A Visual Analysis of Scientific and Technological Innovation Research Based on CiteSpace

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ABSTRACT

In view of 2,853 scientific and technological innovation research articles in the WOS kernel database from 1998 to 2020, this study uses scientometrics method to carry out visual research on research hotspots and evolution context in the field of WOS scientific and technological innovation. With the help of CiteSpace 6.1.R6 visualization analysis tool, it draws knowledge graphs of WOS scientific and technological innovation research, mainly including keyword co-occurrence network graph and mutation distribution table, keyword clustering graph, and keyword timeline graph. Research has shown that science and technology are a primary productive force, scientific and technological innovation is the core driving force for high-quality economic development, and changes in the scientific and technological innovation capabilities of various countries can profoundly affect the international situation. However, the focus of scientific and technological innovation research varied in different periods, mainly manifested in that, firstly, from 1998 to 2006, the research in the field of WOS scientific and technological innovation mainly focused on economic development, with industry scientific and technological innovation, enterprise scientific and technological innovation, academic research in universities, climate change, and other mainstream research hotspots; secondly, from 2007 to 2013, research in the field of WOS scientific and technological innovation mainly focused on coordinated development, with regional scientific and technological innovation, heterogeneous scientific and technological innovation capabilities, energy consumption, and scientific and technological innovation systems as mainstream research hotspots; thirdly, from 2014 to 2020, research in the field of WOS scientific and technological innovation mainly focused on sustainable development, with government innovation policies, carbon emissions, and scientific and technological innovation performance as mainstream research hotspots.

Keywords: *CiteSpace, Scientific and technological innovation, Knowledge graph, Research hotspot, Keyword.*

1. INTRODUCTION

The current global technological revolution and industrial transformation have entered a new era, and scientific and technological innovation, as a powerful catalyst for enhancing national core competitiveness, has become an important competitive means for countries to win strategic opportunities in the global market. With the continuous emergence of innovative technologies at different levels and fields, the international scientific and technological competition pattern is changing rapidly, affecting the adjustment of international division of labor and the comparison of national power. Therefore, countries around the world regard scientific and technological innovation as the strategic cornerstone of national development, formulate policy plans to promote scientific and technological progress, and build governance systems to support scientific and technological innovation. At the turning point of profound changes in the international landscape, as proposed by the 20th CPC National Congress, China still needs to adhere to the core position of scientific and technological innovation in the overall modernization construction. The foundation and key point of national strength and security lie in a self-reliant scientific and technological system and comprehensive and high-level scientific and technological innovation capabilities have gradually become a powerful representative of international discourse power. Therefore, conducting visual analysis of research hotspots and evolution in the field of WOS scientific and technological innovation and tracking international scientific and technological research priorities and cutting-edge hotspots have important guiding significance for improving China's innovation system and enhancing the overall efficiency of China's innovation system.

2. RESEARCH METHODS AND DATA SOURCES

The research methodology and data sources for this study are particularly important for the subsequent in-depth analysis of the characteristics of the field.

2.1 Research Methods

CiteSpace software is a visual analysis software developed by Professor Chen Chaomei, which presents the evolution process of a certain knowledge field by forming a visual co-citation network graph and characterizes the research frontiers and hotspots of this knowledge field through citation node literature and co-citation clustering [1]. The CiteSpace6.1R6 version software mainly includes two commonly used visualization methods: cluster view and timeline view. The cluster view focuses on characterizing the structural features between clusters to outline research priorities, while the timeline view focuses on displaying the relationships between clusters and the historical span of literature in each cluster to depict the evolution of research in this field. For this reason, this research uses CiteSpace software to reveal the hot issues and evolution process of scientific and technological innovation research field through scientometrics analysis of scientific and technological innovation related research literature in the WOS core journal library.

2.2 Data Sources

The data samples were taken from journal literature in the WOS kernel database, with title="technology innovation" or title="technological innovation" as the search criteria, and the literature search time was set to "1998-2020". To ensure the accuracy of data processing, a total of 1,707 articles were obtained by excluding non-paper related literature from the conference. At the same time, using the top 50 as the screening criterion and setting the time slice to 6, knowledge graphs of keyword co-occurrence, keyword clustering, and timeline graph in the field of WOS scientific and technological innovation research were obtained.

3. KEYWORD CO-OCCURRENCE ANALYSIS AND MUTATION DISTRIBUTION IN CHINA'S SCIENTIFIC AND TECHNOLOGICAL INNOVATION RESEARCH

Based on the processing of the above research data, a keyword co-occurrence analysis and mutation distribution analysis in the field of Science and Technology Innovation was carried out.

3.1 Keyword Co-occurrence Analysis

Keywords can be used to determine the research focus of an article and the most frequent keywords in the research field often reveal hot topics in that field.[2] Next, it used keyword co-occurrence in CiteSpace 6.1R3 and selected 1,707 pieces of scientific and technological innovation themed literature from the WOS core journal library over a time span of 1998-2020. At the same time, it set the time from 1998 to 2020 on the sub-board interface, set the years per slice value to 6, and selected "Keyword" as the node type. Finally, a keyword co-occurrence network graph in the field of WOS scientific and technological innovation research was obtained (see "Figure 1").

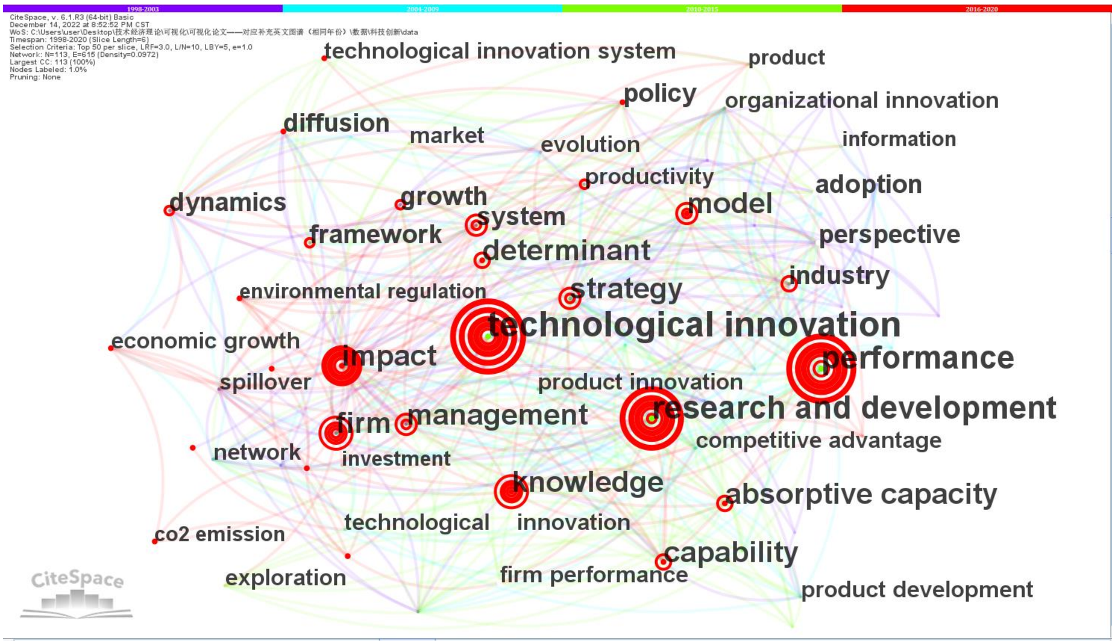

Figure 1 Keyword co-occurrence network graph in the field of WOS scientific and technological innovation research.

In "Figure 1", there are a total of 113 nodes, 615 connections, and a network density of 0.0972. The size of a node is proportional to the frequency of the keywords represented by the node, and the larger the node, the higher the frequency of the node's words.[3] According to "Figure 1", the hot issues of WOS scientific and technological innovation focus on scientific and technological innovation capability, scientific and technological innovation investment, scientific and technological innovation strategy, scientific and technological innovation impact, scientific and technological innovation management, scientific and technological innovation policy, scientific and technological innovation company performance, scientific and technological knowledge management, scientific and technological innovation environment impact, product scientific and technological innovation, industrial scientific and technological innovation, etc.

3.2 Keyword Mutation Distribution

Mutant words reflect hot keywords at different research stages, highlighting professional terms in research literature over a certain time span. The importance of the mutant word in field research can be determined by its year distribution and mutation intensity [4]. Using CiteSpace software, after calculating the literature on scientific and technological innovation in the core journal library of WOS, a table of top 20 mutant words can be obtained, mainly including integration, patent, indicator, science, economics, incentive, technological change, resource based view, collaboration, system, exploration, information technology, implementation, market orientation, governance, exploration service, co2 emission, empirical evidence, and pattern (see "Table 1").

Table 1. Mutation distribution of top 20 keywords in WOS scientific and technological literature

Keywords	Year	Strength	Begin	End	1998 - 2020
integration	1998	6.72	1998	2015	
patent	1998	4.81	1998	2009	
indicator	1998	4.64	1998	2015	
science	1998	4.37	1998	2015	
economics	1998	3.95	1998	2015	
incentive	1998	3.78	1998	2003	
technological change	1998	5.91	2004	2015	
resource based view	1998	5.66	2004	2015	
collaboration	1998	4.36	2004	2015	
system	1998	5.84	2010	2015	
exploration	1998	5.29	2010	2020	
information technology	1998	4.36	2010	2015	
implementation	1998	4.06	2010	2015	
market orientation	1998	3.92	2010	2015	
governance	1998	3.76	2010	2015	
exploitation	1998	3.76	2010	2015	
service	1998	3.48	2010	2015	
co2 emission	1998	6.41	2016	2020	
empirical evidence	1998	4.73	2016	2020	
pattern	1998	3.74	2016	2020	

According to "Table 1", from the keyword mutation distribution, the research hotspots in the field of scientific and technological innovation in China and foreign countries have been constantly changing over time, which can be mainly divided into 4 stages. ① From 1998 to 2003, integrated application of scientific and technological innovation, application of scientific and technological patents, monitoring and incentive mechanisms for scientific and technological innovation, and the relationship between science and technology and the economy became mainstream research hotspots. ② From 2004 to 2009, technological change, resource endowment theory, and collaboration became research hotspots. ③ From 2010 to 2015, technology development, market orientation, government support, and technology service facilities became mainstream research hotspots. ④ From 2016 to 2020, empirical research on greenhouse gas emissions and technological innovation, and technological innovation models became research hotspots.

4. KEYWORD CLUSTERING ANALYSIS OF CHINA'S SCIENTIFIC AND TECHNOLOGICAL INNOVATION RESEARCH

After an initial grasp of the characteristics of research in the field, keyword clustering analysis and keyword timeline analysis are used to explore hot issues at the forefront.

4.1 Keyword Clustering Graph

CiteSpace software provides 4 algorithms to extract cluster labels, which are LSI (latent semantic index), LLR (log likelihood ratio test), TF*IDF weighted algorithm (the system's default automatic label word extraction algorithm) and MI (mutual information algorithm) [5]. By comparison, it can be seen that using the LLR algorithm to extract cluster labels can reduce the possibility of duplicate extraction and is more in line with practical situations. Meanwhile, the numerical value of modularity indicates whether the network can be divided into multiple independent modules. Low modularity means that the network can't be simplified into multiple clusters with clear boundaries, while high modularity means that the network structure is clear and can be accurately divided into multiple clusters. Usually, the reasonable interval for musicality is 0.4~0.8, and the module value within this interval indicates that the network is suitable for clustering [6]. Silhouette can be used to estimate the uncertainty of clustering results and explain various clustering properties. The upper limit of the clustering silhouette value is 1, the lower limit is -1, the reasonable interval is 0.5~0.7, and the confidence interval is 0.7~1. If silhouette>0.5, then the clustering result is reasonable; if silhouette>0.7, then the clustering result is convincing; if silhouette=1, then the cluster is perfectly separated from other clusters [7]. To this end, the keyword clustering graph of literature in the field of WOS scientific and technological innovation research can be obtained through the LLR algorithm (see "Figure 2"), where musculartity Q=0.8805 and silhouette=0.8162, indicating that the clustering network structure is good and the results are reliable.

According to "Figure 2", the research field of WOS scientific and technological innovation mainly includes 8 keyword clusters: #0 technological progress, #1 technological innovation, #2 innovation system, #3 co2 emission, #4 technological diversity, #5 technological innovation system, #6 organization innovation, and #7 technological intensity. Among them, the number ranges from 0 to 7, and the smaller the number, the more keywords are included in the cluster.

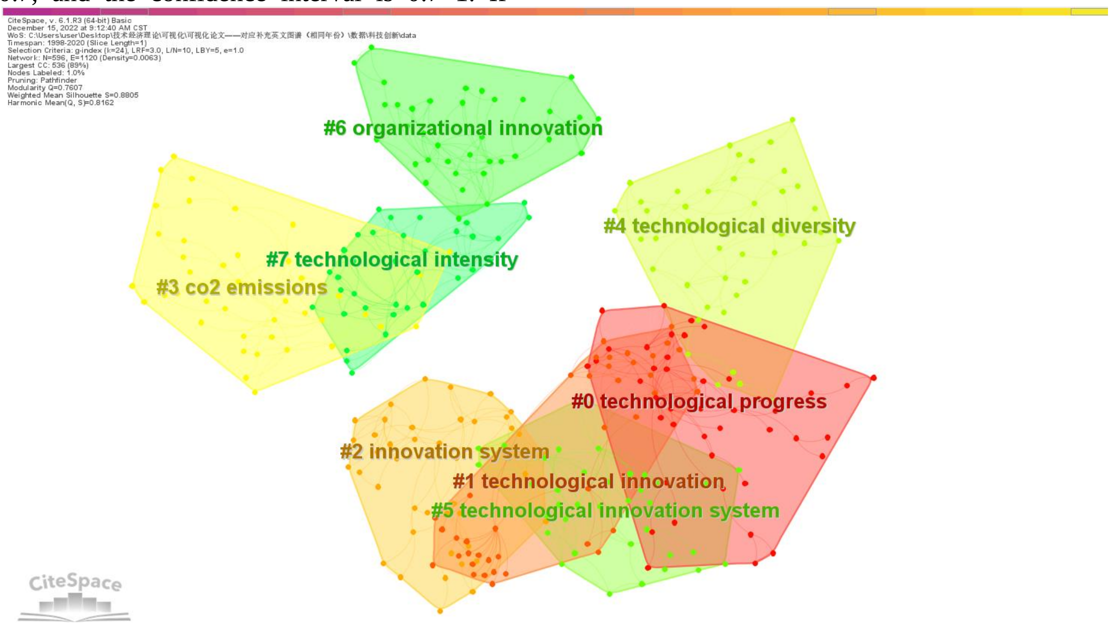

Figure 2 Keyword clustering graph of WOS scientific and technological innovation research field.

4.2 Timeline Analysis

On the basis of keyword clustering analysis, the temporal evolution trend of keyword clustering in literature in the field of WOS scientific and technological innovation research can be further analyzed. Next, it uses the "Timeline" function in CiteSpace software and adjusts the relevant values to obtain a timeline graph of keywords in the field of WOS scientific and technological innovation research (see "Figure 3").

According to "Figure 3", major keyword nodes in this field are concentrated at the front end of the timeline. The reason for this is that in 1995, the Central Committee of the CPC issued the Decision on Accelerating Scientific and Technological Progress, proposing the strategy for invigorating China through science and education, and in 1999, the Central Committee of the CPC issued the

Decision on Strengthening Technological Innovation, Developing High Technology, and Realizing Industrialization, vigorously promoting the development of high-tech and supporting the landing of high-tech enterprises.[8] In the 1870s, Western developed countries have applied sustainable development strategies to industrial development, accumulating rich advanced technologies, always placing scientific and technological innovation at the core of national development, and regarding national innovation capabilities as the key to enhancing international competitiveness.[9]

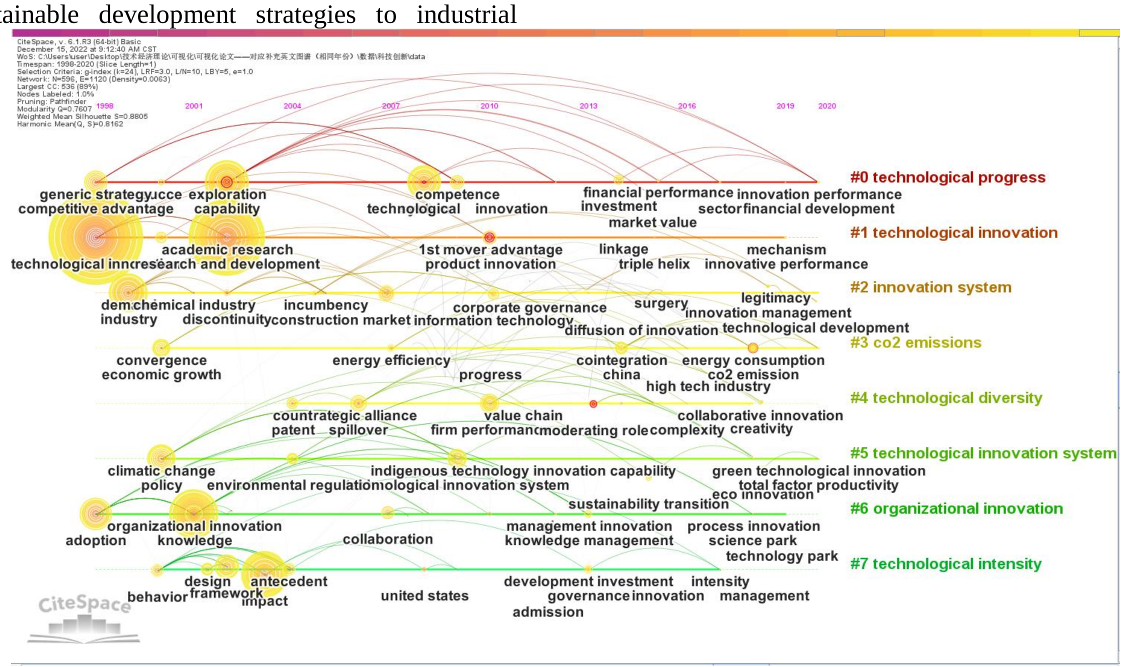

Figure 3 Keyword timeline graph of WOS scientific and technological innovation research.

4.2.1 Longitudinal Analysis

It then analyzes the top 8 keyword clustering timelines in the WOS scientific and technological innovation research field under the overall overview.

Among them,

- The largest keyword node on the cluster "#0 technological progress" timeline is "exploration capability", followed by "technological innovation", "competitive advantage", and "financial performance". Research and development capabilities determine scientific and technological innovation capabilities, and good scientific and technological innovation capabilities can bring competitive advantages to enterprises and improve their financial performance. According to "Figure 3", "innovation" is a research hotspot that runs through the entire research process and frequently appears in other clusters.
- The keyword evolution trend of cluster "#1 technological innovation" is similar to that of cluster "#0 technological progress". The largest keyword node on the clustering timeline is "technological innovation", followed by "research and development", "academic research", and "first mover advantage". After reviewing the literature, it can be seen that R&D (research and development) investment, academic research, and first mover advantage all affect the performance of scientific and technological innovation. Lillis et al. [10] found that R&D investment enhances the R&D performance of high-tech enterprises by studying New Zealand enterprises; Hu Zhijian et al. [11] summarized the characteristics of global R&D investment and found that R&D investment is related to the economic stage of countries. The growth rate of R&D investment in countries around the world is higher than the GDP growth rate, and the R&D investment of countries further rises under the wave of the emerging technological revolution; Caldenini et al. [12] used 15 European countries as examples to study the relationship among academic research, professional technology, and innovation performance. After empirical analysis, they concluded that large innovative enterprises

have a positive impact on local academic knowledge spillovers; Carlos et al. [13] found through analysis of the impact of different strategies on organizational successful innovation that traditional first mover advantage may be surpassed in the context of economic turbulence.

- The cluster "#2 innovation system" has attracted attention since 1999. The earliest and most frequent keyword node on the clustering timeline is "industry", followed by "demand", "construction market", and "corporate governance". Innovative technology is widely applied in the manufacturing industry, which is crucial to the national economic lifeline. The current industrial development has transitioned from 3.0 to 4.0, from the information age to the intelligent age, and the corresponding scientific and technological innovation system should also be improved. Reischauer [14] proposed that in the context of industrial intelligence development, innovation systems covering business, academia, and politics should be institutionalized; The fiercely competitive global market has determined that market demand is a strong driving force for technological innovation. At the same time, due to the strong promotion of sustainable concepts and the rise of social and humanistic concepts, scientific and technological innovation has become the result of the interaction between social demand and market demand. Si Jinluan proposed that Western developed countries have now formed a scientific and technological innovation system that faces market demand and is independently researched and developed by enterprises[15]; The different strategies of corporate governance have a significant impact on the performance of scientific and technological innovation in enterprises. Massis et al. [16] used agency theory to study the impact of family participation on innovation input, activities, and output of family businesses. The results showed that family participation has a direct impact on enterprise innovation.

- The cluster "#3 co2 emissions" has attracted attention since 2000. The clustering timeline mainly includes keyword nodes such as "economic growth", "energy efficiency", "cointegration", "energy consumption", and "high tech industry". Scientific and technological innovation is closely related to economic development and the ecological environment, and scholars have explored the internal connections among these three through cointegration theory and methods. Shahbaz Muhammad et al. [17] took China as an example and found that there is a negative correlation between scientific and technological innovation and carbon emissions, while economic growth and carbon emissions show an inverted U-shaped relationship; Kazi Sohag et al. [18] used the Malaysian region as an example to study and found that scientific and technological innovation has a positive effect on improving energy efficiency in the long term, while per capita GDP has increased energy use in both the short and long term perspectives; Mahmood Ahmad et al. [19] found that policies related to scientific and technological innovation and economic growth can significantly change the ecological footprint, appropriate policies are conducive to restoring natural ecosystems, and scientific and technological progress can help achieve sustainable development goals.

- The largest keyword node in cluster "#4 scientific and technological diversity" is "value chain". Bi Kexin et al. [20] used China's manufacturing industry as an example to analyze the innovation performance and influencing factors of low-carbon technology innovation activities from the perspective of the global value chain. The results showed that government regulation can have a positive impact on the performance of low-carbon technology innovation; Lin Shoufu et al. [21] used 31 provinces in China as an example to analyze the impact of air pollution on technological innovation from the perspective of the innovation value chain. The results showed that air pollution has a significant negative impact on technological innovation performance. The earliest nodes appearing on the clustering timeline for this keyword are "country" and "patent", with relevant literature appearing as early as 2004. In addition, the cluster "#4 technological diversity" also includes important keyword nodes such as "strategic alliance" and "collaborative innovation". High-tech enterprises can carry out collaborative innovation through strategic alliances to achieve mutual benefit and win-win results. Hao et al. [22] used 370 high-tech companies in China as examples to study the impact of business strategic partnerships on collaborative innovation. The research results showed that strategic partnerships have a significant positive impact on collaborative innovation between enterprises.

- The largest keyword node in the cluster "#5 technological innovation system" is "climate change", and the relevant literature first appeared in 2000. In addition, the clustering timeline also includes important keyword nodes such as "indigenous technology", "innovation capability", "eco innovation", and "total factor productivity". The ability to independently research and develop technology and innovate is the cornerstone of establishing a scientific and technological innovation system. Ecological innovation and reducing carbon emissions are the key to improving the scientific and technological innovation system, and total factor productivity is an important indicator for evaluating the scientific and technological innovation system.
- The largest keyword node in cluster "#6 organizational innovation" is "organizational innovation". Organizational innovation can regulate the contradiction between scientific and technological progress and sustainable social development while promoting technological innovation activities. César Camisón et al. [23] studied the relationship between organizational innovation and technological innovation through a survey of Spanish industrial enterprises. The results showed that organizational innovation is conducive to the development of technological innovation and better enhances enterprise performance; Xiao Daiyou et al. [24] found that technological progress can achieve social and ecological sustainable development through the mediating role of organizational innovation. Besides, the clustering timeline also includes important keyword nodes such as "management innovation", "knowledge management", and "process innovation". Management innovation, knowledge management, and process innovation have a strong connection with organizational innovation, which includes innovation at the management level and innovation at the production level.
- The important keyword nodes in the cluster "#7 technological density" are concentrated from 2001 to 2004. The performance of scientific and technological innovation is closely related to regional technology intensity. Lepak [25] took science and technology innovation companies as an example and found that scientific and technological intensity affects the relationship between employment patterns and company performance. In addition, in 2013, sub-important keyword nodes such as "development investment" and "government innovation" also appeared. The adjustment of government innovation policies affects the country's investment in scientific and technological development. Arnoud et al. [26] proposed that the government is not only the regulator of scientific and technological innovation activities, but also the promoter and coordinator. The reasonable formulation of government innovation policies can make innovative technologies more effective in meeting social needs, and high regional technology intensity also affects the formulation of government innovation policies.

Looking at the keyword distribution on various clustering timelines, it is found that scientific and technological innovation has always been a research hotspot in the academic community. With global scientific and technological changes and policy changes, the topic based on scientific and technological innovation has spawned the following hot research issues at different stages: research on the relationship between scientific and technological innovation and ecological environment, economic development, and national policies, research on the impact of scientific and technological innovation on enterprise development, and research on the application of scientific and technological innovation in industries, universities, and other fields. Among them, research on the relationship between scientific and technological innovation and ecological environment has repeatedly appeared on different clustering timelines, indicating that environmental issues have received widespread attention.

4.2.2 Horizontal Analysis

According to "Figure 3", the research on WOS scientific and technological innovation from 1998 to 2020 can be divided into 3 stages. ① From 1998 to 2006, the research in the field of WOS scientific and technological innovation mainly focused on economic development, with industries and enterprises as the main body, combined with academic research results from universities, and considering the environmental impact of climate change, to build a national innovation system. ②

From 2007 to 2013, research in the field of WOS scientific and technological innovation mainly focused on coordinated development, with regional scientific and technological innovation as the main focus, focusing on heterogeneous scientific and technological innovation capabilities, considering the environmental impact of energy consumption, and improving the national innovation system. ③ From 2014 to 2020, research in the field of WOS scientific and technological innovation mainly focused on sustainable development, with the overall improvement of national innovation capacity as the main focus, combined with government innovation policies, considered the environmental impact of carbon emissions, and emphasized the performance of scientific and technological innovation while further improving the national innovation system.

5. CONCLUSION

Using CiteSpace 6.1.R6, the keyword co-occurrence network graph, keyword clustering graph, and keyword timeline graph of research literature in the field of WOS scientific and technological innovation are drawn. Research has shown that the focus of research in the field of WOS scientific and technological innovation varies in different periods. From 1998 to 2006, the main focus was on economic development; from 2007 to 2013, the main focus was on coordinated development; from 2014 to 2020, the main focus was on sustainable development. At the same time, ecological environment issues have always been of great concern, and research on the relationship between scientific and technological innovation and ecological environment at different stages of development is reflected in hot keywords in different forms. Overall, research in the field of WOS scientific and technological innovation mainly focused on the relationship between scientific and technological innovation and ecological environment, economic development, and national policies, research on the impact of scientific and technological innovation on enterprise development, and research on the application of scientific and technological innovation in industries, universities, and other fields.

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REFERENCES

[1] Chaomei C. Searching for intellectual turning points: progressive knowledge domain visualization.[J]. Proceedings of the National Academy of Sciences of the United States of America, 2004,101(01):5303-5310.

[2] Sun Xinyu, Jiang Hua. A Comparative Review of Themes of Domestic and Overseas Higher Education Research [J]. Education Research Monthly, 2014 (01): 19-24. (in Chinese)

[3] Cao Jing, Zhang Peili, Zhou Yali. Analysis of Central Asia Research In Foreign Countries Based on CiteSpaceⅢ [J]. Journal of Library and Information Sciences in Agriculture, 2018,30 (09): 19-26. (in Chinese)

[4] Chen Shaohui, Wang Yan. Analysis of Scientific Knowledge Mapping in the Study of Chinese Social Ideological Trend:Comprehensive Application Based on Citespace and Vosviewer [J]. Journal of Shanghai Jiaotong University (Philosophy and Social Sciences Edition), 2018,26 (06): 22-30. (in Chinese)

[5] Chaomei C, Fidelia I, Jianhua H. The structure and dynamics of cocitation clusters: A multiple - perspective cocitation analysis[J]. Journal of the American Society for Information Science and Technology, 2010,61(7):1386-1409.

[6] Peng Ying, Huang Yin, Chuang Jialiang. Visualization of Knowledge Graph in China's Innovation Network: A Scientometric Analysis Based on CNKI Database Data from 1990 to 2018 [J]. E-Business Journal, 2019 (06): 62-65. (in Chinese)

[7] Chaomei C, Min S. Visualizing a field of research: A methodology of systematic scientometric reviews.[J]. PloS one, 2019,14(10):e0223994.

[8] Chen Qiang, Shen Tiantian. The Evolution of China's Science and Technology Innovation Policy System--Based on 157 Policy Texts from 1978-2020 Quantitative Analysis of Policy Texts [J]. Forum on Science and

Technology in China, 2022 (12): 35-46. (in Chinese)

[9] Song Yijun, Shao Guihua. Actively Introducing, Independently Innovating — Learning Deng Xiaoping's Important Discussion on Introducing Advanced Technology from Abroad [J]. STUDIES ON MAO ZEDONG AND DENG XIAOPING THEORIES, 1999 (06): 59-63. (in Chinese)

[10] A L D, M H A C, H C, et al. Evaluating support for technological research and innovation in some New Zealand businesses: a survey[J]. Research Evaluation, 2002,11(1):37-48.

[11] Hu Zhijian, Feng Chujian. Policies related to promoting scientific and technological progress and innovation in foreign countries [J]. Science & Technology Progress and Policy, 2006 (01): 22-28. (in Chinese)

[12] Calderini M, Scellato G. Academic research, technological specialization and the innovation performance in European regions: an empirical analysis in the wireless sector [J]. Industrial and Corporate Change, 2005,14(2):279-305.

[13] Rios C M, Dans E P. The Early Bird Gets the Worm, But the Second Mouse Gets the Cheese: Non - Technological Innovation in Creative Industries[J]. Creativity and Innovation Management, 2016,25(1):6-17.

[14] Reischauer G. Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing[J]. Technological Forecasting & Social Change, 2018,132:26-33.

[15] Si Jinluan. Technological Innovation: Foreign Experience and China's Option [J]. Contemporary Finance & Economics, 2001 (06): 57-59. (in Chinese)

[16] De Massis A, Frattini F, Lichtenthaler U. Research on Technological Innovation in Family Firms[J]. Family Business Review, 2013,26(1):10-31.

[17] Muhammad S, Chandrashekar R, Malin S, et al. Public-private partnerships investment in energy as new determinant of CO2 emissions: The role of technological innovations in China[J]. Energy Economics, 2019,86(C).

[18] Sohag K, Begum R A, Abdullah S M S, et al. Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia[J]. Energy, 2015,90:1497-1507.

[19] Ahmad M, Jiang P, Majeed A, et al. The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation[J]. Resources Policy, 2020,69.

[20] Bi K, Huang P, Wang X. Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: A case of Chinese manufacturing industry[J]. Technological Forecasting & Social Change, 2016,111:275-284.

[21] Lin S, Xiao L, Wang X. Does air pollution hinder technological innovation in China? A perspective of innovation value chain[J]. Journal of Cleaner Production, 2021,278:123326.

[22] Jiao H, Yang J, Zhou J, et al. Commercial partnerships and collaborative innovation in China: the moderating effect of technological uncertainty and dynamic capabilities[J]. Journal of Knowledge Management, 2019,23(7):1429-1454.

[23] Camisón C, Villar-López A. Organizational innovation as an enabler of technological innovation capabilities and firm performance[J]. Journal of Business Research, 2014,67(1):2891-2902.

[24] Daiyou X, Jinxia S. Role of Technological Innovation in Achieving Social and Environmental Sustainability: Mediating Roles of Organizational Innovation and Digital Entrepreneurship[J]. Frontiers in Public Health, 2022,10:850172.

[25] Lepak D P. Employment Flexibility and Firm Performance: Examining the Interaction Effects of Employment Mode, Environmental Dynamism, and Technological Intensity[J]. Journal of Management, 2003,29(5):681-703.

[26] De Meyer A, Loh C. Impact of information and communications technologies on government innovation policy: an

international comparison[J]. Int. J. of Internet and Enterprise Management, 2004,2(1):1-29.