THE CORRELATION BETWEEN HAZE AND ECONOMIC GROWTH: BIBLIOMETRIC ANALYSIS BASED ON WOS DATABASE

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Abstract. This paper takes 4,225 articles on the relationship between haze and economic growth in the Web of Science database from 1992 to 2017 as the research object, and uses CiteSpace to explore the spatial and temporal distribution, research topics and hot trends of the literature. The results show that: (1) The relevant literature volume keeps growing at a high speed. (2) The cooperative group of high-yield authors represented by Huang GH and Streets DG is basically formed. (3) The research institutions are divided into the top international colleges and universities represented by Tsinghua University and the University of California, Berkeley, as well as the two major groups of international well-known scientific research institutes represented by the Chinese Academy of Sciences and the American Environmental Protection Agency. (4) The cited high literature is concentrated in the six international high level journals such as "Science". (5) The two major cooperation bodies of "the United States–China" and "Holland–France–Italy–Spain" have been formed. (6) The research topics are mainly about the economic mechanism of haze formation, its relationship with economic growth, spatial spillover effects and countermeasures. (7) The research hotspots show trends from "air pollution" and "health" to "PM$_{2.5}$" and "CO$_2$ emission".
Keywords: PM$_{2.5}$, EKC, spatial spillover, knowledge map, CiteSpace, hot trend

Introduction

In recent years, with the continuous expansion of China's population and rapid economic development, energy consumption has been increasing, and air pollution problems such as smog and haze have become increasingly serious. Haze will not only seriously affect people's physical and mental health, but also cause a certain degree of impact on traffic safety, agricultural production, ecological environment and economic development. According to the calculation results of official agencies such as the World Bank and the environmental protection administration, the annual loss due to environmental pollution in China is about 10% of GDP (Zhou, 2011). The high frequency of haze and the great influence have attracted the attention of people from all walks of life. In 2017, Premier Li Keqiang wrote the "resolutely fighting the blue sky defence war" into the government work report.

In addition to natural factors, serious haze pollution is largely attributed to extensive economic development mode and unbalanced industrial structure. Studying and exploring the internal relationship between haze and economic growth will help in finding out the root causes of frequent haze, and put forward the regulation mechanism of coordinating air pollution and economic development represented by haze, so as to provide scientific basis and policy suggestions for regional economic development and

ecological environmental protection, so as to achieve the goal of green development and ecological civilization construction.

The relevant research work in the world has been carried out relatively early. Many scholars have studied the relationship between haze pollution and economic growth from different perspectives, such as the formation mechanism of haze and the analysis of influencing factors, the health economic loss caused by regional particles ($PM_{2.5}$, PM_{10}, etc.), and environmental Kuznets curve test, etc. These documents reflect the research results of this field only in one way, but it is difficult to grasp the dynamic development and hot trend of the international research field in a comprehensive way. Through the method of knowledge map, the research dynamic and development trend of professional field can be presented in the form of visual atlas (Hou et al., 2009). At present, the map of science knowledge has made great achievements in many fields, such as management, pedagogy and so on (Feng et al., 2017). However, the academic circles still lack the bibliometric analysis of the relationship between haze and economic growth. Based on this, this paper selects the bibliography of haze and economic growth in the core collection database of Web of Science (hereinafter referred to as WoS) during 1992-2017 years as the analysis data. Through CiteSpace visualization software, using knowledge mapping method and related tools, this paper makes a holistic and multi-dimensional visualization analysis of the international research on the correlation effect of haze and economic growth. The aim is to sort out the research hot spots and trends of international literature, which not only helps domestic scholars to understand the research status of the correlation between haze and economic growth in the world, track its frontier hot spots, explore and grasp the development trend and potential of this field, but also provide some reference for the haze control and ecological environmental protection in China, whether for academic research or practical.

Materials and methods

Research methods

The development of information technology and bibliometrics provides a basis for the generation of visual software. The visualization software provides a new way for document processing and analysis (Shi and Li, 2016). Based on this, this paper chooses CiteSpace as the main measurement and visualization software, and Excel as an auxiliary measurement tool. Firstly, CiteSpace is used to describe the current research status and hot trend in the field of international haze and economic growth, and then the literature is read critically according to the analysis results provided by the software, so as to summarize the research topics in this field.

Data sources

In order to explore the status of international research in the area of haze and economic growth and ensure the integrity of the literature search, this paper searches relevant literature in the WoS database by means of TS = ((Economic OR Economy) AND ($PM_{2.5}$ OR PM_{10} OR haze OR smog OR air quality OR air pollution). The time span is 1992-2017 , and the literature types are pure scientific documents (ARTICLE), PROCEEDINGS PAPER and EDITORIAL MATERIAL, and a total of 4730 literature data are obtained. Later, using the Remove duplicates function in CiteSpace, the duplicate documents were filtered, and finally 4,225 effective records were obtained.

Results

Time distribution

The amount of document information can reflect the heat level and research process of a certain area to some extent, which is an important part of scientific bibliometrics. According to the statistical results in WoS, the time distribution map of the literature (*Fig. 1*) is drawn by Excel mapping in order to understand the time distribution and growth of the literature on the related effects of haze and economic growth in the world.
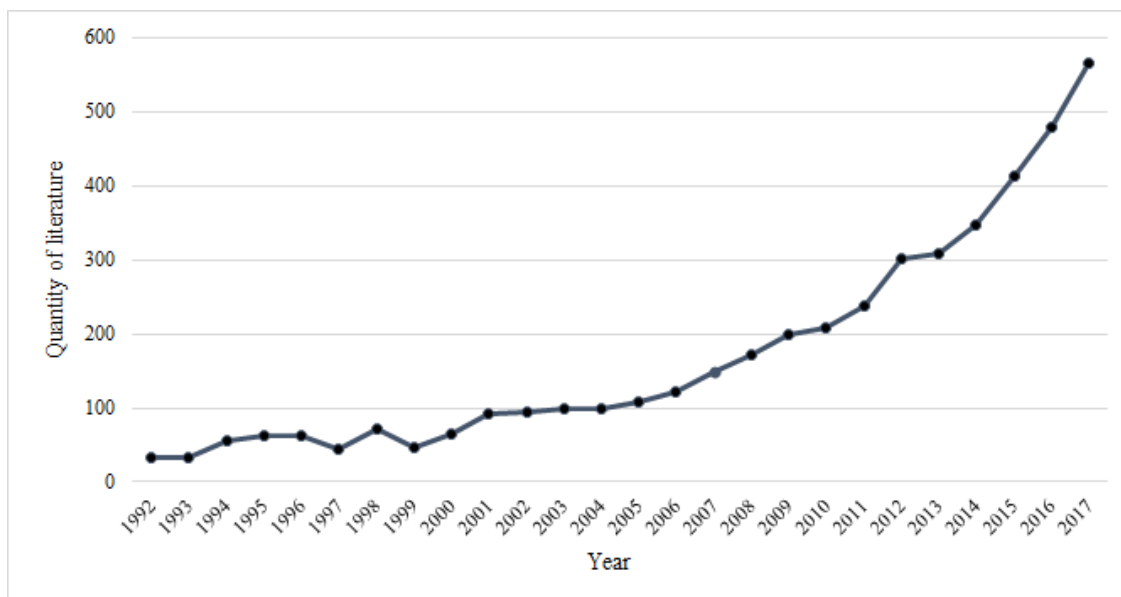

Figure 1. *Time distribution of literature on correlation between haze and economic growth*

As can be seen from *Figure 1*, the international literature on the correlation between haze and economic growth shows a relatively rapid growth trend. One of the reasons is that the number of journals on ecological environment and environmental economy is increasing, but the more important reason is that the problem of haze has become more and more serious in recent years, which has attracted extensive attention and research from scholars all over the world. According to *Figure 1*, the time distribution of relevant literature can be roughly divided into three stages: (1) Stage 1 (1992-2000 year): the number of literature is small, and the fluctuation range is not large, indicating that the international research in this field started very early, but the research progress is relatively slow. (2) Stage 2 (2001-2010 year): In the first half of this phase (2001-2005), the amount of literature fluctuated around 100, and it did not increase until 2006. (3) Stage 3 (2011-2017 year): the stage of rapid literature growth. Since 2011, the continuous broadcasting of $PM_{2.5}$ by the US Embassy has aroused widespread social concern. Academic circles have also paid great attention to the correlation effect between haze and economic growth, and have done a lot of research on it, and achieved a lot of research results. It can be seen that the literature in this stage is gradually increasing, and the growth rate is gradually accelerating.

According to the law of the logical growth curve of literature, the growth of literature can be divided into four stages (Qiu JP, 2007). The first stage is the embryonic stage, the growth of literature is relatively slow; the second stage is the rapid growth stage, the

literature grows sharply; the third stage is the mature stage, the growth rate is slow; the fourth stage is the saturation stage, and the literature growth rate approaches zero. From the above theory, it can be inferred that the literature on the correlation between haze and economic growth is in a state of rapid growth, so it accords with the second stage of literature development, and it is predicted that the volume of literature will remain high growth in the next few years (Sun and Wang, 2016).

Spatial distribution

In this paper, we use the co-occurrence network of the provided by CiteSpace, the co-occurrence network of research institutions, the co-citation network of the periodicals, the shared network function of the country and the region, to analyze the scientific research cooperation network in the field of haze and economic growth in the world from the micro, meso and macro levels, thus showing the spatial distribution characteristics of the field (Liu et al., 2017).

Micro layer – author analysis

1) Author's analysis: initially formed a batch of high-yielding authors

Through the analysis of the amount of the author's publications, we can understand the author's scientific research ability and level, and make a quantitative analysis of the author's publications in the field of the correlation effect haze and economic growth, and can get the international high-yielding author group in this field (Liu et al., 2011).

According to *Table 1*, the most frequently published research topic in the field of haze and economic growth is the Huang GH of North China Electric Power University, who has published 32 articles. According to Price formula (*Eq. 1*):

$$M = 0.749 * (N_{max})^{1/2}$$ (Eq.1)

M is the number of papers, N_{max} refers to the number of the highest producers, the authors who have published more than M are called high-yielding authors (Sun and Wang, 2016). This paper calculates the threshold of high-yielding authors in the field of correlation between haze and economic growth, which is 4.24. Therefore, this paper takes the author whose articles are more than or equal to 5 to be a high-yielding author. There are 46 high-yielding authors (*Table 1*). These high-yielding authors are relatively active in the research field, and have strong scientific research ability. Altogether 397 papers are published, accounting for 9.40% of the total. This indicates that a certain number of high-yielding authors have been formed to some extent in the field of international academia.

2) Author cooperation analysis: high-yielding authors gathered and the rest of the authors dispersed and coexist

In order to identify the core scholars in the research field and their mutual cooperation strength, the author analyzes the literature from the perspective of author's co-occurrence.

In CiteSpace, the time zone is selected from 1992-2017, the time slice is 2, the threshold is "Top N = 30", the other parameters use the default value, Node Types selects the Author, and generates *Figure 2*. *Figure 2* shows that there are 296 nodes and

303 connections in the map, and the density is 0.0069. The node in the map represents the author, the size of the node indicates the author's volume of publications, and the thickness and color of the connection indicate the strength of the cooperation relationship and the year in which the co-occurrence relationship first occurred (Chen et al., 2014).

Table 1. *High-yielding author statistics (Number of documents ≥ 5)*

Number of documents	Name	The year of the first paper	Number of documents	Name	The year of the first paper
32	Huang GH	2008	6	Carmichael GR	1999
25	Zhang Q	2010	6	Chen L	2006
21	Wang Y	2010	6	Li L	2016
18	Liu Y	2010	6	Beig G	2008
15	Zhang Y	2012	6	Hao Y	2016
13	Li Y	2006	6	Hao JM	2010
12	Zaman K	2014	6	Rojas-Rueda D	2016
12	Streets DG	1999	6	Chen JM	2016
12	Zhou Y	2010	5	Dincer I	1998
11	Brajer V	2004	5	Liu XJ	2016
10	Li YP	2008	5	An XQ	2010
9	Guan DB	2014	5	Li J	2016
9	Zhao Y	2010	5	Huo H	2014
9	Wang L	2014	5	Levy JI	2005
8	Wang SX	2014	5	Bi J	2010
8	Liao H	2012	5	Nam KM	2008
8	Li W	2012	5	Amann M	1999
8	Mead RW	2004	5	Zhang J	2014
7	Wang J	2013	5	Guttikunda SK	2014
7	Zhu Y	2014	5	He LY	2016
7	Smith KR	2004	5	Millimet DL	2003
7	He KB	2014	5	Scasny M	2010
6	Paltsev S	2008	5	List JA	2003

As shown in *Figure 2*, a number of nodes are concentrated in the center of the map, and there are many connections between these nodes; at the same time, many isolated nodes are dispersed around it. It shows that there are different degrees of cooperation between the authors of the central region, and the flow of knowledge between each other is better, but the authors in the scattered parts around them lack communication and cooperation and are in a state of isolation. At the same time, most of the node connections in the center of the original map are orange red (corresponding to 2012-2017 year). It shows that the cooperative group has been formed in the last five years. It is now in the stage of strengthening communication and deepening the cooperation. It is expected that the future part of the author will create more research results through cooperation.
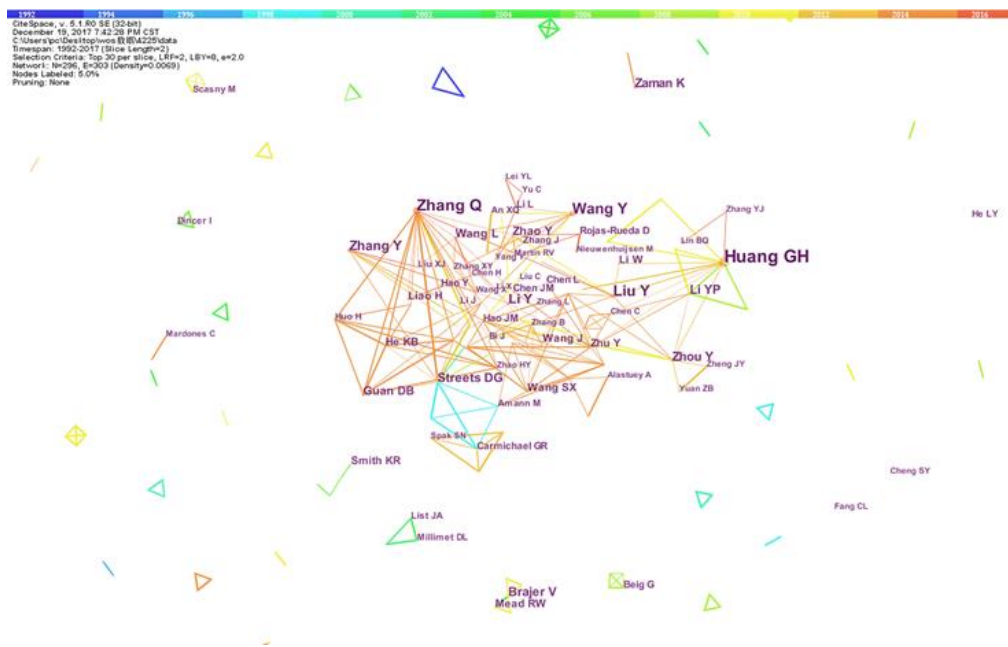
Figure 2. Co-occurrence map of scholars

Meso level – research institutions and periodicals analysis

1) Cooperation analysis of research institutions: focusing on top international universities and research institutes

Research institutes can identify the status and importance of each research institution in the field, and the degree of cooperation between them (Liu et al., 2017). In order to make the map display more concise and clear, the time slice is 4, the threshold "Top 5% per slice" is selected, and the image is "pruned" using the minimum spanning tree algorithm (MST), and *Figure 3* is obtained. As shown in the following figure, there are 165 nodes and 194 connections. The overall density of the network is 0.0143. *Table 2* lists the detailed information of the top 20 institutions.

Figure 3. Co-occurrence map of institutions

Combined with the analysis of *Figure 3* and *Table 2,* we can see: (a) the research power of the correlation between haze and economic growth is concentrated in universities and research institutes. Tsinghua University, Univ Calif Berkeley, Peking University and Harvard University are among the top international universities with environmental and economic advantages. The largest node is the Chinese Acad Sci. Its scientific research level is highly recognized both in China and internationally. (b) There are many connections in the central area of *Figure 3,* and there are scattered nodes in the non-central area. It shows that most of the research institutions in this field work closely, but there are still some institutions that lack cooperation, which should continue to strengthen exchanges and cooperation between institutions.

Table 2. Top 20 institutional information

Frequency	Institution	Country
124	Chinese Acad Sci	China
81	Tsinghua Univ	China
71	Univ Calif Berkeley	U.S.A
71	Peking Univ	China
64	Harvard Univ	U.S.A
55	US EPA	U.S.A
43	Beijing Normal Univ	China
37	Univ Maryland	U.S.A
36	Univ Calif Davis	U.S.A
34	Fudan Univ	China
31	Univ London Imperial Coll Sci Technol & Med	Britain
31	Nanjing Univ Informat Sci & Technol	China
31	North China Elect Power Univ	China
30	Univ N Carolina	U.S.A
29	Nanjing Univ	China
28	Univ Illinois	U.S.A
26	Univ Michigan	U.S.A
26	MIT	U.S.A
25	Univ Utrecht	Netherlands
25	Univ Chinese Acad Sci	China

2) Co-cited analysis of journals: research results concentrate on six high level journals

The "Cited Journal" function is selected to reflect the relevance between the various journals and disciplines by the phenomenon that the two journals are cited by the same document, so as to further analyze the knowledge base distribution in the area of haze and economic growth (Chen et al., 2014). The parameter is set to Top N = 10, and MST is selected for pruning to highlight its main components.

As shown in *Figure 4A,* the journal co citation map has 148 nodes and 355 connections. The density is 0.0326, and there are many nodes in the annual ring. Combined with the analysis of background data, the six journals of "Atmospheric Environment", "Environmental Science & Technology", "Environmental Health Perspectives", "Energy Policy", and "Science of the Total Environment" and "Science" have concentrated most of the research literature on the association effects of haze and

economic growth. The related papers are of academic value, data value and applied value, representing the research hotspots and frontiers in this field. Among the representative journals, the impact factors of "Science", "Environmental Health Perspectives" and "Environmental Science & Technology" from 2016 to 2017 are larger, and the impact factor of Science is even as high as 37.205, which is one of the most authoritative academic journals in the world. All of these show that the correlation between haze and economic growth has received international attention.

Then, through the Spotlight function in CiteSpace, the nodes with high centrality (purple circle nodes) are highlighted (*Fig. 4B*). It can be found that the number of nodes with purple circles in the journal's co-citation map is relatively large. Among them, the intermediary centrality of "Science" and "Energy Policy" is more than 0.2, indicating that these journals are in the key position in the network, which is the object that scholars in this field should focus on (Liu et al., 2017).

(A)   (B)

Figure 4. Co-citation map of journals

The macro level – national co-occurrence analysis: "USA–China", "Holland–France–Italy–Spain" are two largest emerging cooperatives

At the macro level, through the analysis of the national cooperation network, we can understand whether there is a cooperation relationship and the intensity of cooperation among the countries in the field of the correlation effect between haze and economic growth. Therefore, the node selects "Country", the parameter is set to Top N = 10, and the time slice is 2, the result is shown in *Figure 5*.

From the background data analysis of *Figure 5*, 28 countries have published more than 3 papers in the field of the correlation between haze and economic growth, but a large number of documents are obviously concentrated in a few countries. The data show that there are five countries with more than 200 papers, but the total number of papers in these five countries is up to 2941, that is, nearly 70% papers in this field are produced from these countries. Among them, the United States has a very obvious advantage, with a total of 1382 (32.71% of the total), and the centrality is as high as 0.55, indicating that the United States is in a key dominant position in the field of haze and economic growth, with a high achievement and outstanding contribution. China's paper output ranks second, with a total of 770, followed by the UK (a total of 334 articles), Canada (a total of 247 articles) and Germany (a total of 208 articles). In *Figure 5*, the thickness of the connection indicates the strength of the cooperation. The color of the line in the original figure indicates the time of cooperation between

countries. Based on this, it can be concluded that "the United States-Canada" and "Canada-Germany" had close cooperation in the early period (1992-2000). "The United Kingdom-Canada-China" had strong cooperation in the medium term (2001-2008), while the two cooperation bodies of "the USA–China" and "Holland–France–Italy– Spain" were formed in recent years (2009-2017).

Figure 5. *National cooperation network map*

From the analysis of *Figure 5*, we can see that the research power in the field of the correlation effect between haze and economic growth in the world is mainly concentrated in the developed countries such as the USA and the UK, as well as the rapidly developing countries such as China, indicating that these countries are more concerned with the field relative to other countries and have corresponding researchers. At the same time, *Figure 5* shows that there are many links between countries, indicating that their cooperation and exchange are relatively close, which is conducive to the in-depth research in this field and the output of more scientific research results. However, the original map shows that the connection between some countries is a tone, indicating that the cooperation between these countries only existed for a period of time, and has not always maintained cooperation. In the future, countries should strengthen continuous contacts and exchanges, maintain long-term cooperation so as to further promote sustainable development in this field.

Discussion

Research topics

From the previous analysis, we can see that the research literature on the correlation between haze and economic growth is very rich, but the research topic is more scattered. Combined with the high-frequency keyword clustering processed by CiteSpace (*Table 3*), and reading and sorting out the existing literature, the author divides the research topics into four aspects: (1) the economic mechanism of haze formation; (2) the relationship between haze and economic growth; (3) the spatial spillover effect of haze; (4) the countermeasures of haze control.

The economic mechanism of haze formation

Some scholars believe that energy and industrial structure and other factors have led to the emergence of haze weather. Jessie (2006) found that when entering the heavy industry stage, the consumption of coal increased continuously, the $PM_{2.5}$ concentration also increased, and the air pollution problem became more and more serious. Wang et al. (2015) found that the aggravation of haze pollution is mainly caused by the rising consumption of coal energy in industrial production. Improving industrial structure is an important way to control haze. Antonakakis (2017) analyzed the relationship between carbon emissions and economic growth, and found that the increase of global carbon emissions is accompanied by rapid economic growth.

However, some scholars have raised questions and conducted research: Antweiler (2001) established a theoretical model and used the data of SO_2 concentration to test the theory, and finally came to the conclusion that more free trade seems to be favorable to the environment. He (2012) analysed the impact of the three heavy transformation processes on the environment, such as marketization, globalization and decentralization, and concluded that the marketization and decentralization are harmful to the urban environment, while the economic globalization is beneficial to the urban air quality.

The relationship between haze and economic growth

1) Empirical research based on EKC

Panayotou (1993) applied the Kuznets curve to the analysis of the relationship between environmental quality and economic growth, and proposed the EKC hypothesis (an inverted U-shaped relationship between environmental pollution and economic growth) for the first time. Selden and Song (1994) analyzed and found that the per capita emissions of suspended particulate matter, SO_2, NOx and CO had a reverse relationship with GDP per capita. They believed that although emissions would be reduced in the long run, it was expected that global emissions would continue to grow rapidly in the next few decades. Grossman and Krueger (1994) found that economic growth brought about environmental deterioration in the early stages of economic growth and improvement in the later stages; and the turning points of different pollutants were different.

With the deepening of research, different voices have emerged in academia: Ansuategi (2003), by analyzing the panel data of SO_2 emissions in Europe, proposed that EKC would be established only when the pollutants are semi-local and have medium-term effects. Stern (2004) pointed out that there are some problems in EKC hypothesis, such as omission of variable bias, heteroscedasticity and endogeneity. Dinda (2004) combed the related literature, background history and conceptual insights, and summarized two general explanations for the formation of EKC. At the same time, there were some doubts about EKC from the perspective of concept and method. However, Tamazian and Rao (2010) considered the questions raised by the predecessors and examined them again. The results still showed the environmental Kuznets hypothesis was valid.

Hao and Liu (2016) used spatial error model and spatial lag model to analyze the direct relationship between $PM_{2.5}$ and economic development. The results show that the relationship between $PM_{2.5}$ and per capita GDP is inverted U-shaped. Secondary industry has a significant positive impact on urban $PM_{2.5}$ concentrations. Sarkodie et al. (2019) concluded that the per capita $PM_{2.5}$ emissions and income levels showed an

inverted U-shaped curve, which confirmed the validity of the Kuznets curve hypothesis between air pollution and urbanization.

2) Theoretical research

Compared with empirical analysis, the theoretical research in this field is relatively weak: Bovenberg and Smulders (1993) explored the relationship between environmental quality and economic growth in the endogenous economic growth model under the technological change driven by pollution. Chichilnisky (1994) put the environment and pollution into the neoclassical production function and utility function to analyze, and believed that the different property rights created different regional trade motives.

The spatial spillover effect of haze

Many scholars in the world believe that the haze pollution in a certain region will affect the environmental quality of the surrounding areas, and its governance will also affect the surrounding areas. That is, there is a spatial spillover effect of haze. Therefore, it is necessary to explore the relationship between the environment and the economy in the space framework, although it will make the relationship more complex.

In the early twenty-first Century, Anselin (2001), a famous international econometric economist, applied the spatial econometric modeling method to the perspective of environment and resource economy, and studied the importance of spatial factor analysis. Maddison (2007) selected SO_2, NO_2 and other pollutants as the typical measure of air quality, and used the spatial econometric method to establish a model. It was found that there was a spillover effect on the pollution and governance of haze between countries under this model. Poon et al. took Chinese provinces as the research object. By simulating the impact of energy, transportation and trade on local air pollution emissions, it was confirmed that spillover effect did exist in Chinese provinces Poon et al. (2006). Hosseini and Kaneko (2013) used six kinds of weight matrices to create six spatial models, demonstrating that air pollution does have spillover effects between countries. Dimitriou and Kassomenos (2014) studied the origin of $PM_{2.5}$ in Rome and its impact on air quality, indicating that pollutants have potential external spillover effects.

The countermeasures of haze control

According to the policy connotation reflected by EKC, economic growth will ultimately help improve environmental quality, and pollution is only a "by-product" on the growth path (Lu and Sun, 2015). However, accelerating economic growth is not a panacea for improving environmental quality (Arrow et al., 1995). Grossman and Krueger (1995) believed that the effective way to solve the environmental problems is to improve the technology and optimize the industrial structure. Based on the theory of sustainable development, Karki (2005), taking the ASEAN region as an example, believed that in order to maintain sustainable development under the condition of growing economy, comprehensive management of resources and energy was needed. Ma et al. (2019) analyzed haze in eastern and northern China, and believed that emission reduction and regional joint prevention and control would help improve air quality.

Some scholars use the Computable General Equilibrium (CGE) model to study the methods and countermeasures of haze control. Jie (2005) established a static CGE model, and found that under the policy of flue gas desulfurization, the economic growth rate will decrease, and clean energy will be used instead of polluting energy to achieve the purpose of reducing pollution. Based on the CGE model, scholars such as Xu (2009) and Allan (2014) have proposed the idea of using tax tools, including sulfur taxes and carbon taxes, to control haze. Chander (2018) proposed to strengthen the current policy system to solve the haze problem in Indonesia, including the implementation of various tax laws.

Research hotspots and trend analysis

Research hotspots

Keyword co-occurrence network can reflect the current research hotspots in a certain field. Based on this, the network node of CiteSpace is selected as "Keywords", the time slice is 3, the threshold is set to "Top 10% per slice, up to 30", and the Pathfinder algorithm is selected to be simplified. After that, the clustering analysis is carried out, and key words are extracted with LLR (logarithmic likelihood algorithm) as the clustering identifiers. The results are shown in *Figure 6* and *Table 3*.

The upper left corner of *Figure 6* shows that the Q value of the co-occurrence network of haze and economic growth is $0.5682 \geq 0.3$, and the S value is close to 0.5, which indicates that the network structure is significant and the result is basically reasonable. The graph has 221 nodes and 424 connections, with a density of 0.0174. The greater the node is, the higher the number of occurrences is. The nodes with purple outer ring will play an important role in the network. In this paper, the keywords with intermediary centrality (≥ 0.1) are selected to explore the research hotspots in various fields in the different periods, as shown in *Table 4*.
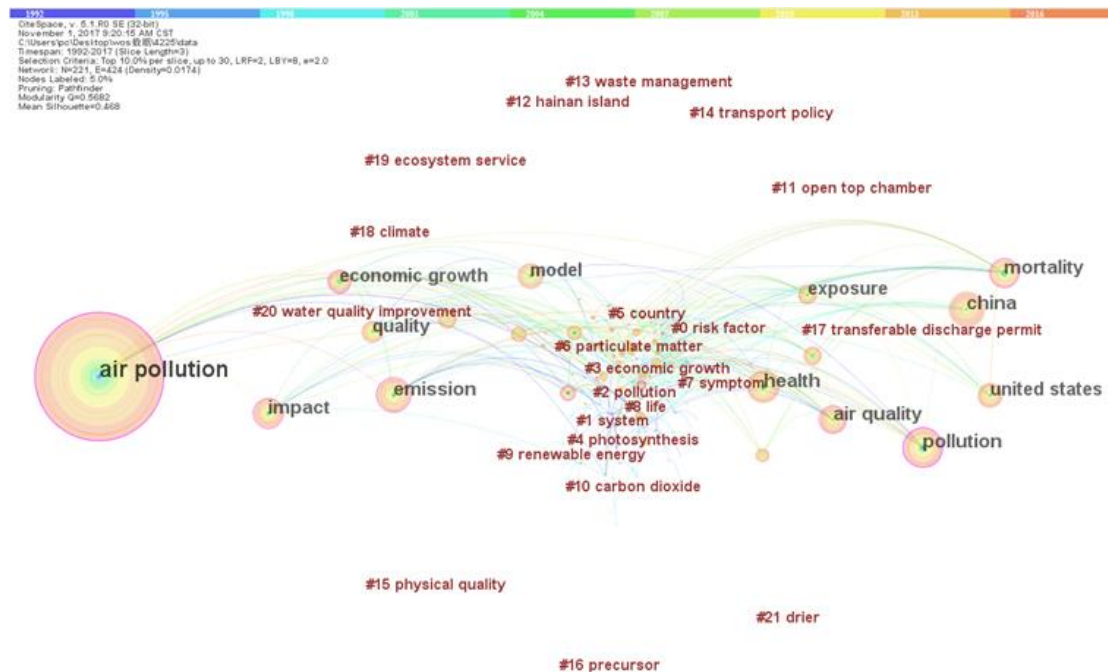

Figure 6. Keywords co-occurrence map

Table 3. Keywords clustering

Serial number	Cluster size	The tightness of clustering	Label	High frequency keywords
0	39	0.617	Risk factor	Health(313); mortality(275); exposure(203)
1	27	0.7	System	Climate change(179); energy(153) performance(112)
2	26	0.549	Pollution	China(330); impact(277); air quality(272)
3	24	0.723	Economy growth	Emission(328); policy(165) environmental Kuznets curve(113)
4	19	0.808	Photosynthesis	Acidification(14); deposition(8); critical load(7)
5	17	0.76	Country	CO_2 emission(103); consumption(46); lead(15)
6	14	0.757	Particulate matter	Aerosol(94); pm_{10}(81); $pm_{2.5}$(65)
7	14	0.771	Symptom	Particle(40); water(15); respiratory health(14)
8	12	0.771	Life	Benefit(63); cost(50); industry(27)
9	11	0.865	Renewable energy	Plant(12); environmental impact(8); greenhouse effect(7)
10	5	0.976	Carbon dioxide	Abscisic acid(6); SO_2(5); transport policy(3)

Table 4. Keywords with intermediary centrality ≥ 0.1

Serial number	Frequency	Centrality	Key word	Serial number	Frequency	Centrality	Keywords
1	1076	0.45	Air pollution	8	228	0.14	Quality
2	365	0.23	Pollution	9	203	0.14	Exposure
3	328	0.22	Emission	10	313	0.13	Health
4	330	0.19	China	11	270	0.12	Air quality
5	275	0.18	Mortality	12	108	0.11	System
6	52	0.18	Children	13	175	0.1	Particulate matter
7	153	0.15	Energy	14	5	0.1	Acid rain

According to the map analysis, the keywords "air pollution", "pollution", "emission", "mortality" and "China" are ranked in the top five, and their co-occurrence frequency is more than 200 times. These keywords with high frequency and centrality represent the issues that researchers have paid close attention to and conducted a lot of research during this period, and play a key pivotal role in the study of the correlation effect between haze and economic growth.

Trend analysis

Timezone view focuses on the evolution trend of research topics over time and their impact on each other. Therefore, the timezone view of keyword co-occurrence network can show the hot trends in the field of the correlation between haze and economic growth in the world. The network node is selected as "Keywords", the time slice is 3, the threshold is set to "Top N = 20", and the MST algorithm is selected for pruning to get the main hot trends in this field. Finally, the time map of the keyword evolution since 1992 is obtained (*Fig. 7*).
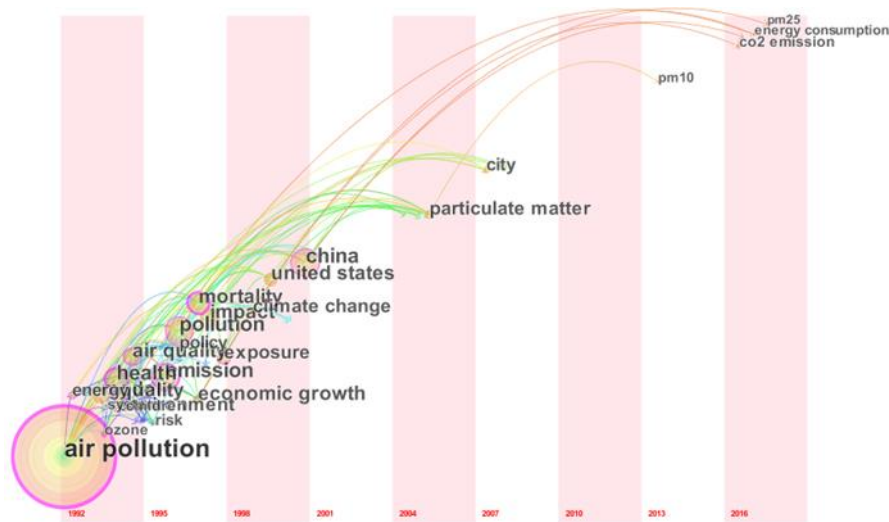
Figure 7. *Keywords time zone map*

Through the analysis of *Figure 7* and its background data, there are many key words in the early stage of the evolution of the correlation between haze and economic growth, such as "air pollution", "health", "economic growth" and "energy". These keywords are the most important focus of the academic community on the correlation between smog and economic growth in the 1990s. Since the 21st century, keywords such as "China", "particulate matter", "city" and "PM$_{2.5}$" "CO$_2$ emission" have attracted wide attention and become the current research hotspot in this field, which may continue to be hot in the future. On the whole, *Figure 7* shows the trend of international research on haze and economic growth.

Conclusion

In view of the fact that the current research has not yet fully demonstrated the development of international research on the correlation between haze and economic growth, and the lack of scientific visual quantitative analysis, this paper systematically analyzed the research on the correlation effect between haze and economic growth by using knowledge map method and CiteSpace tool. The time distribution of the literature in this field is distributed. The author's publications and cooperation in this field is analyzed by using the co-occurrence map of the author. Through the analysis of the research institutions, national co-occurrence and co-cited of journals, the main research forces in the field and the high level journals are found. The research hotspots and trends in this field are explored by using the keyword co-occurrence map and time zone map.

The main conclusions are as follows: (1) In the past sixteen years, the international academia has paid more and more attention to the correlation effect between haze and economic growth, and the literature in this field is increasing. According to the four stages of the logical growth curve of the literature, we can see that it is now in the T$_1$-T$_2$ period (rapid development stage), which has abundant research results, and the growth rate of the literature volume remains relatively high. (2) At the international level, a group of high-yielding authors headed by Huang Guohe of North China Electric Power

University, has been formed in this field, and the cooperation between these high-yielding authors is closer in the last five years and is in the stage of deepening cooperation. But the other authors lack communication and are in a state of isolation. (3) The main research forces in the field are concentrated in the international top universities and scientific research institutes. "The USA-China" and "Holland-France-Italy-Spain" are the main cooperation bodies in recent years. (4) Literature with great value in this field in the world is mainly concentrated on "Science", "Environmental Health Perspectives" and "Environmental Science & Technology". The related papers in these journals represent the hot and frontier research in this field, and have high academic value. (5) The research topics in this field mainly include the economic mechanism of haze formation, the relationship between haze and economic growth, the spatial spillover effect of haze and the countermeasures for haze control. (6) Keywords such as "air pollution", "health", "economic growth" and "energy" have been released in the early stage of the field. Since the 21st century, "China", "particulate matter", "city", "$PM_{2.5}$" and "CO_2 emission" have become the research hotspots.

In short, from the perspective of economic growth, the phenomenon of haze can be studied in many aspects. However, from the perspective of system theory and scientific development concept, the existing research still has the following shortcomings: (1) In terms of research content, there are many studies on the causes and countermeasures of haze, but little attention has been paid to the transmission mechanism of haze and its relationship with economic growth, especially the lack of theoretical research on this issue; (2) In terms of research methods, the normative analysis of haze and economic activities is more, but the empirical analysis of spatial statistics and econometrics is relatively lacking. Therefore, as a hot research topic in the interdisciplinary field of environment and economy, the use of spatial statistics and econometric methods to study whether haze and economic growth are related, and what kind of correlation exists is a further research direction in the future.

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