Renewable and Sustainable Energy Reviews 57 (2016) 1–6

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Natural gas from shale formation: A research profile

Qiang Wang [a,*], Rongrong Li [a,b]

[a] China Energy Think-tank, School of Economic & Management, China University of Petroleum (Huadong), No. 66 West Changjiang Road, Qingdao, PR China
[b] The Research Centre on the Development of Enterprises in Xinjiang, Xinjiang University of Finance & Economics, No. 449, Middle Beijing Road, Urumqi, Xinjiang 830011, PR China

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form
24 October 2015
Accepted 17 December 2015
Available online 31 December 2015

Keywords:
Natural gas from shale formation
Shale gas
Bibliometric analysis
Social network
Water resources

ABSTRACT

With the unfolding shale gas revolution, the literature related to shale gas has grown dramatically, particularly in the past decades. This study aims at providing updated and systemic research information for scientists, researchers, engineers, policymakers, and other stakeholders of shale gas to stimulate wide discussion about the future studies of shale gas through the investigation of shale gas literature cited on the Science Citation Index Expanded Web of Science database between 1990 and 2014. Using bibliometric techniques and the social network method, we attempt to explore three areas of the research profile: (1) country productivity distribution, (2) country collaboration patterns, and (3) research topics analysis. First, the results show that the USA was the largest contributor of the literature on the subject, followed by China and Canada. Moreover, examining overall trends show that the research on shale gas saw a significant growth along with greater participation in the number of countries. Second, the USA was the most frequent partner among all the international collaborative studies. The number of studies in most European countries was not as high as that in Asian countries. However, their collaboration was considerably active in country-to-country collaboration of shale gas. Third, the trend for all research topics is an increasing one, with the exception of *Geochemistry Geophysics*. Particularly, the areas of *engineering*, *energy fuels*, and *geology* have grown sharply over the past two decades. However, *water resources* have become an extremely hot topic since 2012. The research topic analysis results indicate that the current shale gas development is closely related to the three hot topics (*engineering*, *energy fuels*, and *geology*), whereas its future hinges on *water resources*. In conclusion, future studies of shale gas are suggested to stimulate more discussion for the wide community of those interested in shale gas.

Contents

1. Introduction

Natural gas from shale formation is one of the most important energy revolutions of our time and is transforming the global energy market place [1–7]. It has been widely recognized that shale gas will play a large role in meeting future worldwide energy

* Corresponding author. Tel./fax: +86 532 86983286.
E-mail address: qiangwang7@outlook.com (Q. Wang).

http://dx.doi.org/10.1016/j.rser.2015.12.093
1364-0321/

demands and become a significant part of the energy policy mix of many countries [1,3–5,7,8]. With the unfolding shale gas revolution, the literature related to shale gas has grown dramatically, particularly over the past decades.

Existing bibliometric analysis on shale gas has been conducted around patent data. Patent data are widely used to analyze the shale gas field, with patents for shale gas exploitation analyzed using data mining and patent maps. The findings show that shale gas exploitation involves complex technologies and that technological accumulation is a long-term process. For example, the former study is focused on identifying the trends in shale-gas related technologies registered in the U.S. Patent and Trademark Office (USPTO) and to the State Intellectual Property Office of the People's Republic of China (SIPO), respectively, to cluster shale-gas-related technologies [9].

In comparison, few bibliometric analyses on shale gas have focused on literature cited in the Science Citation Index Expanded (SCIE) on the Web of Science database. As we know, it takes roughly one and half-year from application to authorization for a patent. In comparison, much less time is required from submission to publication of literature cited on the SCIE. Furthermore, a patent is a set of exclusive rights granted by a sovereign state to an inventor or assignee for a limited period of time in exchange for detailed public disclosure of the invention. An invention is a solution to a specific technological problem and is a product or a process [10,11], whereas research-based literature is published once accepted by a journal. Thus, literature can provide more updated information for scientists and researchers than patents.

This study is aimed at providing updated and systemic research information for scientists, researchers, engineers, policymakers, and other stakeholders of shale gas through bibliometric techniques that investigate the shale gas literature cited on the SCIE database between 1990 and 2014. To this end, this research has three main goals: (1) to explore the growth of shale gas literature published and identify the productivity distribution by country on this subject; (2) to identify the scientific collaboration and characteristics of the shale gas literature by country level; and (3) to reveal the hottest topics and anticipate future developmental trajectories, and discover the emphasis of research concentration by leading countries.

2. Methodology and data

2.1. Data sources

For the present work, the database of the SCIE, a product of the Thomson Scientific, is utilized to retrieve data from 1965 to 2005 and from 1990 to 2014. SCIE is adopted because it is recognized as the leading English-language supplier of indexing services, providing access to the published information in multidiscipline fields of science and technology [12–14]. In this study, shale gas was selected as key search words as part of the research profile. Our data are collected from the SCI-Expanded citation database in the Web of Science. We use the subject of shale gas as the research term. In total, 3407 papers from 1990 to 2014 are collected.

2.2. Methods

Bibliometrics is a set of methods to quantitatively analyze scientific and technological literature [14–16]. Most historians generally recognize that bibliometrics owes its systematic development largely to Price and Garfield as founders [16,17]. A more unambiguous definition given by White and McCain [17,18] is that bibliometrics is the quantitative study of literature as reflected in bibliographies; its task is to provide evolutionary models of science, technology, and scholarship.

A social network refers to a group of people, each of which has connections of some kind to some or all of the other members of the network [19–21]. In this research, the main method adopted is social network analysis (SNA), including the network structure, for example, drawing the collaboration maps to analyze country collaborative situations.

Collaboration network analysis is a kind of social network analysis. A social network is a network of social relations, reflecting a relationship between actors. In this method, actors in the network are positioned as nodes and the relationships between them are seen as the links between the nodes [22–24].

3. Analyses and results

As an emerging technology, shale gas appears to make good strategic sense, which means there is now a need to better understand the technology development of countries and explore the collaboration among them in this area. However, shale gas research began a long time ago, and it is just recently increasing sharply over the past two decades. In fact, Thomas published the earliest research paper on shale gas in 1951. Before 1990, the number of papers increased slowly, from only one in 1951 to 19 in 1990. The years between 1990 and 2014 saw a period of significant publication on shale gas according to the number of papers cited in the SCIE. Due to national energy strategies, policies and advantages of shale gas, it is obvious that extensive studies on shale gas have been conducted worldwide since 1990. Moreover, the papers on shale gas have increased sharply, reaching 674 in 2014.

3.1. Country productivity distribution

From 1990 to 2014, countries have devoted research to the field of shale gas. The contribution of the different countries is included on the basis of the country affiliation of at least one author of the published paper. The top 30 countries with more than 20 papers are ranked by their number of published articles, as shown in Table 1, which means that there are 30 countries contributing more than 20 papers on shale gas all over the world. Table 1 shows

Table 1
Country productivity distribution of shale gas literature from 1990 to 2014.

Rank	Country	Paper (%)	Rank	Country	Paper (%)
1	USA (US)	1295 (38.01)	16	India (IN)	39 (1.14)
2	China (CN)	454 (13.33)	17	Switzerland (CH)	36 (1.06)
3	Canada (CA)	270 (7.92)	18	Italy (IT)	33 (0.97)
4	England (UK)	246 (7.22)	19	Jordan (JO)	32 (0.94)
5	Germany (DE)	240 (7.04)	20	Egypt (EG)	32 (0.94)
6	Australia (AU)	146 (4.29)	21	Saudi Arabia (SA)	29 (0.85)
7	France (FR)	140 (4.11)	22	Brazil (BR)	29 (0.85)
8	Estonia (EE)	113 (3.32)	23	Iran (IR)	28 (0.82)
9	Turkey (TR)	100 (2.94)	24	Nigeria (NG)	26 (0.76)
10	Russia (RU)	73 (2.14)	25	South Korea (KR)	25 (0.73)
11	Netherlands (NL)	72 (2.11)	26	Denmark (DK)	23 (0.68)
12	Norway (NO)	70 (2.05)	27	South Africa (ZA)	21 (0.62)
13	Poland (PL)	65 (1.91)	28	Morocco (MA)	21 (0.62)
14	Spain (ES)	48 (1.41)	29	Austria (AT)	21 (0.62)
15	Japan (JP)	45 (1.32)	30	Israel (IL)	20 (0.59)

The sum of papers published by the top 30 countries is 3972. A paper may be co-authored by many authors from different countries; therefore, the sum of papers published by each country is larger than the total number of papers. Moreover, the same applies to the country collaboration patterns analysis and research topics analysis. In addition, the papers published by England and Scotland are all merged into England (UK).

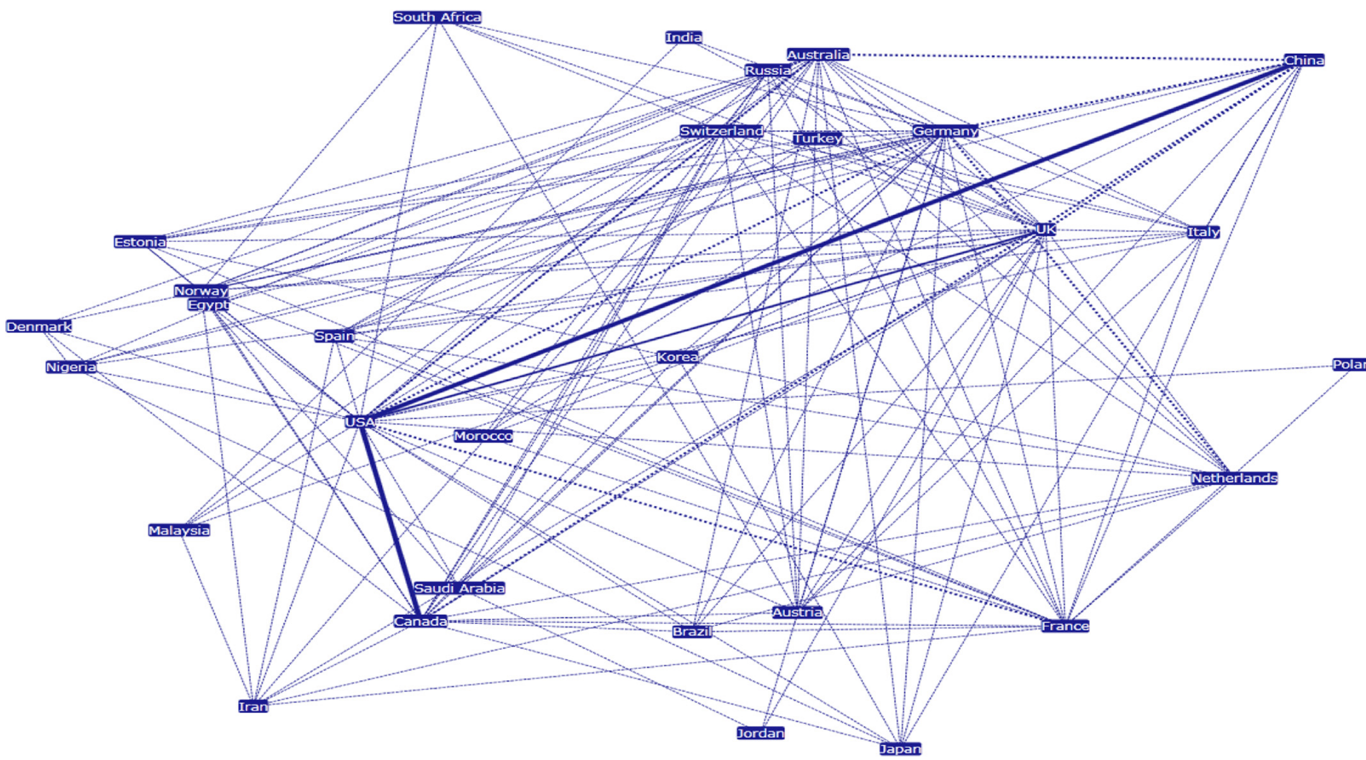

Fig. 1. The cluster analysis of shale gas research across countries.

that the largest contributor is the USA with 1295 papers (38.01%), followed by China and Canada, which are also energy-rich countries. The subsequent countries include England, Germany, Australia, France, Estonia, Turkey, and Russia, in that order, respectively. However, as shale gas-rich countries, the scientific strengths of Russia and Saudi Arabia are not outstanding. The technological advanced nation of Japan just ranks 16, contributing only 45 papers (1.32%). Most countries are focused in the America and Europe, with just three Asian countries.

3.2. Country collaboration patterns

The cluster analysis of shale gas research across countries shown in Fig. 1. The node represents a country and each line represents the collaboration between two countries. In terms of patterns of collaboration, these demonstrate that some countries tend to collaborate with researchers from various countries, e.g., the USA, whereas others, e.g., China and Canada, restrict international collaboration.

The USA was the most-frequent partner among all the international collaborative papers. From Fig. 1, we can see it has a very high centrality in country-to-country collaboration. The collaboration map shows that every country tends to interact more with other countries on shale gas research. We can see that for most European countries like Switzerland, Turkey, Germany, and France, their rankings of papers are not as high as the Asian countries, yet their collaboration is relatively considerable, meaning they are very active in country-to-country collaboration in the shale gas field. Combining Fig. 1 and Table 2, first, it is obvious that the frequency and maximum number of papers by collaboration is with the USA, with the exception of the Netherlands, with a maximum number of collaborative papers with Germany. Second, China has no cooperation with Estonia, Turkey, Russia, Poland, Norway, or the Netherlands; we can see there is no collaboration graph between China and these countries. Third, the cooperation between China and Australia is followed by the cooperation between China and the U.S. This is because Australia is a shale gas-rich country and China has many overseas projects in Australia.

Table 2
The matrix of country collaboration on shale gas from 1990 to 2014.

	US	CN	CA	DE	UK	AU	FR	EE	TR	RU	PL	NO	NL	JP
US	1096	54	43	25	30	25	25	5	3	12	12	9	7	4
CN	54	447	15	16	14	20	3	0	0	0	0	3	0	4
CA	43	15	245	9	7	8	2	0	0	2	0	1	1	2
DE	25	16	9	224	13	13	9	3	7	2	0	8	14	1
UK	30	14	7	13	218	10	6	2	6	2	0	7	3	1
AU	25	20	8	13	10	134	1	0	0	2	0	4	4	1
FR	25	3	2	9	6	1	129	1	0	3	1	7	3	0
EE	5	0	0	3	2	0	1	96	1	1	0	1	1	0
TR	3	0	0	7	6	0	0	1	92	0	0	0	0	0
RU	12	0	2	2	2	2	3	1	0	67	0	2	1	0
PL	12	0	0	0	0	0	1	0	0	0	65	0	0	0
NO	9	3	1	8	7	4	7	1	0	2	0	62	0	0
NL	7	0	1	14	3	4	3	1	0	1	0	0	60	0
JP	4	4	2	1	1	1	0	0	0	0	0	0	0	43

3.3. Research topics analysis

The 3407 papers from 1990 to 2014 all over the world cover a total of 65 research topics in SCIE. We use the citespace software [25] to get the cluster analysis of shale gas research across research topics (see Fig. 2). As shown in Fig. 2, 3407 papers related to conduct shale gas research are under 7 terms. *Engineering*, *Energy Fuels*, *Geology (Geoscience)*, *Geochemistry Geophysics* are the bigger terms and hold the most productive and connected researchers. On the periphery, the *Chemistry, Pyrolysis, Environmental Sciences* (*Environmental Sciences & Ecology*) are productive. In addition, the Fig. 2 also indicates that *Environmental Sciences*, *Environmental Sciences & Ecology* are the emphasis of research in recent years just only orange color; the links and collaboration between topics are very close. In order to examine the trend and development of the

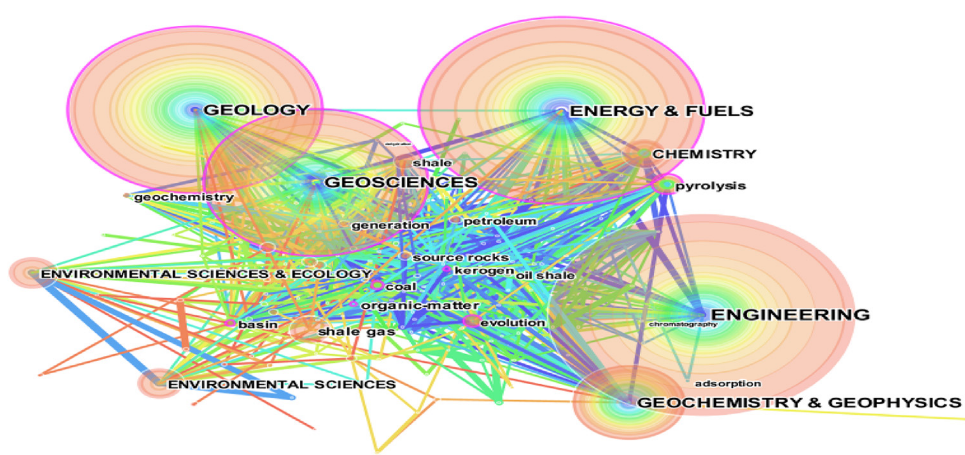

Fig. 2. The cluster analysis of shale gas research across research topics. Notes: 1. Colors represent the year of publication or connection (Color changes from dark blue, light blue, dark green, light green, dark yellow, light yellow, to dark orange, light orange represent the time from early to recently). 2. The thickness refers to the number of publications in that year. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

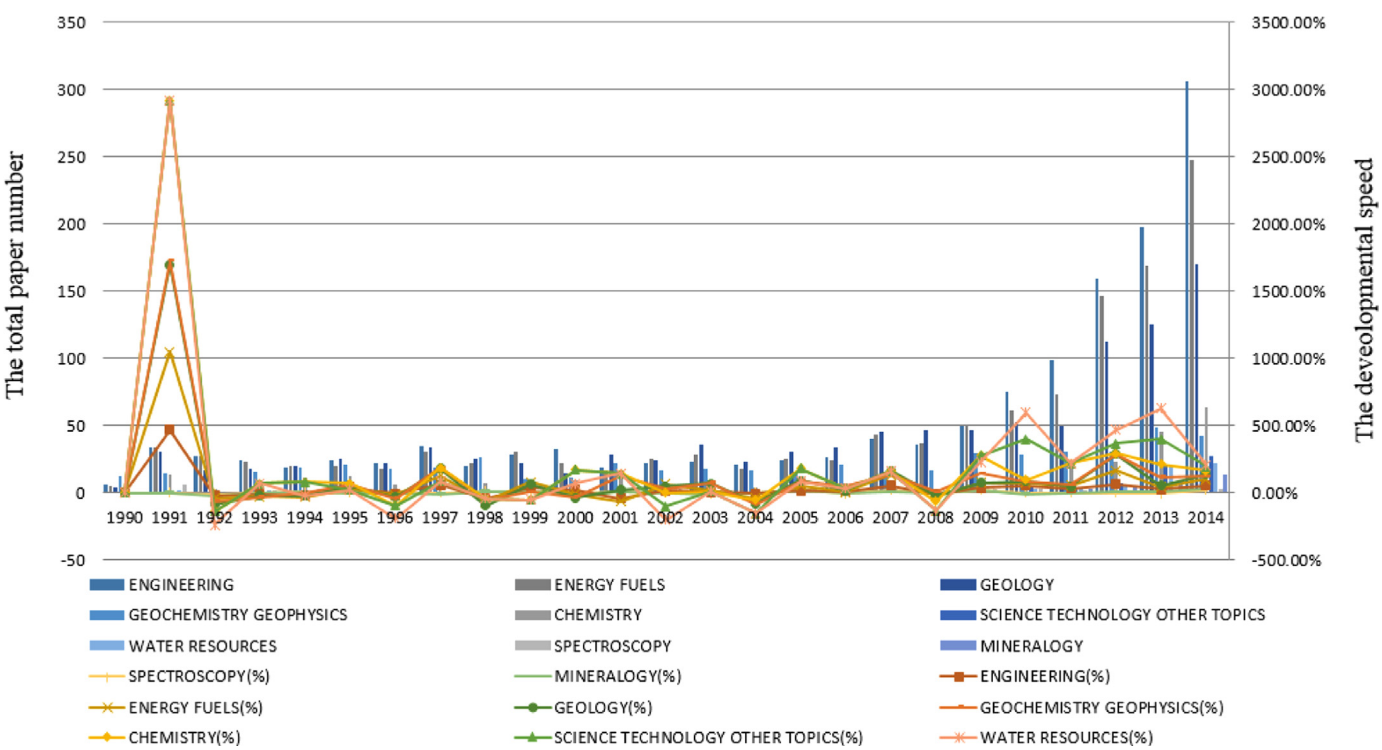

Fig. 3. The development speed and trends for top nine shale gas research topics.

research topics, the top nine research topics are further analyzed (Fig. 3). As shown in Fig. 3, the publications of the top nine research topics are in engineering, energy fuels and geology and have been in lead positions in the last five years. The top three research topics have obvious advantages in quantity, growing sharply since 2011, with the growth rates up 60.61%, 101.37%, and 124.00%, respectively. We note that only Geochemistry Geophysics has declined quickly, however, other research topics demonstrate rapid growth. Because of the low number of papers on these topics, the growth rates of chemistry, science technology other topics, water resources, spectroscopy, and mineralogy have big fluctuations with small changes.

Hot research topics represent the area growing sharply or the new research topic that indicates current research opportunities and suggests directions for future development. The top three research topics engineering, energy fuels and geology see the biggest paper numbers and have grown sharply in the last 25 years, and are the focus of research. Specifically, water resources have had an extremely high increase in publication growth since 2012, which indicates that more attention is being paid to water resources.

The paper numbers relating to water resources before 2012 was under three and grew to 22 in 2014, due largely to the exploitation of shale gas. Hydraulic fracturing involves the high-pressure injection of water and chemicals into the ground to split rock apart and release natural gas. A series of challenges have been posed for protecting water resources [8]. Therefore, more research is focused on water resources, and it can be concluded that water resources would be the emphasis of current hot research on shale gas in the coming years.

On the basis of the research topic analysis worldwide, the topics need to be further analyzed at the country level in order to

Table 3
The research topics for the top 10 countries from 1990 to 2014.

	US	CN	CA	DE	UK	AU	FR	EE	TR	RU	Total
Engineering	492	187	130	44	42	53	32	80	66	24	1360
Energy fuels	364	192	131	61	48	46	26	79	65	22	1216
Geology	375	162	126	91	63	47	36	1	15	25	1057
Geochemistry geophysics	245	58	37	74	48	40	49	0	5	19	536
Environmental sciences ecology	196	20	21	10	13	5	4	16	12	0	309
Chemistry	72	22	7	22	19	6	19	23	16	16	297
Science technology other topics	34	18	3	3	8	2	4	0	0	1	80
Water resources	30	5	9	7	0	3	0	1	1	0	68
Spectroscopy	4	3	1	9	9	0	5	9	4	0	55
Mineralogy	10	4	2	1	3	4	7	1	1	5	45
Mining mineral processing	11	3	1	2	0	2	1	1	0	0	42
Thermodynamics	12	5	0	2	5	0	1	0	0	1	41
Meteorology atmospheric sciences	28	2	1	1	1	1	0	1	1	1	34
Paleontology	11	1	2	4	9	0	3	1	0	0	33
Materials science	10	2	1	0	1	0	5	0	1	0	27
Physics	11	2	1	1	0	1	2	0	0	1	26
Oceanography	5	1	0	2	3	0	3	0	0	4	24
Biotechnology applied microbiology	5	3	0	1	1	0	1	0	2	0	19
Mechanics	6	2	1	0	0	0	1	0	0	0	18
Biochemistry molecular biology	3	4	2	6	1	0	2	1	0	0	18

understand the emphasis, technology and research development of the countries and their focus on shale gas. Table 3 illustrates the top 20 hot research topics for the top 10 countries. It shows that the lead technology country is favored to choose the technical collaborator. The ranking is by the number of papers for every research topic. Among them, the number of papers relating to the top 20 topics is 2648, which is 77.72% of the total number 3407. From the Table, we see that there is a big gap among the top 20 topics. Engineering, energy fuels and geology gradually become the mainstream areas of shale gas research. In these areas the U.S., China, and Canada lead.

The USA has an absolute advantage in the shale gas field. As the analyzed results show, water resources are a hot spot for shale gas research. The USA, Canada and Germany are the biggest contributors in the topic of water resources, followed by China. However, the USA paper number of 30 is six times that of China at 5. Therefore, as a hot research spot, China needs to actively co-operate with the USA Estonia stands out in the chemistry and spectroscopy fields; particularly in spectroscopy where it ranks first.

4. Conclusion

This study takes shale gas as its focus and examines worldwide research activity on it in general and characteristics of shale gas literature from 1990 to 2014 using the database of the SCIE. In this study, we use bibliometric and social network analysis to explore the publication distribution by country, by scientific collaboration, and by research activity, and determine the research trends and hot research topics at the country level. On the basis of the country productivity distribution analysis, country collaboration patterns analysis, and research topics analysis, we address three main areas as follows:

(1) We discuss the worldwide shale gas research situation and country productivity distribution.

Shale gas research began a long time ago but has just recently been increasing sharply over the past two decades. Thomas published the earliest research paper on shale gas in 1951. Before 1990, the number of papers on shale gas slowly increased, from 1 in 1951 to 19 in 1990. The period of 1990 to 2014 was one of the significant growth, based on the number of papers cited in the SCIE database. There were 30 countries contributing more than 20 papers on shale gas during that time. The results show that the largest contributor, the USA, published 1295 papers (38.01%), followed by China and Canada, which are also energy-rich countries. The subsequent countries include England, Germany, Australia, France, Estonia, Turkey, and Russia in that order, respectively. Most countries are from America and Europe, with just three Asiancountries.

(2) We draw a collaboration map and country collaboration patterns are analyzed.

The USA was the most-frequent partner among all the international collaborative papers. We can see that for most European countries such as Switzerland, Turkey, Germany, and France, their ranking by the number of papers is not as high as that in the Asian countries; however, their collaboration is relatively considerable, which means they are very active in country-to-country collaboration in the shale gas field. The cooperation between China and Australia is followed by the cooperation between China and the U.S. This is because Australia is a shale gas-rich country and China has many overseas projects in Australia.

(3) Research topics are discussed and the hottest topics are examined.

The 3407 papers covered a total of 65 research topics in the SCIE database. The publications of the top nine research topics are in engineering, energy fuels, and geology and have been in a lead position over the last five years. We note that only Geochemistry Geophysics has declined quickly, whereas the other research topics demonstrate rapid growth. Engineering, energy fuels, and geology have gradually become the mainstream focus of the shale gas research. In these areas the US, China, and Canada lead. The USA has the absolute advantage in the shale gas field. As the analyzed results show, water resources are a hot spot in shale gas research.

In the future, we intend to extend the research profile of natural gas from shale formation at the institution and author levels and make the comparison between the USA and China to reduce the technology gap. Thus, we can better know the research areas, explain the phenomenon, help improve international collaboration problems, and promote the international collaboration and innovation process in the shale gas technology fields, while providing suggestions for policy-making.

References

[1] Wang Q, Chen X, Jha AN, 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.
[2] Deutch J. The good news about gas, the natural gas revolution and its consequences. Foreign Aff 2012;90:82–93.
[3] Hughes JD. Energy: a reality check on the shale revolution. Nature 2013;494:307–8.
[4] Boersma T, Johnson C. The shale gas revolution: US and EU policy and research agendas. Rev Policy Res 2012;29:570–6.
[5] Malakoff D. The gas surge. Science 2014;344:1464–7.
[6] Arthur JD, Langhus B, Alleman D. An overview of modern shale gas development in the United States. All consulting, 3; 2008 p. 14–17.
[7] Wang Q. China should aim for a total cap on emissions. Nature 2014;512:115.
[8] Brooks D. Shale gas revolution. The New York Times. Novermber 3; 2011.
[9] Lee WJ, Sohn SY. Patent analysis to identify shale gas development in China and the United States. Energy Policy 2014;74:111–5.
[10] Daim TU, Rueda G, Martin H, Gerdsri P. Forecasting emerging technologies: use of bibliometrics and patent analysis. Technol Forecast Soc Chang 2006;73:981–1012.
[11] Narin F. Patent bibliometrics. Scientometrics 1994;30:147–55.
[12] Tsay M-Y. A bibliometric analysis of hydrogen energy literature, 1965–2005. Scientometrics 2008;75:421–38.

[13] De Bakker FG, Groenewegen P, Den Hond F. A bibliometric analysis of 30 years of research and theory on corporate social responsibility and corporate social performance. Bus Soc 2005;44:283–317.

[14] Van Raan AF. Fatal attraction: conceptual and methodological problems in the ranking of universities by bibliometric methods. Scientometrics 2005;62:133–43.

[15] Persson O, Danell R, Schneider JW. How to use Bibexcel for various types of bibliometric analysis. Celebrating scholarly communication studies: a Festschrift for Olle Persson at his 60th birthday; 2009 p. 9–24.

[16] De Bellis N. Bibliometrics and citation analysis: from the science citation index to cybermetrics. Lanham, MD: Scarecrow Press; 2009.

[17] Godin B. On the origins of bibliometrics. Scientometrics 2006;68:109–33.

[18] Narin F. Evaluative bibliometrics: the use of publication and citation analysis in the evaluation of scientific activity. Washington, D.C.: Computer Horizons; 1976.

[19] Newman ME. The structure of scientific collaboration networks. Proc Natl Acad Sci 2001;98:404–9.

[20] Newman ME. Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. Phys Rev E 2001;64:016132.

[21] Hou H, Kretschmer H, Liu Z. The structure of scientific collaboration networks in Scientometrics. Scientometrics 2008;75:189–202.

[22] Wang X, Li R, Ren S, Zhu D, Huang M, Qiu P. Collaboration network and pattern analysis: case study of dye-sensitized solar cells. Scientometrics 2014;98:1745–62.

[23] Cross R, Borgatti SP, Parker A. Making invisible work visible: using social network analysis to support strategic collaboration. Calif Manag Rev 2002;44:25–46.

[24] Newman ME. Scientific collaboration networks. I. Network construction and fundamental results. Phys Rev E 2001;64:016131.

[25] Chen C. CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Soc Inf Sci Technol 2006;57:359–77.