



Review Research on the Concept of Hydrogen Supply Chains and Power Grids Powered by Renewable Energy Sources: A Scoping Review with the Use of Text Mining

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Abstract: The key direction of political actions in the field of sustainable development of the energy sector and economy is the process of energy transformation (decarbonization) and increasing the share of renewable energy sources (RES) in the supply of primary energy. Regardless of the indisputable advantages, RES are referred to as unstable energy sources. A possible solution might be the development of the concept of hydrogen supply chains, especially the so-called green hydrogen obtained in the process of electrolysis from electricity produced from RES. The aim of the research undertaken in the article is to identify the scope of research carried out in the area of hydrogen supply chains and to link this research with the issues of the operation of electricity distribution networks powered by RES. As a result of the scoping review, and the application of the text-mining method using the IRaMuTeQ tool, which includes the analysis of the content of 12 review articles presenting the current research achievements in this field over the last three years (2016–2020), it was established that the issues related to hydrogen supply chains, including green hydrogen, are still not significantly associated with the problem of the operation of power grids. The results of the conducted research allow formulating recommendations for further research areas.

Keywords: hydrogen supply chains; green hydrogen; energy; power grids; renewable energy sources; scoping review; text mining; IRaMuTeQ; decarbonization

1. Introduction

Satisfying the growing demand for energy and reducing the negative impact of the energy sector on the environment and society are two interrelated and most important problems of the modern world [1]. The negative effects of climate change are a great challenge for the energy sector, which is subject to increasing political pressure to limit greenhouse gas emissions, in particular, carbon dioxide emissions [2,3]. The challenges that lie before a decarbonized energy sector are identified in relation to environmental sustainability, security of energy supply, economic stability, and social aspects [4–7]. This is reflected in the package of legislative proposals referred to as the European Green Deal adopted by the European Commission in July 2021, aimed at adjusting the European Union (EU) climate, energy, transport, and tax policy to the goal of reducing net greenhouse gas emissions by least 55 percent by 2030, as compared to the level achieved in 1990. The assumptions of the European Green Deal are to contribute to the transformation of the EU into the first climate-neutral region of the world by 2050 [8–10].

The key direction of political actions in the field of sustainable development of the energy sector is the process of energy transformation (decarbonization) and an increase in the share of renewable energy sources (RES) in the primary energy supply [11,12]. RES technologies provide an excellent opportunity to mitigate greenhouse gas emissions and reduce global warming by replacing conventional energy sources based on natural resources [13–15]. Nevertheless, regardless of the indisputable advantages, RES are referred



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Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). to as unstable energy sources, due to the dependence of produced energy volume on noncontrollable factors, such as weather or time of day [16,17]. The growing share of unstable RES in the energy mix has a number of consequences for the operation of power grids. As the number of RES-based electricity producers grows, the problem of unstable operation of power grids will increase, in particular in the area of distribution grids. Therefore, more and more attention is being paid to the issue of storing energy produced from RES in the context of stabilizing electricity distribution networks, with one of the solutions being the development of hydrogen technologies, in particular, those based on pure hydrogen (the so-called green hydrogen). Green hydrogen may play an increasing role in the process of decarbonizing the energy sector and is gradually becoming one of the key energy carriers used in the European Union [18].

The use of hydrogen technologies in RES stabilization in the context of the operational safety of electricity distribution networks requires both a comprehensive approach and strategic planning in line with the concept of designing a hydrogen supply chain that distinguishes the phases of supply, production, storage, and distribution of electricity [19,20].

Research into hydrogen supply chains is still at an early stage of development. The aim of the research undertaken in the article is to identify the scope of research carried out in the area of hydrogen supply chains, and to link this research with the problems of the operation of electricity distribution networks powered by RES.

In order to achieve the research goal, the following research questions were formulated:

- To what extent does the research take into account the topics of hydrogen supply chains and the functioning of electricity distribution networks?
- To what extent does the previous research take into account the environmental aspect related to the growing share of RES and climate policy objectives?

The research used the Scoping Review (SR) methodology as a tool for aggregating knowledge through the process of mapping and structuring information provided by the literature review. Additionally, as a result of an exploratory test analysis using a textmining tool (IRaMuTeQ software, version 0.7 alpha 2, http://www.iramuteq.org/ accessed on 22 October 2021), it was possible to demonstrate the current state of knowledge and identify research and cognitive gaps. Recommendations were also formulated for future research in the area of hydrogen supply chains in the context of energy transformation processes and the growing share of RES in primary energy production and the implications of these changes for the stable operation of electricity distribution networks.

The article consists of five parts. The first two parts present an introduction to the research topic and the background of the study. The third part describes the SR research methodology and the process of exploratory text analysis (IRaMuTeQ software). The fourth part presents the results of the lexicographic analysis and the analysis of similarity. The final part contains a discussion and conclusions from the research, together with a recommendation for further research.

2. Background of the Study

Among the theoretical achievements to date, individual phases of the functioning of hydrogen supply chains have been the subject of separate studies.

The first in-depth research on the hydrogen supply chain (HSC) was undertaken in 2008–2012. The subject of these studies was primarily the evolution of the hydrogen market, strongly related to transport. Four main components were distinguished in the structure of the hydrogen supply chain: hydrogen production subsystem, hydrogen storage subsystem, hydrogen transportation subsystem, and hydrogen refueling station subsystem [11]. The research focused on the infrastructure for the production and storage of hydrogen, as well as the means and processes of its transport [21]. These studies did not take into account the feedstock phase, which is currently considered an important component of HSC. In the first HSC structures, taking into account the supply phase, four nodes were identified [22]: suppliers of raw materials (local or international), production plants,

storage points, and petrol stations. In this approach, however, the independence of research regarding individual phases of hydrogen supply chains is still visible.

In the latest research (post-2015), hydrogen is more and more often considered an energy carrier and a measure stabilizing the operation of power grids, while the production of hydrogen in the electrolysis process is regarded the optimal solution. Research focuses heavily on the strategic planning of the HSC and the deployment of hydrogen infrastructure. In the structure of HSC, more and more emphasis is being placed on the importance of the supply phase [23].

At the same time, independent in-depth research on each of the HSC phases is intensively developing, due to the existence of many options for their operation. In the supply phase (feedstock), RES (biomass, solar, and wind energy), and nuclear energy are increasingly being analyzed as sources of green hydrogen production [24,25]. Nevertheless, the structure of RES is often overlooked in research. At the same time, it is indicated [26,27] that the art of sustainable use of grid-integrated RES has its roots at the pre-design stage, where appropriate reliability tests are required in order to determine the appropriate place to minimize transmission losses. Only a small number of studies also emphasize the importance of the availability of water as the main raw material in the electrolysis process, as well as oxygen, which is the key raw material in the coal or biomass gasification process [28,29]. In the HSC production phase, steam methane reforming (SMR), biomass and coal gasification (BG and CG, respectively), and finally electrolysis are the three main production technologies analyzed in the research. It is indicated that at present most of the hydrogen is produced using SMR, currently considered the cheapest production method [30]. Nevertheless, significant advantages of electrolysis have been pointed out for the future. Although these technology processes are more expensive, they allow wider use of hydrogen with a low carbon footprint in the energy system [31-33]. The hydrogen storage phase is considered a way to deal with plant downtime and fluctuations in energy demand, as well as a solution to the problem of balancing power grids due to the growing share of energy production from RES [34]. Most of these studies are focused on the technical and economic aspects of HSC design. In the distribution phase, the research focuses on the issue of hydrogen refueling stations [35]. The research also covers the issues of hydrogen transport and factors influencing the choice of hydrogen transport means [36], as well as the issues of social acceptance for the technological revolution based on hydrogen cells taking place in the motorization sector [37].

In terms of further research, it is indicated [38] that, inter alia, it should, to a greater extent, take into account the aspects related to the production of hydrogen from RES and the implications of the increase in the share of RES capacity for the operation of electricity grids. Electrolysis should be considered in the context of storing surplus energy generated from RES and balancing the operation of power grids [39].

The correlation between the functioning of energy supply chains and the hydrogen supply chain is presented in Figure 1.

Identification of the interdependencies of the functioning of energy supply chains with the hydrogen supply chain indicated in Figure 1 is the main subject of the research undertaken in this article.

3. Methodology

The study used the Scoping Review (SR) literature review method, which enables the mapping of literature from a given research area, in particular in terms of the main concepts, theories, types, and sources of knowledge [40]. This method is particularly useful in the literature review of broad areas of research [41] or in the initial stages of research [42], when the research area is not precisely defined and descriptions in scientific publications are dispersed [43]. Scoping Reviews identify research gaps through the selection and synthesis of existing knowledge [44,45]. They are also used to inform about research plans and to identify implications for policy or practice regarding decision making [46].

In the analysis of the collected research material, traditional techniques (in-depth study of the content of articles) and statistical text-mining techniques with the use of the IRaMuTeQ software were used. The main source of data on literature sources was the Web of Science Core Collection (WoS) database.



Figure 1. Energy supply chain cooperating with the hydrogen supply chain. Source: own elaboration.

In line with the adopted SR methodology, the literature review process included the following stages:

- 1. Formulating research question;
- 2. Identifying relevant sources;
- 3. Selecting research;
- 4. In-depth study of the research content using narrative technique and exploratory text mining using the IRaMuTeQ software;
- 5. Reporting test results.

In the first stage of SR, the main research question was formulated:

What do we know about the possibilities of stabilizing energy networks based on renewable energy sources using hydrogen technologies?

Based on this research question, the searching criteria for literature and qualifying literature for further analysis were established in the second stage. Three main keywords were designated: *hydrogen, power grid,* and *renewable sources*. The formulated keywords allowed for an initial selection of literature items based on titles and abstracts (screening 1). A three-stage search in the WoS database was conducted, which resulted in the identification of 479 literature references. From the selected database of 479 articles, 201 references that were not directly related to the research topic were rejected. For the most part, the subject of these articles was related to hydrogen vehicles, obtaining hydrogen from carbon captured from the air (CSS), and hydrogen batteries. Moreover, non-English language articles and articles without abstracts were rejected.

As a result, 278 articles were qualified for further analysis.

In the third stage of SR, another selection of research was made from the list of 278 articles for further analysis (screening 2). In order to minimize errors related to the omission of articles important for the purpose of the research, additional research questions were formulated:

- What do we know about renewable energy systems that use green hydrogen for energy storage?
- What do we know about methods and models for stabilizing energy networks based on hydrogen storage systems?

- How do hydrogen supply chains that include a storage cell function?
- What factors are taken into account when identifying the locations of hydrogen storage facilities?

The formulated additional research questions were used to determine additional keywords that were included in the further stage of selecting articles in the WoS database: hydrogen, supply chain, storage, renewable sources, model, location, power grid, and electrolysis. The indicated keywords were cross-used in a four-step search. As a result, an additional 33 articles (after eliminating duplicates from the first search), strictly corresponding to the aim of the research and not identified during the first search, were obtained.

Finally, 311 articles from the WoS database were selected for the initial analysis of the full texts of articles, including:

- 197 original research;
- 1 book chapter;
- 76 conference proceedings papers;
- 37 review articles.

In the fourth stage of the research, from the selected list of 311 articles, 37 review articles were initially chosen. The choice of only review articles was dictated by the fact that such publications are the most comprehensive form of research synthesis in a given area. Review articles in accordance with the methodologies of a systematic literature review should be analyzed in the first place (before the original scientific articles). Moreover, the structure and descriptive nature of review articles (mostly text material) make them best suited for content analysis using text-mining tools (here: the IRaMuTeQ software). A selected group of 37 review articles was subjected to an in-depth analysis of the full content in terms of the adopted research objective. On this basis, from the list of 37 review articles, 12 articles that most closely corresponded to the research questions posed were selected. The articles were published in the period 2016–2020. The list of 12 selected review articles that include an overview of the current research results in the analyzed subject is presented in Appendix A.

The summary of the selection process of literature sources in the SR process is presented Figure 2.





In the fifth stage of the research, a selected group of 12 review articles was subjected to the process of text mining. Exploratory text mining is a multidisciplinary field derived from data mining, information retrieval, data extraction, text categorization, and probabilistic modeling. It uses, among others, statistical methods or machine learning. The creator of the concept of text mining is Marti A. Hearst [47], who defined it as "a process aimed at discovering by computer of new, previously unknown information from written resources".

The goal of a process defined in this way is to find relevant, previously unknown, and comprehensive knowledge from unstructured text data.

In line with the adopted methodology, the process of exploratory text analysis consisted of several phases [48]:

- 1. Text extraction (characterized in the first part of the methodology).
- 2. Text unification—the goal of this stage is to convert all documents to one consistent text format, as documents obtained from various sources may differ significantly from each other.
- 3. Transformation—the modification of a collection of texts into a form that enables further analysis.
- 4. Analysis of transformed texts.

Based on the process of exploratory text analysis presented above, individual activities were performed to present the obtained research results. The selected 12 texts were standardized during the next stage. The process of exploratory test analysis was carried out using the IRaMuTeQ software. (It should be noted that computer-assisted text analysis is increasingly more often used by researchers in a wide variety of fields [49-51]. Text analyses are used by scientists dealing with cultural analyses [50], linguists [49], historians [52], or those dealing with sociology [53] or anthropology [54].) The IRAMUTEQ software (French: Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires) is used in an increasing number of studies involving reviews of literature in various fields of science, e.g., [55,56]. IRaMuTeQ is a free open-source program that uses the analytical capabilities of the R program. It belongs to the category of IT tools in the field of data mining for extracting data from text materials, structuring them by searching for key words, phrases, sentences, and their coding in the form of numerical variables, and then their statistical processing in order to discover (and often also visualize) the relationships between them. The purpose of using the IRaMuTeQ software resources in this study is to validate the obtained text interpretations as part of a literature review.

The 12 selected texts were standardized in accordance with the requirements of the IRaMuTeQ technique [57–59]. The preparation of the text for analysis consisted in:

- Deleting any graphs, tables, figures, or footnotes in the text. Moreover, the following were also removed: the content of the header and footer, title, abstracts and keywords written in English, literature list, personal data of the author/authors and affiliation, words considered in this analysis as the so-called stop words (these are, among others: the words "introduction", "ending", "abstract", "summary" constituting the chapter titles; words "table", "drawing", "table", "fig", which were found in in the name of tables and figures, the word "source" under the figures/tables).
- The following characters were removed from the text body (a text body is a set of units to be analyzed, while a unit is a fragment or whole article): quotation mark ("), apostrophe ('), dash (-); dollar sign (\$), percent (%), period (...). Note: The asterisk (*) can only be used on command lines.
- Text-formatting elements were removed: justification, bold, italics, etc.
- It was decided that in the case of acronyms and abbreviations, the full names would not be used (i.e., they would remain in the form as used by the authors of the articles).

After the text was prepared, a preliminary analysis of the text was performed based on the classical lexicographic analysis. As a result, basic information about the average frequency of words was obtained, which were then reduced to basic lexical units, as well as, inter alia, identifying the active forms. (The program replaced all terms with their canonical form (lemmatization step): plural, singular, or verb forms with infinitives. The program then identified the terms as "active forms" (i.e., content words such as nouns, verbs, and adjectives) or as "complementary forms" (i.e., function words such as prepositions, particles, and some common verbs and adverbs), with only the former being taken into account in the analyses. Subsequently, each article was divided into text segments (ECUs) consisting of several successive lines—usually marked with punctuation—which should contain a minimum number of words (15 by default), and contextual units (CUs) made by combining consecutive ECUs so that each CU contains the minimum number of active forms (12 by default).) This was a necessary step to perform a similarity analysis [60]. Similarity analysis is based on graph theory. It allows analyzing the closeness and the relationship between terms (in our case, between the active forms in the Elementary Context Units—ECU). Examples of the use of similarity analysis in the research process can be found in many studies from various fields of science, e.g., [61,62]. The analysis process begins by calculating the degree of association between all active forms in pairs, and then sequentially reducing the number of associations until a linked tree without cycles is obtained. The results of the analysis are obtained in the form of a graphic tree made up of lexical items, with the central topic and the peripheral items attached to it. The closer the lexical position is to another, the closer they are to the same segment of text. Similarly, the more branched the similarity tree, the broader the link between the terms and the search object.

4. Results

Based on the classic lexicographic analysis, information was obtained, e.g., with average word frequency (Figure 3).



Figure 3. The thirty most common words with their respective frequencies. Source: own elaboration based on an analysis in the IRAMUTEQ software.

As previously indicated, the analysis of similarity allows the identification of cooccurring words, providing information about their interrelationships, which helps identify the structure of the text corpus. Coexistence was used as an index of similarity. There were 2438 items on the word list accepted for analysis. The repetition scale ranged from 1260 for the word "energy" to 1 for the words "abate" or "abstraction". When performing similarity analyses based on such a long list, one would expect a situation in which words characterized by a low number of repetitions would make it difficult to identify the relationship between words with a higher repetition frequency. Hence, it was decided to limit the number of words based on which the similarity analysis would be performed. A list of words was extracted, making it possible to obtain nearly half of the repetitions from the list of active words. Such a situation should allow finding the most important relationships between words, and the legibility of the graphic presentation of the achieved results.

Although such a research procedure is characterized by rationality, it introduced a limitation in selecting words to the analysis, which, although occurring less frequently, are significantly related to the formulated research goals. Hence, the authors, using the knowledge obtained from studying the content of pre-selected 311 articles, used the brainstorming method to make a subjective selection of words that would achieve the adopted research goal. The word set is presented in Appendix B.

To sum up, two variants of the similarity analysis were adopted. The first variant is an analysis based on the first 189 words in the active word list. Whereas, the basis of the second variant of the analysis is a list of intentionally selected words from the list of active words (the same number as in the first case), important to the research team from the point of view of the research subject.

The first variant of the analysis according to the most common of the so-called first 189 words.

The analysis on the basis of the first 189 words allowed identifying the main concept —the word "energy", around which a set of related words was created, as well as five words (i.e., "storage", "system", "power", "model", and "hydrogen") around which further sets of words were formed. It should be noted that the word "energy" coexists with the words "storage" and "system" to form practically one large set. Subsequent identified words (e.g., "power", "hydrogen", and "model") form disjoint sets of words related to the concept of "energy" but remote from that word (Figure 4).



Figure 4. The results of the similarity analysis of the first 189 words. Source: own elaboration based on an analysis in the IRAMUTEQ software.

Taking into account the identified number of repetitions of individual words, the thickness of the lines between individual words and the font size of individual words, it can be indicated that the strongest co-occurrences exist between the pairs of words "energy"

and "system" (it can be properly considered that it is one set), "energy" and "storage", as well as "energy" and "power". The coexistence between "energy" and "hydrogen" can be observed to a lesser extent.

The first set of words that is formed around the word "energy" includes, among others, the following terms: "electricity", "system", "supply", "renewable", "source", "process", "economic", "consumption", and "price". The identified words in this set (Figure 5) indicate the issues of electricity production, energy supply sources and consumption discussed in the articles. The word "energy" is closely related to the word "system", which, in turn, is strongly associated with terms that indicate research, design, and the search for solutions and energy systems.



Figure 5. The set of words focused around the word "energy". Source: own elaboration based on an analysis in the IRAMUTEQ software.

Another word set, which is in fact part of the previous one, was formed around the word "storage". It is thematically similar to both the technical aspects of the storage process (technology, heat, battery, material, load, cycle, and discharge) and research in the economic dimension: "demand", "high", "capacity", "fluctuation", "cost", "investment", "compare", and "reduction".

Another set was created around the word "power" and it characterizes the technical issues of energy networks. The central word of this set concerns the words "generation", "surplus", "solar", "wind", "pv" (photovoltaic), "operation", "network", and "grid" (Figure 6). The word "model" is related quite distantly to the word "power".

The last set that was formed around the word "hydrogen" is the least related to the word "energy", as compared to the previously indicated words such as "power", "storage", or "system". This collection includes a variety of terms. The following words or phrases are closest to the central word: "production", "produce", "infrastructure", "vehicle", "transport", "ptg" (power-to-gas), and "fuel" (Figure 7). The set hydrogen is connected with the set "gas". The use of words such as "vehicle", "station", and "cell" indicates addressing the issue of hydrogen fueled vehicles. Whereas "electrolysis" and the very distant word "water" indicate that the issues of production technology, the so-called green hydrogen, were discussed in the research. To sum up, this set mainly covers the technical aspects of hydrogen production and transportation.



Figure 6. The set of words focused around the word "power". Source: Own elaboration based on the analysis in the IRAMUTEQ software.



Figure 7. The set of words around the word "hydrogen". Source: Own elaboration based on the analysis in the IRAMUTEQ software.

The Second Variant of the analysis according to purposefully selected 189 words.

The second variant of the analysis for deliberately selected words practically confirms the observations presented above. The same "anchor" words were identified, around which disjoint sets of words were formed. The identified sets are linked by the word "energy", together with a set of words that accompany it (Figure 8). The analysis of the meaning of the individual words that make up the sets is similar to that presented above. The only difference is the number of words around the word "hydrogen", which in this variant of the analysis is more numerous, as it results from the research interests of the team (Figure 9).



Figure 8. The results of the similarity analysis of the selected 189 words. Source: Own elaboration based on the analysis in the IRAMUTEQ software.



Figure 9. The set of words focused around the word "hydrogen" in the case of the analysis of intentionally selected words. Source: Own elaboration based on the analysis in the IRAMUTEQ software.

5. Discussion

The analysis of the above research results with the use of text-mining points to the discussion about the results achieved. The use of exploratory text analysis and the IRaMuTeQ software allowed the defining of the main thematic links in the analyzed area of research identified in selected review articles. They mainly focus on the issues of energy, energy systems, and storage. The results of the analysis with the use of text mining confirmed the subjective conclusions of the authors, obtained as a result of the traditional in-depth analysis of the full content of 12 selected review articles. The study of the first variant, covering the 189 most common words, indicates a large separability of the key sets focused around the words *energy*, *storage*, *hydrogen*, *power*, and *model*. The analysis of the layout and interrelationships of the main sets of words allows for the conclusion that the issues focused on the words *system* and *energy* are related to those regarding *power*, which, in turn, are directly related to modeling, but constitute a separate and distant scope of issues. The set centered around the word *hydrogen* with a small *gas* subset is quite weakly related to the *energy* set and the remote *storage* subset.

The analysis based on the frequency of occurrence and interrelationship of the first 189 words also indicates the main thematic scope of the research. In this comparison, the technical and economic approach dominates in each set created. The main elements of the energy system and the features describing the technical aspects of the process of energy production and delivery are indicated. In the area of economic concepts, the emphasis is mainly put on parameters related to the management and measurement of the production and energy supply process, e.g., *capacity*, *requirements*, *order*, *cycle*, *price*, and increasing its effectiveness, e.g., optimization, reduce, improve, prove, flexibility, and depend. Taking into account the identified number of repetitions, line thickness, and font size of individual words, it can be concluded that economic concepts are of a secondary nature to technical concepts. Economic concepts are more clearly emphasized in research related to energy storage, where the words *cost* and *capacity* play an important role. A separate area is the *model* set. It points to the great effort of researchers dealing with modeling issues mainly in the area related to the *power* set. The words that stand out here are *forecast*, *production*, develop, uncertainty, and plan, a fact which indicates the significant importance of research in the area of modeling power systems and the selection of appropriate research methods (method and approach). The composition of the terms around hydrogen indicates that the conducted research primarily focuses on the technical aspects of hydrogen production and transport. The issue of green hydrogen produced from renewable energy sources is not intensely reflected in articles presenting the state of knowledge in recent years. It is worth noting that in this main comparison of the most common words, there are no issues related to environmental impact, efforts aimed at the decarbonization of the economy, or linking energy production and consumption with the pursuit of climate neutrality. Although such words as, i.e., wind, pv, solar, and turbine occur in the set power; biomass and emission in the *energy* set; as well as the word *electrolysis* in the *hydrogen* set—the font size and the way of connection indicates their relatively marginal nature.

On the other hand, when analyzing the results of the research in the second variant of purposefully selected 189 words, it should be remembered that mainly words related to research in the area of clean (green) energy and taking into account to a greater extent the research on the use of hydrogen were included there. Thus, words related to the technical aspects of fossil energy production and distribution were removed.

In this arrangement, there are still major word sets focused around *energy*, *power*, and *hydrogen*. Furthermore, a separate area of connections around the word *storage* was selected, and by combining the sets of *power* and the *model*, the connections of research related to these concepts were emphasized. Despite the intervention in the process of selecting the most common words, this variant of the study also proves the separability of the main thematic sets; although, they were approximated.

Interestingly, this analysis setup shows that the concepts of hydrogen and renewable energy are dispersed across most sets. Thus, the terms referring to the concept of hydrogen supply chains appear both in the *hydrogen (hscn—hydrogen supply chain network)* and *power* (*hsc, hscnd—hydrogen supply chain network design*) sets. Moreover, in the *power* set, there are words indicating that research on the production of energy from renewable energy sources, including *wind, solar, pv, photovoltaics, rotor, offshore, reconversion, turbine,* and *farm,* is being carried out. The combination of the words also points to the problem of supplying power grids with energy from RES, e.g., *uncertainty, sun, winter, meteorological, flow, surplus, peak, maximum,* and *stability,* presented in the research. In the *energy* set, words related to energy sources and its supplies are present around this concept, including *source, resource, biomass, geothermal,* and *conversion*. There are also words pointing to the energy transformation process, e.g., *transformation, sustainability, consumption, policy, clean, pollution, balance,* and *emission*. The *storage* set, in addition to pointing to various methods of energy storage, has also distant concepts related to the production of the so-called green hydrogen, i.e., *electrolysers, electrolyzer,* and *hydro.* On the other hand, *hydrogen* is still the set located the furthest from the other main sets. The analysis of the words and their

set located the furthest from the other main sets. The analysis of the words and their connections allows us to conclude that the conceptual spectrum covers the entire range of hydrogen supply chains, starting from the concepts related to the supply phase (gas, feedstock, raw, and fossil), through the production phase production, produce, electrolysis, methanation, power-to-gas, ptg, on-site, pem—proton exchange membrane electrolysis, oxygen, and water), up to the distribution phase (fuel station, cell, refuel, refueling, hfcv—hydrogen fuel cell vehicle, car, and vehicle). Research in the area of transport and infrastructure (infrastructure, transport, transportation, delivery, and road) is important.

It is worth noting that in the purposefully selected variant of words, terms such as *environment*, *sustainability*, *transition*, *green*, *greenhouse*, *footprint*, and *pollution* were revealed and related. It should be noted, however, that the words pointing to research aimed at accelerating the energy transformation and decarbonizing the economy or contributing to the achievement of climate neutrality, which are among the main contemporary development goals, are rare and peripheral.

6. Conclusions

In view of the need to limit the use of fossil fuels and apply zero or low-emission solutions, the subject of the so-called green hydrogen generated from electricity produced from renewable energy takes on particular importance. It is a new research area that integrates theoretical achievements in the field of hydrogen supply chains as well as the operation and development of power grids. The indicated common area is of great scientific and application importance.

The current research on hydrogen technologies indicates that the use of hydrogen in the economy requires the preparation of systems for its acquisition, production, and distribution, which are referred to as hydrogen supply chains. Within this area, the key issues are not only the development and selection of appropriate production technologies, suitable infrastructure, or forms of transport. It is also important to comprehensively design and manage the processes carried out in the supply, production, storage, and distribution phase of hydrogen, as well as coordinated investment in hydrogen technologies [63], so that they are effective and best support the achievement of socio-economic goals.

As a result of the scoping review, and the application of the text-mining method using the IRaMuTeQ software, which includes the analysis of the content of 12 reviews presenting the current research achievements in this field over the last three years (2016–2020), it was established that the issues related to hydrogen supply chains, including green hydrogen, are still not significantly associated with the issue of the operation of power grids. The analysis of similarity allowed the distinguishing of sets focused around the words: *energy and storage, power, model,* and *hydrogen.* In both variants of the research (the first 189 most common words and the deliberately selected 189 words), all thematic sets are disjoint. The concepts related to HSC are sporadic and diffuse. Apart from identifying them in the set gathered around the word *hydrogen*, they can also be found in other sets. This confirms the early stage of development of HSC research and its fragmented nature. Therefore, the conducted research, based on the WoS database, indicates that at the current stage of research, there is no common research area integrating the concept of HSC and the operation of power grids.

Moreover, the previous research mainly focuses on technical aspects, while the economic approach is rather complementary. The research conducted so far has focused primarily on the broadly understood effectiveness of the technical infrastructure for hydrogen production. Environmental, social, and legal aspects are not significantly represented in the mainstream research included in the reviewed articles. Only in the second research variant, the analysis of similarity showed the connections of words reflecting the main challenges concerning, inter alia, decarbonization of the economy and pollution issues. However, even in this deliberate choice of words, the indicated issues are marginal and peripheral.

The results of the conducted research fill the existing research gap. Firstly, a shortage of research was identified in the area of links between power grids and hydrogen supply chains, in particular, green hydrogen supply chains. Secondly, it indicates that the research conducted so far is of a narrow nature and focuses mainly on technical and technological aspects. There is no interdisciplinary approach to the presented issues. Thirdly, the research carried out to a small extent takes into account today's socio-economic challenges regarding energy transformation, decarbonization of the economy, and the need to achieve climate neutrality goals.

Certain limitations were identified in the research process. Due to the pioneering subject matter, they concern the applied research methodology and its limitations. In the literature on the subject regarding scoping review, it is noted that in addition to strengths, there are also weaknesses of this type of review [33]. They mainly include the inability to accurately assess the studies included in the analysis. Being aware of the mentioned weaknesses and wanting to reduce their occurrence in the scoping review, the authors of this paper focused only on the analysis of reviews presented in the WoS database. In principle, this was to guarantee the high quality of the researched content (reviewed manuscripts, indexed in WoS database). However, at the same time, it could have resulted in the omission of other important studies (peer-reviewed publications not indexed in the WoS database).

Moreover, the analysis of similarity was limited to reviews on research in the field of energy networks and hydrogen. In these articles, the teams of authors chose research examples on their own, due to the adopted goal of the publication. At this stage, the first selection of research examples was made, which resulted in referring to the examples of the latest research, as well as focusing on the dominant threads. This could have resulted in the omission of the so-called niche research.

Moreover, limitations also result from the use of the IRaMuTeQ software. There was a need to limit the number of words in the analysis so that the obtained pictures of connections were legible.

Taking into account the described research limitations, the contribution of the conducted research to the scientific achievements should be emphasized. Identifying the above gaps has allowed us to find a new research area of great cognitive, research, and application value. This is an important area due to the contribution of science in the implementation of the indicated goals of a civilized nature. On the basis of the research findings, there is a need to continue the already in-depth research of an interdisciplinary nature, covering not only technical and technological aspects, but also economic, management, environmental, and social issues.

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Appendix A

Table A1. List of article titles included in the text analysis.

No.	Author/Authors	Article Title	Journal Title	Year of Publication	Keywords	Citation Position
1	Blanco, H.; Faaij, A.	A review at the role of storage in energy systems with a focus on Power to Gas and long-term storage	Renewable & Sustainable Energy Reviews	2018	Energy storage; Energy modelling; Flexibility; Power to Gas.	[64]
2	Lin, R.H.; Ye, Z.Z.; Wu, B.D.	A review of hydrogen station location models	International Journal of Hydrogen Energy	2020	Hydrogen; Location; Model; Review.	[65]
3	Ausfelder, F.; Beilmann, C.; Bertau, M.; Brauninger, S.; Heinzel, A.; Hoer, R.; Koch, W.; Mahlendorf, F.; Metzelthin, A.; Peuckert, M.; Plass, L.; Rauchle, K.; Reuter, M.; Schaub, G.; Schiebahn, S.; Schwab, E.; Schuth, F.; Stolten, D.; Tessmer, G.; Wagemann, K.; Ziegahn, K.F.	Energy Storage as Part of a Secure Energy Supply	Chembioeng Reviews	2017	Energy storage technology; Energy supply, Optimization.	[66]
4	Maggio, G.; Nicita, A.; Squadrito, G.	How the hydrogen production from RES could change energy and fuel markets: A review of recent literature	International Journal of Hydrogen Energy	2019	Hydrogen; Renewable energy sources; Hydrogen economy; Energy market; Fuel market.	[39]
5	Li, L.; Manier, H.; Manier, M.A.	Hydrogen supply chain network design: An optimization-oriented review	Renewable & Sustainable Energy Reviews	2019	Hydrogen; Supply chain; Network design; Optimization models.	[24]

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Table A1.	Cont.
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No.	Author/Authors	Article Title	Journal Title	Year of Publication	Keywords	Citation Position
6	Oyekale, J.; Petrollese, M.; Tola, V.; Cau, G.	Impacts of Renewable Energy Resources on Effectiveness of Grid-Integrated Systems: Succinct Review of Current Challenges and Potential Solution Stra	<i>Energies</i> Itegies	2020	Concentrated Solar Power; Photovoltaic; Biomass And Geothermal Energy; Wind Energy; Renewable hydrogen and fuel cells; Electrochemical energy storage; Thermal energy storage; Renewable power grid technical challenges; Renewable energy vehicle-to-grid; Artificial intelligence for renewable Energy.	[27]
7	Gotz, M.; Lefebvre, J.; Mors, F.; Koch, A.M.; Graf, F.; Bajohr, S.; Reimert, R.; Kolb, T.	Renewable Power-to-Gas: A technological and economic review	Renewable Energy	2016	Power-to-Gas; Electrolysis Methanation; SNG; Renewable energy	[67]
8	Maryam, S.	Review of modelling approaches used in the HSC context for the UK	International Journal of Hydrogen Energy	2017	Hydrogen supply chains; Hydrogen infrastructure; Optimization; GIS-based approaches; System dynamics.	[68]
9	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	International Journal of Hydrogen Energy	2019	Hydrogen; Energy carrier Decentralized energy system; Decarbonization; Power-to-gas; Renewable sources.	[38]

Table A1. Cont.

No.	Author/Authors	Article Title	Journal Title	Year of Publication	Keywords	Citation Position
10	Ahmed, R., Sreeram, V., Mishra, Y., & Arif, M.D.	A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization	Renewable and Sustainable Energy Reviews	2020	Solar power; Forecasting technique; Wavelet transform Deep convolutional neural network; Long short term memory; Optimization Forecast accuracy.	[69]
11	Ahmed, S.D., Al-Ismail, F.S., Shafiullah, M., Al-Sulaiman, F.A., & El-Amin, I.M.	Grid integration challenges of wind energy: A review	IEEE Access	2020	Angular stability; Energy storage system; Fault ride-through capability; Frequency response; Grid codes; Reactive power support; Voltage stability; Wind intermittency.	[70]
12	Zhang, C., Cheng, H., Liu, L., Zhang, H., Zhang, X., & Li, G.	Coordination planning of wind farm, energy storage and transmission network with high-penetration renewable energy	International Journal of Electrical Power & Energy Systems	2020	Integrated wind farm; Energy storage system; Transmission expansion planning; Decentralized ATC algorithm; Multi-regional planning; High-penetration renewable energy.	[71]

Appendix B

N	List of 1	A List of Purposefully	
N0.	Words	Frequency of Occurrence	Chosen Words
1	energy	1260	energy
2	storage	1114	storage
3	power	1036	power
4	system	880	system
5	hydrogen	870	hydrogen
6	cost	596	cost
7	model	591	model
8	grid	476	grid
9	wind	464	wind
10	demand	448	demand
11	electricity	415	electricity
12	capacity	400	capacity
13	high	391	process
14	process	380	gas
15	process	370	gas
15	gas	360	renewable
10	nleat	241	feilewable
17	plant	541	ruer
18	production	314	technology
19	renewable	304	supply
20	fuel	304	network
21	technology	303	solar
22	time	301	generation
23	study	300	source
24	supply	294	pv (Photovoltaic)
25	low	257	efficiency
26	network	254	produce
27	increase	250	turbine
28	base	242	station
29	reduce	236	price
30	solar	227	output
31	include	225	load
32	forecast	220	value
33	generation	216	cell
34	large	201	electrolysis
35	require	197	operation
36	datum	196	investment
37	consider	190	transmission
29	consider	102	
20	source	192	incut
39	approach	191	in fue atoms
40		100	mirastructure
41	emciency	100	Pg
42	due	182	performance
43	need	181	size
44	battery	181	voltage
45	application	180	economic
46	46 produce 177		store
47	case	176	limit
48	result	174	transport
49	turbine	168	distribution
50	current	165	surplus

Table A2. Lists of the first and purposefully selected words used in the analysis of similarity.

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	List of 1	A List of Purposefully	
N0.	Words	Frequency of Occurrence	Chosen Words
51	station	158	optimization
52	price	158	balance
53	output	158	uncertainty
54	option	150	conversion
55	operate	149	requirement
56	method	149	design
57	compare	147	facility
58	well	146	resource
59	provide	146	industrial
60	load	146	vehicle
61	value	145	condition
62	sector	145	development
63	cell	142	consumption
64	temperature	140	electrical
65	problem	140	water
			pvpf
66	electrolysis	137	(Photovoltaic power
	-		forecasting)
67	potential	133	fluctuation
68	biomass	133	electric
69	solution	131	discharge
70	challenge	129	variable
71	market	127	chain
72	natural	126	area
73	plan	125	cycle
74	operation	124	product
75	investment	124	emission
76	integration	124	liquid
77	control	124	industry
78	transmission	123	technical
79	location	123	strategy
80	term	122	flow
81	research	122	parameter
82	input	122	environmental
83	unit	121	transportation
84	infrastructure	121	seasonal
85	pg	120	maximum
86	performance	120	farm
87	show	118	density

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generator

site

local

economy

curtailment

peak

cavern

fossil

carrier

oxygen

hybrid

decision

frequency

transition

steam

carbon

stability

pathway

Table A2. Cont.

size

voltage

numb

economic

prediction

future

year

store

type

penetration

flexibility

limit

lead

amount

generate

focus

develop

transport

N	List of 1	A List of Purposefully	
N0.	Words	Frequency of Occurrence	Chosen Words
106	represent	106	feedstock
107	distribution	106	consumer
108	surplus	105	pressure
109	optimization	104	mobility
110	balance	104	long term
111	uncertainty	103	irradiance
112	total	103	household
113	level	103	volume
114	depend	103	refuel
115	conversion	103	policy
116	function	102	hsc
110	i	101	(hydrogen supply chain)
117	scale	101	convert hscn
118	material	101	(Hydrogen supply chain network)
119	thermal	100	capability
120	requirement	100	ability
121	design	100	weather
122	chemical	100	nto
123	propose	99	operator
124	facility	99	management
121	resource	98	asification
125	range	98	car
120	industrial	96	car
127	avist	90	distribute
120	vehicle	90	utilization
129	venicie	95	
150	condition	95	hscnd
131	development	94	(Hydrogen supply chain network design)
132	consumption	94	grid_integrated
133	factor	93	safety
134	electrical	93	protection
135	water	92	reliability
136	small	92	quantity
137	pypf	92	installation
138	optimal	92	raw
139	main	91	construction
140	fluctuation	89	tank
141	electric	89	stationary
142	alternative	89	spatial
1/3	scenario	88	pem
143	form	88	oloctrolyzor
145	achiovo	80	rotor
145	long	00	docontrolizo
140	instal	07	wield
147	listal	07	TISK
148	discharge	87	converter
149	variable	86	climate
150	technique	85	regulation
100	lead	108	trequency
101	amount	108	transition
102	generate	107	steam
103	focus	107	carbon
104	develop	107	stability
105	transport	106	pathway

Table A2. Cont.

N	List of 18	A List of Purposefully	
N0.	Words	Frequency of Occurrence	Chosen Words
106	represent	106	feedstock
107	distribution	106	consumer
108	surplus	105	pressure
109	optimization	104	mobility
110	balance	104	long term
111	uncertainty	101	irradiance
111	total	103	household
112	loval	103	volumo
115	demand	103	volume
114	depend	103	refuel
115	conversion	103	hsc
116	runction	102	(hydrogen supply chain)
117	scale	101	hscn
118	material	101	(Hydrogen supply chain
110	.1 1	100	network)
119	thermal	100	capability
120	requirement	100	ability
121	design	100	weather
122	chemical	100	ptg
123	propose	99	operator
124	facility	99	management
125	resource	98	gasification
126	range	98	car
127	industrial	96	security
128	exist	96	distribute
129	vehicle	95	utilization
130	condition	95	large_scale
131	development	94	nscna (Hydrogen supply chain network design)
132	consumption	94	grid integrated
132	factor	03	safoty
135	alastrias	95	safety
134	electrical	93	protection
135	water	92	reliability
136	small	92	quantity
137	pvpf	92	installation
138	optimal	92	raw
139	main	91	construction
140	fluctuation	89	tank
141	electric	89	stationary
142	alternative	89	spatial
143	scenario	88	pem
144	form	88	electrolyzer
145	achieve	88	rotor
146	long	87	decentralize
147	instal	87	risk
148	discharge	87	converter
1/0	variable	86	climate
142	tochnique	00 95	rogulation
100	tectunque	00 05	regulation
151	point	65	photovoltaic
152	improve	85	distance
153	addition	85	tootprint
154	order	84	environment
155	methane	84	delivery

Table A2. Cont.

N	List of 1	A List of Purposefully	
N0.	Words	Frequency of Occurrence	Chosen Words
156	chain	83	clean
157	algorithm	83	transformation
158	reduction	82	sustainability
159	ther	81	power_to_gas
160	expansion	81	utility
161	day	81	mechanism
162	cover	81	electrolysers
163	area	81	on_site
164	review	80	small_scale
165	cycle	80	green
166	twh	79	electrolyser
167	specific	79	photovoltaics
168	effect	79	hydro
169	constraint	79	greenhouse
170	impact	78	pollution
171	average	78	biomass
172	analysis	78	thermal
173	rate	77	methantion
174	product	77	geothermal
175	emission	77	social
176	set	76	reconversion
177	country	76	hfcv
177	country	70	(hydrogen fuel cell vehicle)
178	work	75	meteorological
179	liquid	75	hydroelectric
190	ovpost	75	fc
100	expect	75	(Fuel Cells)
181	additional	75	full_load
182	industry	74	business
183	region	73	winter
184	employ	73	refuelling
185	role	72	offshore
186	researcher	72	logistic
187	present	72	bulk
188	period	72	sun
189	issue	72	road

Table A2. Cont.

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