Study on Bibliometric Visualization of Sustainable City Based on VOSviewer (2008-2021)

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Abstract. In order to clarify the co-research, research hotspots and knowledge evolution in the field of sustainable city, a visualization analysis of 1816 articles about sustainable city in the Web of Science was conducted by using bibliometrics method based on VOSviewer. The conclusions are listed as follows. (1) The citable documents of sustainable city have shown a rapid upward trend, with increasing attention and rising research hot spot, year by year, since 2015. (2) Scholars should strengthen the construction of global academic community, and China should be more extensive and in-depth cooperation with and scientific research institutions in European and American countries or regions. (3) The research dimension of sustainable city has been greatly expanding under the continuous development of complex algorithm, data science and artificial intelligence, Hence，the interdisciplinary characteristics of this research field, such as intersections, comprehensiveness and systematicness, are becoming increasingly prominent.

1 Introduction

As city is the crystallization of human civilization, people live in a city to enjoy its attribute of providing a better life. However, since the industrial revolution, rapid urbanization has brought a series of problems, such as environmental pollution, heat island effect, urban waterlogging, traffic congestion and social differentiation. In 1987, the report, *Our Common Future*, of the World Commission on Environment and Development (WCED) put forward the concept of Sustainable Development for the first time, emphasizing that development "should meet the demands of contemporary people without endangering the ability of future generations to meet their demands"[1]. Sustainable city is proposed based on sustainable development as a contemporary paradigm for building an ideal city in the future, that is, " a city sustainable in the three dimensions of environment, society and economy, with sustainable use of resources and have high risk resistance". The early definition of sustainable city pays more attention to environmental issues. Although the concept includes social dimension, it is still not prominent. With the promotion of urbanization and the enhancement of public participation awareness, the definition focuses on balancing the concepts of green and economy while achieving the balance among various development objectives. In recent years, information and communication technologies based on data science have become more and more mature, which can provide new ideas and technical support for solving complex and diversified problems in urban development[2].

Sustainable city research mainly focuses on quantitative model, evaluation index, spatial planning and design. In terms of quantitative models, scholars have developed such models as extended metabolism[3], comprehensive conceptual framework[4], future urban development[5], micro-urban ecosystem sustainability index and the comprehensive sustainable assessment of land[6]. Sustainable city assessment indicators include city scale and community scale. In terms of city scale, Ecological Footprint (EF), City Development Index (CDI), City Sustainability Index (CSI) are single assessment indicators of sustainable city, but the index system, which is constructed through environmental, economic, social and ecological aspects, is a composite assessment indicator of sustainable city[7-9]; In terms of community scale, LEED-ND, BREEAM and CASBEE-UD are the community-scale assessment indicator tools for sustainable city with a far-reaching impact[10], with some other scholars who have used eco-label to measure the environmental performance of buildings[11]. In terms of the spatial planning and design of sustainable city, Pincetl have tried to connect the three research paths of urban ecosystem services, urban metabolism and urban political ecology to form a new idea for sustainable urban spatial planning[12]. Some scholars have discussed the impact of urban intensive and compact development on urban green space and its planning, and promoted sustainable urban construction through network optimization layout strategy[13]. Pearson et al. believe that urban agriculture can promote the benign development of sustainable city, and have reviewed the studies on urban agriculture from three dimensions of society, economy and environment[14]. Other scholars consider that the spatial planning and design of sustainable city should be a complex and interdisciplinary comprehensive design, and the future

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sustainable city should fully consider the integration of historical heritage, land mix, ecological architecture, public space at different spatial scales, so as to make the city more resilient, attractive and livable [15-16].

After decades of development, sustainable city has been promoted in theory and tried in practice in many countries around the world. With the deepening of cross and interdisciplinary research, the scientific research achievements in the field of sustainable city have seen explosive growth. Traditionally, for accurately grasping the knowledge evolution of a certain research field, scholars usually need to read a large number of literature materials and make professional judgments, but it is inevitable to be disturbed by subjective factors, such as scholars' research level, depth and preference. In order to further objectively, clearly and comprehensively present the development context, research hotspots and evolution characteristics of sustainable city, and further discuss the difficulties and opportunities encountered in the process of sustainable city development, this paper makes an in-depth study on the field of ecological agriculture by using bibliometrics and visualization tools, In order to provide meaningful reference for the theoretical development and practical ideas of sustainable cities this paper uses bibliometrics method and visualization tools to conduct in-depth research in the field of ecological agriculture, looking forward to providing meaningful reference for the theoretical development and practical thinking of sustainable city.

2 Materials and Methods

2.1 Data Sources

Bibliometric analysis should be based on high-quality sci-tech text data, while the content of Web of Science (WoS) database can cover the fields natural science, social science, engineering technology, art and humanities, with its full coverage, comprehensiveness and authority[17]. Therefore, this study uses the Web of Science (WoS) database as the retrieval source. On November 4, 2021, electronic resources provided by the Library of Xi'an University of Technology were retrieved into the Web of Science™ Core Collection, with All Years as the time span of the retrieved data and "TS: (Sustainable City) OR TS: (Sustainable Cities)" as the retrieval fields. A total of 1816 literatures were retrieved, with the time spanning from 2008 to 2021 in literature distribution.

2.2 Analysis Tools and Methods

It is necessary to rely on the assistance of computers for mining valuable information from massive Sci-Tech literature. Since the introduction of auxiliary visualization in scientometrics analysis, a number of valuable scientific knowledge atlas tools, such as VOSviewer, CiteSpace and CitNetExplore, have appeared in the field of scientific knowledge atlas[18]. In view of the characteristics of Web of Science (WoS) database and the powerful scientific metrology and visual analysis function of VOSviewer, the software is selected in this study as a tool for bibliometric analysis to convert a large number of literature data into a visual atlas to discover the laws and imperceptible things hidden in a large number of historical literature data, so that researchers and practitioners can understand knowledge in a more direct way. In addition, the calculation and ordering of measurement indicators are completed in Excel 2013, and the drawing of data presentation in Origin Pro 9.2.

3 Results and Discussion

3.1 Analysis of Annual Literature Volume and Annual Cumulative Citation Frequency

As can be seen from Fig. 1, the annual literature volume of sustainable city shows an overall upward trend from 2008 to 2021. The volume of literature in 2008 reached the lowest in the past years, with only 15 articles. The volume of literature in 2021 was in the highest level during 14 years, with 319 articles, accounting for 17.6% of the total. The literature distribution of sustainable city research can be divided into three stages: low-speed growth period (2008-2010), fluctuation stagnation period (2011-2014), and high-speed growth period (2015-2021). From 2008 to 2010, the annual increase of literature was less than 20, with a slow growth. During the period of fluctuation stagnation (2011-2014), the volume of literature in 2012 decreased by 7 compared with 2011, and there was a slight increase in 2013 and 2014, but the increase was so slight and almost stagnated. After 2015, the annual literature volume showed a trend of rapid growth, and especially the literature volume in 2019 increased the most (60 more than that in 2018). In addition, according to the annual cumulative citation frequency, the literature was cited the most frequently in 2017 (2701 times), but the least frequently in 2008 (243 times). The citation frequency per document was the highest in 2011 (26.9 times), with 2014 (25.1 times) and 2015 (23.9 times) ranking the second and third, respectively. In short, the field of sustainable city still has a high degree of attention and research heat.

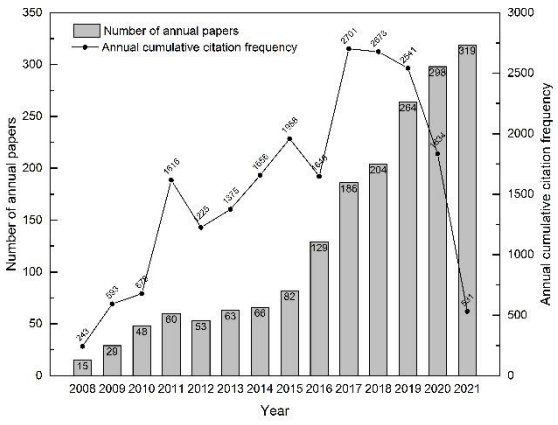

Fig. 1. Inter-annual variation and annual cumulative citation frequency of literature publications from 2008 to 2021.

3.2 Network Analysis of Co-research

Co-research refers to the behavior of scholars working together for the common purpose of producing new scientific knowledge. In practical work, co-research can also be presented as co-authorship, co-institution and co-countries (co-region). Price, the father of scientometrics, believes that with the in-depth development of interdisciplinary and marginal disciplines, the average number of collaborators on a collaborative paper will increase[19]. After analysis, the co-author network in the research field of sustainable city is relatively scattered, indicating that the co-researcher in practical work of the field is not very close with each other, but the co-institution and co-country (co-region) are relatively close.

Fig. 2 shows the largest sub-networks of co-institution in the research field of sustainable city, with the size of nodes as the volume of publications of institutions, the color of nodes as the class group of institutions obtained by default clustering method, and the connection between nodes as the relationship and intensity of co-institutions. The wider the connection is, the stronger the cooperation intensity will be.

Among the largest sub-networks of co-institution in the research field of sustainable city, research institutions with publications over 400 include Chinese Academy of Sciences (CAS, Citations=720), Arizona State University (ASU, Citations=705), University of British Columbia (UBC, Citations=631), Humboldt State University (HSU, Citations=546), Delft University of Technology (TU Delft, Citations=466), The University of Tokyo (UTokyo, Citations=448), University of Wageningen (Wageningen UR, Citations=429), Stockholm University (Wageningen UR, Citations=418) and Fudan University (FDU, Citations=418).

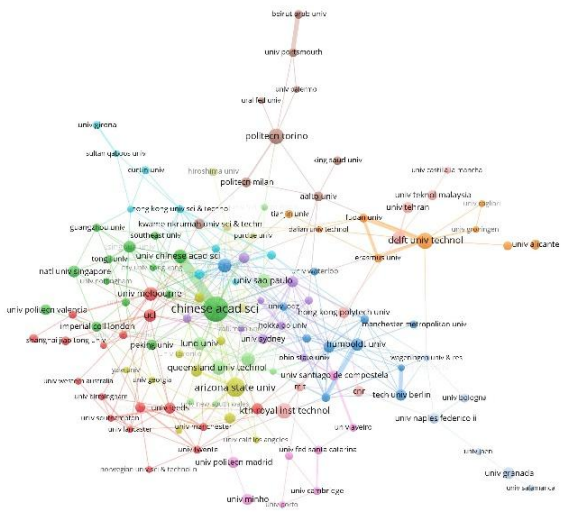

Fig. 2. The largest sub-networks of co-institution.

In terms of research categories, Chinese Academy of Sciences is similar to National University of Singapore, University of Chinese Academy of Sciences, City University of Hong Kong and Tsinghua University (Cluster=2). Arizona State University is similar to University of British Columbia, Beijing Normal University and University of Toronto (Cluster=4). Humboldt State University is similar to The University of Tokyo and Stockholm University (Cluster=3). Delft University of Technology is similar to Fudan University (Cluster=7). In terms of co-institution relation and strength, Chinese Academy of Sciences is closely cooperated with University of Chinese Academy of Sciences. There is also close cooperation among Delft University of Technology, Fudan University and Erasmus University Rotterdam.

It can be seen from Table 1 that, in terms of scientific co-country (or co-region) in the sustainable city field, China (251), America (205), Spain (165), England (146) and Italy (145) rank the top five co-countries in the number of published documents, and America (4028), China (3142), England (2923), Netherlands (2364) and Australia (2354) rank the top five in the cited documents, indicating that there is no lack of high-quality classic documents of the sustainable city field in America, compared with other countries (or regions).

Table 1. The top ranked items of co-country by documents.

Documents	Country	Citations	Cluster
251	China	3142	6
205	America	4028	5
165	Spain	1755	1
146	England	2923	6
145	Italy	1568	1
110	Australia	2354	7
101	Germany	1744	3
76	Netherlands	2364	5
74	Japan	1279	2
72	Sweden	1898	1

3.3 Analysis of Co-keywords

The word frequency analysis method in scientometrics research can be used to study the knowledge structure, development trend and research hotspot in a certain scientific field. Fig. 3 refers to the density diagram of co-keyword in the sustainable city field. The warmer the color is, the higher the frequency of the co-keywords will be. According to the 30 co-keywords with the strongest occurrences listed in Table 2 and their occurrence years, it can be seen that the four keywords, Sustainable Cities (236), Sustainability (172), Sustainable City (167) and Sustainable Development (110) in 2017, as well as the keywords, Smart City (103) and Smart Cities' (79) in 2019, have been the current research hotspots in the field of sustainable city.

From 2008 to 2010 (low growth period), there was no high-frequency co-keywords in the field of sustainable city, indicating that there was no research hotspot and no clear knowledge structure in this field. Research hotspots from 2011 to 2014 (fluctuation stagnation period) focused on sustainable aspects of urban design, urban

architecture and eco-city, which can be seen from the four co-keywords, Eco-city (8) and Architecture (8) in 2013, Urban Design (9) and Sustainable (8) in 2014. From 2015 to 2021 (rapid growth period), in addition to the research hotspots on the high-frequency co-keywords such as Sustainable or Sustainability, there have also been changes in the knowledge structure of sustainable city, placing emphasis on Urban Environment (10) in 2015, focusing on Industrial Ecology (16) in 2016, paying attention to Urban Planning (58), Climate Change (45), Urbanization (38), Urban Agriculture (26) and Resilience (25) in 2017, probing into Sustainable Urban Development (27), Smart Sustainable Cities (24), and Green Infrastructure (22) in 2018, turning to Smart City (103)/Cities (79), Urban Heat Island (23), and Circular Economy (21) in 2019, and tending to be Sustainable Development Goals (36), Internet of Things (19) and Deep Learning (8) in 2020 and 2021 from the research perspective of sustainable city.

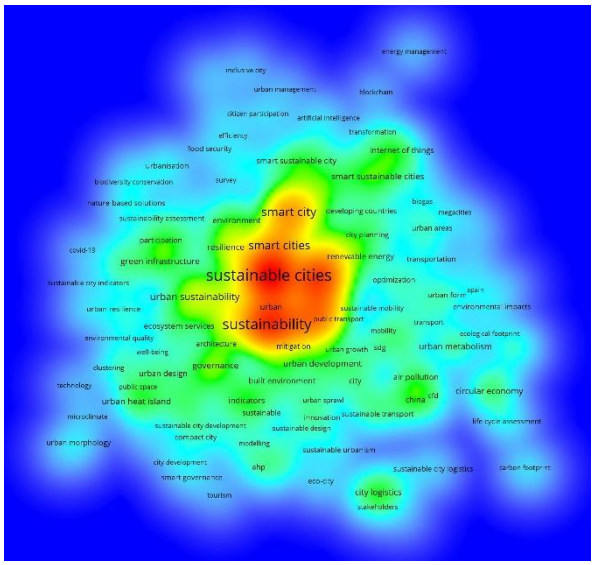

Fig. 3 Density graphic of co-keywords in the research field of sustainable city.

In summary, the evolution in the research field of sustainable city is characterized by those concepts related to ecology, environment and development are always running through the field. However, before 2017, more attention was paid to the planning and design of sustainable city in the context of GIS technology. From 2017 to 2019, emphasis was placed on how to maintain a city's own basic structure and function by preventing, absorbing and adapting to external interference[20]. The application of big data, Internet of Things and artificial intelligence has greatly expanded the research dimension of sustainable city for nearly two years[21].

Table 2. Top 30 keywords with the strongest influences.

Occurrences	Keywords	Year
236	sustainable cities	2017
172	sustainability	2017
167	sustainable city	2017
110	sustainable development	2017
103	smart city	2019
79	smart cities	2019
58	urban planning	2017
45	climate change	2017
41	urban sustainability	2018
38	urbanization	2017
36	sustainable development goals	2020
34	cities	2017
27	sustainable urban development	2018
26	urban agriculture	2017
25	resilience	2017
24	smart sustainable cities	2018
23	urban heat island	2019
22	green infrastructure	2018
21	circular economy	2019
19	internet of things	2020
19	environment	2016
16	industrial ecology	2016
15	gis	2016
14	urban design	2014
11	sustainable	2014
10	urban environment	2015
9	eco-city	2013
8	deep learning	2021
8	mitigation	2015
8	architecture	2013

3.4 Document Citation Network Analysis

In the VOSviewer, the correlation among documents is determined by the number of citations among them[22]. There are 21 documents with citations greater than 100 times in the research field of sustainable city (Fig. 4).

The most frequently cited document was written by Haase et al. in 2014 (Citations=429, Cluster=11), aiming to make people better understand and govern the complex urban system dominated by human beings by understanding the operation, service functions and internal changes of urban ecosystem[23]. In addition, Dobbs et al., under the same cluster (Cluster=11), published a document (Citations=429) discussing how to better plan sustainable city by optimizing landscape structure from the aspects of various ecosystem services and hazards of urban forests[24].

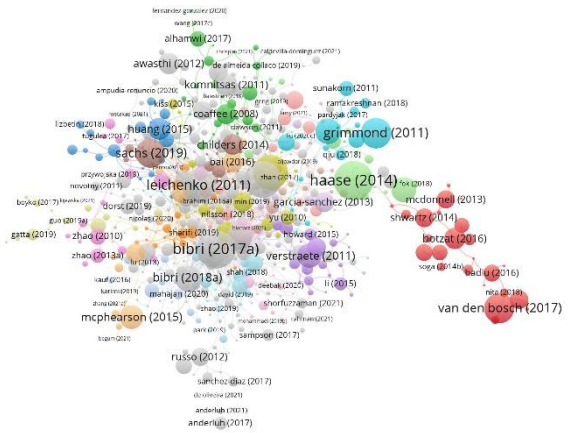

Fig. 4 Document citation analysis network of sustainable city.

The third most cited document (Citations=354, Cluster=28) counted the emerging concepts related to city in global policies and practices over the past few decades through comprehensive bibliometrics analysis. It has been found that Sustainable City is the largest node in the co-keyword network, and closely related to the concepts of Ecological City and Green City, but Smart City has gradually occupied a dominant position in urban planning policies in recent years[25]. Bibri and Krogstie wrote a document (Citations=378, Cluster=23) in 2017, emphasizing that the current difficulties faced by sustainable city construction and development can be solved by establishing a smart sustainable cities model or development framework with persuasive theory and practice, which can provide researchers and practitioners with valuable and pioneering references different from the past[26].

The realization of sustainable city requires not only the understanding of ecosystem, but also the systematic understanding of the relationship among urban ecosystem, urban residents and biodiversity (Cluster=1). Nature-based Solutions (NBS), as nature-inspired, nature-supported and nature-based dynamic solutions that address a variety of social challenges in a resource-efficient and adaptive manner while providing economic, social and environmental benefits, is playing an increasingly important role in urban and human health sustainability[27].

In short, the document citation network analysis in the research field of sustainable city can reflect the correlation among documents from the clustering characteristics and strength relationship. On the whole, there are many research dimensions of sustainable city. Under the background of globalization, this field has gradually shifted from the interpretation and analysis of concepts to the discussion of urban environment, ecology, livability and equity issues. Spatial planning tends to adopt a comprehensive method from a systematic perspective, and landscape design emphasizes the organic integration of geographical, ecological, cultural, aesthetic, social and economic dimensions in a reasonable way. Urban management supports public participation and actively explores the collaborative mechanism of different interest groups.

4 Conclusions

Based on the bibliometrics theory, 1816 documents in the field of sustainable city on the Web of Science database were visually analysed. From 2015 to now, the citable documents of sustainable city have shown a rapid upward trend, with increasing attention year by year and increasing research heat. In terms of building academic community of sustainable city, the scientific co-research of scholars needs to be strengthened. Although there has been a certain scale of institutional and national (or regional) academic communities, it is necessary to further enhance the in-depth cooperation among Chinese and European and American scientific research institutions (or countries/regions), and share the latest scientific research achievements and successful practical experience through international academic exchanges. The knowledge evolution in the research field of sustainable city always runs through such concepts as ecology, environment and development. However, in recent years, based on the development of complex algorithms, data science and artificial intelligence, the research dimension of sustainable city has been greatly expanded. In addition, according to the document citation network, the research in this field can increasingly reflect the interdisciplinary characteristics, intersection, comprehensiveness and systematicness. Sustainable city will be the focus of urban planning, landscape architecture and landscape ecology in a quite long time at present and even in the future, so that it can be conducive to providing reference for researchers, managers and practitioners with the use of visualization method.

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