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Global performance and development on sustainable city based on natural science and social science research: A bibliometric analysis

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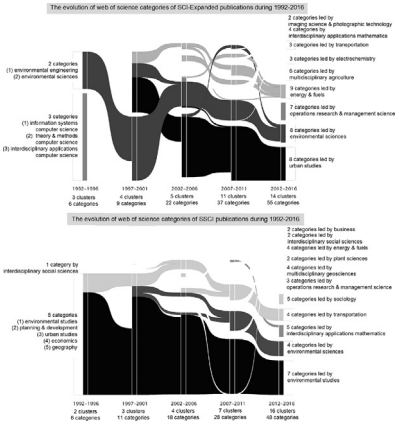
HIGHLIGHTS

- A bibliometric analysis was conducted to investigate sustainable city research in SCI and SSCI.
- Sustainable city research in natural science and social science were well-matched in quantity.
- China ranked first in SCI-EXPANDED, while the USA took the lead in SSCI.
- More interdisciplinary integration was undergoing in both SCI and SSCI.
- Climate change, China, and resilience in sustainable city research were reviewed and discussed.

GRAPHICAL ABSTRACT

Mapping the evolution among categories of SCI-EXPANDED and SSCI publications during 1992–2016.



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ABSTRACT

Sustainable city has been a global concern in recent years, involving natural science and social science research. However, few studies have attempted to map the global research of sustainable city. This study aimed to reveal the global performance and development of sustainable city research during 1992 to 2016, using a bibliometric analysis based on Science Citation Index Expanded (SCI-EXPANDED) and Social Sciences Citation Index (SSCI) on Web of Science. Research performance, research emphases and trends were illustrated by bibliometric indicators and newly developed visualization tools, like Science of Science (Sci2), Gephi, and alluvial diagram. Sustainable city research in natural science and social science were well-matched in quantity, and had similar and different characteristics in terms of different investigated aspects. China ranked first in natural science research, while the USA was the leading country in social science research. More categories and clusters were involved in sustainable city field, indicating more interdisciplinary integration was undergoing. Energy and fuels in natural science field, and interdisciplinary applications mathematics in social science field started to attract more attention. Statistical analysis of words in title, author keywords, and *KeyWords Plus* has been investigated to monitor the development of sustainable city research. Finally, three critical issues in sustainable city research based on the clues by the analysis of these keywords were reviewed and discussed.

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1. Introduction

The term of sustainable city was derived from the concept of sustainable development. Sustainable development was first defined in 1987 by the Brundtland Commission (Bartelmus, 2003), formally the World Commission on Environment and Development (WCED, 1987), solicited by the United Nations. This concept was enhanced by the United Nations Conference on Environment and Development at the Earth Summit, Rio de Janeiro, in 1992 (UNCED, 1992). In 1995, Kahn wrote that the paradigm of 'concepts, definitions, and key issues in sustainable development: the outlook for the future' described in Agenda 21, in three conceptual pillars. These pillars were economic sustainability, social sustainability, and environmental sustainability (Kahn, 1995). Recently, the Sustainable Development Goals (SDGs) and the broader 2030 Development Agenda (United Nations General Assembly, 2015), with the goal 11 of the SDGs were listing as sustainable cities and communities (Jandl, 2017).

Sustainable cities made contribution to sustainable development (Satterthwaite, 1997; Baccini, 1997; Lo and Chung, 2004). Fig. 1 showed important international movement on the sustainable development and cities. Richard first coined the term "ecocity" in his 1987 book, entitled "Ecocity Berkeley: building cities for a healthy future", which has been gradually spread to almost every aspect of our lives. Even though the basis of official definition has been criticized as being vague and lacking operability (Register, 1987), it still provided us a platform for raising constructive questions and reaching an ideological consensus. The concept of sustainable city was defined as "*Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations*" (*Subject Matters*, 2009). With the rapid urbanization movement throughout the world, it was predicted by the United Nations that 66% of the population will live in urban areas or cities by 2050 (UN, 2014). To make cities safe and sustainable means ensuring access to safe and affordable housing, upgrading slum settlements, investment in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive (SDG, 2016). Sustainable city research which was linked to various missions and involves multiple disciplines, well deserved a comprehensive analysis to combine its development, research status and frontier trends.

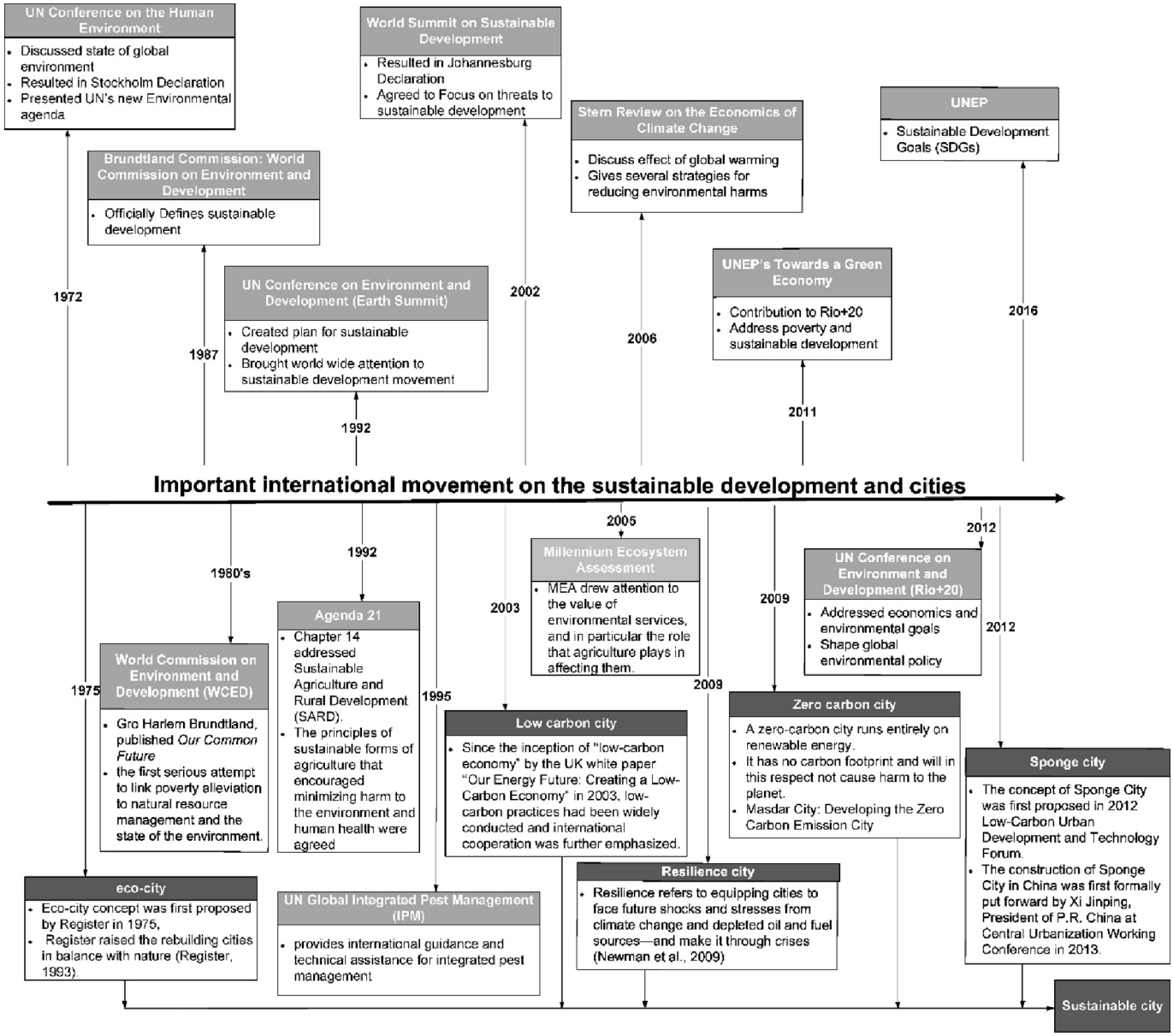

Fig. 1. Important international movement on the sustainable development and cities.

A common research instrument for this analysis is the bibliometric method which has widely been used to measure scientific progress in many disciplines of science and engineering, such as Honduras (Monge-Nájera and Ho, 2017), tea research (Wambu et al., 2017), psychology (Ho and Hartley, 2016). Recently, the bibliometric method has been employed to map different research themes of sustainable development, for example, environmental education for sustainable development in Spanish scientific journals during 2001–2010 (Villaverde and Ruiz, 2012), sustainability and sustainable development during 1991–2016 (Olawumi and Chan, 2018), transportation infrastructure during 2000–2017 which has an enormous impact on sustainable development (Wang et al., 2018). These studies provided researchers and practitioners with an extensive and in-depth understanding of the salient research themes, trends and pattern of sustainable development research worldwide. As for the research of sustainable city, due to China's important role in promoting low-carbon city development, a bibliometric approach and big data mining were adopted to uncover the scholars and the public perceptions on low carbon cities in China (Cai et al., 2017). The concept of sustainable city has gained worldwide attention recently which had enhanced its implementation. However, few studies have attempted to map the global sustainable city research involving both natural science and social science fields.

This study aimed to map the global research patterns and trends of sustainable city research during 1992 to 2016 from multiple perspectives, using a bibliometric analysis and newly developed visualization tools, like Science of Science (Sci2), gephi, and alluvial diagram. The analysis and results will help scientific researchers better understand the research status and frontier trends in sustainable city field, allow researchers to know the current research interests and patterns in this field, and provide useful information and references for further investigation and publication strategies.

2. Methodology

Bibliographic data were retrieved from Science Citation Index Expanded (SCI-EXPANDED) and Social Science Citation Index (SSCI) of Web of Science Core Collection of Clarivate Analytic. The related phrase of "sustainable city" were searched in the topic field between 1992 and 2016 in both SCI-EXPANDED and SSCI database. The searching terms and strategy of sustainable city research were displayed in Fig. 2. There were 1457 publications in SCI-EXPANDED database, and 1605 publications in SSCI database by the searching keywords. Another recently developed filter of 'front page', which filtered publications with the searching keywords in their front page including article title, abstract, and author keywords (Fu et al., 2012), was employed to removed articles with searching keywords only in *Keywords Plus*. *KeyWords Plus* provides searching terms extracted from the titles of papers cited in each new article (Garfield, 1990), therefore the articles which can only be searched out by *KeyWords Plus* were more likely unrelated to sustainable city. The articles with searching keywords only appeared in *KeyWords Plus* were excluded by the filter of front page. Finally, 1280 SCI-EXPANDED articles and 1267 SSCI articles with searching keywords in their front pages were retrieved for further analysis (Fig. 2). The full record of each article on Web of Science Core Collection and the number of annual citations was downloaded into Microsoft Excel 2016 and additional coding manually performed.

The origin country for each paper were obtained from the affiliated addresses by all authors of it. To reduce the error from database, the data from Web of Science has been checked and reclassified. Articles originating from England, Scotland, Northern Ireland, and Wales were included under the head of the United Kingdom (UK). Articles from Federal Republic of Germany (Fed Rep Ger) and Germany were reclassified as originating from Germany (Ho, 2012). Moreover, the visualization software tools like Science of Science (Sci2), gephi, and alluvial diagram were employed to provide visual insights of sustainable city research. This study first focused on overall research performance of sustainable city, with major focus on publication output, publication performance of countries, major shifts, splits and clusters of subject categories. The research emphases and trends were identified in the second subsection according to words in title, author keywords, *KeyWords Plus*, and three critical issues on the sustainable city.

3. Results and discussion

3.1. Research performance

3.1.1. Characteristics of publication output

The publication output of sustainable city research during the time span of 1992 through 2016 was summarized. There were none articles found in 1992 in SCI-EXPANDED and three articles published in 1992 in SSCI, while the number of articles rose to 242 in 2016 in both SCI-EXPANDED and SSCI databases. The annual number of articles and pages increased considerably. The average article length fluctuated slightly, with an overall average length of 11 (SCI-EXPANDED) and 15 (SSCI) pages. The number of authors per article rose from 1992 to 2016, with the overall average of 2.8 (SCI-EXPANDED) and 2.1 (SSCI) authors per article. Thirty-one references were cited per article on average in SCI-Expanded, while there were on average 40 references per

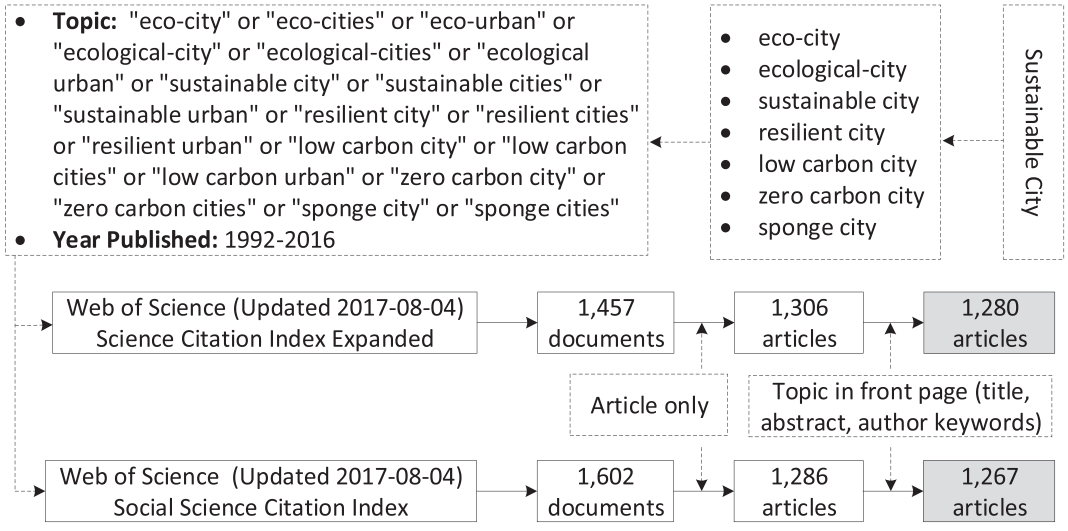

Fig. 2. Search methodology on sustainable city.

article in SSCI database articles. Fig. 3 showed that the growth rate of articles in the later period was even higher in comparison with the period from 2002 to 2016 (SCI-EXPANDED), 2004 to 2016 (SSCI). This performance could be partly explained by the fact that national and city governments struggled to accommodate the rising population in urban areas. It could also be predicted that the number of scientific papers on the topic of sustainable city research will increase at a high growth rate in the near future.

3.1.2. Publication performance by countries

With respect to publication performances by countries, the open source Sci2 Tool (Sci2, 2009) (http://sci2.cns.iu.edu) and Gephi tool (https://gephi.org/) were employed to support geospatial studies. To identify in-depth collaboration relationship of countries, Fig. 4 reveals international collaboration and global geographical distribution of SCI-EXPANDED and SSCI sustainable city research. The color of country region represented the number of total publications of one country. The darker the country region was, more publications it published. The line between two countries meant that there was collaboration relationship between these two countries. The thickness of the line indicated the international collaboration intensity between two countries. China published the most SCI-EXPANDED publications, while the USA published the most SSCI publications. As for both SCI-EXPANDED and SSCI publications, the internationally collaborating pairs of the USA–China, and the USA–Europe, China–Europe were notable. There were 365 collaborating pairs of SCI-EXPANDED publications and 294 collaborating pairs of SSCI publications. Moreover, in terms of collaboration intensity from the thickness of the lines in Fig. 4, it is also obviously that international collaboration of SCI-EXPANDED researchers was much more frequently and intensively than SSCI researchers in sustainable city field.

3.1.3. Research shifts by web of science categories

To reveal changes in the structure of sustainable city, alluvial diagrams have been used to highlight and summarize the significant structural changes of Web of Science categories (Rosvall and Bergstrom, 2010). Fig. 5 showed an alluvial diagram illustrating changes in the area of sustainable city. This set of categories showed the major shifts in the last 25 years of sustainable city field. Each significant cluster for the categories networks in five five-year periods of 1992–1996, 1997–2001, 2002–2006, 2007–2011, and 2012–2016, occupied a column in the diagram and was horizontally connected to preceding and succeeding significant clusters by stream fields. Each block in a column represented a cluster and the height of the block reflected the change flow of the research area. The clusters were ordered from bottom to top by their size with mutually nonsignificant fields placed together and separated by half the standard spacing. Changes in the clustering structure from one period to the next were represented by the mergers and divergences that occurred in the ribbons linking the blocks at different periods during 1992–2016. Darker color was used to indicate the significant subset of each cluster. Interdisciplinary has been ongoing from two and three clusters in 1992–1996 to 14 and 16 clusters during 2012–2016 based on SCI-EXPANDED and SSCI publications.

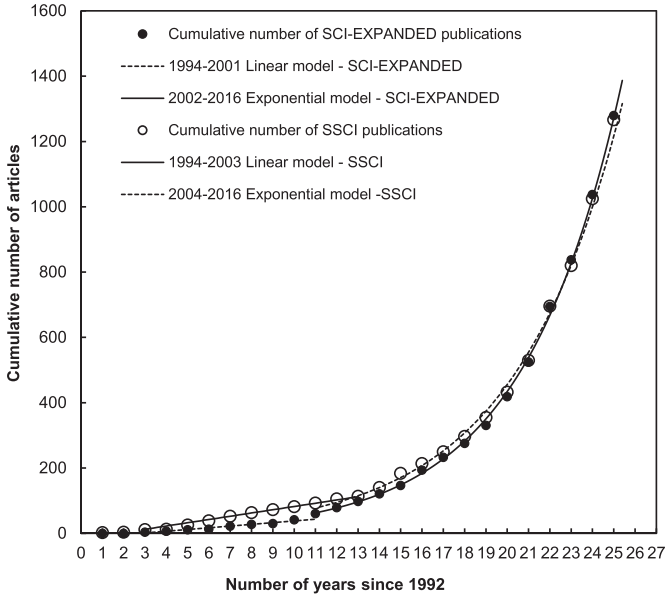

Fig. 3. Cumulative number of articles by year during 1992–2016.

As for SCI-EXPANDED publications, the environmental sciences and engineering cluster of 1992–1996 period grew to eight categories including environmental sciences, green and sustainable science and technology, water resources, geosciences, multidisciplinary engineering, environmental meteorology and atmospheric sciences, marine and freshwater biology, and geological engineering in 2012–2016 period. Urban studies cluster became mature and stand-alone cluster during the investigated period. The computer science cluster grew from covering three categories in 1992–1996 period to seven categories under the leading category of operations research and management science in 2012–2016 period. Besides, energy and fuels were clustered together during 2012–2016 with several subsets from the past 20 years, indicating increasing attention on this category.

According to the evolution of SSCI publications, environmental studies cluster during 1992–1996 gradually split to environmental studies, environmental sciences, and transportation clusters during 2012–2016. Transportation changed from splits to being clustered together in 2012–2016 period, while interdisciplinary applications mathematics category emerged during 2012–2016 with weak linkage to the past. In general, more involved categories and clusters in sustainable city field indicated that more interdisciplinary integration were undergoing. Environmental studies and sciences were mainstream disciplines in this field, while energy and fuels in natural science field, and interdisciplinary applications mathematics in social science field started to attach more attention recently.

3.2. Research emphases and trends

Distribution of title words, words in abstract, authors' keywords, and *KeyWords Plus* over different periods of time have been thoroughly examined to identify research emphases and trends (Zhang et al., 2010; Wang and Ho, 2016). Including words in title, author keywords, and *KeyWords Plus* together could minimize limitations of each kind of words, such as the uncompleted meaning of single words in title, the small sample size for author keywords, and the indirectly relationship between *KeyWords Plus* and the research emphases (Fu and Ho, 2013). Words in title, author keywords, and *Keywords Plus* of sustainable city articles were calculated and ranked by total 25-year and five 5-year sub-periods: 1992–1996, 1997–2001, 2002–2006, 2007–2011, and 2012–2016. Tables 1a–3a, 1b–3b listed most frequently used words in title, author keywords, and *Keywords Plus* of sustainable city research from SCI-Expanded and SSCI.

3.2.1. Analysis of words in titles

Authors carefully selected words in titles since the title of publication appeared thought-provoking to readers and could be employed to detect research focuses. The words in title were analyzed to understand the inferences of the scientific literature and the highly demanding research areas (Mao et al., 2010; Wang and Ho, 2016). In SCI-EXPANDED database, excluding the searching terms of sustainable city, "case", "development", "water", "management", and "China" were the most popular title words which appeared in more than 100 publications' titles (Table 1a). Only three words: "assessment", "design", and "model" did not appeared in the list of top 20 most frequently used title words of SSCI. Except searching terms, the word "environmental"

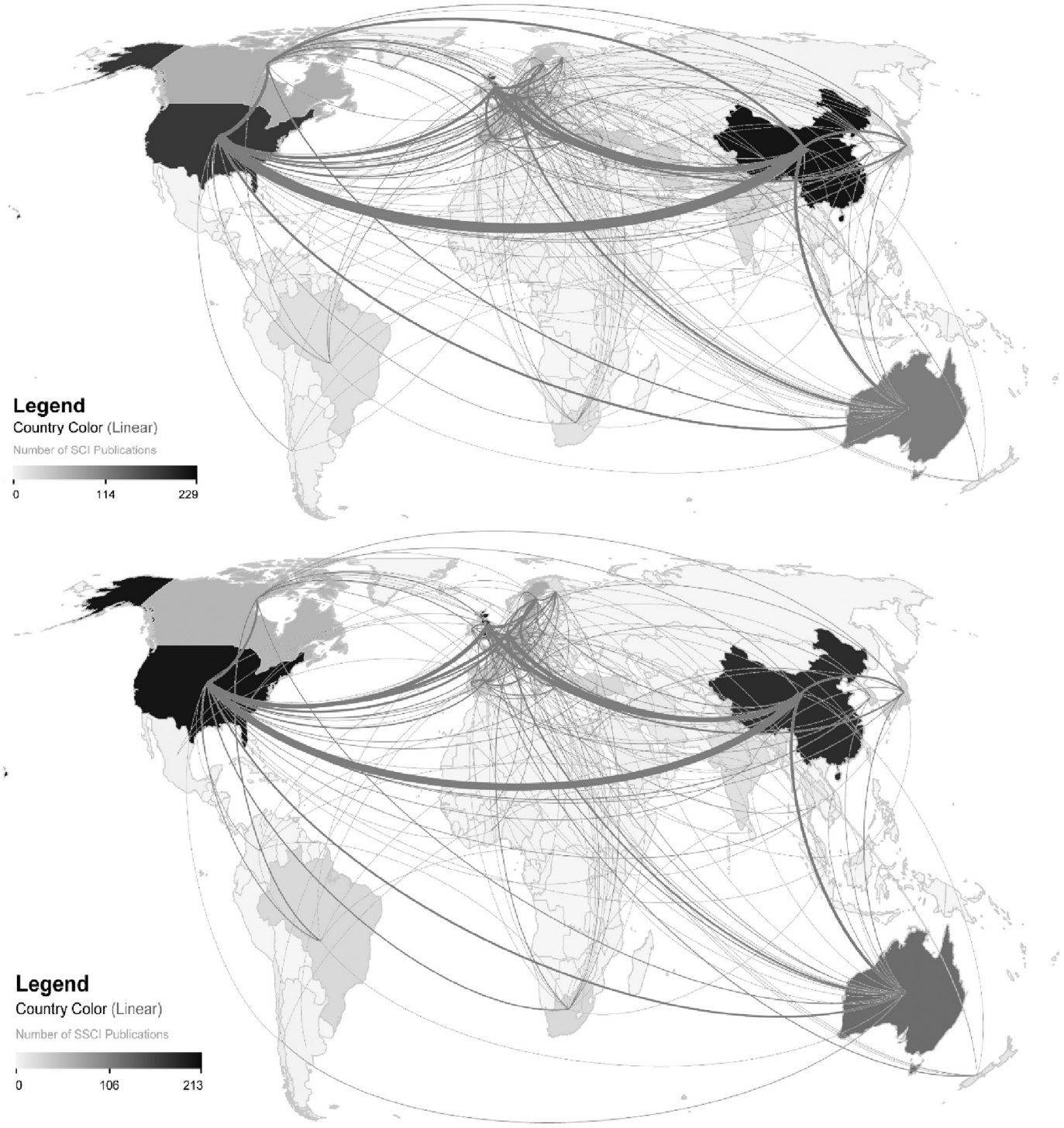

Fig. 4. International collaboration and global geographical distribution of SCI-EXPANDED and SSCI sustainable city research.

had been most frequently used in article titles in the period of 1992–1996, but was ranked 19th in the period 2012–2016. In terms of SSCI database, "management", "policy", "governance", and "climate-change" were the top four title words in the period of 2012–2016 (Table 1b).

3.2.2. Analysis of author keywords

Author keywords analysis may reveal the most areas of interest to researchers. Chiu and Ho (2007) used the distribution of author keywords to examine tsunami research after the Indonesia tsunami. Author keywords could help track the research hotspots and major directions of scientific research (Li et al., 2009; Fu and Ho, 2013). Tables 2a and 2b showed the 20 most frequently author keywords in SCI-EXPANDED and SSCI database, respectively. The top 20 author keywords showed that most of these words were shared by different disciplines in SCI-EXPANDED database (Table 2a). The "sustainability", "sustainable urban development", "urban planning", "sustainable cities", and "climate change" were the leading author keywords with no less than 50 frequencies for both SCI-EXPANDED and SSCI publications. The "climate change" related articles increased from zero during 1992–2010 to 4th ranking in SCI-Expanded and 6th position in SSCI in the period of 2012–2016. "China" was the only country which was used in author

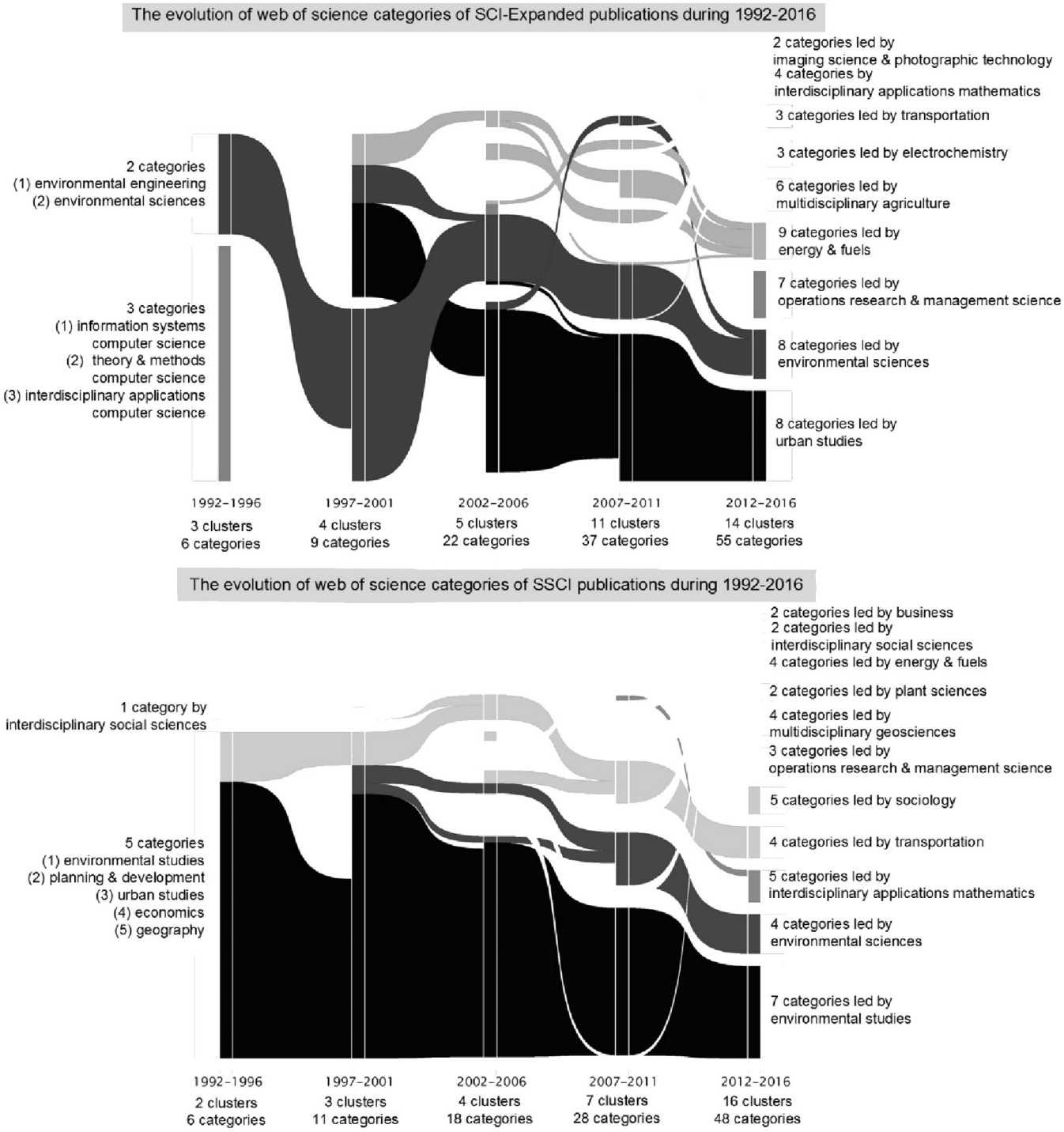

Fig. 5. Mapping the evolution among categories of SCI-EXPANDED and SSCI publications during 1992–2016.

keywords in the sustainable city research. It is noticeable that there were no articles using "resilience" as author keywords during 1992–2001, but rose to 9th place in the period 2012–2016 in both SCI-Expanded and SSCI. These performances indicated that climate change and resilience were research hotspots and frontiers in sustainable city research. Most author keywords in Tables 2a and 2b were the same between SCI-EXPANDED and SSCI, while only five author keywords were different. The author keywords of "industrial ecology", "urban metabolism", "urban ecology", "SUDs", and "GIS" were unique top words in SCI-EXPANDED publications, while "eco-city", "urban agriculture", and "planning" were unique top words in SSCI publications.

3.2.3. Analysis of KeyWords Plus

According to Garfield (1990), *KeyWords Plus* could be extracted from the titles of cited documents in authors' biodata placed either in their bibliographies or footnotes in the Web of Science database, leading to augment the total words in titles and author keywords indexing. Like the author keywords, most words were repeated for SCI-EXPANDED and SSCI publications. However, most of the repeated words got different ranks in SCI-EXPANDED database and SSCI database. *KeyWords Plus* were used by multiple research areas of sustainable city: "cities", "management", "city", "systems", "model", "urbanization", "China", "energy", and "climate-change" in SCI-EXPANDED database. "Management",

Table 1a
Top 20 most frequently used title words (SCI-EXPANDED).

Title words	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Urban[a]	712	1 (56)	8 (9.1)	2 (35)	1 (62)	1 (55)	1 (56)
Sustainable[a]	381	2 (30)	1 (45)	1 (48)	2 (43)	2 (32)	2 (27)
City[a]	156	3 (12)	2 (27)	5 (13)	7 (10)	7 (11)	3 (13)
Case[a]	153	4 (12)	N/A	10 (6.5)	9 (10)	6 (12)	3 (13)
Development[a]	152	5 (12)	N/A	3 (23)	3 (17)	4 (13)	6 (11)
Cities[a]	146	6 (11)	8 (9.1)	4 (16)	4 (12)	7 (11)	5 (11)
Water[a]	134	7 (10)	N/A	6 (10)	11 (8.6)	3 (14)	7 (10)
Management[a]	123	8 (10)	8 (9.1)	6 (10)	9 (10)	4 (13)	8 (8.7)
China[a]	110	9 (8.6)	N/A	N/A	20 (4.8)	7 (11)	8 (8.7)
Systems[a]	96	10 (7.5)	8 (9.1)	10 (6.5)	6 (11)	15 (5.1)	10 (7.8)
Sustainability[a]	86	11 (6.7)	N/A	6 (10)	11 (8.6)	11 (6.3)	11 (6.6)
Planning[a]	83	12 (6.5)	N/A	N/A	4 (12)	13 (5.9)	12 (6.3)
Energy[a]	76	13 (5.9)	N/A	10 (6.5)	45 (1.9)	10 (8.8)	15 (5.6)
Assessment	66	14 (5.2)	N/A	N/A	32 (2.9)	21 (3.7)	13 (6.2)
System[a]	62	15 (4.8)	N/A	10 (6.5)	7 (10)	14 (5.5)	20 (3.9)
Green[a]	60	16 (4.7)	N/A	10 (6.5)	105 (1.0)	28 (2.9)	14 (5.7)
Design	54	17 (4.2)	8 (9.1)	24 (3.2)	23 (3.8)	24 (3.3)	18 (4.5)
Model	53	18 (4.1)	N/A	N/A	20 (4.8)	28 (2.9)	16 (4.6)
Environmental[a]	52	19 (4.1)	3 (18)	24 (3.2)	45 (1.9)	17 (4.4)	19 (4.1)
Carbon[a]	50	20 (3.9)	N/A	N/A	N/A	21 (3.7)	16 (4.6)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same title words both appearing in the top 20 most frequently used list of SCI-EXPANDED and SSCI database.

"policy", and "governance" were the new emphasis keywords in SSCI database (Tables 3a and 3b).

3.2.4. Issues on the sustainable city

The keywords analysis above provided important clues for the potential issues on the future of sustainable city research. Further studies are required to explore the sustainable city research and its applications. Therefore, three research critical issues: climate change, China, and resilience in sustainable city research can be consisted of the facets as follows.

(1) Climate change issue in sustainable city research

"Development", "sustainable urban development", "sustainable development", and "urban development" in top keywords list indicated development of sustainable city was one of the most important issues in sustainable city. Climate change was one of the most significant huge challenges facing the world, which could also be seemed as a critical issue for sustainable cities. The urban areas were significant sources of greenhouse gas emissions and were vulnerable to the impacts of climate change. The development of adaptation plans (vulnerability assessment of natural disasters impact to cities) should be established.

(2) Sustainable city research about China

It was unusual "China" ranked in the lists in terms of top title words, author keywords, and *KeyWords Plus* based on both SCI-EXPANDED and SSCI research. "China" was also the only one country which appeared in top keywords lists. Obviously, China attached great importance to the development of sustainable city. Sustainable development at the city level has become more popular in China. Scholars began to pay more attentions on the relevant research perspectives. For instance, the potential influence of Chongqing's low carbon development plan on energy consumption and carbon emissions up to 2020 has been analyzed based on different policy scenarios (Liu et al., 2012). China's Five-Year-Plan for national growth does place environmental sustainability as a central pillar for research and policy. The 12th Five-Year-Plan (China Briefing, 2013) seeks US$5.5 billion (RMB3.4 trillion) in investment spread across 8 sectors: pollutant reduction, living standard improvement, rural environmental protection, ecological preservation, environmental risk prevention, nuclear safety, environmental infrastructure, and environmental monitoring (China Briefing, 2013).

With the sustainable issue, "sponge city" was put forward by Chinese government in 2013. "Sponge city" was not a new term created by China. It emerged in the West and has been widely received in China in recent years. The term was first used by western scholars in a population study to describe the fact that cities concentrate and absorb the surrounding rural populations like a sponge (Budge, 2006). With regard to China's concept, "sponge city" was a vivid description of urban environment acting like a sponge to absorb and release water naturally. This concept represented a new urban development mode, among which the natural environment under urbanization should be protected and restored to ensure its ecosystem service function of water conservation (Liu et al., 2017).

(3) Resilience in sustainable city research

Resilience emerged according to the analysis of author keywords in SCI-EXPANDED and SSCI. It was interesting that resilience has gained

Table 1b
Top 20 most frequently used title words (SSCI).

Title words	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Urban[a]	704	1 (56)	2 (38)	2 (48)	1 (66)	1 (57)	1 (55)
Sustainable[a]	438	2 (35)	1 (65)	1 (54)	2 (45)	2 (37)	2 (30)
Development[a]	183	3 (14)	3 (23)	3 (25)	4 (15)	3 (17)	5 (13)
City[a]	182	4 (14)	5 (15)	5 (14)	7 (11)	4 (14)	3 (15)
Cities[a]	175	5 (14)	8 (7.7)	4 (20)	3 (21)	8 (11)	4 (14)
Case[a]	146	6 (12)	19 (3.8)	9 (7.1)	6 (12)	5 (13)	6 (12)
Planning[a]	135	7 (11)	6 (12)	9 (7.1)	5 (13)	6 (13)	8 (10)
Sustainability[a]	126	8 (10)	8 (7.7)	5 (14)	8 (7.8)	7 (12)	9 (9.4)
China[a]	108	9 (8.5)	8 (7.7)	40 (1.8)	10 (5.9)	13 (6.0)	7 (10)
Transport	64	10 (5.1)	N/A	9 (7.1)	10 (5.9)	9 (7.2)	13 (4.3)
Management[a]	62	11 (4.9)	19 (3.8)	9 (7.1)	14 (4.9)	9 (7.2)	16 (4.1)
Water[a]	59	12 (4.7)	N/A	16 (3.6)	26 (2.9)	9 (7.2)	13 (4.3)
Green[a]	56	13 (4.4)	N/A	40 (1.8)	109 (1.0)	24 (3.2)	10 (5.5)
Environmental[a]	55	14 (4.3)	8 (7.7)	9 (7.1)	49 (2.0)	9 (7.2)	23 (3.5)
Systems[a]	55	14 (4.3)	8 (7.7)	16 (3.6)	14 (4.9)	37 (2.4)	12 (4.8)
Policy	51	16 (4)	N/A	7 (11)	49 (2.0)	17 (4.0)	18 (4.0)
Carbon[a]	50	17 (3.9)	N/A	N/A	N/A	18 (3.6)	11 (4.9)
Energy[a]	49	18 (3.9)	N/A	16 (3.6)	26 (2.9)	14 (4.4)	18 (4.0)
Towards	48	19 (3.8)	N/A	16 (3.6)	19 (3.9)	18 (3.6)	18 (4.0)
Approach	46	20 (3.6)	19 (3.8)	7 (11)	10 (5.9)	27 (2.8)	29 (3.1)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same title words both appearing in the top 20 of SCI-EXPANDED and SSCI database.

Table 2a
Top 20 most frequently used author keywords (SCI-EXPANDED).

Author keywords	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Sustainability[a]	105	1 (9.2)	N/A	1 (21)	2 (9.3)	1 (11)	1 (8.3)
Sustainable urban development[a]	77	2 (6.7)	N/A	9 (4.2)	4 (8.1)	2 (7.5)	2 (6.4)
Urban planning[a]	56	3 (4.9)	N/A	5 (8.3)	6 (7.0)	8 (3.3)	3 (5.0)
Sustainable cities[a]	50	4 (4.4)	N/A	9 (4.2)	12 (3.5)	3 (5.9)	5 (4.0)
Climate change[a]	50	4 (4.4)	N/A	N/A	18 (2.3)	5 (4.2)	4 (4.8)
Sustainable development[a]	48	6 (4.2)	N/A	1 (21)	4 (8.1)	5 (4.2)	7 (3.3)
Urbanization[a]	41	7 (3.6)	N/A	N/A	2 (9.3)	8 (3.3)	8 (3.1)
China[a]	39	8 (3.4)	N/A	N/A	7 (5.8)	11 (2.5)	6 (3.5)
Cities[a]	34	9 (3.0)	N/A	9 (4.2)	1 (12)	11 (2.5)	14 (2.1)
Sustainable urban water management[a]	31	10 (2.7)	N/A	N/A	N/A	4 (5.4)	13 (2.3)
Urban sustainability[a]	29	11 (2.5)	N/A	3 (17)	45 (1.2)	17 (1.7)	12 (2.5)
Sustainable city[a]	28	12 (2.4)	N/A	9 (4.2)	8 (4.7)	11 (2.5)	14 (2.1)
Industrial ecology	26	13 (2.3)	N/A	N/A	45 (1.2)	5 (4.2)	17 (1.9)
Urban metabolism	26	13 (2.3)	N/A	N/A	N/A	27 (1.3)	10 (2.9)
Ecosystem services[a]	25	15 (2.2)	N/A	N/A	45 (1.2)	49 (0.84)	11 (2.8)
Resilience[a]	25	15 (2.2)	N/A	N/A	N/A	113 (0.42)	9 (3.0)
Urban development[a]	24	17 (2.1)	N/A	4 (13)	12 (3.5)	27 (1.3)	17 (1.9)
Urban ecology	21	18 (1.8)	N/A	N/A	8 (4.7)	17 (1.7)	20 (1.6)
Urban[a]	21	18 (1.8)	N/A	9 (4.2)	18 (2.3)	113 (0.42)	14 (2.1)
SUDs	18	20 (1.6)	N/A	N/A	45 (1.2)	17 (1.7)	20 (1.6)
GIS	18	20 (1.6)	N/A	9 (4.2)	18 (2.3)	113 (0.42)	19 (1.8)
Governance[a]	18	20 (1.6)	N/A	5 (8.3)	45 (1.2)	49 (0.84)	20 (1.6)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same author keywords both appearing in the top 20 of SCI-EXPANDED and SSCI database.

considerable attention over recent years in both theories and decision-making practices in developing a sustainable city. As our society grew more complex and the environments became less certain, it was increasingly difficult to make our social, economic, and ecological systems sustainable. There were "shocks" that may cause systems to fail, and be prepared to recover from the failure. The ability to withstand these shocks and recover from the failure was called resilience (Maruyama, 2016). The most important issue addressed by resilience was the water sector in city. Butler et al. (2014) descripted a conceptual framework to link the emerging threats of climate change and variability, rapid urbanization and population growth, energy constraint and tightening environmental regulation through to their consequences on social, economic and environmental recipients. The framework allowed identification of the role and need for mitigation, adaptation and coping strategies (Butler et al., 2014).

4. Conclusions

The bibliometric method and visualization tools were employed to figure out research performance, research emphases and trends of sustainable city research based on natural science dataset of SCI-EXPANDED and social science dataset of SSCI. There were both similarities and differences for natural science and social science. The quantity of natural science research on sustainable city balanced that of social science research on sustainable city, indicating that sustainable city research was a comprehensive field, involving soft science as well as hard science almost equally.

A steady increase of publications in the cumulative curve of both SCI-EXPANDED and SSCI articles, while more categories and clusters in sustainable city field were involved, indicating more interdisciplinary integration were undergoing. Environmental studies and sciences

Table 2b
Top 20 most frequently used author keywords (SSCI).

Author keywords	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Sustainability[a]	108	1 (10)	N/A	4 (11)	3 (8.6)	1 (10)	1 (11)
Sustainable urban development[a]	83	2 (8.0)	N/A	4 (11)	6 (5.7)	2 (10)	2 (7.7)
Sustainable development[a]	74	3 (7.1)	N/A	4 (11)	1 (13)	4 (7.8)	4 (6.3)
Urban planning[a]	69	4 (6.6)	N/A	11 (5.3)	5 (7.1)	3 (8.8)	5 (6.1)
China[a]	59	5 (5.7)	N/A	N/A	6 (5.7)	14 (2.1)	3 (6.7)
Sustainable cities[a]	56	6 (5.4)	N/A	2 (16)	2 (10)	5 (6.7)	8 (4.4)
Climate change[a]	46	7 (4.4)	N/A	N/A	33 (1.4)	6 (5.2)	6 (4.6)
Urban sustainability[a]	46	7 (4.4)	N/A	1 (21)	14 (2.9)	10 (2.6)	6 (4.6)
Urbanization[a]	32	9 (3.1)	N/A	N/A	3 (8.6)	21 (1.6)	12 (3.0)
Sustainable city[a]	30	10 (2.9)	N/A	11 (5.3)	14 (2.9)	9 (3.6)	13 (2.6)
Governance[a]	29	11 (2.8)	N/A	11 (5.3)	N/A	21 (1.6)	9 (3.3)
Eco-city	28	12 (2.7)	N/A	N/A	33 (1.4)	21 (1.6)	11 (3.2)
Resilience[a]	27	13 (2.6)	N/A	N/A	33 (1.4)	106 (0.52)	9 (3.3)
Cities[a]	26	14 (2.5)	N/A	N/A	6 (5.7)	10 (2.6)	15 (2.2)
Urban development[a]	25	15 (2.4)	N/A	2 (16)	10 (4.3)	35 (1.0)	15 (2.2)
Urban agriculture	24	16 (2.3)	N/A	4 (11)	33 (1.4)	14 (2.1)	15 (2.2)
Ecosystem services[a]	22	17 (2.1)	N/A	N/A	33 (1.4)	106 (0.52)	13 (2.6)
Urban[a]	21	18 (2.0)	N/A	N/A	10 (4.3)	35 (1.0)	18 (2.1)
Planning	20	19 (1.9)	N/A	11 (5.3)	6 (5.7)	14 (2.1)	25 (1.5)
Sustainable urban water management[a]	19	20 (1.8)	N/A	N/A	N/A	7 (4.7)	27 (1.3)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same author keywords both appearing in the top 20 of SCI-EXPANDED and SSCI database.

Table 3a
Top 30 most frequently used *KeyWords Plus* (SCI-EXPANDED).

KeyWords Plus	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Cities[a]	149	1 (15)	N/A	1 (13)	1 (9.4)	1 (14)	1 (16)
Management[a]	110	2 (11)	N/A	1 (13)	4 (7.5)	2 (10)	2 (12)
City[a]	90	3 (9.3)	N/A	N/A	1 (9.4)	5 (6.9)	3 (10)
Systems[a]	86	4 (8.9)	N/A	N/A	7 (5.7)	2 (10)	4 (9.0)
Model[a]	71	5 (7.3)	N/A	N/A	4 (7.5)	4 (7.5)	5 (7.3)
Urbanization[a]	54	6 (5.6)	N/A	N/A	38 (1.9)	30 (2.3)	6 (6.7)
China[a]	51	7 (5.3)	N/A	N/A	38 (1.9)	5 (6.9)	11 (5.2)
Energy[a]	50	8 (5.1)	N/A	N/A	38 (1.9)	7 (5.7)	9 (5.3)
Climate-change[a]	50	8 (5.1)	N/A	N/A	38 (1.9)	7 (5.7)	9 (5.3)
Land-use[a]	48	10 (4.9)	N/A	N/A	N/A	9 (4.6)	8 (5.4)
Performance	46	11 (4.7)	N/A	N/A	N/A	19 (2.9)	7 (5.6)
Sustainability[a]	44	12 (4.5)	N/A	N/A	38 (1.9)	11 (4.0)	12 (4.9)
Areas[a]	42	13 (4.3)	N/A	N/A	7 (5.7)	11 (4.0)	15 (4.4)
Quality	42	13 (4.3)	N/A	N/A	1 (9.4)	9 (4.6)	19 (3.9)
Impact[a]	39	15 (4.0)	N/A	N/A	15 (3.8)	30 (2.3)	13 (4.5)
Policy[a]	38	16 (3.9)	N/A	1 (13)	15 (3.8)	72 (1.1)	13 (4.5)
Environment[a]	36	17 (3.7)	N/A	N/A	7 (5.7)	14 (3.4)	21 (3.7)
System[a]	36	17 (3.7)	N/A	N/A	15 (3.8)	30 (2.3)	17 (4.1)
Ecosystem services[a]	34	19 (3.5)	N/A	N/A	15 (3.8)	72 (1.1)	17 (4.1)
Health[a]	34	19 (3.5)	N/A	N/A	N/A	19 (2.9)	19 (3.9)
Governance[a]	33	21 (3.4)	N/A	N/A	38 (1.9)	N/A	15 (4.4)
Design[a]	33	21 (3.4)	N/A	N/A	38 (1.9)	19 (2.9)	21 (3.7)
Biodiversity[a]	32	23 (3.3)	N/A	N/A	38 (1.9)	19 (2.9)	23 (3.5)
Growth[a]	31	24 (3.2)	N/A	N/A	N/A	14 (3.4)	24 (3.4)
Ecology[a]	29	25 (3.0)	N/A	N/A	15 (3.8)	30 (2.3)	25 (3.1)
Impacts[a]	29	25 (3.0)	N/A	N/A	15 (3.8)	30 (2.3)	25 (3.1)
Vegetation	27	27 (2.8)	N/A	N/A	38 (1.9)	19 (2.9)	28 (2.9)
Consumption	26	28 (2.7)	N/A	N/A	N/A	19 (2.9)	28 (2.9)
Urban[a]	25	29 (2.6)	1 (100)	N/A	N/A	19 (2.9)	30 (2.6)
Landscape	24	30 (2.5)	N/A	N/A	38 (1.9)	14 (3.4)	36 (2.3)
Emissions	24	30 (2.5)	N/A	N/A	15 (3.8)	30 (2.3)	32 (2.4)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same *KeyWords Plus* both appearing in the top 30 of SCI-EXPANDED and SSCI database.

Table 3b
Top 20 most frequently used *KeyWords Plus* (SSCI).

KeyWords Plus	*TP*	91–16 *R* (%)	92–96 *R* (%)	97–01 *R* (%)	02–06 *R* (%)	07–11 *R* (%)	12–16 *R* (%)
Cities[a]	212	1 (21)	N/A	1 (20)	1 (18)	2 (13)	1 (24)
City[a]	143	2 (14)	N/A	8 (4.0)	2 (15)	1 (16)	2 (14)
Management[a]	96	3 (10)	N/A	N/A	6 (4.8)	3 (6.5)	3 (11)
Policy[a]	82	4 (8.2)	N/A	3 (8.0)	3 (8.1)	6 (5.4)	4 (8.9)
Governance[a]	63	5 (6.3)	N/A	N/A	41 (1.6)	15 (3.2)	5 (7.7)
Climate-change[a]	62	6 (6.2)	N/A	N/A	41 (1.6)	9 (4.9)	6 (7.1)
Model[a]	58	7 (5.8)	N/A	N/A	N/A	3 (6.5)	7 (6.3)
Systems[a]	58	7 (5.8)	N/A	N/A	3 (8.1)	10 (4.3)	9 (6.2)
Land-use[a]	55	9 (5.5)	N/A	8 (4.0)	N/A	10 (4.3)	7 (6.3)
China[a]	52	10 (5.2)	N/A	N/A	41 (1.6)	6 (5.4)	11 (5.6)
Urbanization[a]	48	11 (4.8)	N/A	N/A	41 (1.6)	54 (1.6)	10 (6.0)
Energy[a]	44	12 (4.4)	N/A	8 (4.0)	16 (3.2)	5 (5.9)	16 (4.1)
Sustainability[a]	43	13 (4.3)	N/A	8 (4.0)	41 (1.6)	15 (3.2)	12 (4.8)
Politics	42	14 (4.2)	N/A	8 (4.0)	16 (3.2)	15 (3.2)	14 (4.5)
Transport	40	15 (4.0)	N/A	3 (8.0)	41 (1.6)	12 (3.8)	16 (4.1)
Framework	39	16 (3.9)	N/A	8 (4.0)	N/A	54 (1.6)	12 (4.8)
Growth[a]	38	17 (3.8)	N/A	N/A	N/A	6 (5.4)	19 (3.8)
Environment[a]	37	18 (3.7)	N/A	N/A	6 (4.8)	15 (3.2)	19 (3.8)
Areas[a]	36	19 (3.6)	N/A	N/A	6 (4.8)	25 (2.7)	19 (3.8)
Health[a]	36	19 (3.6)	N/A	N/A	N/A	15 (3.2)	16 (4.1)
Ecosystem services[a]	33	21 (3.3)	N/A	N/A	16 (3.2)	N/A	15 (4.3)
Design[a]	31	22 (3.1)	N/A	N/A	41 (1.6)	15 (3.2)	25 (3.3)
Urban[a]	31	22 (3.1)	N/A	8 (4.0)	N/A	15 (3.2)	25 (3.3)
Patterns	31	22 (3.1)	N/A	3 (8.0)	N/A	15 (3.2)	27 (3.2)
Impacts[a]	30	25 (3.0)	N/A	N/A	16 (3.2)	25 (2.7)	27 (3.2)
Impact	30	25 (3.0)	N/A	N/A	41 (1.6)	36 (2.2)	24 (3.4)
System[a]	30	25 (3.0)	N/A	N/A	41 (1.6)	54 (1.6)	22 (3.6)
Sustainable development	29	28 (2.9)	N/A	N/A	41 (1.6)	15 (3.2)	32 (3.0)
Ecology[a]	29	28 (2.9)	N/A	N/A	16 (3.2)	156 (0.54)	22 (3.6)
Biodiversity[a]	28	30 (2.8)	N/A	N/A	41 (1.6)	36 (2.2)	27 (3.2)

TP: total number of articles; *R*: rank; N/A: not available.
[a] The same *KeyWords Plus* both appearing in the top 30 of SCI-EXPANDED and SSCI database.

were mainstream disciplines. Energy and fuels in natural science field, and interdisciplinary applications mathematics in social science field started to attach more attention. Natural science and social science were two aspects which researchers, managers, and policy makers should raise, cannot neglect either.

China, the USA, the UK and Australia were the most productive countries in both SCI-EXPANDED and SSCI databases. The identification of attractive collaborators and effectiveness of collaboration among countries were revealed to present who are the prior national partners for policy makers and researchers.

Research trends as shown by analysis of words in titles, author keywords and *KeyWords Plus* indicated that emphasis of sustainable city changed with time. Three critical issues including climate change, research about China, and resilience in sustainable city research were reviewed and discussed. Climate change was the big issue in sustainable city field. The adaptation planning for climate change towards an urban city was important for governments every countries. Chinese national plan and government's policy on sustainable city accelerated China's development, prompting productive and creative research, such as the leading position worldwide and the new term of sponge city. Resilience in sustainable city emerged as a prominent research issue, which could withstand the shocks and recover from the failure. These critical issues need to be attached more attention in the future. The statistics analysis of words in titles, author keywords and *KeyWords Plus* could be applied in other fields to help find the critical issues for researchers and policy makers.

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