground Hydrogen-Natural Gas Co-Storage Using the Energy Hub Approach. *Ind. Eng. Chem. Res.* **2017**, *56*, 2310–2330. [CrossRef]
58. Guandalini, G.; Campanari, S.; Romano, M.C. Power-to-Gas Plants and Gas Turbines for Improved Wind Energy Dispatchability: Energy and Economic Assessment. *Appl. Energy* **2015**, *147*, 117–130. [CrossRef]
59. Maroufmashat, A.; Fowler, M.; Sattari Khavas, S.; Elkamel, A.; Roshandel, R.; Hajimiragha, A. Mixed Integer Linear Programing Based Approach for Optimal Planning and Operation of a Smart Urban Energy Network to Support the Hydrogen Economy. *Int. J. Hydrogen Energy* **2016**, *41*, 7700–7716. [CrossRef]
60. Jha, S.K.; Bilalovic, J.; Jha, A.; Patel, N.; Zhang, H. Renewable Energy: Present Research and Future Scope of Artificial Intelligence. *Renew. Sustain. Energy Rev.* **2017**, *77*, 297–317. [CrossRef]
61. Sharafi, M.; ELMekkawy, T.Y. Multi-Objective Optimal Design of Hybrid Renewable Energy Systems Using PSO-Simulation Based Approach. *Renew. Energy* **2014**, *68*, 67–79. [CrossRef]

62. Dagdougui, H.; Minciardi, R.; Ouammi, A.; Robba, M.; Sacile, R. A Dynamic Decision Model for the Real-Time Control of Hybrid Renewable Energy Production Systems. *IEEE Syst. J.* **2010**, *4*, 323–333. [CrossRef]
63. Derrouazin, A.; Aillerie, M.; Mekkakia-Maaza, N.; Charles, J.P. Fuzzy Logic Controller versus Classical Logic Controller for Residential Hybrid Solar-Wind-Storage Energy System. *AIP Conf. Proc.* **2016**, *1758*, 030055. [CrossRef]
64. Schirone, L.; Pellitteri, F. Energy Policies and Sustainable Management of Energy Sources. *Sustainability* **2017**, *9*, 2321. [CrossRef]
65. Kostelac, M.; Herenčić, L.; Capuder, T. Planning and Operational Aspects of Individual and Clustered Multi-Energy Microgrid Options. *Energies* **2022**, *15*, 1317. [CrossRef]
66. Okonkwo, P.C.; Barhoumi, E.M.; Mansir, I.B.; Emori, W.; Uzoma, P.C. Techno-Economic Analysis and Optimization of Solar and Wind Energy Systems for Hydrogen Production: A Case Study. *Energy Sources Part A Recovery Util. Environ. Eff.* **2022**, *44*, 9119–9134. [CrossRef]
67. Jasinski, M.; Najafi, A.; Homaee, O.; Kermani, M.; Tsaousoglou, G.; Leonowicz, Z.; Novak, T. Operation and Planning of Energy Hubs Under Uncertainty—A Review of Mathematical Optimization Approaches. *IEEE Access* **2023**, *11*, 7208–7228. [CrossRef]
68. Islam, M.K.; Hassan, N.M.S.; Rasul, M.G.; Emami, K.; Chowdhury, A.A. Green and Renewable Resources: An Assessment of Sustainable Energy Solution for Far North Queensland, Australia. *Int. J. Energy Environ. Eng.* **2022**. [CrossRef]
69. Alzahrani, A.; Ramu, S.K.; Devarajan, G.; Vairavasundaram, I.; Vairavasundaram, S. A Review on Hydrogen-Based Hybrid Microgrid System: Topologies for Hydrogen Energy Storage, Integration, and Energy Management with Solar and Wind Energy. *Energies* **2022**, *15*, 7979. [CrossRef]
70. Wimalaratna, Y.P.; Afrouzi, H.N.; Mehranzamir, K.; Siddique, M.B.M.; Liew, S.C.; Ahmed, J. Analysing Wind Power Penetration in Hybrid Energy Systems Based on Techno-Economic Assessments. *Sustain. Energy Technol. Assess.* **2022**, *53*, 102538. [CrossRef]
71. Pei, W.; Zhang, X.; Deng, W.; Tang, C.; Yao, L. Review of Operational Control Strategy for DC Microgrids with Electric-Hydrogen Hybrid Storage Systems. *CSEE J. Power Energy Syst.* **2022**, *8*, 329–346. [CrossRef]
72. Ogbonnaya, C.; Abeykoon, C.; Nasser, A.; Turan, A.; Ume, C.S. Prospects of Integrated Photovoltaic-Fuel Cell Systems in a Hydrogen Economy: A Comprehensive Review. *Energies* **2021**, *14*, 6827. [CrossRef]
73. Herenčić, L.; Melnjak, M.; Capuder, T.; Andročec, I.; Rajšl, I. Techno-Economic and Environmental Assessment of Energy Vectors in Decarbonization of Energy Islands. *Energy Convers. Manag.* **2021**, *236*, 114064. [CrossRef]
74. Naderipour, A.; Abdul-Malek, Z.; Nowdeh, S.A.; Kamyab, H.; Ramtin, A.R.; Shahrokhi, S.; Klemeš, J.J. Comparative Evaluation of Hybrid Photovoltaic, Wind, Tidal and Fuel Cell Clean System Design for Different Regions with Remote Application Considering Cost. *J. Clean. Prod.* **2021**, *283*, 124207. [CrossRef]
75. Jahannoosh, M.; Nowdeh, S.A.; Naderipour, A.; Kamyab, H.; Davoudkhani, I.F.; Klemeš, J.J. New Hybrid Meta-Heuristic Algorithm for Reliable and Cost-Effective Designing of Photovoltaic/Wind/Fuel Cell Energy System Considering Load Interruption Probability. *J. Clean. Prod.* **2021**, *278*, 123406. [CrossRef]
76. Van Eck, N.J.; Waltman, L.; Dekker, R.; Van Den Berg, J. A Comparison of Two Techniques for Bibliometric Mapping: Multidimensional Scaling and VOS. *J. Am. Soc. Inf. Sci. Technol.* **2010**, *61*, 2405–2416. [CrossRef]