Green Smart Cities: A Bibliometric Analysis and Science Mapping Method

Wei-Ling Hsu[1,*], Chen-Yuan Chiu[1], Yuanyuan Lu[2], Miao Qiao[3] and Haiying Xu[3]

[1]School of Civil Engineering, Jiaying University, No. 100 Meisong Road, Meizhou, China

[2]School of Civil Engineering and Architecture, Suqian University, Huanghe Street, Suqian, China

[3]School of Urban and Environmental Science, Huaiyin Normal University, No. 111, West ChangJiang Road, Huai'an, China

*corresponding author

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Abstract: As a novel topic, green smart cities are gaining acceptance. With a focus on green smart cities, this study employed the Science mapping method and VOS viewer science mapping to analyze research papers from the Web of Science database. This analysis method has been widely adopted as a research instrument for investigating a specific field of knowledge or for visualizing networks to provide a more complete picture of a particular topic. The analysis identified the most crucial journals, keywords, co-authorships, authors, and countries active in the field of green and smart city research. The study also provided an overview of the literature on green and smart cities and linked research topics with the trend of research development to serve as a reference for future researchers. In addition, it can also guide the government to formulate appropriate policies to promote the development of green smart cities.

1. Introduction

In response to escalating urban environmental problems resulting from increasing urbanization, scholars have been studying the development trend of future smart cities and have proposed that green smart cities may resolve conflict that may arise between humans and the natural environment during smart city development [1]. As a new topic, green smart cities are becoming increasingly accepted. In the joint 2015 publication Green and Smart Urban Development Guidelines [2], China Development Bank Capital, Energy Innovation, and Energy Foundation indicated the necessity of integrating green and smart concepts, suggesting that the strategic application of smart technologies can resolve various challenges encountered in the process of constructing a green city. With the increasingly crucial role of environmental protection in urban development, green and low-carbon practices have become a key global trend. This study employed a bibliometric method to evaluate the status of green and smart urban development and a scientometric method to analyze the current research focuses relating to green smart cities.

At the end of the 19th century, Ebenezer Howard proposed the concept of a "garden city" in his book Garden Cities of To-morrow, suggesting that the future trend of urban development would be directed toward a new type of city incorporating countryside into the urban space. A garden city is an ecocity that combines urban and rural spaces to satisfy all types of societal needs; the concept and thought process of a garden city development, which has contributed to the subsequent promotion and development of ecocities, focuses on solving urban development problems. In A Smart World: A Development Model for Intelligent Cities, Abdoullaev argued that a true smart city develops sustainably [3]. Smart cities—with their integrative, comprehensive, and systematic nature—achieve sustainable economic, social, and ecological development [4]. The concept of smart cities are not limited to a specific purpose but encompasses diverse practices, such as using resources wisely, reducing pollutant emissions, managing waste effectively, and adopting energy-saving approaches to facilitate lighting and heating efficiency [5]. The construction of green smart cities relies on the coordinative development of green and smart factors, with green development constituting an internal

part of smart city construction, and smart factors providing a numerical model for green development [6]. The two factors are ultimately integrated and mutually promote each other. Using a citation database, we performed a bibliometric analysis of green smart city publications. By analyzing search results, research trends and publishing patterns can be identified. Therefore, information, including publication year, journal, etc., can be obtained to analyze trends and characteristics. This review article helps grasp the research trends and hotspots of contemporary green smart cities to understand the researched topics comprehensively. It can also help scholars identify the most prominent journals and researchers for potential collaboration or publication opportunities. In addition, it can also guide the government to formulate appropriate policies to promote the development of green smart cities.

2. Methods

2.1. Bibliometric Method

Bibliometric analysis involves analyzing related studies to provide an overview of a research field [7]. The Web of Science (WoS) database was employed for bibliometric analysis of publications on green smart cities. An analysis of the search results, including data such as the publication year and journal, can identify research trends and characteristics as well as publication patterns [8]. This analysis method has been widely adopted as a research tool for investigating a certain field of knowledge or for visualizing networks to provide a broader picture of a target topic [7].

2.2. Scientometric Analysis

Scientometric analysis is used to determine the status of a knowledge field and the evolution of a research field and involves analysis of journals, keywords, active countries, researchers, citations, cocitations, and bibliographies in a research area [9]. Rapid technological development has facilitated the application of a range of science mapping software used to illustrate various scientific research factors graphically [10]. VOSviewer was selected for the scientometric analysis in this study for its applicability for knowledge mining and large network visualization [11].

3. Results

3.1. Publications

The minimum number of documents was set to seven in VOSviewer. Among all 168 journals extracted from the WoS database, 13 met this threshold. Figure 1 presents the clusters of research sources and the interrelationships among them. On the basis of Bradford's law, the scientometric analysis established the respective cores of the 13 journals. In Figure. 1, the size of the words and nodes offer an visual representation of the number of publications of a journal, with a larger word and node size indicating more publications [11]. Citation information was used to determine the influence of a work in a particular research field [12].

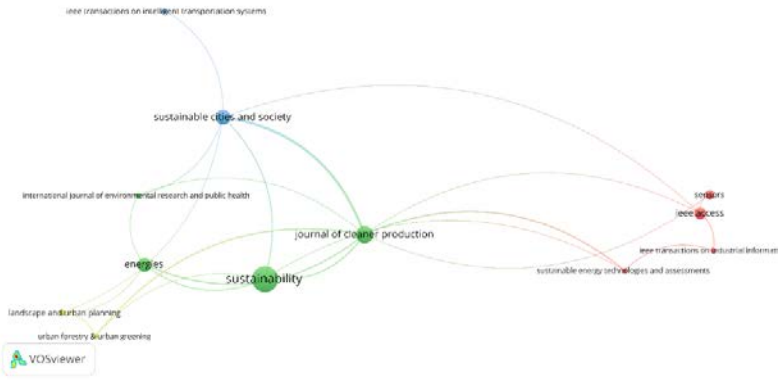

Figure 1 Mainstream journals on green smart cities.

Table 1 illustrates the number of documents, average number of citations, total number of citations,

and normalized average number of citations in each journal. The study quantified the influence of these journals on research related to green smart cities and revealed the three most influential journals to be Sustainability, Journal of Cleaner Production, and Sustainable Cities and Society. These journals are considered authoritative sources on green smart city research. The search results also revealed the development trend of said research.

Table 1 Number of citations in each journal.

Table Head	Number of Documents	Number of Citations	Average Publication Year	Average Citation	Avg. Norm. Citation
Sustainability	54	318	2019	5.89	0.59
Journal of Cleaner Production	32	1356	2018	42.38	1.89
Sustainable Cities and Society	28	797	2019	28.46	1.59
Energies	25	230	2019	9.20	0.49
Ieee Access	21	303	2018	14.43	0.75
Sensors	15	389	2018	25.93	0.57
Landscape and Urban Planning	10	337	2015	33.70	1.09
Ieee Transactions on Intelligent Transportation Systems	9	69	2019	7.67	1.88
Sustainable Energy Technologies and Assessments	8	18	2020	2.25	0.44
Ieee Transactions on Industrial Informatics	8	407	2018	50.88	1.88
International Journal of Environmental Research And Public Health	8	57	2019	7.12	0.55
Urban Forestry & Urban Greening	7	134	2018	19.14	1.04

According to the information presented in Figure 1 and Table 1, the most prolific journals in terms of publications were Sustainability and Journal of Cleaner Production; IEEE Transactions on Industrial Informatics and Journal of Cleaner Production had the most citations.

3.2. Keyword Cooccurrence

Keywords represent the main content of a research discussion [13], and a systematic analysis of keywords can provide directions for future research [14]. Therefore, the keywords of published works were analyzed using VOSviewer, with the minimum number of keyword occurrences set to 11 according to Zipf's law. Initially, 49 out of all 2824 keywords met the threshold; keywords with similar meanings, such as "city," "IoT," "green," and "network," were subsequently excluded, reducing the sample to 35 keywords, as presented in Figure 2 and Table 2.

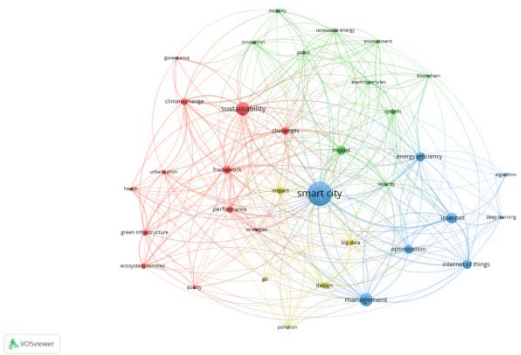

Figure 2 Keyword cooccurrences in green smart city research.

Table 2 Keyword cooccurrences.

Keywords	Occurrence	Average Publication Year	Average Citation	Avg. Norm. Citation
Smart city	97	2019	16.02	1.18
Sustainability	51	2019	19.84	1.26
Internet	38	2019	15.68	1.45
Management	48	2019	11.73	1.03
Framework	28	2018	53.61	1.42
Internet of things	31	2019	26.48	1.97
model	32	2018	24.03	0.89
Climate-change	23	2018	37.48	1.44
Challenges	27	2019	24.04	1.34
Energy efficiency	33	2019	20.27	1.25
Optimization	32	2019	12.66	0.91
Big data	19	2019	23.84	2.13
Impact	26	2019	16.85	0.97
Performance	24	2019	27.29	1.20
Green infrastructure	21	2019	14.86	1.21
Systems	26	2019	18.54	0.92
Design	24	2019	17.79	0.69
Ecosystem services	19	2018	14.47	0.81
Policy	11	2017	59.45	1.52
Security	12	2019	15.00	2.68
Urbanization	15	2019	11.40	0.79
Environment	13	2018	19.08	1.06
Innovation	13	2019	15.62	1.00
Renewable energy	13	2018	41.69	1.43
Electric vehicles	15	2019	18.93	1.20
Mobility	14	2018	20.29	1.07
Blockchain	12	2020	9.00	1.08
Health	11	2019	16.36	0.83
Strategies	11	2019	46.64	2.17
Quality	11	2019	14.73	1.28
Governance	11	2019	15.73	0.89
Pollution	12	2019	6.33	0.85
Deep learning	11	2020	11.64	2.41
Algorithm	13	2019	12.62	0.87
Gis	15	2017	22.92	0.85

According to the node size, distance between nodes, and connecting lines between keywords depicted in Figure 2, the most frequently occurring terms included but were not limited to “smart city,” “cities,” “sustainability,” “internet,” “management,” “framework,” and “Internet of Things.” The node size represents the occurrences of keywords, with a larger node indicating more occurrences [13]. The connecting line between two keywords indicates the strength of the connection between keywords in green smart city research.

Belonging to the same cluster, “smart city,” “internet,” “management,” and “energy efficiency” were closely connected to one another. In another cluster, “cities,” “sustainability,” “framework,” and “challenges” also exhibited strong connections among one another. Additionally, close connections were noted between keywords from different clusters, such as between “systems” and “sustainability” and between “model” and “management.” The strongest connection among all keywords was between “smart city” and “sustainability.” Furthermore, the most common keywords were “smart city,”

“sustainability,” “internet,” “management,” and “framework.”

3.3. Coauthorship Analysis

The minimum number of published works was set to 2 in VOSviewer. In the sample of 1936 authors, 95 met the selection threshold. The names of the most influential authors are reported in Figure 3 and Table 3 As presented in Figure 3, the authors were divided into two types, and their research networks were identified; the size of the cluster indicates the strength of research connections among authors.

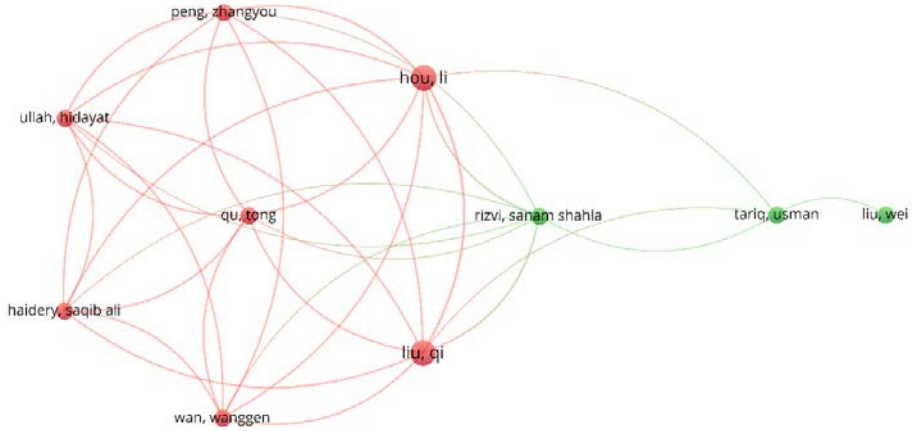

Figure 3 Coauthorship analysis in green smart city research.

Table 3 Number of citations in each scholar.

Scholar	Number of Documents	Number of Citations	Average Publication Year	Average Citation	Avg. Norm. Citacion
Hou, Li	3	7	2020	2.33	0.29
Liu, Qi	3	7	2020	2.33	0.29
Peng, Zhangyou	2	7	2020	3.5	0.44
Qu, Tong	2	7	2020	3.5	0.44
Rizvi, Sanam shahla	2	3	2020	1.5	0.19
Liu, Wei	2	0	2021	0	0
Wan, Wanggen	2	7	2020	3.5	0.44
Tariq, Usman	2	0	2021	0	0
Ullah, Hidayat	2	7	2020	3.5	0.44
Haidery, Saqib ali	2	7	2020	3.5	0.44

As listed in Table 3, the following five indicators were analyzed: total link strength, number of published works, number of citations in the WoS database, average publication year, and average number of citations per work. The first three indicators reflect the generation of research results and the influence of an author within the research field. Table 3 also lists the most influential authors in the field of green smart city research. Green smart city research is a relatively new field, and these authors published their related works in 2020, which explains the small number of citations. Compared with other authors, Li Hou and Qi Liu published the most related works. Other authors with major contributions to this research field included Zhangyou Peng and Tong Qu, who had also collaborated with each other on this research, as illustrated in Figure 3. According to the average publication year, emerging researchers such as Wei Liu and Usman Tariq published their works in 2021. The normalized average number of citations represented the average level of influence of researchers on a yearly basis. Although they did not have the most publications, Zhangyou Peng, Tong Qu, Wanggen Wan, Hidayat Ullah, and Saqib ali Haidery had the highest average number of citations per work and were the most influential authors according to the yearly average. These authors have contributed greatly to the green smart city literature.

3.4. Publications

Being cited in other works indicates an article's level of influence within its research field. Publications were analyzed using VOSviewer, with the minimum number of citations set to 43; of all 477 articles, 45 met this threshold. Figure 4 depicts the most influential articles based on the number of citations. Bibri (2017) was at the forefront, having authored a series of research articles and having made considerable contributions to the green smart city literature. Table 4 lists the full titles, number of links, and total number of citations of these articles.

Figure 4 Science map of the most influential green smart city publications.

Table 4 Most influential green smart city publications

Scholar	Title	Numbere of citations	Average publication year	Average citation	Avg.Norm. citation
Bibri(2017)	Smart sustainable cities of the future: an extensive interdisciplinary literature review	417	2017	417	9.63
De jong(2015)	Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization	384	2015	384	5.62
Colding(2017)	an urban ecology critique on the' smart city" model	75	2017	75	1.73
Macke(2018)	smart city and quality of life: citizens' perception in a brazilian case study	65	2018	65	2.40
Sodiq(2019)	Towards modern sustainable cities: review of sustainabillity principles and trends	56	2019	56	3.00
Farhan(2018)	towards green computing for internet of things: energy oriented path and message scheduling approach	44	2018	44	1.62

The most cited article over the last decade was by Bibri (2017), who studied future sustainable cities through a cross-disciplinary literature review; De Jong (2015) was the second most cited author over the same period. As the third most cited, Colding (2017) investigated the relationships between Brazilian citizens' perception and evaluation of smart cities and quality of life and proposed possible directions for subsequent research including sustainable, intelligent, adaptable, low-carbon, ecocentric, and knowledge cities.

3.5. Countries Active in Green Smart City Research

VOS viewer was employed to further establish and evaluate each country's contribution to the global research on green smart cities, with the minimum numbers of publications and citations set to 11 and 60, respectively. Of all 77 countries included, 19 met these thresholds. Figure 5 and Table 5 report the countries that have been actively engaged in researching green smart cities over the last decade.

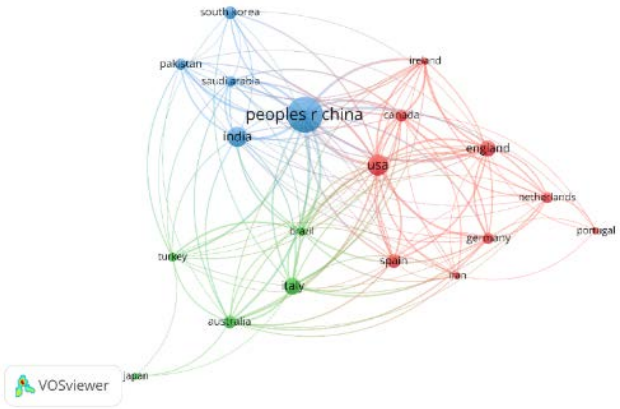

Figure 5 Countries active in green smart city research.

China, England, the United States, Australia, India, and Italy exhibited active participation in green smart cities. In relation to the number of documents and total number of citations, Chinese and US researchers ranked highest, followed by those in England, the Netherlands, India, and Canada (Tables 5 and 6).

Higher average numbers of citations were noted in developed countries including the Netherlands, England, Canada, the United States, Portugal, and Ireland; however, the number in Brazil, a developing country, was higher than that in the Netherlands, England, and Canada. Also a developing country, China had a larger average number of citations than did the developed countries of Japan and Australia (Table 7). According to the average number of citations, Brazil had the highest level of influence—on a yearly average—in green smart city research among all developing countries. The developed countries with a relatively high level of influence were Canada, Australia, Ireland, and Spain (Table 8). Although Japan, the United States, Ireland, the Netherlands, Canada, and Spain had less citations on average compared with Brazil, they had a longer history of researching green smart cities (Tables 9 and 10).

Table 5 Number of publications of the 19 countries most active in the research field(From high to low).

Country	Developing/Developed Countries	Continent	Weight (Links)	Weight (Total Link Strength)	Weight (Documents)
China. P. R.	Developing	East Asia	17	85	132
England	Developed	West Europe	17	54	38
U.S.	Developed	North America	15	52	58
Australia	Developed	Oceania	15	43	27
India	Developing	South Asia	13	38	55
Italy	Developed	South Europe	16	37	42
Saudi Arabia	Developing	West Asia	13	35	20
Pakistan	Developing	South Asia	11	34	22
Spain	Developed	South Europe	14	34	31
South Korea	Developed	East Asia	11	31	27
Germany	Developed	Central Europe	11	28	22
Netherlands	Developed	West Europe	11	27	21
Brazil	Developing	South America	14	25	15
Canada	Developed	North America	12	22	24
Iran	Developing	West Asia	11	21	12
Ireland	Developed	West Europe	9	14	11
Japan	Developed	East Asia	11	13	11
Portugal	Developed	South Europe	7	7	12
Turkey	Developing	West Asia	6	8	15

Table 6 Number of citations of the 19 countries most active in the research field (From high to low).

Country	Developing/Developed Countries	Continent	Number of Citation
China. P. R.	Developing	East Asia	2236
U.S.	Developed	North America	1372
England	Developed	West Europe	1191
Netherlands	Developed	West Europe	698
India	Developing	South Asia	628
Canada	Developed	North America	593
Brazil	Developing	South America	510
Italy	Developed	South Europe	471
Spain	Developed	South Europe	392
Germany	Developed	Central Europe	385
Australia	Developed	Oceania	352
Pakistan	Developing	South Asia	237
South Korea	Developed	East Asia	220
Portugal	Developed	South Europe	212
Ireland	Developed	West Europe	189
Turkey	Developing	West Asia	177
Japan	Developed	East Asia	164
Saudi Arabia	Developing	West Asia	137
Iran	Developing	West Asia	100

Table 7 Average number of citations of the 19 countries most active in the research field.

Country	Developing/Developed Countries	Continent	Average Citation
Brazil	Developing	South America	34.00
Netherlands	Developed	West Europe	33.24
England	Developed	West Europe	31.34
Canada	Developed	North America	24.71
U.S.	Developed	North America	23.66
Portugal	Developed	South Europe	17.67
Germany	Developed	Central Europe	17.50
Ireland	Developed	West Europe	17.18
China. P. R.	Developing	East Asia	16.94
Japan	Developed	East Asia	14.91
Australia	Developed	Oceania	13.04
Spain	Developed	South Europe	12.65
Turkey	Developing	West Asia	11.80
India	Developing	South Asia	11.42
Italy	Developed	South Europe	11.21
Pakistan	Developing	South Asia	10.77
Iran	Developing	West Asia	8.33
South Korea	Developed	East Asia	8.15
Saudi Arabia	Developing	West Asia	6.85

Table 8 Normalized average number of citations of the 19 countries most active in the research field.

Country	Developing/Developed Countries	Continent	Average Citation
Brazil	Developing	South America	34.00
Netherlands	Developed	West Europe	33.24
England	Developed	West Europe	31.34
Canada	Developed	North America	24.71
U.S.	Developed	North America	23.66
Portugal	Developed	South Europe	17.67
Germany	Developed	Central Europe	17.50
Ireland	Developed	West Europe	17.18
China. P. R.	Developing	East Asia	16.94
Japan	Developed	East Asia	14.91
Australia	Developed	Oceania	13.04
Spain	Developed	South Europe	12.65
Turkey	Developing	West Asia	11.80
India	Developing	South Asia	11.42
Italy	Developed	South Europe	11.21
Pakistan	Developing	South Asia	10.77
Iran	Developing	West Asia	8.33
South Korea	Developed	East Asia	8.15
Saudi Arabia	Developing	West Asia	6.85

Table 9 Average publication year of the ten earliest countries to research green smart cities (From earliest to latest).

Country	Developing/Developed Countries	Continent	Average Publication Year
Japan	Developed	East Asia	2018.09
U.S.	Developed	North America	2018.10
Ireland	Developed	West Europe	2018.30
Netherlands	Developed	West Europe	2018.48
Canada	Developed	North America	2018.78
Spain	Developed	South Europe	2018.86
Brazil	Developing	South America	2018.93
England	Developed	West Europe	2019.00
Italy	Developed	South Europe	2019.12
Australia	Developed	Oceania	2019.32

The various quantitative comprehensive analyses conducted in this study (e.g., information summarized in Table 5) reflected the potential correlations between a country's academic publications affecting green smart cities. Articles relating to these factors may have encouraged some developing countries, such as China and Brazil, to publish academic research on green smart cities.

Table 10 Average publication year of the ten earliest countries to research green smart cities (From latest to earliest).

Country	Developing/Developed Countries	Continent	Average Publication Year
Pakistan	Developing	South Asia	2020.23
Saudi Arabia	Developing	West Asia	2020.00
India	Developing	South Asia	2019.84
Iran	Developing	West Asia	2019.82
Turkey	Developing	West Asia	2019.67
Portugal	Developed	South Europe	2019.45
Germany	Developed	Central Europe	2019.43
China. P. R.	Developing	East Asia	2019.38
South Korea	Developed	East Asia	2019.37
Australia	Developed	Oceania	2019.32

4. Conclusions

Bibliometric and scientometric methods were used in this study to identify key characteristics of green smart city research. In the bibliometric search, titles and abstracts of works published between 1995 and 2022 in the WoS database were extracted, with the sample eventually reduced to 477 articles. The scientometric method was used to establish the science map and analyze information on keywords, coauthorships, citations, and countries active in the research field. This review study established the trend and major topics of contemporary research on green smart cities, enabling researchers to gain a comprehensive understanding of their research topics and to identify the main journals and researchers relevant in their field for potential collaboration or publication opportunities. The results can also provide governments with insights into the establishment of appropriate policies for the development of green smart cities.

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