sustainability

Article

Global Research Trends on Shale Gas from 2010–2020 Using a Bibliometric Approach

Temitope Love Baiyegunhi [1], Christopher Baiyegunhi [1,*] and Benedict Kinshasa Pharoe [2]

1 Department of Geology and Mining, School of Physical and Mineral Sciences, University of Limpopo, Sovenga 0727, South Africa; lovetemitope18@gmail.com
2 Department of Geology, University of Fort Hare, Alice 5700, South Africa; bpharoe@ufh.ac.za
* Correspondence: christopher.baiyegunhi@ul.ac.za

Abstract: In the last few decades, shale gas resources have attracted much global attention as potential sources for clean and affordable energy. Due to this fact, coupled with the increasing energy shortfall, shale gas has become an increasingly attractive energy prospect from both an environmental and economic perspective. This development has led to the rapid growth in the number of researchers and publications in the field of shale gas. Although there are few review articles on the state of research on shale gas, the literature lacked a bibliometric analysis. This study is intended to fill the research gap by carrying out a bibliometric analysis of 9247 shale gas articles that were published between 2010 and 2020. The Web of Science database was used to collect the data. The analysis was performed to identify the most productive authors, institutions, countries, and sources, and to visualize existing collaborations as well as provide valuable information which could form the basis for establishing future collaboration. The analysis results revealed that Li J has the highest number of publications on shale gas whereas Loucks RG is the most cited author. The top three countries with the highest number of publications in shale gas research are China, USA, and Canada, while the China University of Petroleum (Beijing), China University of Geosciences, and Southwest Petroleum University China were the three top institutions with the highest number of publications. Fuel, International Journal of Coal Geology, and Marine and Petroleum Geology are the journals with the highest number of published articles on shale gas. The keyword analysis indicated that shale gas, hydraulic fracturing, pore structure, permeability, adsorption, kinetics, pyrolysis, organic matter, thermal maturity, and numerical simulation are the predominant research topics. This showed the multi-dimensional and multi-faceted character of the shale gas field. Besides, it appeared to be an exciting topic for further study that is based on a detailed evaluation of the shale gas literature. In fact, shale gas, hydraulic fracturing (fracking), CO_2 sequestration, kinetic, gas adsorption, diffusion, and simulation are becoming emerging research hotspots. The bibliometric analysis that was presented in this study has revealed valuable information about the most active institutions and countries, and the most influential authors in the field of shale gas which could form the basis for establishing future collaboration. Furthermore, it can help researchers to understand the global research trend in shale gas as well as provide references for establishing future research directions.

Keywords: shale gas; research trend; bibliometric analysis; scientific production; collaboration network

check for updates

Citation: Baiyegunhi, T.L.; Baiyegunhi, C.; Pharoe, B.K. Global Research Trends on Shale Gas from 2010–2020 Using a Bibliometric Approach. *Sustainability* **2022**, *14*, 3461. https://doi.org/10.3390/su14063461

Academic Editor: Adam Smoliński

Received: 1 December 2021
Accepted: 18 January 2022
Published: 16 March 2022

1. Introduction

The production of commercial quantities of shale gas was very uncommon several decades ago [1,2]. However, with the recent boom or commercial production of shale gas from the Barnett Shale in the central Texas, United States of America (USA), many countries and exploration companies are intensifying their pursuit for the shale resource plays, expecting to find and exploit the next Barnett Shale. The natural gas that is extracted from underground shale deposits is globally known as shale gas, and it has become a progressively vital source of natural gas in the United States (US) over the past decade and interest has spread to Canada, Europe, Asia, and Australia (Figure 1; Table 1). The methods that were used for the Barnett Shales are now being applied to other sedimentary basins in the world, where conditions (i.e., organic-rich and thermally matured shales) are favorable for coaxing natural gas from the shales. Shale gas denotes a self-sourced unconventional natural gas that occurs primarily within fine-grained, low-permeability and organic-rich siliciclastic sedimentary rocks [3]. Despite the prefix 'shale', this natural gas can also occur within a variety of rocks other than shale, including mudstones, siltstones, and carbonates [3,4]. Shale gas is generated and stored in-situ as adsorbed gas in kerogen and clay particles, and as free gas in the intergranular pore spaces and fractures [3]. It can also be stored as solute gas in bitumen and organic matter [5]. As more countries are showing keen interest in the shale gas revolution, exploration companies are realizing that an integrated method is vital to success.

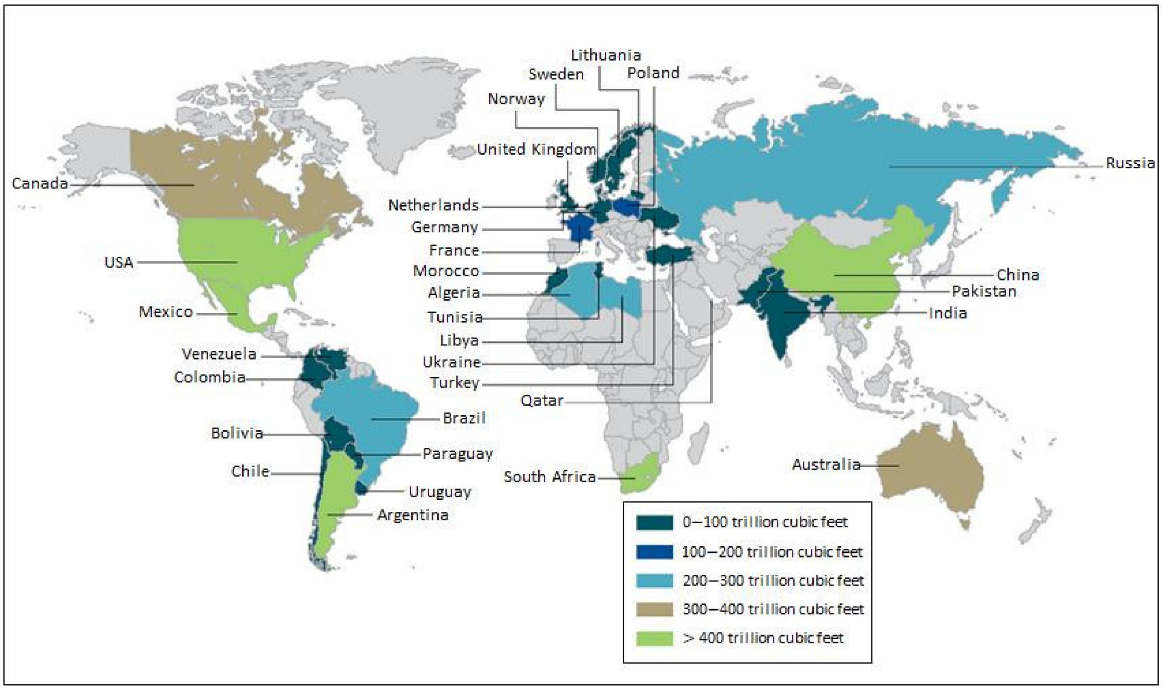

Figure 1. Map showing the distribution of global shale gas resources [1]. Note: Russian has the largest proven natural gas reserve of nearly 1570 tcf. However, data on shale gas reserve is not available. Also, data on Russia and Middle East were not provided by EIA due to reasons such as lack of information availability.

Table 1. Technologically recoverable global shale gas reserve estimates [1].

Country	Shale Gas Reserves in Trillion Cubic Feet (tcf)
France	180
Poland	187
Brazil	226
Algeria	231
Libya	290
Canada	388
Australia	396
South Africa	485
Mexico	681
Argentina	774
United States (US)	862
China	1275
Others	647

The discovery of shale gas is one of the most significant energy revolutions in the last two decades and it is effectively changing the global energy market to date [6–13]. Shale gas represents a new opportunity or chance to strengthen energy security and at the same time, reducing emissions [14,15]. As a typical developing technology, shale gas has attracted global attention from the governments, non-governmental organizations (NGO's), and researchers, which has led to the rapid growth rate of vital information on shale gas [16,17]. Fracking, also known as hydraulic fracturing, is a method of extracting oil and gas from the earth by drilling deep wells and injecting a mixture of liquids and chemicals at high pressure. Presently, the development of shale resources (shale gas) does not only bring new or innovative opportunities, but it also comes with some challenges (risks) or uncertain results. These risks have grown over time due to unknown factors and could vary with geographical locations.

The prospect of fracking in the Karoo has sparked a heated debate. The main concerns about shale gas exploration and extraction are the use of water and the environmental impact of hydraulic fracturing (i.e., fluid migration and shale degassing are poorly or not well understood). Excessive water use, chemical spills at the surface, the effects of sand mining for use in the hydraulic fracturing process, surface water quality degradation from waste fluid disposal, groundwater quality degradation, and induced seismicity from the injection of waste fluids into deep disposal wells are all environmental issues that are specifically related to hydraulic fracturing. Most of the people and farming activity in the Karoo depends on groundwater. With fracking requiring a large volume of water, nearly 20,000 m^3 per borehole [5,7], it poses a serious challenge with regards to water shortage. There is also the possibility that methane will migrate to the surface after the shale has been fractured. The Karoo also has a unique underground structure with many underground water channels, which may present new risks that have not been encountered at previously established sites in the USA. Other air contaminants are released during the various drilling procedures, which include the construction and operation of the well site, transportation of materials and equipment, and waste disposal. Some of the pollutants that are released by drilling include benzene, toluene, xylene, and ethyl benzene (BTEX), particulate matter and dust, ground level ozone, or smog, nitrogen oxides, carbon monoxide, formaldehyde, and metals that are found in diesel fuel combustion, and exposure to these pollutants has been linked to short-term illness, cancer, organ damage, nervous system disorders, birth defects, and even death [11–14]. The fracking debate is difficult to understand; pro-fracking supporters are frequently the same people who deny that humans are causing global warming. Fracking is big business and companies with vested interests are attempting to sway public opinion. So far, impact studies for fracking in the Karoo have been based on estimates, with those in favor of fracking seemingly using the best case scenario figures [4]. However, anti-fracking groups make exaggerated claims as well. Both sides' credibility is close to nil. This debate exemplifies how some scientific disagreements may not be resolved.

Over the last 10 years, fracking has changed that balance and led to a new boom in oil and gas production globally; especially in the USA. Some change comes from the oil price cycle, while some change comes from the increasing concern of environmental health. The total quantity of crude oil production in the USA has roughly tripled in the decade spanning from 2010 to 2020. Over the same time period, the amount of total US oil consumption that was provided by imports fell substantially. Likewise, prices across the board reflected the increased production. The timeliness of international collaboration has significantly assisted in reducing the risks that are associated with shale gas exploration and exploitation. There is a general belief that collaboration is very good and important in research, and it should be practiced or encouraged [18]. According to [19], research collaboration is an important way to develop as scientists. This development refers to improvement in terms of skills, knowledge, ideas, and information that is embodied in persons, and ultimately impact persons' performance in the near future. The exploration and exploitation of shale gas is becoming more complicated as the regional geology of the area differs, making collaboration or teamwork necessary [20]. With most countries looking for cleaner sources of energy and the rapid growth in shale gas research, geoscientists are specializing in a particular research field with limited skills or exposure to advance technology [21]. Hence, the interaction with others is important to gain new knowledge. [22] indicated that research collaboration among scientists is a crucial form that reflects scientific interactions, which often leads to "contact and connections for future work". As reported by [23], in a survey of 195 university professors, 90% of the respondents shows that research collaboration brings about new knowledge, information and ideas. Scientific collaboration facilitates the increase in scientists' skills and knowledge, irrespective of whether collaboration is between junior scientists and experienced scientists, or between scientists of the same career status [24]. Specifically, research collaboration with an experienced scientist exposes the inexperienced scientist to the knowledge new ideas, information, and skills that are regarded to be difficult to acquire [25].

Countries all over the world are promoting the advancement of collaboration between researchers and institutions. The rate of international collaboration has significantly increased over the years with the belief that such collaboration will bring about several benefits (i.e., cost-savings, greater creativity, higher quality, and more impactful research). Owing to the increasing or rising need for collaboration between researchers, bibliometric analysis of research collaborations is also growing fast, from both the institutional and country levels through to the individual level [26–29]. The bibliometric technique is a quantitative statistical analysis method that is widely used to provide a general idea of extensive publications and to understand the present status quo in that particular research field [30–34]. As documented by [35,36], bibliometric analysis is a vital tool to researchers because it helps in determining the research trend and hotspots of a particular study subject and provides references for establishing future research directions and collaboration international with other institutions and countries. However, despite the fact that a substantial number of publications are available on the different aspects of shale gas, very few bibliometric analyses has been performed on shale gas literature, resulting in the lack of information on the global research trend of shale gas and the level of research contributions in the field is unknown or poorly documented. Hence, the purpose of this study is to reveal the basic characteristics of the scientific activities in shale gas research between 2010 and 2020. The study also investigates research performance as well as examines the most influential authors and collaboration networks on institutional and individual levels. The objective of the study is to provide valuable shale gas information to any section of society, policymakers, and businesses that are involved in shale gas development. To achieve the objective of this study, the following research questions were addressed:

- What is the global research trend of scientific publications on shale gas from 2010 to 2020?
- What information can be generated or revealed from this trend?
- What are the future research directions in the field of shale gas?

The answers to the aforementioned research questions would enable stakeholders (i.e., (governments, non-governmental organizations (NGO's), scientific community, etc.):

- to recognize the most productive authors, institutions, sources, and countries in this research area,
- to know the leading research paths and impact from authors, sources, countries, and research topics in the shale gas literature,
- to understand how publications on shale gas are clustered or understand the collaboration network of this research field,
- to provide vital information for future research directions and to develop publication strategies.

The paper is structured as follows: Section 2 gives an overview of shale gas and major bibliometric articles in this field. The methodology is documented in Section 3. Section 4 deals with the results and discussion of the bibliometric analysis. In addition, Section 4 presents the conclusions of the study and outlines possible directions for future research.

2. Methodology and Data

In this study, the bibliometric technique was employed to quantitatively appraise the shale gas literature. This method is summarized in Figure 2 and described in Sections 2.1 and 2.2.

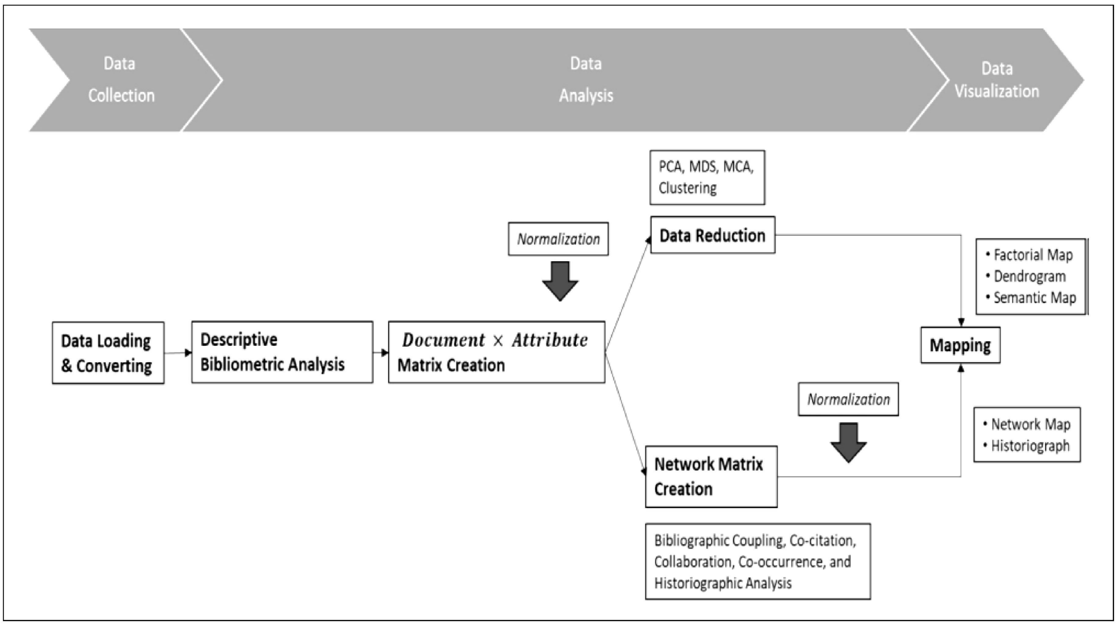

Figure 2. Methodology flow chart (adapted from [37,38]).

2.1. Data Sources and Collection

The science citation index (SCI) database is thought to be the most reliable bibliographic resource and it has been widely used to study the trends of research in different scientific fields [39–42]. To retrieve the related articles for this study, the Web of Science SCI Expanded database (online version) was accessed on the 10 October 2021. The Science Citation Index Expanded (SCIE) database was used and it was chosen because it covers most of the vital or relevant journals in the fields of natural sciences [43,44]. The search was "shale gas", and the retrieval time was from 2010 up to 2020. Some search restrictions were applied during data collection. For example, the document type was limited to "article" and language to "English". The search document type was limited to articles to ascertain the quality of the review as articles go through a rigorous peer-reviewed process. Also, the language was limited to English because English is the most frequently or widely used language in scientific publications [45]. As reported by [46], about 97–100% publications in Google Scholar are written in English, and for unique citations, the percentage ranges from 65–80% (unique cited documents that were published in the English language in the earth and life Sciences area are over 70%). According to [46], Chinese is the second most frequently used language in publication and no non-English natural or geoscience journals are ranked within the top 50 Scimago rankings [47]. From the search, a total of 9262 articles were generated and these articles were verified and examined based on their content or contribution to the research topic "shale gas". Thereafter, the bibliographic information of the 9262 publications was exported as a plain text file and downloaded for bibliometric analysis (Table 2). The "full record" was used when exporting the data and the downloaded information included authors, title, affiliation of the authors, year of publication, citations, author keywords, keywords plus, countries of publications, institutions, journals, and citations.

Table 2. Summary of the data that were used for the bibliometric analysis.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2010:2020
Sources (journals, books, etc)	817
Documents	9247
Average years from publication	3.88
Average citations per documents	16.75
Average citations per year per doc	2.791
References	1
DOCUMENT TYPES	
Article	9247
DOCUMENT CONTENTS	
Keywords plus (ID)	10,646
Author's keywords (DE)	16,186
AUTHORS	
Authors	17,856
Author appearances	45,276
Authors of single-authored documents	240
Authors of multi-authored documents	17,616
AUTHORS COLLABORATION	
Single-authored documents	316
Documents per author	0.518
Authors per document	1.93
Co-Authors per documents	4.9
Collaboration index	1.97

2.2. Data Analysis and Visualization

The collected data (in plain text file) was imported into RStudio (version: v.3.4.1) with the bibliometrix R-package. The shiny app (biblioshiny) of the bibliometrix package was used to process and analyzed the bibliographic data. The data was checked for completeness, duplicate publications, and misspelled elements before the analysis and no irregular data or missing information was found. Hence, the network analysis was performed with the same amount of data that were exported from the Web of Science SCI Expanded database (9262 publications). The network analysis was separated into three parts as suggested by [48]. These parts are:

(1) Word, keyword, and co-keyword analyses;
(2) Scientific collaboration mapping; and the
(3) Top authors, sources, and keywords relations.

The "word, keyword, and co-keyword analyses" were performed to describe and visualize the structure of scientific fields of a particular group of publications [48]. As was indicated by [49], the level of scientific collaboration can be determined using the citation and co-citation analyses. The scientific collaboration in "shale gas" research was mapped and analyzed using the outcomes of the co-authorship network of countries and the citation network of authors, countries, and sources. The top authors, sources, and keywords relationships were established using the three fields plot of the Biblioshiny package. This tool allows the visualization of the major items of three selected fields (i.e., authors, authors' keywords, sources) and illustrates how the selected items are interlinked or related using a Sankey diagram. The biblioshiny app was used to create conceptual maps and a co-citation network. Thereafter, a presentation was made on the research trends and directions for future research in the field of shale gas.

2.3. Limitations

Despite the fact that efforts were made to carry out the bibliometric analysis in the best and most accurate manner, this study still has some limitations. As indicated in Section 2.1, the analysis was performed using the WoS-indexed publications only. Consequently, there could be a possibility that it is not totally complete as there might be very few important publications on shale gas that are not part of the WoS database. Nevertheless, the WoS database gives the highest quality standard. The use of a single type of language (English) and document (article) could also limit the generalizable fact that is acceptable in all the countries across the globe. Considering the fact that over 95% of the publications in Google Scholar are written in English [46], the limitation could be negligible.

3. Results and Discussion

The bibliometric analysis commenced with the description of the general bibliometric statistics. Afterwards, the study examined the authors (i.e., authors contributions, citations, keywords, and affiliations); sources (i.e., journal's contributions, H-index, and citations); countries of research (i.e., country's contributions, H-index, and citations); relationship between the authors-sources-country; and the collaboration network between the authors, affiliations (institutions), and countries.

3.1. General Statistics (Publication Output and Growth)

The bibliometric analysis covered a period of 11 years of scientific production, spanning from 2010–2020. The characteristics of the 9247 articles on shale gas within the survey period are presented in Table 1. These articles were published by 17,856 authors in 817 journals, with 45,276 author appearances, 0.52 article/author, 1.93 authors/article, 4.90 co-authors/article, and a collaboration index of 1.97. The average citations/articles and citations/year/article are 16.75% and 2.79%, respectively. The annual number of published articles increased annually from 2010 to 2020, while the average article citations per year peaked in 2012 (Figure 3).

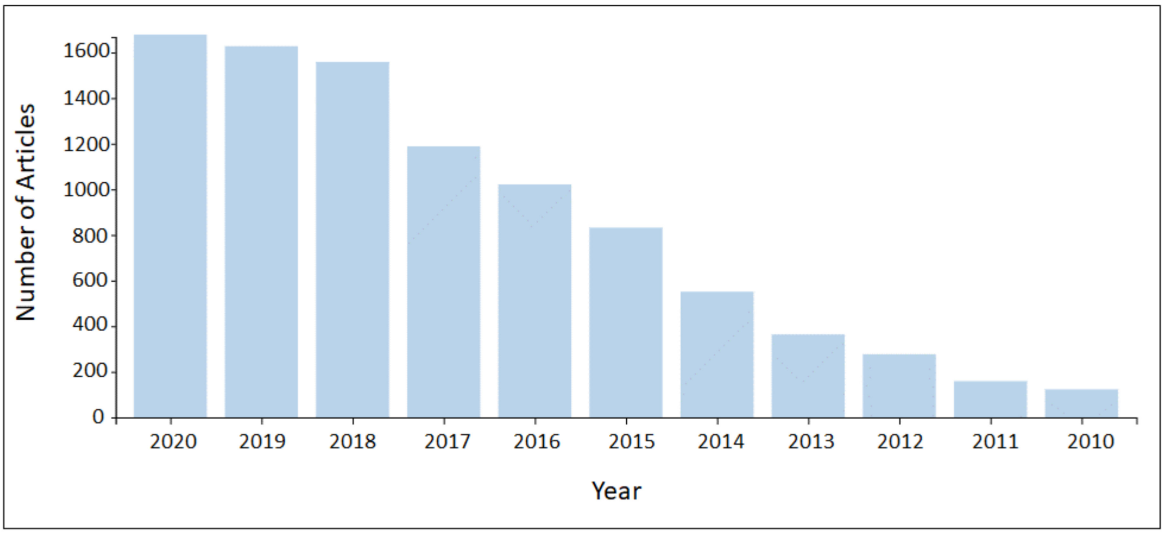

Figure 3. The annual number of articles that were published from 2010 to 2020 (author's elaboration using biblioshiny).

3.2. Authors

The authors contributions, affiliations, and authors' citations in shale gas research as well as the author's keywords, total number of citations, and the dominance ranking factor are discussed in this section.

3.2.1. Authors Contributions and Citations

The number of publications (articles) and number of citations of the 20 top ranking authors are shown in Figure 4 and Table 3. Figure 4 shows that Li J has the highest number of publications with 136 articles, followed by Jiang ZX with 126 articles, and Wang Y with 120 publications. In most of the publications, the aforementioned authors served as co-authors and as the main or primary authors in few publications. The number of times that a specific article was cited can reveal its influence in this field [50]. With regards to research citations on shale gas (Table 3), Loucks (2012) has the highest number of citations with a total citations (TC) rate of 1068 (averaging 106.6 TC/year), followed by Clarkson (2013) with 834 citations (averaging 92.7 TC/year), and Chalmers (2012) with 798 citations (averaging 79.8 TC/year). This shows that these articles offer high-quality information on shale gas-related research. The remaining 17 authors have less than 100 publications during the survey period (Figure 4).

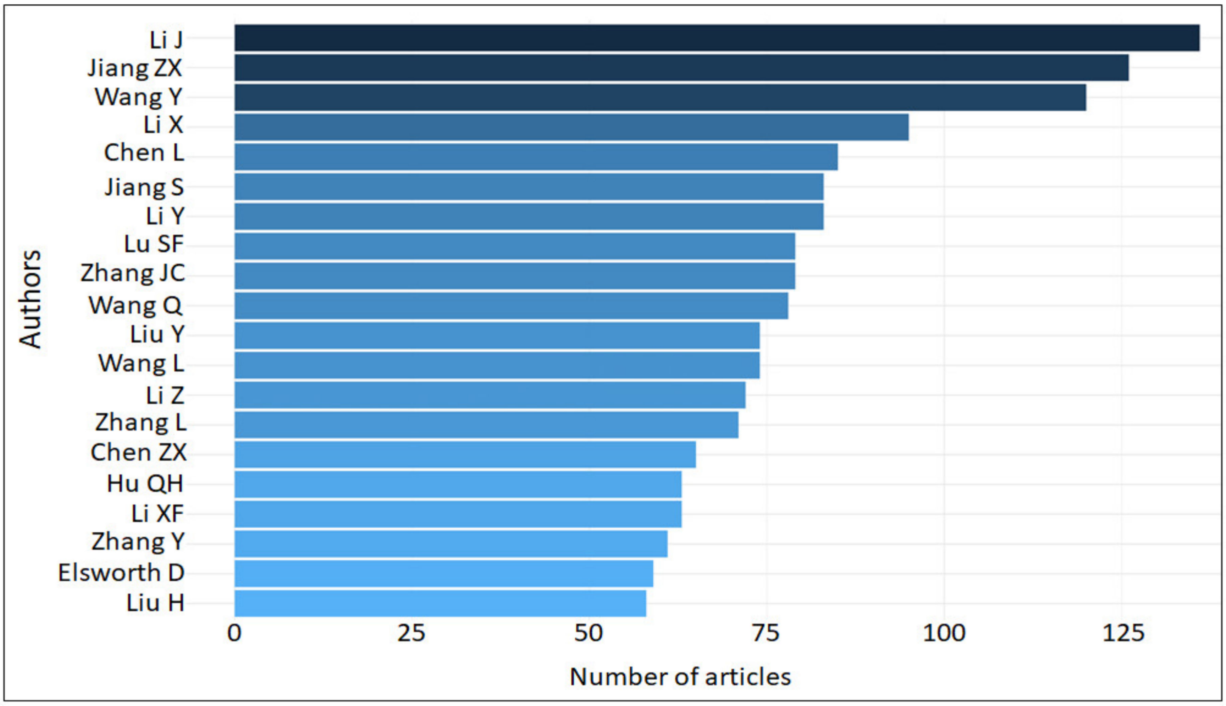

Figure 4. Top 20 ranking authors with the highest number of publications.

Table 3. Top 20 ranking authors with the highest number of citations.

AUTHOR	YEAR	DOI	JOURNAL	TOTAL CITATIONS (TC)	TC PER YEAR	NORMALIZED TC
LOUCKS RG	2012	10.1306/08171111061	AAPG BULL	1068	106.8	18.95
CLARKSON CR	2013	10.1016/j.fuel.2012.06.119	FUEL	834	92.67	17.16
CHALMERS GR	2012	10.1306/10171111052	AAPG BULL	798	79.80	14.16
OSBORN SG	2011	10.1073/pnas.1100682108	P NATL ACAD SCI USA	766	69.64	15.08
ZHANG TW	2012	10.1016/j.orggeochem.2012.03.012	ORG GEOCHEM	615	61.50	10.91
MILLIKEN KL	2013	10.1306/07231212048	AAPG BULL	572	63.56	11.77
GREGORY KB	2011	10.2113/gselements.7.3.181	ELEMENTS	495	45.00	9.75
KUILA U	2013	10.1111/1365-2478.12028	GEOPHYS PROSPECT	487	54.11	10.02
SLATT RM	2011	10.1306/03301110145	AAPG BULL	455	41.36	8.96
KARGBO DM	2010	10.1021/es903811p	ENVIRON SCI TECHNOL	419	34.92	12.19
MASTALERZ M	2013	10.1306/04011312194	AAPG BULL	404	44.89	8.31
CURTIS ME	2012	10.1306/08151110188	AAPG BULL	381	38.10	6.76
GASPARIK M	2014	10.1016/j.coal.2013.06.010	INT J COAL GEOL	359	44.88	9.87
BURNHAM A	2012	10.1021/es201942m	ENVIRON SCI TECHNOL	344	34.40	6.11
JACKSON RB	2013	10.1073/pnas.1221635110	P NATL ACAD SCI USA	336	37.33	6.91
MIDDLETON RS	2015	10.1016/j.apenergy.2015.03.023	APPL ENERG	334	47.71	11.39
JI LM	2012	10.1016/j.apgeochem.2012.08.027	APPL GEOCHEM	330	33.00	5.86
YANG F	2014	10.1016/j.fuel.2013.07.040	FUEL	323	40.38	8.88
TIAN H	2013	10.1016/j.marpetgeo.2013.07.008	MAR PETROL GEOL	322	35.78	6.63
WARNER NR	2012	10.1073/pnas.1121181109	P NATL ACAD SCI USA	317	31.70	5.63

3.2.2. Author's Keywords

The author's keywords in articles are a tool to help indexers and search engines find relevant papers. If database search engines can find the authors' keywords, readers will be able to find the manuscript too. This will increase the number of people that are reading the manuscript and will likely lead to more citations. This information could be used to identify the research trend as well as the gaps in discussion and related fields that could be of interest as research areas. The top 50 commonly used keywords in the articles are presented in the form of a Word TreeMap. The TreeMap in Figure 5 outlines the blend of potential keywords, signifying shale gas and hydraulic fracturing. Shale gas is the most used keyword, whereas CO_2 sequestration is the least used keyword. Focusing on the keywords, other research areas which could be of interest are hydraulic fracturing or fracking, pore structure, shale reservoir, numerical simulation, and CO_2 sequestration. The topic dendrogram that is represented in Figure 6 shows the hierarchical order as well as the links between the keywords that are produced by the hierarchical clustering. The vertical lines and cut in Figure 6 facilitates the investigation and interpretation of the different clusters.

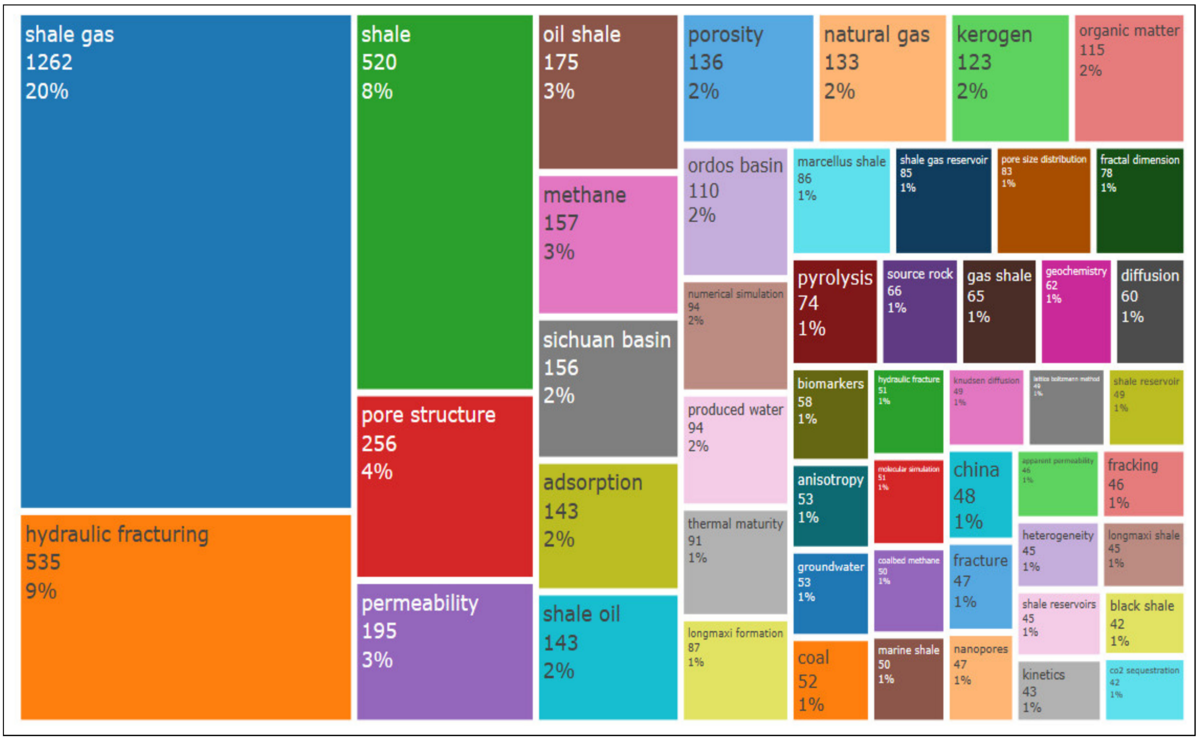

Figure 5. Word TreeMap (Source: Author's elaboration using Biblioshiny).

The topic dendrogram (Figure 6) is not aimed at finding the perfect level of connections between clusters, but it is projected to assess the approximate number clusters to ease further investigation or discussion on the research topic. With regard to the oil shale and pyrolysis (Figure 6), they are grouped into two major strands. The first strand focuses on kinetics, pore structure, and shale reservoirs, and the second strand deals with the source rock characteristics, numerical simulation, hydraulic fracturing, and organic geochemistry of the reservoir rocks that are associated with hydrocarbon generation. Critically examining the second strand, which is the strand with the largest subdivisions and developments, different research areas of interest as well as the associated or related fields can be defined or outlined. For example, if we consider the ongoing global attention on unconventional natural gas resources (i.e., hydraulic fracturing of shale source rock) as potential sources of clean and affordable energy, then we can see the importance of identifying the relationship between kinetics and mechanism of pyrolysis, and the production of synthetic motor fuels and chemical products. In the depletion of hydrocarbon resources (i.e., oil and natural gas), problems that are associated with the conversion of solid fossil fuels (i.e., coal and shale) into motor fuels and chemicals have now become of significant importance. Specifically, there has been a fast growing interest in the processing of organic carbon-rich shales (oil shale) for different fuels and chemical products.

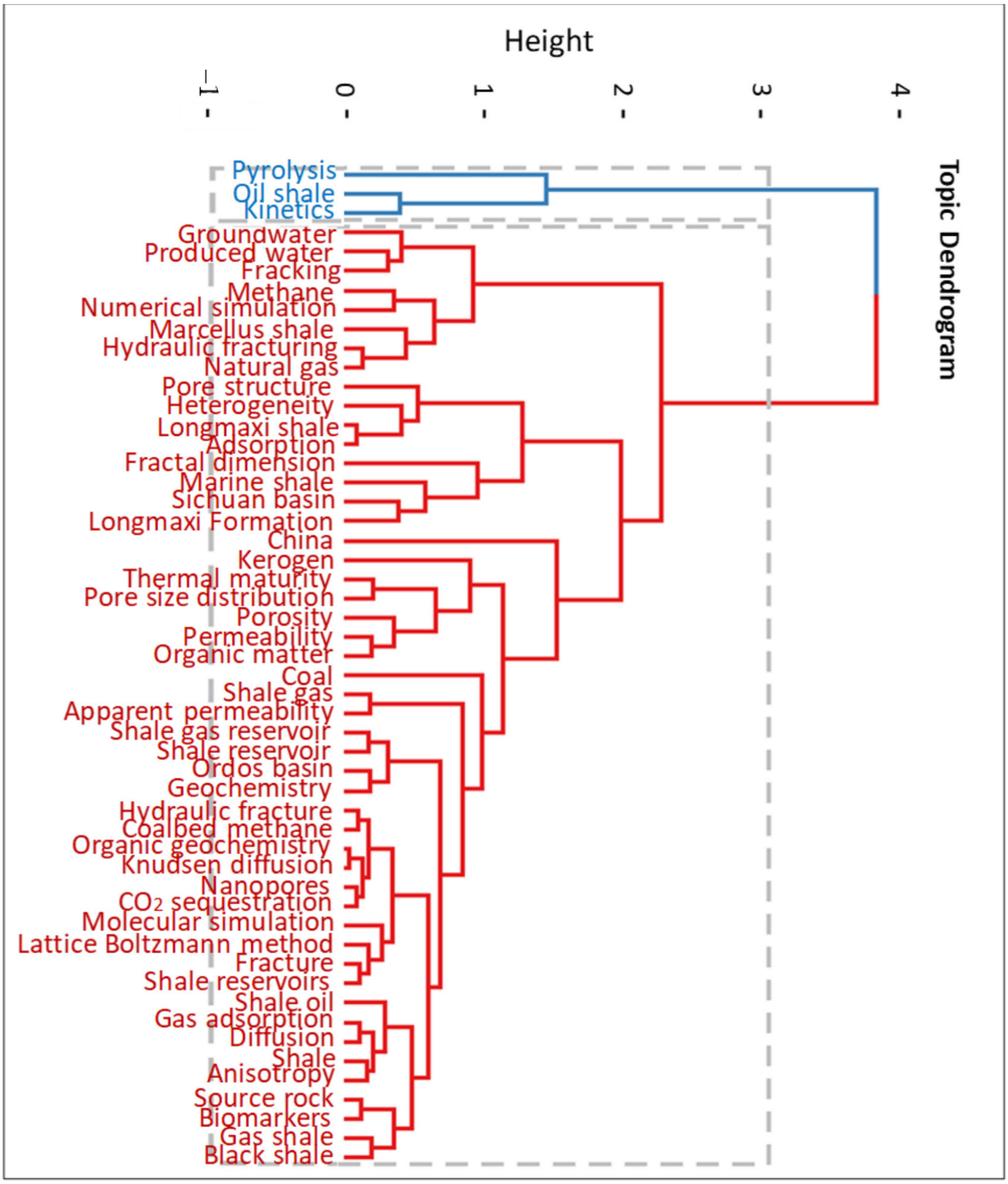

Figure 6. Topic dendrogram (Source: Author's elaboration using Biblioshiny).

As reported by [51], the world resources of oil shale on a shale oil basis are approximately 2.9 billion barrels. Nevertheless, the commercial processing of oil shale is only done or performed in a few countries (i.e., United States, China, Australia, Brazil, and Russia). Despite the fact that studies on the conversion of oil shale into synthetic motor fuels and chemical products started in the first half of the 20th century, to date, such problems still persist and are now a current or potential research interest. Serious research and development works are ongoing in the United States, China, Australia, Brazil, Russia, and other countries with substantial oil shale reserves. Scientifically, the conversion of oil shale into fuel and chemical products can be achieved using two main techniques. First, by gasification through which the organic matter of shale is transformed into a mixture of carbon oxides and hydrogen. Secondly, by pyrolysis along with the formation of solid, liquid, and gaseous products. The second technique is mostly used or proposed. This is due to the large quantity of data that have been gathered or generated on the kinetics and mechanism of the pyrolysis of liquid oil and raw gas materials as well as the application of the processes and process models. However, to date, studies on the pyrolysis of solid fuel, especially, oil shale, are still at the research level. A single method to the thermal processing of oil shale is hard to determine and the process parameters and implementation are also challenging to optimize due to the changes in the properties and composition of oil shale from different deposits and/or environment. The composition and quantitative ratios between the pyrolysis products of oil shale depend on, but are not limited to, the grain-size composition, kerogen source and type of kerogen, nature of organic matter, thermal maturity, burial depth, rate of heating, final process temperature, and pressure, etc. The aforementioned characteristics or parameters are shown on the word cloud of the author's keywords (Figure 7). Also, the word cloud in Figure 7 shows phrases that are related to the hydrocarbon exploitation, such as frackability, numerical simulation, pore size distribution, gas adsorption, and well stability.

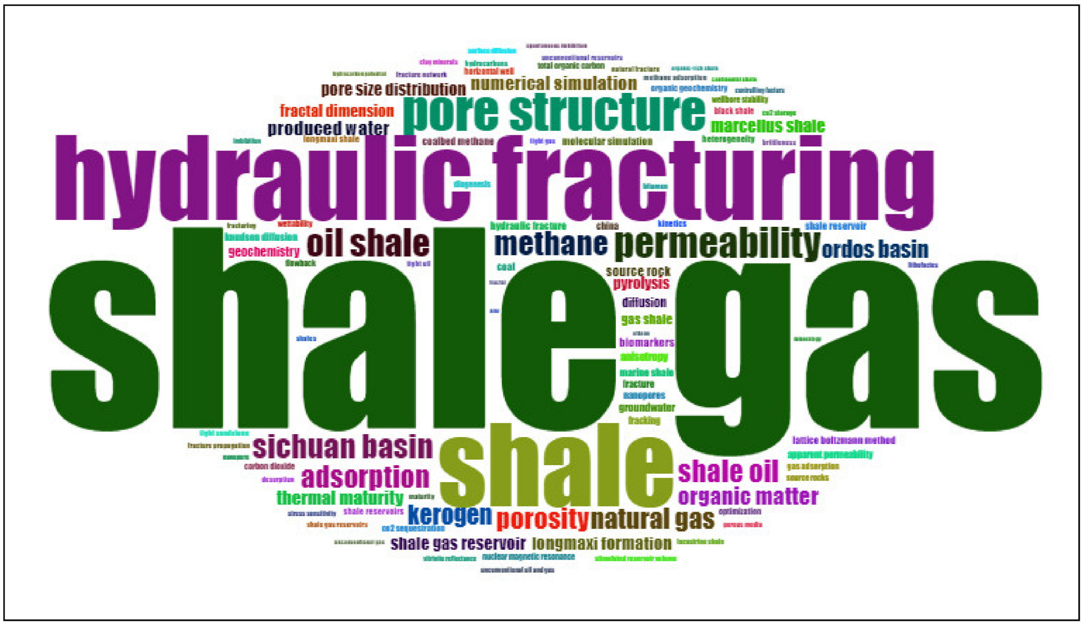

Figure 7. Word cloud of shale gas keywords (Source: Author's elaboration using Biblioshiny).

The trend topic of the author's keyword (Figure 8) was determined to reveal the search trends for the period spanning from 2012–2020. The identified research topics in 2012 are related to the heating rate and unconventional hydrocarbons. In 2013, the research recognized a number of articles that dealt with petroleum potential of sedimentary basins. Studies on oil shale ash, organic carbon, and gas hydrates dominated in 2014. The identified research topics in 2015 were related to maceral types and origin, shale gas, and unconventional hydrocarbons. In 2016, the research identified a number of articles that were related to vitrinite reflectance, unconventional gas, gas shale, oil shale, coal, and source rocks. The identified research topics in 2017 pertained to diagenesis, thermal maturity, kerogen types, and porosity. Most of the research studies in 2018 focused on organic-rich shale, methane gas, permeability, and hydraulic fracturing of the shale reserves and their environmental impact. In 2019, the research recognized a number of articles that dealt with reservoirs controlling factors, tight oil, shale reservoirs, and tight sandstones. The identified research topics in 2020 were related to tortuosity, surface roughness, nanometer-scale pores, and CO_2 adsorption. Also, the dynamic of the time-dependent occurrence of author keywords (word growth) was investigated based on the annual number of occurrences in publications. The analysis results revealed that 16,186 keywords were used in publications (Table 2). As depicted in Figure 8, the annual occurrences for the ten main author's keywords increased over time, although some of the keywords grew more rapidly than others. The keyword with the highest annual growth in occurrences over time was shale gas, peaking in 2018 and slightly decreasing thereafter (Figure 9).

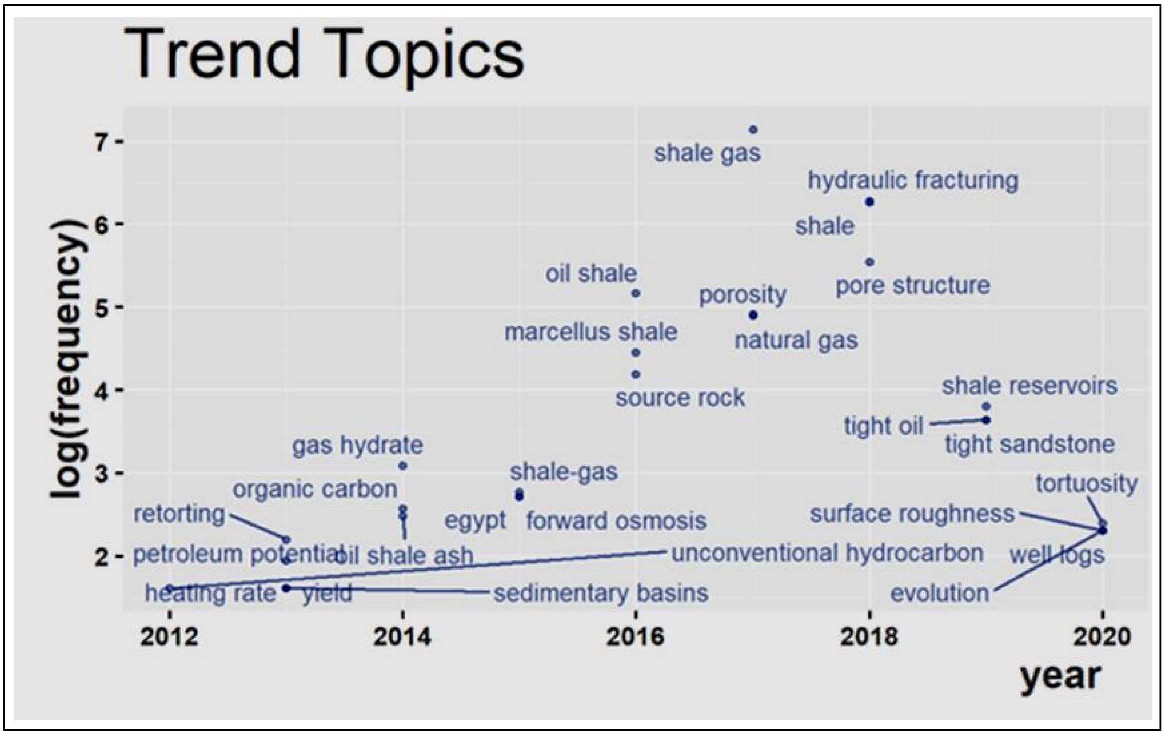

Figure 8. Trend topics of shale gas keywords (Source: Author's elaboration using Biblioshiny).

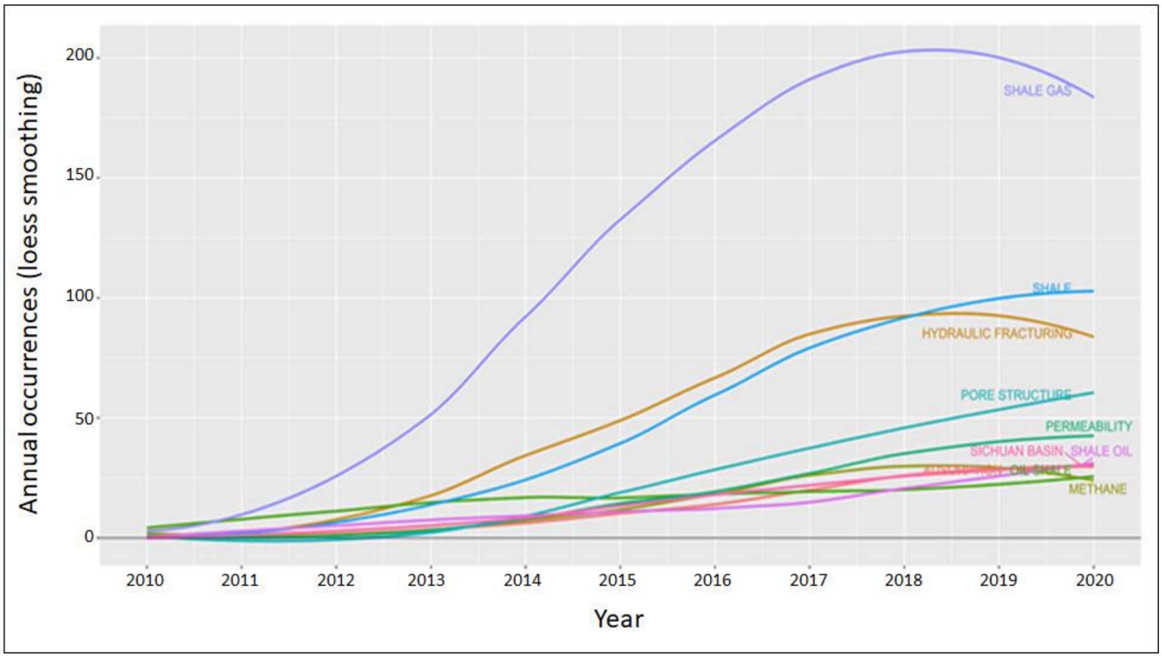

Figure 9. Word growth of shale gas keywords (Source: Author's elaboration using Biblioshiny).

3.2.3. Authors Affiliations

A total of 3557 affiliations were identified in this survey, showing the involvement of different institutions in shale gas studies. The top 20 authors' affiliations with shale gas publications are shown in Table 4. These top 20 authors' affiliations have a total of 7427 articles that were published between 2010 and 2020. China University of Petroleum (Beijing) was the most productive affiliation with 1561 publications, followed by China University of Geosciences with 754 publications. The Southwest Petroleum University China and China University of Mining and Technology are third and fourth, with publications of 604 and 485, respectively. China University of Petroleum (East China) occupied the fifth position with 482 publications. The top 20 journals have publications that were greater than 130 for the survey period (2010–2020).

Table 4. Author's affiliations in articles on shale gas (Source: Authors' elaboration using biblioshiny).

Ranking	Affiliations	Articles
1	China University of Petroleum (Beijing)	1561
2	China University of Geosciences	754
3	Southwest Petroleum University China	604
4	China University of Mining and Technology	485
5	China University of Petroleum (East China)	482
6	Pennsylvania State University	415
7	University of Texas at Austin	394
8	University of Calgary	333
9	University of Chinese Academy of Sciences (UCAS)	311
10	Texas A&M University	308
11	Research Institute of Petroleum Exploration and Development (RIPED)	299
12	Chengdu University of Technology	215
13	Institute of Geology and Geophysics (IGG)	198
14	Chongqing University	178
15	University of Alberta	167
16	Yangtze University	154
17	Stanford University	152
18	Research Institute of Petroleum Exploration & Development, Petro China	145
19	Shandong University of Science and Technology	138
20	University of Utah	134

3.3. Journals

A total of 817 journals were explored in this survey (Table 2), showing the extent of publication distribution and the global research interest in unconventional hydrocarbons, in particular, shale gas. Table 5 shows the list of the top 20 journals in which results from shale gas-related studies were mostly being published. A total of 4541 articles are presented in Table 5, representing about 49.1% of the total number of publications from 2010–2020. The Journal of Natural Gas Science and Engineering was the most productive journal with 693 publications, followed by the Journal of Petroleum Science and Engineering with 598 publications. The Marine and Petroleum Geology was third, with 463 publications and Fuel occupied the fourth position with a total number of 445 publications. The top 20 journals all have publications that were greater than 70 for the survey period (2010–2020). With regards to the journal citations, Fuel was the most cited journal with 12,350 citations, followed by the Journal of Natural Gas Science and Engineering Energy with 11,074 citations, the International Journal of Coal Geology had 9864 citations, and Marine and Petroleum Geology had 9477 citations. The top three most productive journals in terms of the number of publications that were generated from 2010–2020 relatively lagged behind with the fourth productive journal (Fuel) being the most cited journal during the survey period. In general, journals with high citations usually have a high H-index (Table 5) and tend to have a more important academic effect in shale gas research. In terms of the source or journal growth, the annual production of shale gas-related articles gradually increased from 2010 up to 2020 for the Journal of Petroleum Science and Engineering, Marine and Petroleum Geology, Fuel, and Energy & Fuels (Figure 10). Although the Journal of Petroleum Science and Engineering experienced a relatively higher production from 2017–2020. On the contrary, the amount of publications in the Journal of Natural Gas Science and Engineering increased from 2012 up to 2016 and thereafter steadily decreased until 2020 (Figure 10).

Table 5. Journals with the highest number of publications in the shale gas literature indexed in the Web of Science (WoS) database.

Ranking	Source	H-Index	G-Index	Tc	Np	Py-Start
1	Fuel	56	89	12,350	445	2010
2	International Journal of Coal Geology	55	86	9864	303	2011
3	Marine and Petroleum Geology	51	75	9477	463	2010
4	Environmental Science and Technology	50	84	8165	181	2010
5	Journal of Natural Gas Science and Engineering	45	61	11,074	693	2011
6	AAPG Bulletin	38	87	7912	149	2010
7	Energy and Fuels	38	65	6732	417	2010
8	Journal of Petroleum Science and Engineering	36	56	6975	598	2010
9	Petroleum Exploration and Development	29	54	3290	132	2012
10	SPE Journal	26	47	2702	137	2010
11	Energy	24	40	1803	73	2011
12	Scientific Reports	22	35	1371	72	2013
13	Science of the Total Environment	20	35	1526	92	2013
14	Industrial and Engineering Chemistry Research	20	33	1349	84	2011
15	Energies	14	19	860	188	2011
16	Interpretation-A Journal of Subsurface Characterization	12	15	509	130	2013
17	Oil Shale	12	15	463	85	2010
18	Energy Exploration and Exploitation	11	18	575	97	2011
19	Arabian Journal of Geosciences	10	15	372	103	2010
20	Geofluids	8	16	388	99	2013

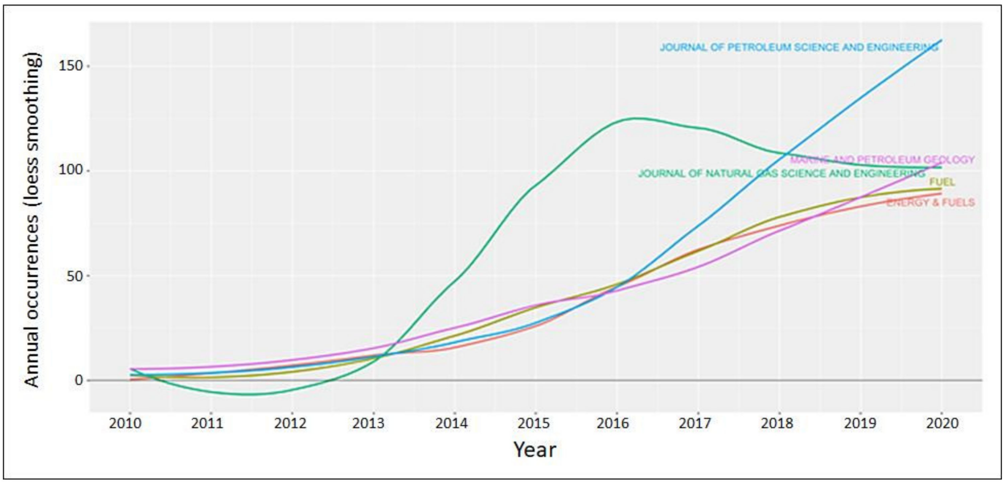

Figure 10. Source growth (Source: Author's elaboration using the biblioshiny).

3.4. Country Scientific Production

The number of publications and citations of the 20 top ranking countries are shown in Table 6. China had the highest production with 11,606 publications, followed by the United States with 6488 publications, and Canada with 1124 publications. The United Kingdom and Australia were third and fourth with publications of 734 and 668, respectively. Each of the remaining 17 countries still had more than 100 publications during the survey period (Table 6). According to the number of citations, the United States was the most cited country with a total number of citations of 61,748 (averaging 12.3 citations/year), followed by China with 51,128 citations (averaging 23.3 citations/year) and Canada with 10,541 citations (averaging 22.8 citations/year). These high numbers of citations perhaps suggest that these countries have a high influence in shale gas research. China held a leading position in terms of publication quantity, however, the United States came first in terms of citations, meaning that research works from the United States are more consulted and referenced as compared to publications from China. This is evidenced in the average number of article citations per year where the United States held the leading position (Table 6).

Table 6. Top 20 countries with the highest number of publications and citations in the shale gas literature indexed in the Web of Science (WoS) database.

Ranking	Country	Publications	Total Citations	Average Article Citations per Year
1	China	11,606	51,128	12.335
2	United States	6488	61,748	26.558
3	Canada	1124	10,541	22.816
4	United Kingdom	734	4218	16.038
5	Australia	668	3834	18.257
6	Germany	474	5403	31.596
7	France	307	2015	20.99
8	India	295	1370	11.513
9	Korea	241	1078	10.78
10	Poland	233	767	6.185
11	Saudi Arabia	194	557	8.439
12	Iran	177	703	8.369
13	Norway	173	1303	23.691
14	Russia	159	283	3.931
15	Japan	156	769	19.718
16	Brazil	143	401	8.020
17	Netherlands	132	742	19.526
18	Italy	128	538	12.810
19	Pakistan	125	124	3.647
20	Egypt	119	443	7.772

3.5. Top Authors, Keywords, Sources and Country Relations

The relationship between the authors, authors' keywords, sources, and country were visualized using the Biblioshiny's Three Fields Plot. These elements (i.e., authors, authors' keywords, and sources) were plotted on the Three Fields diagram in the form of rectangles with different colour codes. As indicated by [52], the "height of the rectangles depended on the value of the sum of the relations arising between the elements that the rectangle represents (one of the elements in the authors' keyword, author, and source diagram) and the diagram of other elements". The more relationships between the elements, the higher (in terms of height) the rectangles representing the elements. The Three Fields diagrams for research in the shale gas literature are depicted in Figures 11 and 12. Figure 11 shows the relationship between the main authors, authors' keywords, and sources, while the relationship between the main authors, authors' keywords, and country, is depicted in Figure 12. The analyses revealed the countries in which shale gas research was performed as well as the journals in which they are often published their research findings. Also, it shows the research topics (the topics that are represented by the authors' keywords,) that are related to shale gas. The analysis of the top authors, sources, and keywords shows that there are three authors (i.e., Jiang ZX, Li J, and Chen I) and five sources (i.e., Marine and Petroleum Geology, Journal of Natural Gas Science and Engineering, Energy and Fuels, Journal of Petroleum Science and Engineering, and Fuel) with strong relationships in literature regarding shale gas research. Also, Figure 12 indicates that most of the aforementioned research works were carried out in China and the United States.

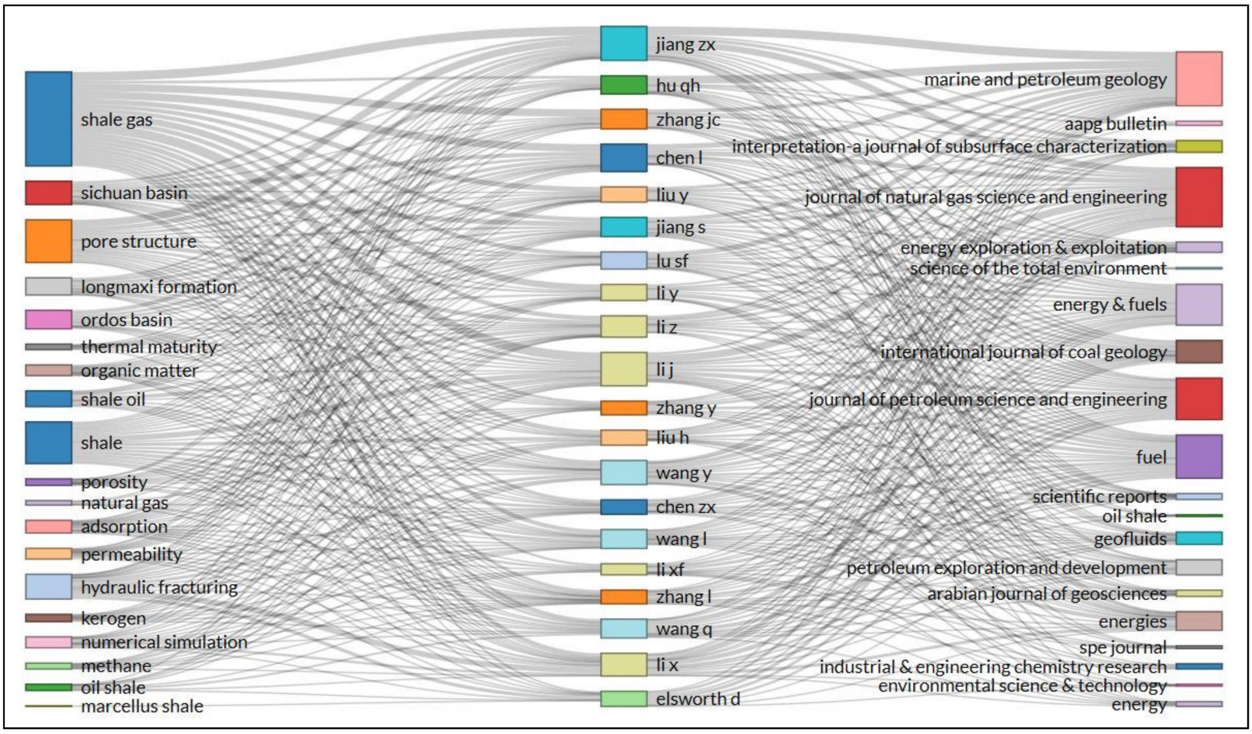

Figure 11. Relationships between authors' keywords (left), authors (middle), and sources (right) for research in the shale gas literature.

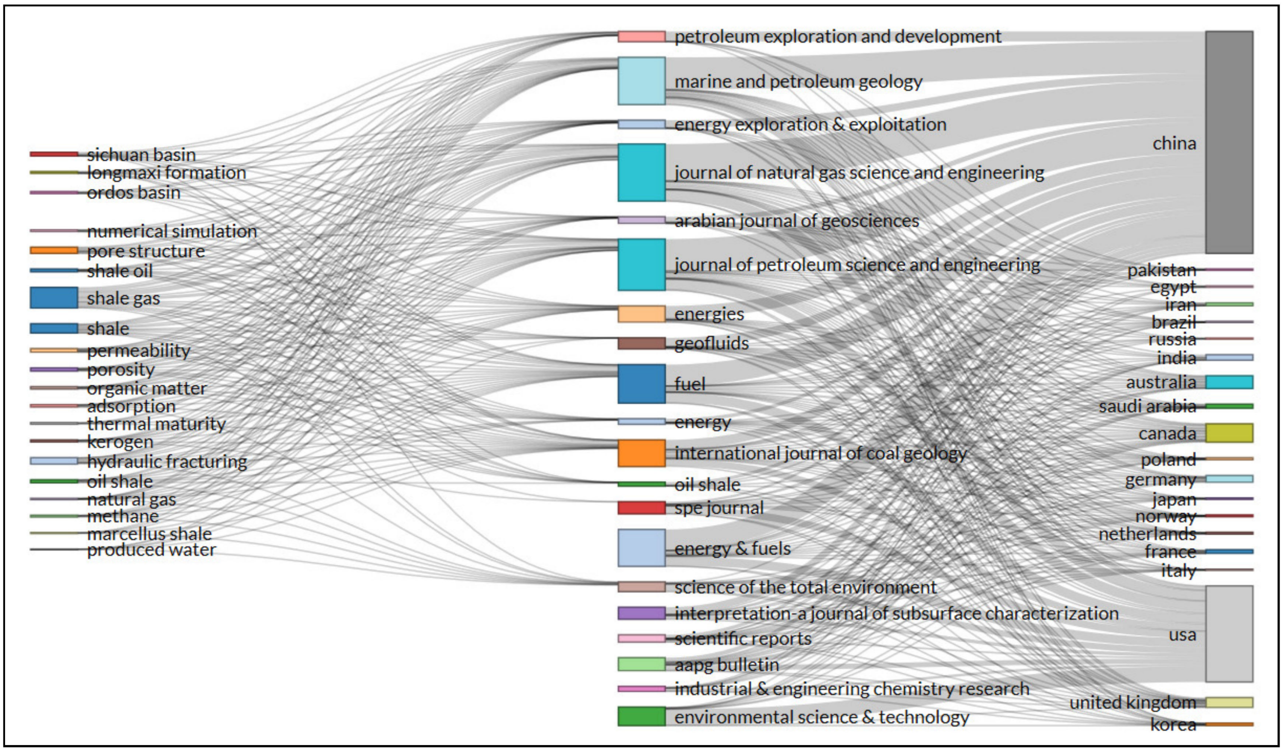

Figure 12. Relationships between authors' keywords (left), sources (middle), and authors (country) for research in the shale gas literature.

3.6. Collaboration Network

The global scientific collaboration between authors, affiliations (institutions), and countries as well as the research hotspots could be unraveled with the visualization of co-authorship existences between different countries. The networks that show such research collaboration between countries in the shale gas literature are illustrated in Figures 13–15. The size of the rectangle depicts the number of occurrences of co-authorship. The strength of the research collaboration was revealed by the distance between the rectangles in individual pairs. The more collaboration between the authors, institutions, and countries, the thicker and shorter the line between the two rectangles representing the two different authors, institutions, or countries. The total connection strength of a country and institution (affiliation) is shown by the number of publications in which the authors of a given paper denotes the two countries and institutions that are involved. As observed in the generated collaboration network (Figure 13), there were 92 countries that were represented by authors collaborating in the shale gas literature. China and the United States have the strongest or highest international collaboration of authors, followed by China and United Kingdom, and the United States and Canada (Figure 13). Australia, Germany, and France have high numbers of publications, nevertheless their international research collaboration was relatively low. The co-authorship network of institutions in the literature (Figure 14) shows that the China University of Petroleum and China University of Geosciences have the highest institutional co-authorship, followed by China University of Petroleum and Southwest Petroleum University. With regards to collaboration between authors, Jiang ZX, Chen I, and Song Y have the highest co-authorship, followed by Chen ZX, Wu KL, and Li J (Figure 15). The aforementioned information about the authors and sources with the highest number of publications and citations could assist future researchers of shale gas publications in planning and implementing an appropriate collaboration and publication strategy.

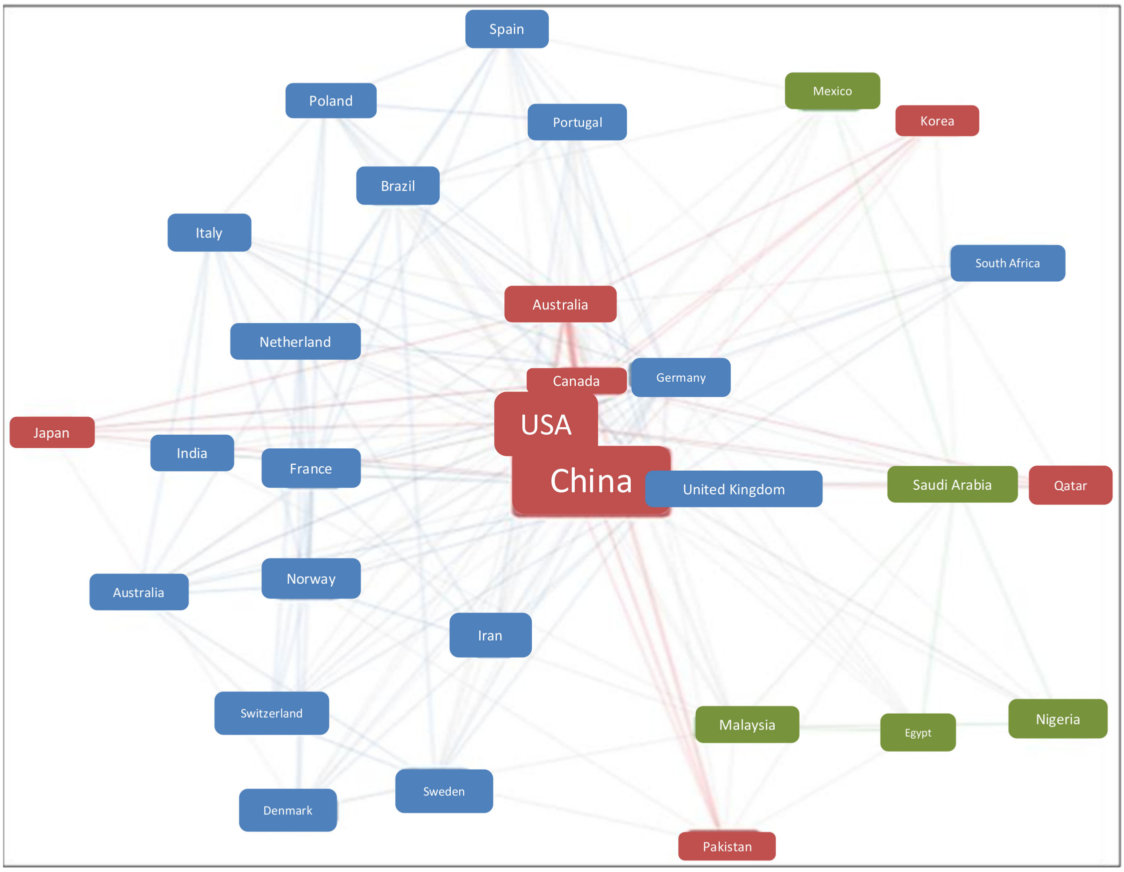

Figure 13. Co-authorship network of countries (Source: Author's elaboration using Biblioshiny).

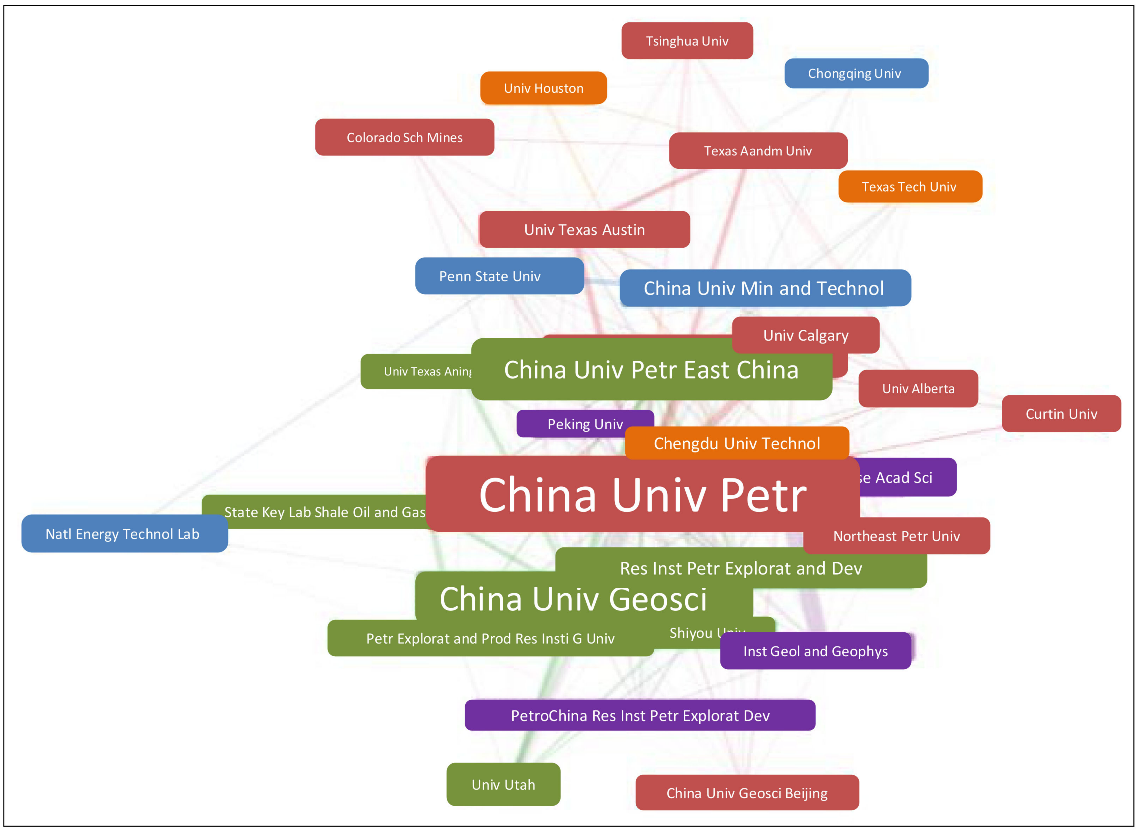

Figure 14. Co-authorship network of institutions or affiliations (Source: Authors' elaboration using Biblioshiny).

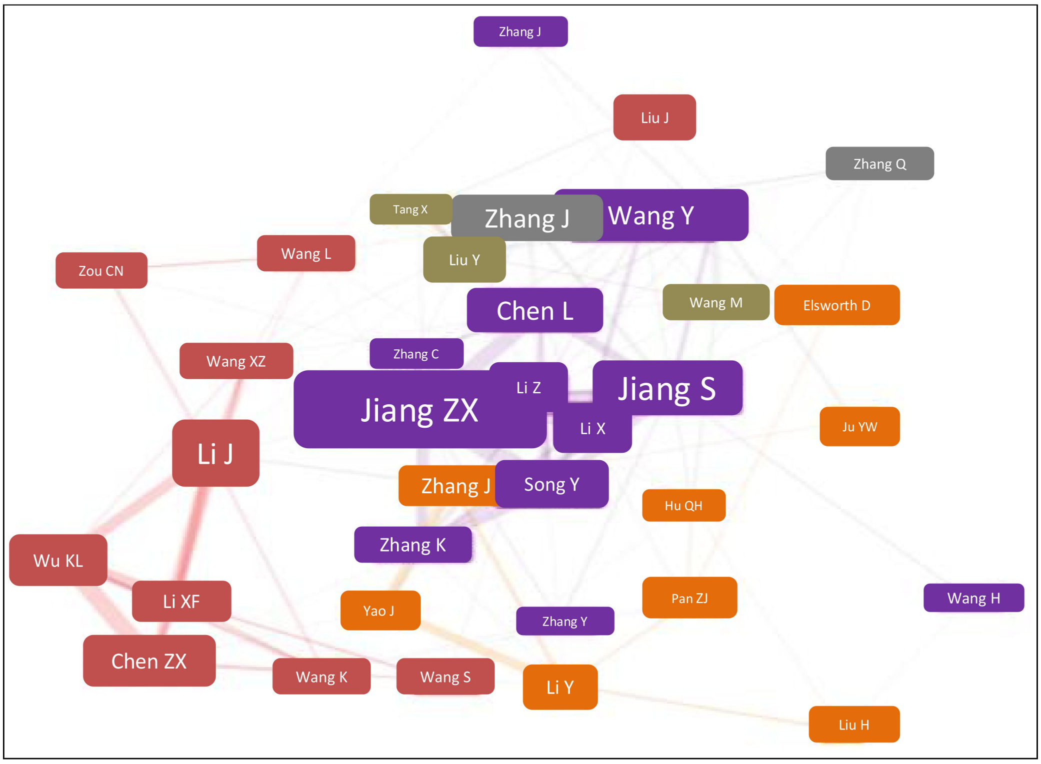

Figure 15. Co-authorship network of authors (Source: Author's elaboration using Biblioshiny).

4. Conclusions and Directions for Future Research

The success of the development of shale gas, especially in the USA, has created a lot of interest and attention in other countries in the world, in particular those that possess the potential of these resources. Considering the fact that many countries in the world are faced with the challenges of generating enough energy or power to meet the current and future demands of energy, it is extremely important to find solutions that would allow countries to meet the challenges of generating clean and sustainable energy. One of them is the shale gas concept, but its exploration and exploitation requires improvement in the present information and technical know-how. Therefore, scholars, companies, and policymakers that are responsible for energy development should have a broad theoretical knowledge in shale gas research. They should also familiarize themselves with the achievements and failures of companies/countries that have already attempted to exploit shale gas for energy production to benefit from their positive experience and avoid repeating their mistakes. For this reason, a bibliometric review of the publications on shale gas was presented with the information involving authorship, keywords, citation, countries, journals, institutions, authorship, and keywords. This was done so the current and future research trend of shale gas can be unraveled.

This article revealed that research on shale gas has witness continued growth around the world, which can be observed by its production and citations over the years. In general, the number of studies or publications on shale gas considerably improved during the survey period (2010–2020). China, USA, and Canada are the top three countries with the highest number of publications (productivity) in shale gas research. Based on the social network analysis, it was observed that China had a significant number of collaborations with the USA, Canada, Australia, Japan, and Pakistan. Nevertheless, there is still a lot of space for more international collaboration in this field. The China University of Petroleum (Beijing) is the institution with the highest number of articles on shale gas. Fuel, International Journal of Coal Geology, and Marine and Petroleum Geology are the top three journals with the highest number of published articles on shale gas. Li J takes the leading position in terms of the number of publications, while Loucks RG has the highest number of citations. The network analysis resulted in more interesting findings. The co-occurrence network of authors' keywords revealed that research in the shale gas is mostly concerned the following topics: 'hydraulic fracturing', 'pyrolysis', 'pore structure', 'kinetics', 'CO_2 sequestration', 'adsorption', and 'numerical simulation'. This showed the multi-dimensional and multi-faceted character of the shale gas field. Besides, it appeared to be an exciting topic for further study based on a detailed evaluation of the shale gas literature. Likewise, the Word TreeMap also showed that hydraulic fracturing, pore structure, kinetics, numerical simulation, and CO_2 sequestration are the unexplored topics that can be studied further by researchers. The bibliometric analysis revealed the most frequent topics (i.e., author keywords) as well as the most productive authors, countries, institutions, and sources in the shale gas research. Identifying the sources with the highest number of publications and citations could be used by future researchers on shale gas studies to espouse an appropriate publication strategy. Furthermore, the results show valuable information about the most active countries and institutions, and the most influential authors in the shale gas field, which could become the basis for establishing future collaboration. The results of the analysis could also be useful for practitioners and decision-makers because they could highlight publications that are the most influential in terms of the shale gas development, as evidenced by their number of citations.

The results that were obtained also showed that more studies are required in the field of shale gas, especially in Africa. Despite the fact that that Africa is contains fossil fuels (i.e., natural gas), the number of publications concerning the shale gas in Africa countries is very limited as compared to China, USA, and Europe. Thus, shale gas studies will be an important future research avenue in Africa. The main directions of future work will be related to pyrolysis (organic matter type and quality), CO_2 sequestration, kinetic, gas adsorption, diffusion, simulation, economic potential, hydraulic fracturing (fracking) and the associated geological hazards and ways to reduce their impact, and how this raises awareness in the community. The global future research directions on shale gas would be related to the time-component in the analyzed data (i.e., what has changed in the scientific interests over the last five years), and the possible correlation between scientific interest (i.e., scientific publications), public interest (i.e., social media), industrial (i.e., patents), and regulatory interest (i.e., standards). As indicated in Section 2.3 (Limitation), future research could profitably extend our analytical approach to include other databases (i.e., Scopus) and document types (i.e., conference proceedings and book chapters), and develop a detailed global vision of the shale gas literature, and include other languages (i.e., Chinese, Spanish, French, and German).

Author Contributions: Conceptualization, T.L.B. and C.B.; methodology, T.L.B., C.B. and B.K.P.; software, T.L.B., C.B. and B.K.P.; validation, T.L.B., C.B. and B.K.P.; formal analysis, T.L.B., C.B. and B.K.P.; investigation, T.L.B., C.B. and B.K.P.; resources, T.L.B., C.B. and B.K.P.; data curation, T.L.B., C.B. and B.K.P.; Writing—Original draft preparation, T.L.B. and C.B.; Writing—Review and editing, T.L.B., C.B. and B.K.P.; visualization, T.L.B.; supervision, C.B.; project administration, T.L.B., C.B. and B.K.P.; funding acquisition, T.L.B. All authors have read and agreed to the published version of the manuscript.

Funding: This publication and research were partially funded by the University of Fort Hare and University of Limpopo, South Africa.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Energy Information Administration. World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States. 2013. Available online: http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf (accessed on 10 October 2021).
2. Yang, Y.F.; Reniers, G.; Chen, G.H.; Goerlandt, F. A bibliometric review of laboratory safety in universities. *Saf. Sci.* **2019**, *120*, 14–24. [CrossRef]
3. Jiang, Z.; Zhang, W.; Liang, C.; Wang, Y.; Liu, H.; Chen, X. Basic characteristics and evaluation of shale oil reservoirs. *Pet. Res.* **2016**, *1*, 149–163. [CrossRef]
4. Baiyegunhi, C.; Liu, K.; Wagner, N.; Gwavava, O.; Oloniniyi, T.L. Geochemical Evaluation of the Permian Ecca Shale in the Eastern Cape Province, South Africa: Implications for Shale Gas Potential. *Acta Geol. Sin. Engl. Ed.* **2018**, *92*, 1193–1217. [CrossRef]
5. Speight, J.G. *Shale Gas Production Processes*; Elsevier: Oxford, UK, 2013; pp. 3–48.
6. Arthur, J.D.; Langhus, B.; Alleman, D. An overview of modern shale gas development in the United States. *All Consult.* **2008**, *3*, 14–17.
7. Boersma, T.; Johnson, C. The shale gas revolution: US and EU policy and research agendas. *Rev. Policy Res.* **2012**, *29*, 570–586. [CrossRef]
8. Deutch, J. The good news about gas. *Foreign Aff.* **2011**, *90*, 82–93.
9. Hughes, J.D. Energy: A reality check on the shale revolution. *Nature* **2013**, *494*, 307–315. [CrossRef] [PubMed]
10. Wang, Q.; Chen, X.; Jha, A.N.; Rogers, H. Natural gas from shale formation–the evolution, evidences and challenges of shale gas revolution in United States. *Renew. Sustain. Energy Rev.* **2014**, *30*, 1–28. [CrossRef]
11. Murphy, J. Turning point: On the cusp of an energy revolution. *Nat. Resour. Environ.* **2016**, *31*, 53–64.
12. Wang, Q.; Li, R. Journey to burning half of global coal: Trajectory and drivers of China's coal use. *Renew. Sustain. Energy Rev.* **2016**, *58*, 341–347. [CrossRef]
13. González, M.Y.V. Shale gas: Opportunities and challenges between Mexico and the United States. *Nat. Resour. J.* **2016**, *56*, 313–327.
14. Malakoff, D. The gas surge. *Science* **2014**, *344*, 1464–1471. [CrossRef]
15. Wang, Q. China should aim for a total cap on emissions. *Nature* **2014**, *512*, 115–129. [CrossRef]
16. Wang, Q.; Chen, X. Energy policies for managing China's carbon emission. *Renew. Sustain. Energy Rev.* **2015**, *50*, 470–479. [CrossRef]
17. Bilgen, S.; Sarıkaya, İ. New horizon in energy: Shale gas. *J. Nat. Gas Sci. Eng.* **2016**, *35*, 637–645. [CrossRef]
18. Borrett, S.R.; Moody, J.; Edelmann, A. The rise of network ecology: Maps of the topic diversity and scientific collaboration. *Ecol. Model.* **2014**, *293*, 111–138. [CrossRef]

19. Fisher, J.; Govindarajan, V. Profit center manager compensation: An examination of market, political and human capital factors. *Strateg. Manag. J.* **1992**, *13*, 205–217. [CrossRef]
20. Zeng, A.; Shen, Z.; Zhou, J.; Wu, J.; Fan, Y.; Wang, Y.; Stanley, H.E. The science of science: From the perspective of complex systems. *Phys. Rep.* **2017**, *714*, 1–73. [CrossRef]
21. Jones, B.F. The burden of knowledge and the "death of the renaissance man": Is innovation getting harder? *Rev. Econ. Stud.* **2009**, *76*, 283–317. [CrossRef]
22. Abbasi, A.; Hossain, L.; Wigand, R. Social capital and individual performance: A study of academic collaboration. *arXiv* **2011**, arXiv:1112.2460.
23. Melin, G. Pragmatism and self-organization: Research collaboration on the individual level. *Res. Policy* **2000**, *29*, 31–40. [CrossRef]
24. Bozeman, B.; Boardman, C. *Research Collaboration and Team Science: A State-of-the-Art Review and Agenda*; Springer Briefs in Entrepreneurship and Innovation; Springer: Berlin/Heidelberg, Germany, 2014; pp. 43–54.
25. Oettl, A. Reconceptualizing stars: Scientist helpfulness and peer performance. *Manag. Sci.* **2012**, *58*, 1122–1140. [CrossRef]
26. Bimber, B. Information and political engagement in America: The search for effects of information technology at the individual level. *Polit. Res.* **2001**, *54*, 53–67. [CrossRef]
27. Gauthier, I.; Tarr, M.J.; Moylan, J.; Skudlarski, P.; Gore, J.C.; Anderson, A.W. The fusiform "face area" is part of a network that processes faces at the individual level. *J. Cogn. Neurosci.* **2000**, *12*, 495–504. [CrossRef]
28. Bercovitz, J.; Feldman, M. Academic entrepreneurs: Organizational change at the individual level. *Organ. Sci.* **2008**, *19*, 69–89. [CrossRef]
29. Kwiek, M. The European research elite: A cross-national study of highly productive academics in 11 countries. *High. Educ.* **2016**, *71*, 379–397. [CrossRef]
30. Chen, D.; Liu, Z.; Luo, Z.H.; Webber, M.; Chen, J. Bibliometric and visualized analysis of emergy research. *Ecol. Eng.* **2016**, *90*, 285–293. [CrossRef]
31. Li, X.; Wu, P.; Shen, G.Q.; Wang, X.Y.; Teng, Y. Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. *Autom. Constr.* **2017**, *84*, 195–206. [CrossRef]
32. Van Nunen, K.; Li, J.; Reniers, G.; Ponnet, K. Bibliometric analysis of safety culture research. *Saf. Sci.* **2018**, *108*, 248–258. [CrossRef]
33. Yang, F.; Qiu, D. Exploring coal spontaneous combustion by bibliometric analysis. *Process. Saf. Environ. Prot.* **2019**, *132*, 1–10. [CrossRef]
34. Wang, Q.; Su, M.; Li, R. Is China the world's blockchain leader? Evidence, evolution and outlook of China's blockchain research. *J. Clean. Prod.* **2020**, *264*, 121–132. [CrossRef]
35. Boudry, C.; Baudouin, C.; Mouriaux, F. International publication trends in dryeye disease research: A bibliometric analysis. *Ocul. Surf.* **2018**, *16*, 173–179. [CrossRef]
36. Geng, Y.; Chen, W.; Liu, Z.; Chiu, A.S.F.; Han, W.Y.; Liu, Z.Q.; Zhong, S.Z.; Qian, Y.Y.; You, W.; Cui, X.W. A bibliometric review: Energy consumption and greenhouse gas emissions in the residential sector. *J. Clean. Prod.* **2017**, *159*, 301–316. [CrossRef]
37. Aria, M.; Cuccurullo, C. Bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
38. Firdaus, A.; Razak, M.F.A.; Feizollah, A.; Hashem, I.A.T.; Hazim, M.; Anuar, N.B. The rise of "blockchain": Bibliometric analysis of blockchain study. *Scientometrics* **2019**, *120*, 1289–1331. [CrossRef]
39. Zhuang, Y.; Liu, X.; Nguyen, T.; He, Q.; Hong, S. Global remote sensing research trends during 1991–2010: A bibliometric analysis. *Scientometrics* **2013**, *96*, 203–219. [CrossRef]
40. Liu, X.; Zhang, L.; Hong, S. Global biodiversity research during 1900–2009: A bibliometric analysis. *Biodivers. Conserv.* **2011**, *20*, 807–826. [CrossRef]
41. Fu, H.Z.; Ho, Y.S. Highly cited Antarctic articles using science citation index expanded: A bibliometric analysis. *Scientometrics* **2016**, *109*, 337–357. [CrossRef]
42. Li, R.; Wang, X.; Liu, Y.; Zhang, S.; Hanif, O. Research status and collaboration analysis based on big data mining: An empirical study of Alzheimer's disease. *Technol. Anal. Strateg. Manag.* **2020**, *33*, 379–395. [CrossRef]
43. Braun, T.; Schubert, A.; Zsindely, S. Nanoscience and nano-tecnology on the balance. *Scientometrics* **1997**, *38*, 321–325. [CrossRef]
44. Yu, H.; Wei, Y.M.; Tang, B.J.; Mi, Z.; Pan, S.Y. Assessment on the research trend of low carbon energy technology investment: A bibliometric analysis. *Appl. Energy* **2016**, *184*, 960–970. [CrossRef]
45. Cisneros, L.; Ibanescu, M.; Keen, C.; Lobato-Calleros, O.; Niebla-Zatarain, J. Bibliometric study of family business succession between 1939 and 2017: Mapping and analyzing authors' networks. *Scientometrics* **2018**, *117*, 919–951. [CrossRef]
46. Martín-Martín, A.; Orduna-Malea, E.; Thelwall, M.; Delgado López-Cózar, E. Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *J. Informetr.* **2018**, *12*, 1160–1177. [CrossRef]
47. North, M.A.; Hastie, W.W.; Hoyer, L. Out of Africa: The underrepresentation of African authors in high-impact geoscience literature. *Earth-Sci. Rev.* **2020**, *208*, 103–162. [CrossRef]
48. Zhang, J.; Yu, Q.; Zheng, F.S.; Long, C.; Lu, Z.X.; Duan, Z.G. Comparing keyword plus of WoS and author keywords: A case study of patient adherence research. *J. Assoc. Inf. Sci. Technol.* **2016**, *67*, 967–972. [CrossRef]
49. Eck, N.J.; Waltman, L. Visualizing Bibliometric Networks. In *Measuring Scholarly Impact*; Ding, Y., Rousseau, R., Wolfram, D., Eds.; Springer: Cham, Switzerland, 2014; pp. 285–320.

50. Wang, Q.; Su, M. Integrating blockchain technology into the energy sector—From theory of blockchain to research and application of energy blockchain. *Comput. Sci. Rev.* **2020**, *37*, 100275. [CrossRef]
51. Dyni, J.R. Geology and Resources of Some World Oil-Shale Deposits. In *Scientific Investigations Report 2005–5294*; USGS: Reston, VA, USA, 2006; pp. 52–94. Available online: https://pubs.usgs.gov/sir/2005/5294/pdf/sir5294_508.pdf (accessed on 17 January 2022).
52. Janik, A.; Ryszko, A.; Szafraniec, M. Scientific Landscape of Smart and Sustainable Cities Literature: A Bibliometric Analysis. *Sustainability* **2020**, *12*, 779. [CrossRef]