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Research status of shale gas: A review

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ABSTRACT

The shale gas revolution has resulted in a sharp growth in the number of researchers and collaborative work in this area, particularly during the past few decades. This study aims to provide unprecedented and invaluable shale gas information to businesses, policymakers, and any part of society involved in shale gas development. Using bibliometric and collaboration techniques, our study focuses (on an individual level) on the development trends in shale gas research. We examine the most influential authors and explore the characteristics and implications of collaboration networks and patterns in shale gas literature between 1990 and 2014. Much of our information was obtained from the Science Citation Index Expanded (SCIE) database. Author collaboration analysis software that has been independently developed was used to further explain core author contributions and trends, as well as collaboration networks. We primarily focus on three research areas: (1) the quantity and growth trend of the number of authors exploring shale gas, (2) author productivity distribution, and (3) an analysis of author collaboration networks. First, our results reveal three developmental stages. The period from 1990 to 2008 was the early stage and characterized by steady development. The years between 2008 and 2013 witnessed rapid growth, before that growth slowed notably after 2013. The annual growth rate of the number of new authors was determined to be approximately 980%. This finding also indicates that shale gas is becoming a fast-developing and popular research topic. Furthermore, Horsfield B from the German Research Centre for Geosciences has been the dominant contributor to date, followed by Krooss BM and Ballice L. The top 15 authors are mainly from Germany, the USA, Canada, Estonia, Jordan, and China. Our collaboration network and pattern analysis reveals that the two biggest clusters of cooperation are comprised of Horsfield B and Ballice L. We also discovered that most authors have a specific collaboration, such as that between Williams PT and Jaber JO, both of whom are from the Al-Ahliyya Amman University.

1. Introduction

Natural gas is a mixture of light, flammable hydrocarbons, primarily composed of methane (CH4). The discovery of natural gas is one of the most important energy revolutions of our time, virtually transforming the global energy marketplace [1–8]. Shale gas represents a new opportunity to strengthen energy security while reducing emissions [2,4,9–14]. As a typical emerging technology, shale gas has attracted significant attention from researchers, resulting in a virtual information explosion [15,16]. The unfolding shale gas revolution has experienced sharp growth in the number of researchers and collaborative work in the field of shale gas research, particularly during the past few decades. At present, the development of shale gas not only brings innovation opportunities; some uncertain results have also arisen, due to unknown factors. However, international collaboration speeds up the research process and reduces the degree of risk. This is significantly beneficial to those involved in the exploration of shale gas technology. As a consequence, a need exists for information specialists, who can help explore and identify information, the properties of the scientific activities and collaboration networks that are useful to specific stakeholders.

It is widely assumed that collaboration is a good thing and should be encouraged [17,18]. Countries from all over the world have fostered the development of collaboration between researchers. The level of international collaboration has been increased, in the sincere belief that collaboration will bring about many benefits, such as cost-savings and more impactful research. With the growing need for scientific collaboration, bibliometric studies of research collaboration have also extended quickly, from country and institutional levels to the most detailed individual level [19–22]. Even relationships between authors that are based on the characteristics of published literature have been studied for decades [23–26]. However, despite the increasing amount of research being conducted in the field of shale gas engineering and patent analysis, few attempts have been made to gather systematic data

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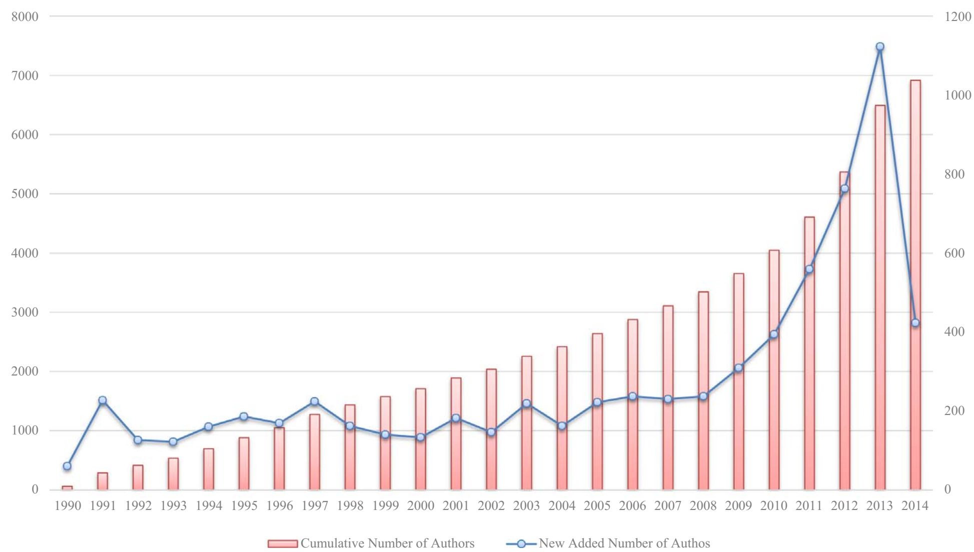

Fig. 1. The trend of cumulative and newly added number of authors by year.

at an individual level. In addition, very few studies have considered the turn-number of authors (the number of papers with first, second, or subsequent-named authorships). As such, the degree of contributions in the field has not been reflected. A review of author collaborations is also needed, in order to refine the assessing impact [27].

This study aims to reveal the basic properties of the scientific activities related to shale gas. We also evaluate research performance and examine the most influential authors and collaboration networks on an individual level. Our objective is to provide unprecedented and invaluable shale gas information to businesses, policymakers, and society, and we would undoubtedly wish to promote the international collaboration and innovation processes involved in the field of shale gas development.

Our paper focuses (on an individual level) on investigating the current development trends in shale gas research. We examine the most influential authors and explore the characteristics of collaboration networks, as well as any patterns in shale gas literature from 1990 to 2014. We obtained much of this information from the Science Citation Index Expanded (SCIE) database. To this end, our research is focused on three goals: (1) to explore the quantity and growth trend of authors; (2) to reveal the core researchers in the field of shale gas by identifying the total number of papers produced by specific authors, according to sequence (i.e., first, second or subsequent-named authors) and by discovering the top 15 authors published on a yearly basis, and (3) to disclose the characteristics of scientific collaboration in shale gas literature, based on the authors.

2. Methodology and data

2.1. Data sources

The widely-accepted Science Citation Index (SCI) database is deemed to be the most reliable bibliographic resource and has been widely applied to reveal patterns in a variety of scientific fields [28–31]. To obtain our data source, we accessed the online version of the Web of Science SCI Expanded database, as this database covers most of the important journals in the fields of natural and medical sciences [32,33]. We used the subject of “shale gas” as the research term to collect 3407 papers, all of which were published from 1990 to 2014.

2.2. Methods

The extent of collaboration cannot be easily determined using the traditional methods of survey and observation. Bibliometric methods offer a convenient and non-reactive tool for studying research collaboration. As a valuable tool for literature analysis, bibliometrics can effectively capture the rules of discipline development. Bibliometrics also has a wide application in different knowledge domains [34,35]. Bibliometric quantification is an effective way to show the emergence and development of a new technology [32,36,37], because bibliometrics is effectively a set of methods used to quantitatively analyze scientific and technological literature [38–40]. Most historians generally recognize that bibliometrics owes its systematic development largely to Price and Garfield, as the method's founders [40–42]. The traditional bibliometric method analyzed the research trends of certain fields mainly from their publication output, subject category and journal, author, country and research institute, keyword frequencies, and other factors [43–46]. In recent years, however, bibliometric network analysis has been increasingly applied as a means to analyze the relationships between keywords, countries and research institutes, and authors. The common network analysis includes a co-word analysis [47], co-citation analysis [48,49], co-authorship analysis [50,51], and co-publication analysis [52], among others.

Collaboration network analysis is one type of social network analysis. A social network is a network of social relationships, effectively reflecting the relationships between the participants [53–55]. In large-scale research projects, a team of researchers can collaborate in areas such as data collection, data processing, and idea generation. Common modes of author collaboration include those between teacher and pupil, and between colleagues, supervisor and assistant, as well as related-field collaboration between different institutions or countries [35]. Author collaboration network and pattern analysis provides a comprehensive visual resource at the individual level. In this paper, we use the software Insight to conduct the collaboration network analysis [56].

3. Analysis results and discussion

3.1. Quantity of authors and growth trend

As indicated earlier, the shale gas-related literature published from 1990 to 2014 was obtained from the SCIE database. According to the statistical analysis results on this literature, the SCIE database contained 6915 researchers who wrote about shale gas during this time span. The number of authors in this field is an important indicator in measuring the development trend of specific scientific research.

Fig. 1 shows the trend of development in the number of newly added authors, as well as the cumulative number of authors by year.

Based on the growth rate, the development trend can be roughly divided into three stages. The period of 1990–2008 was the early stage, characterized by steady development. The years 2008–2013 witnessed rapid growth in the number of authors writing about shale gas. This period was followed by the last stage (after 2013), when the slowdown in the number of new authors was notable. In the early stage, there was steady growth in the number of newly added authors. The cumulative number of authors rose from 60 to 6915. We can also see from Fig. 1 that the 2008–2013 period also experienced significant growth in the number of newly added shale gas authors. During this period, the number of new authors rose from 237 to 1123. In 2014, the cumulative number of authors rose to its highest total level of 6915. This was nearly twice the number of the previous period (2008–2013). Fig. 1 shows that 2008 and 2013 are the two peaks of exponential growth in both the cumulative number of authors and the number of newly added authors. As a typical emerging technology, shale gas has attracted considerable attention, especially given its ease of production. It is interesting to note that 3073 billion cubic meters of shale gas was produced globally in 2008, and 3409 billion cubic meters was produced in 2013, according to the Statistical Review of World Energy 2015 [57]. Hence, the global production of shale gas increased from 2008 to 2013, and this increase corresponds to the two peaks of exponential growth in the cumulative and newly added number of authors, before growth in the latter category significantly fell after 2013. Thus, the development trend of the number of cumulative and newly added authors is consistent with the development of shale gas production. From another perspective, Fig. 1 illustrates that the annual growth rate in the number of newly added authors is approximately 980%, which also indicates that shale gas has become a popular and fast-developing research topic since 2008.

3.2. Author productivity distribution

Following our examination of author numbers, we studied author productivity distribution over time. We used independently-developed collaboration and cluster analysis software to examine the total paper number, turn-number, institutions, and countries. The result was a list of the top 15 most productive authors in shale gas research (see Table 1). Double-counting of articles may occur here, because an article may have been written by more than one author. As shown in Table 1, the first number in the turn-number column represents the number of papers for which the researcher was the first-named author. This designation indicates that he or she had done the greatest amount of work on the paper. The second number indicates the number of papers for which the researcher was the second-named author, while the third number represents the number of papers for which the researcher was the third or subsequent sequence=named author. For example, Horsfield B has a total number of 35 papers and a turn-number of "2; 17; 16." These numbers specifically indicate that, specifically as relates to the field of shale gas, Horsfield B published two papers as the first-named author, 17 papers as the second-named author, and 16 papers as the subsequent sequence-named author. In terms of mass (number of co-authorship articles), Horsfield B, from the German Research Centre for Geosciences, is the dominant contributor (with 35 papers), followed by Krooss BM and Ballice L. Subsequent authors include Dittrick P, Littke R, Kuusik R, Tiikma L, Bustin RM, Clarkson CR, Snow N, Williams PT, Mastalerz M, Jaber JO, Xiao XM, and Han XX, in that order. With 35 papers, Horsfield B is responsible for the majority of the global total of papers produced on shale gas research. The number of papers in which Horsfield B is the first-author ranks him as the 13th most active researcher in the field of shale gas. The top 15 authors, with the exception of Dittrick P and Snow N, are from universities or research institutes.

Dittrick and Snow are writers with the Oil & Gas Journal. Their papers (in terms of number of first-author publications) rank first and third, respectively. They wrote these papers independently and without the cooperation of others. In Fig. 3, Dittrick and Snow are depicted as the two red big circles with no lines connecting them to the other authors. The top 15 authors are mostly based in America and European countries, with just a handful from three Asian countries. The top 15 authors are mainly from Germany, the USA, Canada, Estonia, Jordan, and China. Xiao XM, from the Guangzhou Institute of Geochemistry at the Chinese Academy of Science, and Han XX, from Shanghai Jiao Tong University, are the most active researchers in shale gas in China.

The number of papers published by these top 15 authors in terms of year of publication is also an important indicator used to measure the developmental trends of specific scientific research. Statistical analysis shows that the trend and change in the number of papers published by these top 15 authors in any given year (as depicted in Fig. 2) is similar to the corresponding trend in the number of cumulative and newly added authors in those years, as shown in Fig. 1. From Fig. 2, we can see that the top 15 authors did not publish any papers related to shale gas between 1990 and 1994. These years, however, were followed by a period of stable productivity. Then, the number of papers published by these top 15 authors grew rapidly from 2008 onwards, until hitting the peak of 43 published papers in 2013.

Fig. 2 also provides details about the changes in the number of papers published by these top 15 authors each year. For instance, Williams PT's most productive research period was from 1998 to 2002, during which the author's total number of papers ranked 11th. Similarly, Jaber JO was most productive between 1997 and 2005, while Williams PT contributed as much as Horsfield B in 1998. Dittrick P, Bustin RM, Clarkson CR, Snow N, and Han XX only began their research of shale gas in more recent years. These authors could be

Table 1
Ranking of top 15 authors in shale gas research by total number of papers.

No	Name	Number	Turn number	The paper number of first-author rank	Institution	Country
1	Horsfield B	35	2; 17; 16	13	German Research Centre for Geosciences	Germany
2	Krooss BM	23	4; 4; 15	8	RWTH Aachen University	Germany
3	Ballice L	21	16; 3; 2	2	Ege University	Turkey
4	Dittrick P	21	21; 0; 0	1	Oil & Gas Journal	USA
5	Littke R	20	1; 7; 12	14	RWTH Aachen University	Germany
6	Kuusik R	17	4; 2; 11	9	Tallinn University of Technology	Estonia
7	Tiikma L	17	4; 5; 8	10	Tallinn University of Technology	Estonia
8	Bustin RM	17	1; 13; 3	15	the University of British Columbia	Canada
9	Clarkson CR	16	9; 6; 1	5	The University of Calgary	Canada
10	Snow N	16	16; 0; 0	3	Oil & Gas Journal	USA
11	Williams PT	15	7; 3; 5	6	Al-Ahliyya Amman University	Jordan
12	Mastalerz M	14	3; 4; 7	11	Indiana University	USA
13	Jaber JO	14	12; 2; 0	4	Al-Ahliyya Amman University	Jordan
14	Xiao XM	13	3; 7; 3	12	Guangzhou Institute of Geochemistry, Chinese Academy of Science	China
15	Han XX	12	5; 2; 5	7	Shanghai Jiao Tong University	China

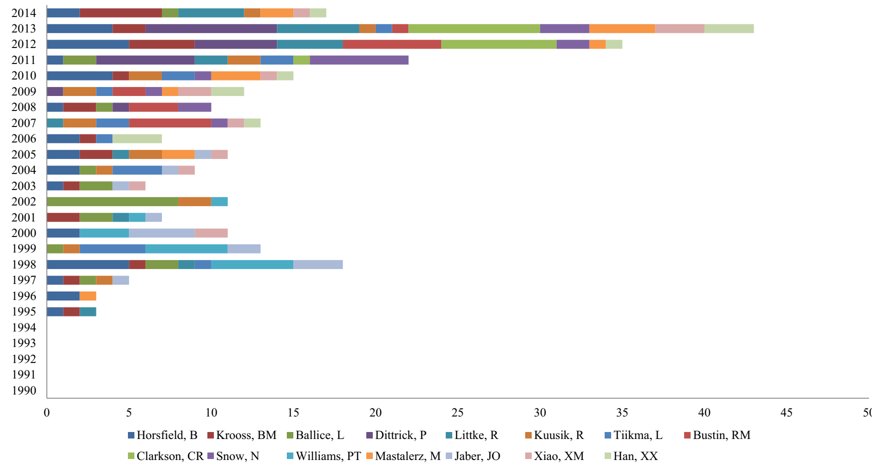

Fig. 2. Top 15 authors in shale gas research: number of papers published each year.

considered to be the new and emerging forces in the shale gas field. On the other hand, Horsfield, Krooss, Ballice, Littke, Kuusik, Tiikma, Mastalerz, and Xiao have been conducting shale gas research continuously for the past two decades.

3.3. Author collaboration network

We use collaboration and cluster analysis software that has been independently developed, in order to examine the author collaboration network and pattern, as shown in Fig. 3. The size of a node represents the total number of papers published by an author. The bigger the node is, the larger the total number of published papers. The lines represent collaboration between authors. The thicker the line is, the larger the total number of co-authored published papers. The colors represent the number of papers according to the order of the author. Red represents the number of papers with first-named authorship, green indicates the number of papers with second-named authorship, while yellow specifies the number of papers for which the researcher was the third or subsequent-named author. Once again, the bigger the circle is, the larger the total number of papers.

The total number of papers (as well as the number of papers with first, second, or subsequent sequence-named authorships) depicted in Fig. 3 corresponds to the data provided in Table 1. In general, the higher the degree of cooperation is, the more sufficient the cooperation. The, exceptions to this rule are Dittrick P and Snow N, who, as independent writers with the Oil & Gas Journal, did not collaborate with other authors. The author cooperation network and pattern analysis shows that Jarvie DM, Philp RP, Xiao XM, and Kuusik R have been the main collaborators. The two biggest clusters of cooperation are with Horsfield B and Ballice L. In fact, most authors have a specific collaboration, such as that between Williams PT and Jaber JO, who are both from the Al-Ahliyya Amman University. As can be seen from Fig. 3, collaboration in shale gas research has been on the rise at the author level in recent years. This in turn indicates a potentially closer relationship between authors within the same domain, as well as a greater opportunity for further collaboration in line with the corresponding increasing interest in this field of research.

4. Conclusion

In this study, we aim to reveal the basic properties of the scientific activities and evaluate research performance. We examine the most influential authors and collaboration networks on an individual level. Our goal is to provide unprecedented and invaluable shale gas information to businesses, policymakers, and society. We would also undoubtedly hope to promote international collaboration and the innovation processes involved in the field of shale gas development. Using bibliometric and collaboration techniques, we obtained literature data (published from 1990 to 2014) from the Science Citation Index Expanded (SCIE) database. We used author collaboration analysis software to obtain our analysis results. Based on the results, we address three main areas, as follows:

(1) Analysis of quantity and growth trend of author numbers

In the first section of this paper, we explored the basic properties of the scientific activities and conducted an evaluation

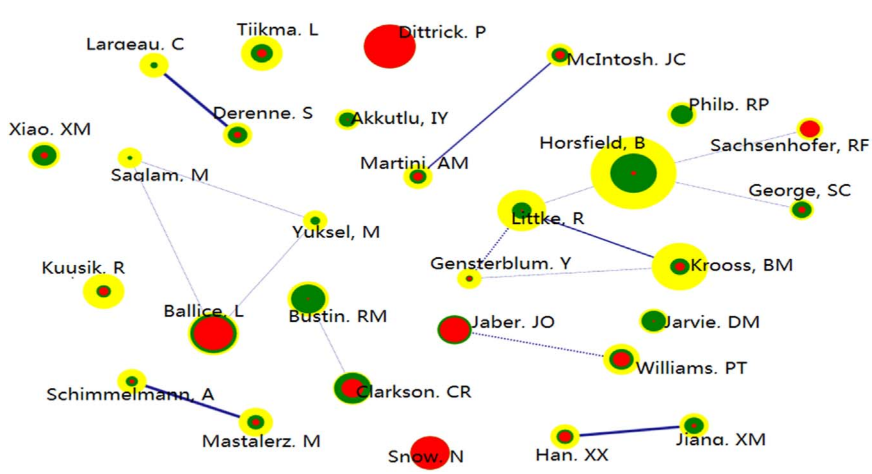

Fig. 3. Author collaboration network and pattern analysis.

of research performance. Our data were collected from the Web of Science SCI Expanded database. We used the subject of shale gas as the research term to collect 3407 papers dealing with the subject. All these papers were published from 1990 to 2014. The results of our study reveal that the period from 1990 to 2008 was the early stage. This period was characterized by steady development. The years 2008–2013 experienced rapid growth in the number of shale gas articles published, as well as the number of authors. This period was followed by the last stage (after 2013), which experienced a notable slowdown in the growth of these numbers. In 2014, the cumulative number of authors was at its highest point (6915), which was nearly twice that at the end of the previous period (in 2008). Therefore, the annual growth rate in the number of newly added authors was approximately 980%. This finding also indicates that, since 2008, shale gas has become a popular and fast-developing research topic.

(2) Examination of author productivity distribution and number of papers published by the top 15 authors, based on the year of publication

In the second section, we revealed the most influential authors. This was done by evaluating the core author contributions and trends, and the turn-number (the number of papers with first, second, or subsequent sequence-named authorships). Horsfield B, from the German Research Centre for Geosciences, has been the dominant contributor, with 35 papers. This author's number of first-author papers ranks him as the 13th most active researcher in the field of shale gas. Horsfield B is followed by Krooss BM, and Ballice L. In addition, Dittrick P and Snow are writers with the Oil & Gas Journal. These authors' published paper numbers, in terms of first-author papers, rank first and third, respectively. Dittrick P and Snow wrote their papers independently and without the cooperation of others. The top 15 authors are mainly from Germany, the USA, Canada, Estonia, Jordan, and China. Xiao XM from the Guangzhou Institute of Geochemistry of the Chinese Academy of Science and Han XX from Shanghai Jiao Tong University are the most active researchers in shale gas in China.

(3) Examination of author collaboration network and pattern analysis

In the third section, we independently developed the collaboration networks and clearly showed collaboration statuses. The total number of papers (as well as the number of papers with first, second, or subsequent sequence-named authorships) depicted in Fig. 3 corresponds to the data provided in Table 1. Collaboration in shale gas research has been on the rise at the author level in recent years. This indicates the potential exists for closer relationships between authors within the same domain and a greater opportunity for collaboration in line with the corresponding increase in interest in the field of shale gas research.

Last but not least, we intend to extend our research on cooperation networks by combining our existing work at author level with that at country and institution level. This will enable us to gain a deeper and clearer view of developments in the field of shale gas research. We believe that factors and indexes should be included in our discussion, in order to discover further insights into the current fixed collaboration patterns and to identify the most influential authors. This would enable us to better explain the phenomenon and help offer solutions to existing problems in forming effective cooperation. We could also better promote innovation in emerging technology fields (such as shale gas) and provide suggestions for stakeholders.

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