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ORIGINAL RESEARCH ARTICLE

The analysis of knowledge visualization of the status of international entrepreneurship research—Based on view of the method of co-word analysis

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ABSTRACT

Based on the perspective of the keyword co-word network, firstly, the total number and scale of keyword relationships are measured. Secondly, the centrality of the keyword-co-word network is analyzed, including point degree centrality, point middle centrality, point proximity centrality, and point feature vector centrality. Thirdly, the k-kernel analysis of the keyword-co-word network is carried out. Finally, some meaningful research conclusions at the forefront of international eco-city research from 1961 to 2011 are drawn.

Keywords: ecological city; research frontier; co-word analysis; knowledge graph

1. Introduction

In 1960, Bopegamage published the article "A detailed approach to the study of urban ecology" in the first issue of volume 9 of the Journal of Sociological Bulletin and put forward the idea of "urban ecology" for the first time in academia. In 1971, UNESCO put forward the "comprehensive ecological research on human settlements" (MAB 11th plan) at the 16th session and put forward the concept of "ecological city" for the first time. It clearly proposed to study cities from the perspective of ecology with comprehensive ecological methods, which promoted the wide application of ecological theory and the planning, construction, and research of ecological cities, ecological communities, and ecological villages all over the world. The concept of "eco city" not only reflects the desire of human beings to seek their own development but also reflects the improvement of human understanding of the relationship between man and nature[1]. Since the 1970s, with the continuous development of computer technology, the research methods of eco city have been constantly updated. Today, what is the trend at the frontier of international eco-city research? What is its distribution? What are the characteristics? This paper intends to explore this problem from the perspective of knowledge mapping in scientometrics and, based on keyword co-words, network analysis.

2. Data sources and research methods

According to the retrieval formula TS (urban ecology, or eco city or ecopolis, sustainable city, or

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urban ecological sustainability), the subject retrieval of the web of science is carried out. The time span is 1961–2011, the document format is "English article", the four databases of SCI-Expanded, SSCI, CPCI-S, and CPCI-SSH are selected, the number of articles downloaded is 3,947, and the last update time of the data is March 19, 2012.

High-frequency vocabulary is a natural language vocabulary expressing the theme concept of literature. It is a collection of high-frequency vocabulary of a large number of academic research results in a long-term domain in the academic research field, which can reveal the overall content characteristics of research results, the internal relationship between research contents, academic research frontiers, development trends, etc[2]. Because the key words or title words of a document are the concentration and refinement of the core content of the article. Therefore, if a keyword or title word appears repeatedly in the literature in its field, it can reflect that the research topic represented by the keyword or title word is the research frontier in this field[3].

From the 3,947 articles downloaded, 6,923 keywords were extracted, with a total frequency of 11,313 and an average of 163 for each keyword. On this basis, the keywords with the top 50 frequencies (**Table 1**) were extracted, with a total frequency of 1,655, accounting for 146% of the total frequency, and an average of 331 for each keyword. According to the average frequency of occurrence, the 50 high-frequency keywords basically represent the academic status of the forefront of international eco-city research in the past 50 years.

Table 1. 50 key words with high frequency in international eco city Research (1961–2011)

Serial number	Word frequency	Key word	Serial number	Word frequency	Key word	Serial number	Word frequency	Key word
1	203	Urban ecology	18	26	Planning	35	16	Habitatfragmentation
2	135	Sustainable development	19	26	Sustainable cities	36	16	Resilience
3	124	Sustainability	20	24	Management	37	16	Species richness
4	112	Urbanization	21	23	Urban development	38	15	Landscape
5	64	Ecology	22	23	Water quality	39	15	Australia
6	49	China	23	22	Birds	40	15	Ecosystem services
7	48	Landscape ecology	24	21	Remote sensing	41	14	Landscape metrics
8	43	Urban planning	25	20	Fragmentation	42	14	Energy
9	39	Urban	26	20	Sustainable urban development	43	14	Sustainable transport
10	38	GIS	27	20	Urbanisation	44	14	Community
11	36	Land use	28	19	Governance	45	13	Urban sprawl
12	34	Biodiversity	29	19	Urban environment	46	13	Poverty
13	32	Conservation	30	19	Urban regeneration	47	12	Waste management
14	32	Industrial ecology	31	18	Urban sustainability	48	12	Pollution
15	32	Cities	32	18	Disturbance	49	12	Diversity
16	29	Climate change	33	18	Political ecology	50	12	Eutrophication
17	27	Environment	34	17	Ecological footprint			

This study mainly adopts the social network analysis method. The social network analysis method with relationships as the basic analysis unit has been widely used in many disciplines, such as sociology, psychology, and economics. Social network analysis is an empirical research method that takes relationships as the basic unit, mainly analyzing relationship data. "Social network" refers to the collection of social actors and their relationships; that is, a social network is a collection composed of multiple points and connections between points.

Keywords are natural language words that express the subject concepts of documents. Co-word analysis is an important method to study the phenomenon of keyword co-occurrence. It is to count the number of occurrences of a group of

words in the same document, cluster these words on this basis to reflect the affinity and alienation between these words, and then analyze the structural changes of the disciplines and topics represented by these words.

The keyword co-word matrix (**Table 2**) presents the co-word data between keywords. It represents the co-word relationship network between keywords. In the co-word relationship network, a network of vertices and edges is formed. Vertices are those representative key words. The co-word relationship between keywords is represented by edges, so that a keyword-co-word relationship network can be formed. In this network, individual network analysis and overall network analysis can be carried out to reveal the knowledge structure characteristics of the network. A main purpose of co-word relationship network analysis is to determine the network structure between these representative keywords and study the quantitative distribution characteristics of the network under the interaction of vertices to reveal the changes in knowledge structure at the forefront of international eco-city research.

Table 2. Common word matrix of 50 high-frequency keywords in international eco city Research (part)

	Urban ecology	Sustainable development	Sustainability	Urbanization	Ecology	China
Urban ecology	0	0	0	13	0	0
Sustainable development	0	0	0	5	0	0
Sustainability	0	0	0	5	0	0
Urbanization	13	5	5	0	0	0
Ecology	0	0	0	0	0	0
China	0	0	0	0	0	0

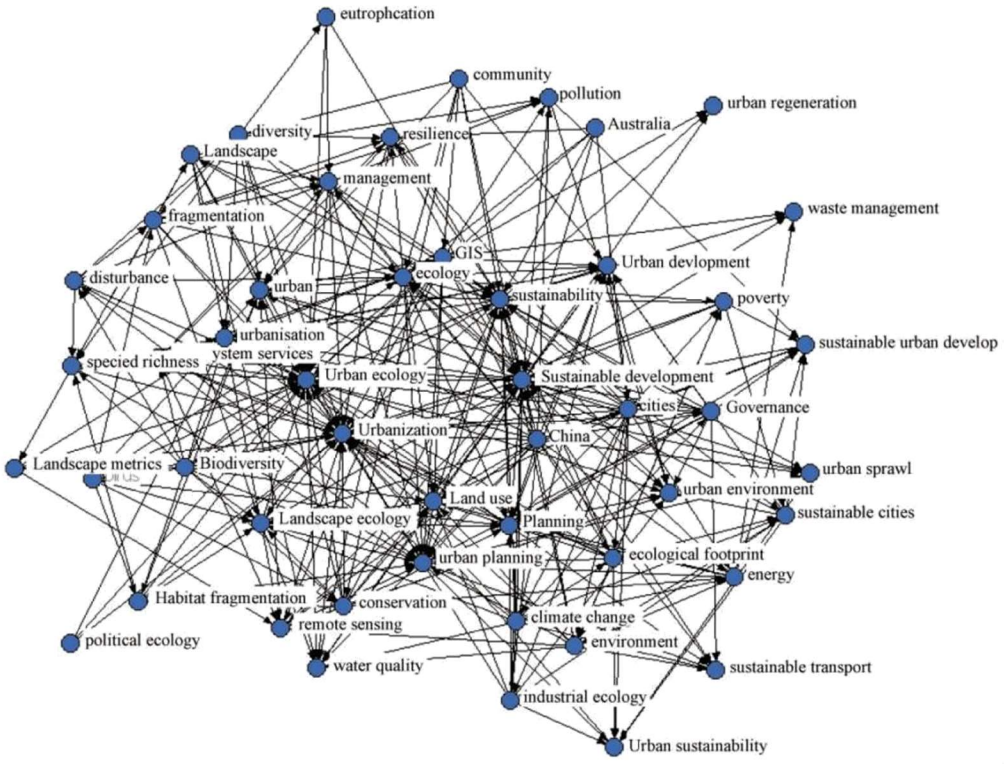

Figure 1. Overall knowledge map of international eco-city research frontier co-word network.

2. Frontier atlas and analysis results

2.1. Measurement of keyword size and ties

If the keyword co-word network is taken as a whole network, the composition and scale of the co-word network, the density of the whole network, and the distance of keywords in the whole network can be revealed. In the case of individual network

analysis of keywords, two measurement indicators are used to reveal the "individual scale" of each keyword in the overall network[4]. "Size" refers to the "scale" of the keyword individual network (excluding "self"); for example, the individual network scale of urban ecology is "31", indicating that there are 31 keywords "closely related" to it. "Ties" refers to the "total number of relationships", that is, the total number of direct and indirect connections between a keyword and all other keywords, but does not include the relationship between each keyword and "self".

It can be seen from **Table 3** that the size values of urban ecology, urbanization, sustainability, sustainable development, urban planning, China, land use, landscape ecology, ecology, etc. are relatively large, indicating that these keywords have more co-word relations with other keywords. At the same time, their tie value is also relatively large, indicating that there are more direct or indirect co-word relationships with other keywords.

Table 3. Measurement of keyword scale and total number of relationships

Key word	Size	Ties	Key word	Size	Ties
Urban ecology	31.00	150.00	Landscape metrics	6.00	8.00
Urbanization	33.00	166.00	Sustainable urban development	9.00	17.00
Biodiversity	16.00	60.00	Diversity	12.00	30.00
Cities	20.00	92.00	Ecology	20.00	63.00
Sustainability	32.00	161.00	Ecological footprint	14.00	55.00
Sustainable development	35.00	191.00	Landscape	10.00	22.00
Urban planning	22.00	95.00	Urban	15.00	42.00
Industrial ecology	10.00	24.00	Land use	2.000	99.00
Sustainable cities	11.00	23.00	Urban regeneration	3.00	3.00
Ecosystem services	10.00	29.00	Governance	13.00	44.00
GIS	19.00	75.00	Community	8.00	19.00
Remote sensing	12.00	34.00	Water quality	10.00	27.00
China	24.00	116.00	Resilience	11.00	33.00
Habitat fragmentation	9.00	26.00	Management	14.00	45.00
Landscape ecology	17.00	71.00	Urban sustainability	7.00	9.00
Conservation	14.00	47.00	Australia	6.00	14.00
Energy	11.00	26.00	Urban environment	11.00	16.00
Fragmentation	12.00	30.00	Poverty	9.00	25.00
Environment	13.00	42.00	Sustainable transport	7.00	14.00
Climate	15.00	45.00	Urbanisation	15.00	42.00
Species richness	10.00	23.00	Pollution	8.00	10.00
Birds	10.00	27.00	Waste management	4.00	4.00
Disturbance	9.00	18.00	Urban sprawl	6.00	9.00
Planning	1.00	81.00	Political ecology	3.00	2.00
Urban development	15.00	52.00	Eutrophication	4.00	5.00

2.2. Centrality analysis

In the social network, the status of each node is different. Some nodes are in the core position, which plays a key role in the dissemination of information in the network. Centrality is a frequently used indicator to measure the position of nodes. It is based on the simple idea that information can be easily transmitted to the nodes in the center of the network. In other words, the central node is easier to obtain information, or it controls the dissemination of information.

Degree centrality

The degree centrality of node x can be divided into two categories: absolute centrality and relative centrality, which is also known as standardized centrality. When the scale of the graph is different, the local centrality of the points in different graphs cannot be compared, and the relative centrality can make up for this defect. The absolute centrality of point x is the number of other points directly connected to point x, which is expressed as. The relative $C_D = d(n_i) = \sum_i X_{ij} = \sum X_{ji}$ centrality is the ratio of the absolute centrality of the point to the

maximum possible degree of the point in the figure. The formula is $C_D = d(n_i)/(g-1)$ expressed as, where X_{ij} is the value of 0 or 1, which represents whether node i recognizes the relationship with node j, and g is the number of nodes in this network[5].

Figure 2 visually shows the centrality of the common word network at the forefront of international eco city research. The larger the dot, the greater the degree, indicating that it is in the central position and has extensive information exchange with other keywords. **Table 4** shows the values of centrality corresponding to each keyword in **Figure 2**.

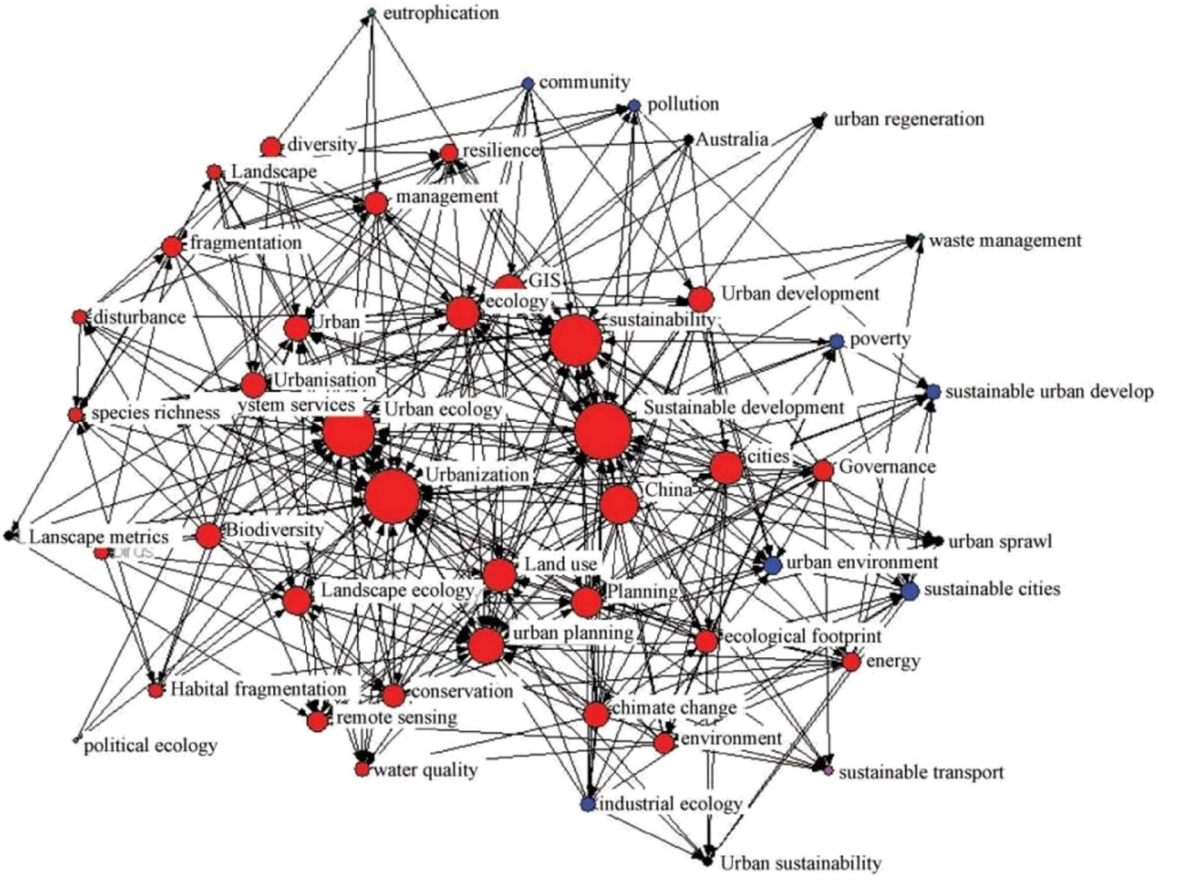

Figure 2. Knowledge map of point degree centrality of international eco city research frontier co-word network.

Table 4. Centrality of keywords

Key word	Centrality (%)	Key word	Centrality (%)	Key word	Centrality (%)
Urban ecology	16.641	Environment	3.925	Urbanisation	2.669
Sustainability	14.914	Sustainable cities	3.768	Sustainable urban development	2.512
Sustainable development	13.972	Birds	3.768	Water quality	2.198
Urbanization	13.972	Conservation	3.768	Poverty	2.198
Cities	8.320	Governance	3.611	Urban environment	2.198
China	7.064	Remote sensing	3.454	Landscape metrics	2.041
Urban planning	6.750	Fragmentation	3.297	Community	1.884
Biodiversity	6.279	Management	3.140	Pollution	1.570
Planning	36.000	Industrial ecology	3.140	Australia	1.413
Ecology	5.495	Ecosystem services	2.983	Urban sustainability	1.413
Land use	4.867	Energy	2.826	Urban sprawl	0.004
Landscape ecology	4.710	Habitat fragmentation	2.826	Urban regeneration	0.004
GIS	4.710	Landscape	2.669	Waste management	0.004
Urban	4.396	Resilience	2.669	Eutrophication	0.003
Urban development	4.082	Species richness	2.669	Political ecology	0.002
Ecological footprint	4.082	Disturbance	2.669		

Between centrality of points

The middle centrality of a point measures the degree to which actors control resources. if a point is on the geodesic (the shortest distance) of other point pairs, the point has a high middle centrality. This concept measures the extent to which a point is in the "middle" of other points. In this sense, it acts as a bridge to communicate with others. The middle centrality formula of the point $C_B(n_i) = \sum_{j<k}(n_i) / g_{jk}$ is, g_{jk} which is the number of shortcuts from actor i to actor j.

As shown in **Figure 3**, the larger the dot in the figure, the greater the intercentrality. At the same time, **Table 5** shows that the value of the intermediate centrality is also greater, which shows that these keywords play an important "intermediary" role in the information communication of the co-word network.

According to the previous research content on point centrality, the node with the largest point centrality is basically the same as the node with the largest middle centrality. This shows that in international eco-city research, urban ecology, sustainability, sustainable development, and urbanization are not only in the "core" position but also in the "bridge" position. They are highly concerned by academic research and are the concentrated embodiment of the forefront of eco-city research. The common word network points at the forefront of international eco-city research.

Closeness centrality of points

The centrality of a point is a degree that is not controlled by others. If the "distance" between a point and all other points in the network is very short, the point is said to have a high degree of proximity to the center (also known as the overall center). The point is "close" to many other points. The centrality of a point is the sum of the shortcut distance between the point and all other points in the figure. Its expression is, $C(i) = \sum_{j=1}^{n} d_{ij}$ and its center is the distance from node i to j. The smaller the centrality of a node, the more central the node is the standardized expression of near centrality is: $C_n(i) = (n-1)/C_i$.

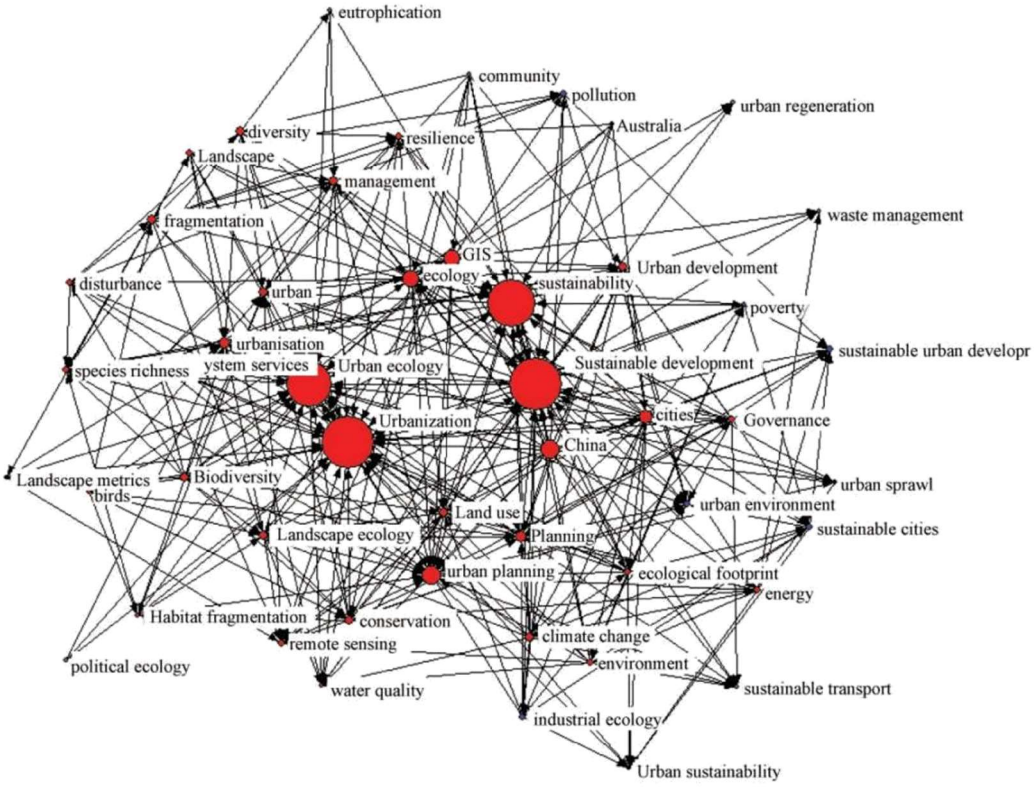

Figure 3. Knowledge map of intermediate centrality.

Table 5. Middle centrality of keywords

Key word	Middle centrality (%)	Key word	Middle centrality (%)	Key word	Middle centrality (%)
Urban ecology	1.376	Environment	0.304	Urbanisation	0.000
Sustainability	3.603	Sustainable cities	0.526	Sustainable urban development	0.043
Sustainable development	4.544	Birds	0.111	Water quality	0.000
Urbanization	0.517	Conservation	0.549	Poverty	0.142
Cities	1.091	Governance	0.073	Urban environment	0.000
China	0.000	Remote sensing	0.474	Landscape metrics	0.067
Urban planning	1.679	Fragmentation	0.889	Community	0.000
Biodiversity	0.000	Management	0.639	Pollution	0.392
Planning	1.070	Industrial ecology	0.084	Australia	0.000
Ecology	1.943	Ecosystem services	0.407	Urban sustainability	0.108
Climate change	0.716	Diversity	0.563	Sustainable transport	0.023
Land use	0.920	Energy	0.387	Urban sprawl	0.232
Landscape ecology	1.093	Habitat	0.120	Urban regeneration	0.000
GIS	0.701	Landscape	0.292	Waste management	0.000
Urban	0.000	Resilience	0.130	Eutrophication	0.014
Urban development	0.170	Species richness	0.199	Political ecology	0.000
Ecological footprint	0.475	Disturbance	1.143		

Figure 4 shows several points at the edge of the figure, such as eutrophication, community, pollution, urban regeneration, waste management, sustainable urban development, urban sprawl, energy, sustainable transport, etc. The dots representing the keywords are large, it shows that it is less close to the center, that is, to a certain extent, it is less controlled by other keywords in the forefront of international eco city research, so it is in a position of relatively less attention in academic research. The values shown in **Table 6** further verify this conclusion.

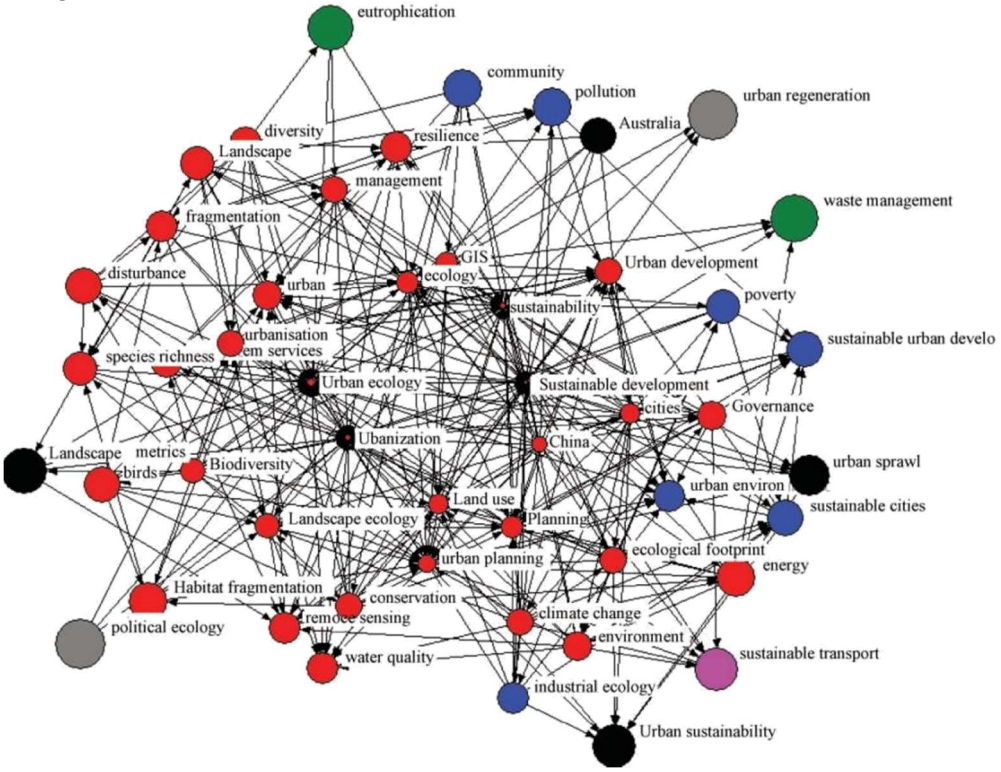

Figure 4. Knowledge map of proximity to centrality of common word network points at the forefront of international eco city research.

Table 6. Centrality of keywords

Key word	Centrality (%)	Key word	Centrality (%)	Key word	Centrality (%)
Urban ecology	7.040	Environment	2.487	Urbanisation	10.470
Sustainability	4.512	Sustainable cities	4.631	Sustainable urban development	5.088
Sustainable development	5.819	Birds	2.041	Water quality	12.963
Urbanization	12.189	Conservation	2.128	Poverty	2.759
Cities	2.083	Governance	2.173	Urban environment	7.967
China	2.000	Remote sensing	3.525	Landscape metrics	2.477
Urban planning	8.072	Fragmentation	2.426	Community	2.000
Biodiversity	2.000	Management	2.844	Pollution	3.001
Planning	3.533	Industrial ecology	2.173	Australia	2.000
Ecology	2.437	Ecosystem services	2.267	Urban sustainability	9.125
Climate change	2.126	Diversity	2.315	Sustainable transport	5.976
Land use	3.017	Energy	2.376	Urban sprawl	8.478
Landscape ecology	3.306	Habitat fragmentation	2.173	Urban regeneration	5.983
GIS	2.372	Landscape	2.549	Waste management	5.990
Urban	6.102	Resilience	2.691	Eutrophication	2.361
Urban development	6.464	Species richness	2.759	Political ecology	2.000
Ecological footprint	2.173	Disturbance	2.217		

Centrality of eigenvector of points

The purpose of eigenvector centrality research is to find the most core node based on the overall network structure, without paying attention to the "local" pattern structure. At present, eigenvector has become a standardized measure to describe the centrality of nodes. Its purpose is to find the core members in the network in the sense of the overall structure of the network.

Figure 5 and **Table 7** show that urban ecology, sustainability, sustainable development, urbanization, cities, China, urban planning and other eigenvector values are in the forefront, which further proves that these keywords are the direction of close attention in the front of international eco city research in the past 50 years.

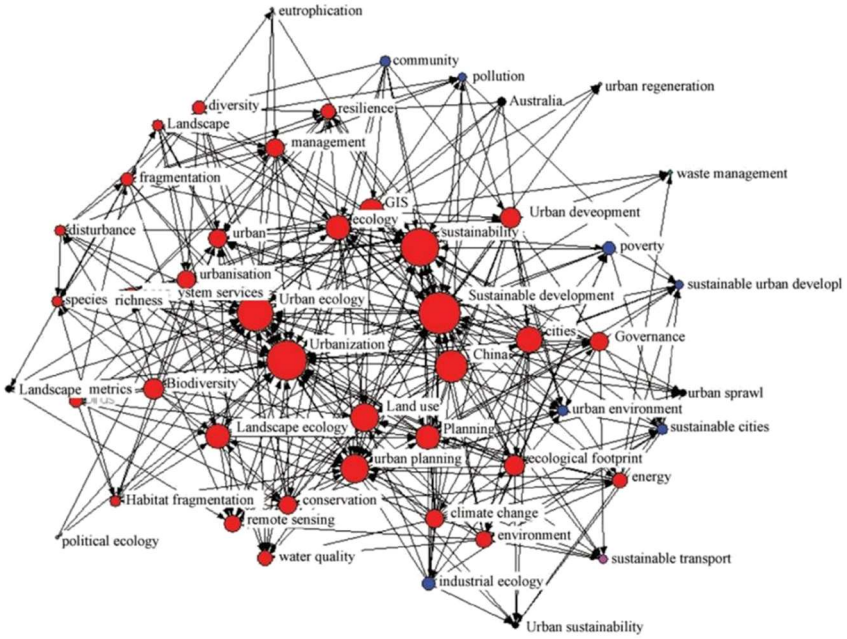

Figure 5. Feature vector centrality knowledge map of common word network points at the forefront of international eco city research.

Table 7. Centrality of feature vector of keywords

Key word	Centrality of eigenvector (%)	Key word	Centrality of eigenvector (%)	Key word	Centrality of eigenvector (%)
Urban ecology	54.153	Environment	17.779	Urbanisation	8.601
Sustainability	47.146	Sustainable cities	9.437	Sustainable urban development	8.007
Sustainable development	43.901	Birds	16.615	Water quality	10.014
Urbanization	52.431	Conservation	16.914	Poverty	9.955
Cities	35.450	Governance	14.109	Urban environment	4.975
China	26.407	Remote sensing	9.931	Landscape metrics	10.496
Urban planning	29.748	Fragmentation	13.949	Community	7.497
Biodiversity	29.743	Management	10.906	Pollution	3.891
Planning	22.051	Industrial ecology	9.741	Australia	8.057
Ecology	14.426	Ecosystem services	16.635	Urban sustainability	4.780
Climate change	21.176	Diversity	97.09	Sustainable transport	4.595
Land use	18.892	Energy	11.455	Urban sprawl	3.661
Landscape ecology	16.702	Habitat fragmentation	12.362	Urban regeneration	4.568
GIS	15.016	Landscape	10.226	Waste management	3.680
Urban	14.184	Resilience	13.131	Eutrophication	2.779
Urban development	14.949	Species richness	13.362	Political ecology	2.626
Ecological footprint	19.734	Disturbance	11.286		

2.3. Co-word network k-kernel analysis

K-kernel is a concept based on the degree of a point. The degree of a point is the measurement of its adjacent points, that is, the number of lines connected to the point. K-kernel means that the points in a subgraph are adjacent to at least k other points in the subgraph. By changing the K value, different subgraphs will be obtained. With the increase in K value, k-core members will gradually decrease, and the relationship between members will become closer[6].

In the keyword co-word network of this paper, **Figure 6** is the k-core overall network of keyword co-words at the forefront of international eco-city research. When k = 3, urban regeneration appears. When k = 4, eutrophication and waste management appear. When k = 6, in Australia, urban sustainability, landscape metrics, and urban sprawl appear. When k = 7, sustainable transport appears. When k = 8, there will be community, pollution, poverty, sustainable urban development, urban environment, sustainable cities, and industrial ecology, which reflect the hierarchical changes of keyword co-word network structure at the forefront of international eco-city research from 1961 to 2011.

When k = 9, the number of key words is the largest, that is, the highest level of k-core is 9, as shown in **Figure 7**, that is, 22 keywords in 9-core are the core keyword group with the strongest connection and the closest relationship in the whole keyword co-word network, in which each keyword has a co-word intensity greater than 1 with at least 9 keywords in the same core, which is an academic zone with great attention at the forefront of international eco-city research.

The hierarchical changes of the international eco-city research frontier reflected by the k-kernel analysis of the keyword co-word network can be considered a further complement to the research on the centrality of the keyword co-word network.

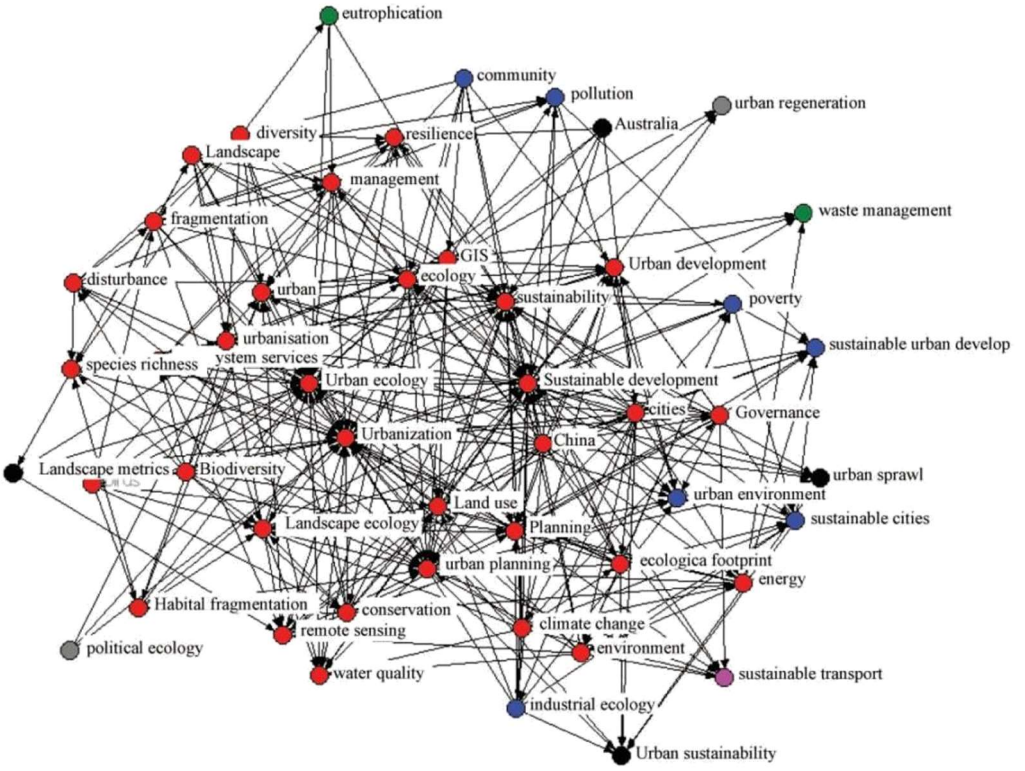

Figure 6. Common word network knowledge map at k = 3, 4, 6, 7, 8 and 9.

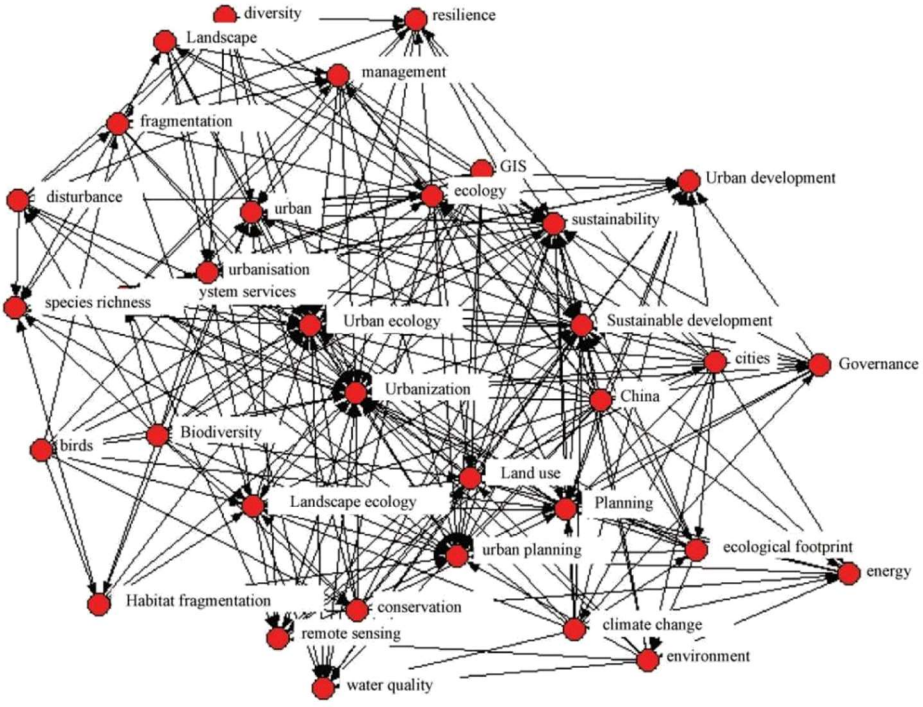

Figure 7. Common word network knowledge map when k = 9.

3. Conclusions

Using the knowledge map method in scientometrics to analyze the frontier fields of discipline development, which has a successful precedent in many studies, Based on the perspective of key co-word networks, this paper makes multi-angle, hierarchical, and complementary research on the research frontier of international eco-city in the past 50 years from the centrality and k-core analysis of keyword co-word networks by using large-scale

network analysis software (UCINET) and visualization technology. In the follow-up research, if we can combine other aspects, such as the CO citation of authors, the CO citation of journals, the CO citation of literature, or use other software, such as Vosview or Citespaceii, for further research, we believe that we will get some more meaningful research results.

Conflict of interest

The authors declare no conflict of interest.

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