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Review

A Review of Human Settlement Research on Climate Change Response under Carbon-Oriented: Literature Characteristics, Progress and Trends

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Abstract: Climate issues have affected the sustainable development of global human settlements, and carbon, an essential factor affecting climate change, has become a hotspot of academic concern. This paper analyzes the research characteristics, stages and planning of carbon-oriented climate change response research in human settlements based on the literature related to research on carbon-oriented human settlements for climate change, hereinafter referred to as RCHSCC, included in the Web of Science core database since 1991, using CiteSpace and VOSviewer bibliometric software. Based on the analysis of the literature and discipline distribution, research hotspots and priorities, this paper classifies the RCHSCC into four stages: early exploration, relationship building, integrated development and deepening collaboration. Based on keyword clustering, annual overlap and keyword emergence analysis, this paper predicts that future research will have three major trends regarding climate risk management, carbon technology enhancement and urban safety and resilience research. The study aims to analyze the distribution characteristics and evolution of research on carbon-oriented human settlements for climate change from 1991 to 2022. The RCHSCC predicts three major trends in the future—climate risk management, carbon technology upgrading and urban security and resilience—and offers three recommendations for governments and planners in terms of climate change adaptation and low-carbon and efficient development in human settlements.

Keywords: bibliometrics; carbon orientation; climate change; hotspots; human settlements; trend forecast

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1. Introduction

Human settlement research originated in 1968 in Constantinos Apostolos Doxiadis' "An Introduction to the Science of Human Settlements", which introduced the basic concept of human settlements, including the physical settlement, the surrounding natural environment and human activities and their constituent societies [1]. Subsequently, Howard [2], Geddes [3] and Mumford [4] gradually expanded the definition, constitutive system and connotation of human settlement science. In 1980, Wu Liangyong, a Chinese Academy of Sciences and Chinese Academy of Engineering scholar, established the Chinese science of human settlements environment by combining China's characteristics [5]. With the further development of the concept of human settlements, the current human settlement research mainly focuses on the classification of human settlements [6], connotation definition [7], objectives [8] and other types of theoretical construction, but some scholars also focus on the technical enhancement of human settlements, such as high-precision maps [9], data simulation [10], quality evaluation and continuity of human settlements at different spatial scales [11] and adaptation assessment [12], such as the rural scale [13] and suburban scale [14]. The study of human settlements is gradually gaining attention.

Carbon neutrality has emerged as a critical pathway and target to reduce the impacts and risks of climate change. The majority of CO_2 emissions originate from human settlements, both rural and urban [15]. Carbon is an essential factor influencing climate change;

climate risks have continued to affect areas such as national security, economic security, human health, infrastructure and ecosystem stability [16,17], and the characterization of climate change caused by carbon emissions has become a focus of research in the scientific literature. The relevant literature is shown in Table 1.

Table 1. RCHSCC-related policies.

Time	Institutions	Main Content
28 February 22	IPCC	Climate Change 2022: Impacts, Adaptation and Vulnerability, stating that carbon can be reduced through carbon management in industry, zero-carbon buildings, use of new technology energy sources and natural carbon sequestration and storage to limit global warming [18].
9 August 21	IPCC	Climate Change 2021: The Natural Science Basis states that intense, rapid and sustained reductions in carbon dioxide and other greenhouse gas emissions are needed to limit global warming [19].
30 November 21	Institute of Energy; Environment and Economy; Tsinghua University	Release of the 2021 Carbon Neutral Targets and Climate Risk Climate Change Economic Damage Assessment, Achieving carbon neutrality targets is a necessary strategy to manage climate risks effectively. China could avoid approximately 80% (USD 134 trillion) of cumulative climate change losses between 2020 and 2100 [20].
27 October 21	The State Council of the People's Republic of China	China's Policies and Actions to Address Climate Change would promote the synergy of carbon peaking, carbon neutrality and pollution reduction to join the new concept of China's response to climate change [21].
30 November 2021	UNEP	They proposed Six Solutions to the Climate Crisis, including promoting sustainable low-carbon alternatives and reducing carbon emissions in cities [22].

Although the human settlement environment response to climate change [15,23] and carbon and climate-related studies [24–28] have been performed in the current carbon-neutral context, RCHSCC based on bibliometrics has not yet emerged. We searched the Web of Science core database with TS = (carbon) AND TS = (human settlements OR living environments OR human settlement environment) AND TS = (climate) AND TS = (review) AND ALL = (CiteSpace), with the literature type as paper and language as English, with 0 results, and the search date was 28 August 2022. Although there are some relevant review studies (112), we have yet to see hotspot predictions based on an overview of study characteristics and phases. Therefore, it is necessary to comb through the relevant literature on RCHSCC to clarify its research characteristics and stages and discover its research lineage. Modern bibliometric and visual analysis has been commonly used in many subject areas to reveal the network of relationships, knowledge lines and major trends among disciplines [29]. We seek to accurately and intuitively grasp the research hotspots and evolution patterns of RCHSCC, explore its research characteristics and hotspot trends and provide development directions for the future development of RCHSCC. This can allow researchers to quickly understand the development trends of related research, identify research priorities and obstacles and conduct follow-up research more efficiently, in a targeted and systematic way.

2. Methods

In order to effectively identify RCHSCC's evolutionary features and hotspot trends, this study uses CiteSpace and VOSviewer bibliometric software to analyze the relevant literature to explore research hotspots and trends. Compared with the traditional bibliometric methods, the visual analysis of scientific knowledge mapping is more intuitive and readable. However, the use of a single bibliometric software program is also reflected in the existing studies with functional defects and a lack of validation of the analysis results.

CiteSpace [30] and VOSviewer [31] are knowledge mapping software programs for conducting bibliometric analysis, revealing trends and dynamics in the scientific literature and performing co-word analysis, co-citation analysis and literature coupling analysis. Compared with traditional mathematical statistics software, CiteSpace and VOSviewer have a higher frequency of use and breadth of dissemination [32]. In particular, CiteSpace provides access to domain-specific quantitative and visual information [33] and makes it easier to identify keyword clustering and temporal partitioning for a given research area [34]; VOSviewer has a more intuitive visual advantage in keyword co-occurrence and annual overlap analysis [31].

The research direction of this paper considers the advantages of CiteSpace and VOSviewer research. First, in this paper, we use CiteSpace to identify the keywords of RCHSCC [30], plot the temporal partition of RCHSCC keywords and countries and classify their re-research development stages accordingly (Section 3.2). Second, in this paper, we use VOSviewer to plot the keyword co-occurrence network and annual overlap of RCHSCC and combine the timeline map of CiteSpace and the prominent word map in recent years to summarize the distribution, evolution and emergence of RCHSCC hotspots (Section 4.1). Finally, this paper synthesizes the prediction of RCHSCC hotspot trends based on the bibliometric analysis results of CiteSpace and VOSviewer (Section 4.2).

In this paper, WOS, the most significant English literature database, was selected as the database and combined with CiteSpace and VOSviewer for visualization and clustering analysis. From a multivariate, time-phased and dynamic perspective, the scientific knowledge mapping analysis was conducted on 950 relevant works of literature included in the Web of Science core database during 1991–2022 in order to accurately and intuitively grasp the research characteristics of the field and explore the characteristics of the literature distribution, research stages, hotspots and trends of RCHSCC. Using the Web of Science Core Collection (hereafter referred to as WOS) as the data source, the search period was 27 August 2022, with all years (default 1975–2022). The search mode of "topic" + "document type" was used, and "carbon" + "human settlements OR human settlement" was used. We used (human settlements OR living environments OR human settlement environment) + climate" as the subject term, and the language of the literature was limited to "English". "A total of 934 entries were obtained, with the earliest year being 1991. The framework of RCHSCC is as follows (Figure 1).

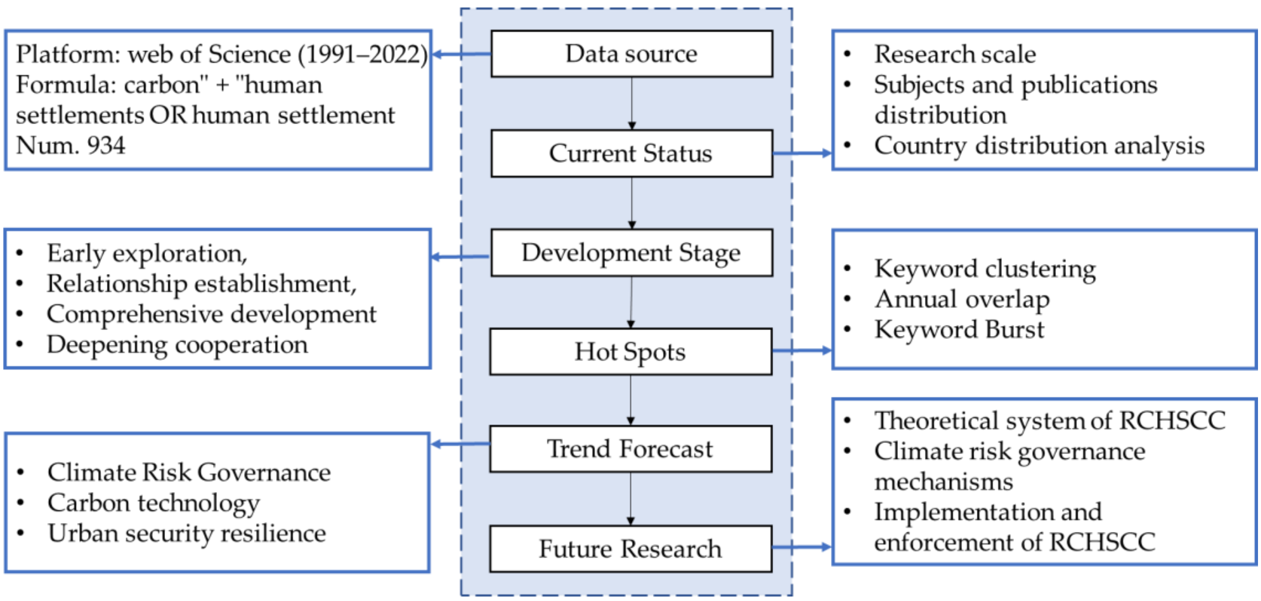

Figure 1. RCHSCC's framework.

3. Results

The volume of knowledge, disciplinary characteristics and leading countries of the research field can be reflected by the volume changes, disciplines and country distribution of the literature. Therefore, this paper analyzes the characteristics of RCHSCC in terms of papers, disciplines, publications and countries.

3.1. Current Status of RCHSCC

3.1.1. Research Scale

The online analysis function of WOS demonstrates that the overall number of publications in this field shows a fluctuating upward trend (Figure 2). It shows that the annual number of publications before 2012 was small (less than 40 publications per year); the number of publications fluctuated slightly between 2013 and 2018, and the number of publications increased significantly after 2016 (60 publications in 2016 and 104 publications in 2021, an increase of approximately 1.7 times). The number of articles is expected to be above 120 in 2022. The increased attention to RCHSCC indicates that this topic is gradually becoming one of the current research hotspots.

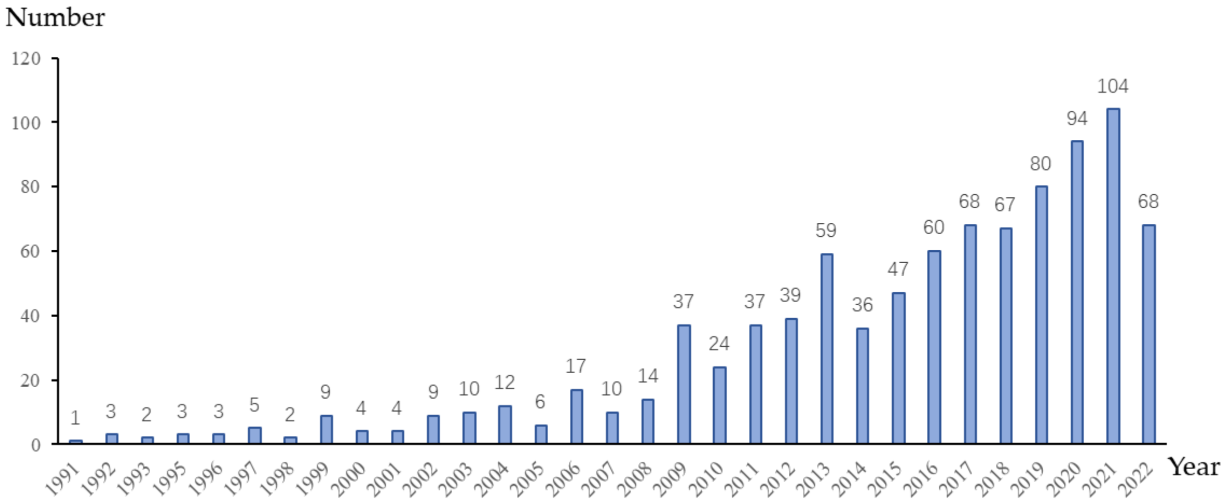

Figure 2. Number of RCHSCC articles issued from 1991–2022.

3.1.2. Subject and Publication Distribution

In terms of disciplinary distribution, RCHSCC is mainly concentrated in Environmental Sciences Ecology (37.69%), Geology (21.41%), and Science Technology (10.17%), while Urban Studies (1.71%) accounts for a relatively small number of disciplines. This shows the multidisciplinary nature of the research and the potential of urban planning research (Figure 3).

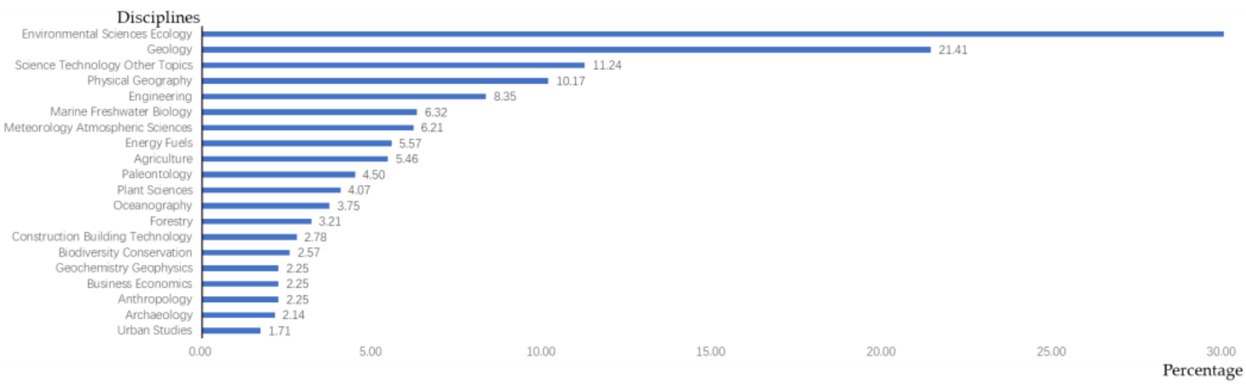

Figure 3. Distribution of RCHSCC disciplines (top 20).

Regarding source publications, there are 532 titles, among which the most published journals are PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY and SCIENCE OF THE TOTAL ENVIRONMENT, accounting for 2.57% and 2.03%, respectively (Figure 4), with the top 10 publications mainly on ecology and sustainable development.

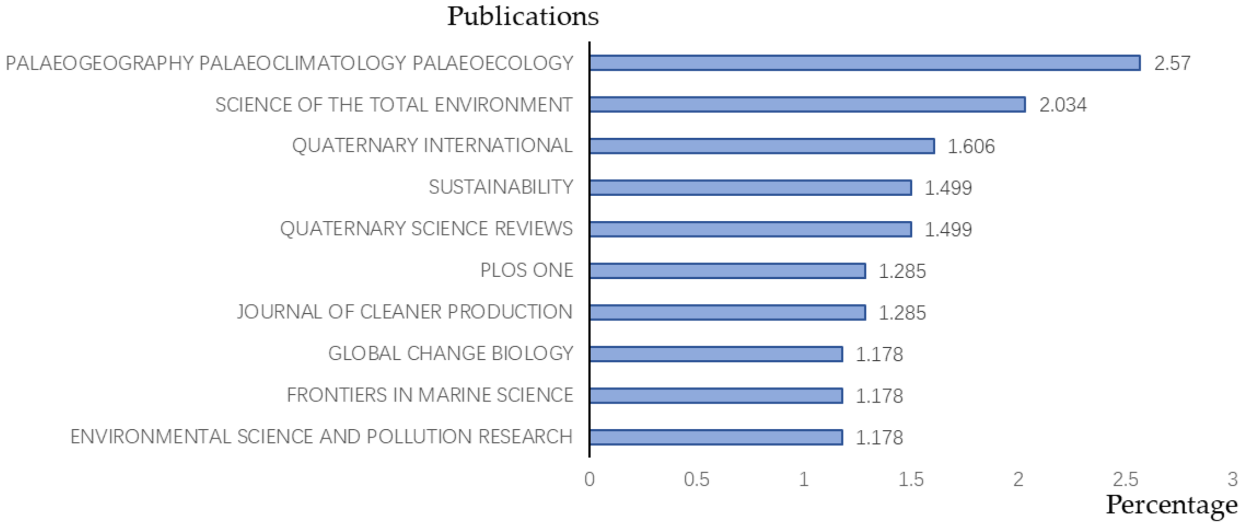

Figure 4. Percentage distribution of the number of articles issued by RCHSCC source publications (top 10).

3.1.3. Country Distribution Analysis

In this paper, we obtain the RCHSCC country co-occurrence map (Figure 5) using the CiteSpace country co-occurrence analysis function. Each node in the map represents a country, and there is a positive correlation between the number of country articles and the node's size. The more articles that are published, the larger the node is. As seen in Figure 4, the USA has the highest number of 293 publications, followed by UK (138 publications). The outermost purple circle highlights the centrality of countries, and strong centrality countries have a significant international influence in the cooperation and exchange of RCHSCC, with Sweden (0.49) and New Zealand (0.34) being the countries with highest centrality in the graph. The number at the bottom of Figure 4 indicates the year of publication. It shows that UK (1992) was the country presenting the earliest research, while China did not start research until 2003. Overall, the United States is the country with the most research and the most significant amount of literature. China has more publications (134) but started later and has a lower centrality (0), indicating that the overall citation rate of published papers is low and there is a lack of high-impact papers.

3.2. Development Stage of RCHSCC

Combined with the analysis in Section 2, this paper analyzes the time zone mapping of the RCHSCC literature using CiteSpace (Figure 6). In this paper, we use the keyword analysis function of CiteSpace to obtain the distribution map of RCHSCC hotspots in time zones (Figure 5). Each node in the map represents a keyword, and the frequency of keyword occurrence is positively correlated with the size of the node. The higher the frequency of the keyword, the larger the node. The keywords are ranked according to the order of appearance years. The centrality and frequency of RCHSCC high-frequency keywords are shown in Table 2. In this paper, the stages of RCHSCC development are divided into four phases, namely early exploration, relationship establishment, comprehensive development and deepening cooperation, combining the policy, literature distribution characteristics and keyword centrality and frequency at different stages. We identify the high-frequency co-citation literature and review the main research progress and research characteristics of each stage.

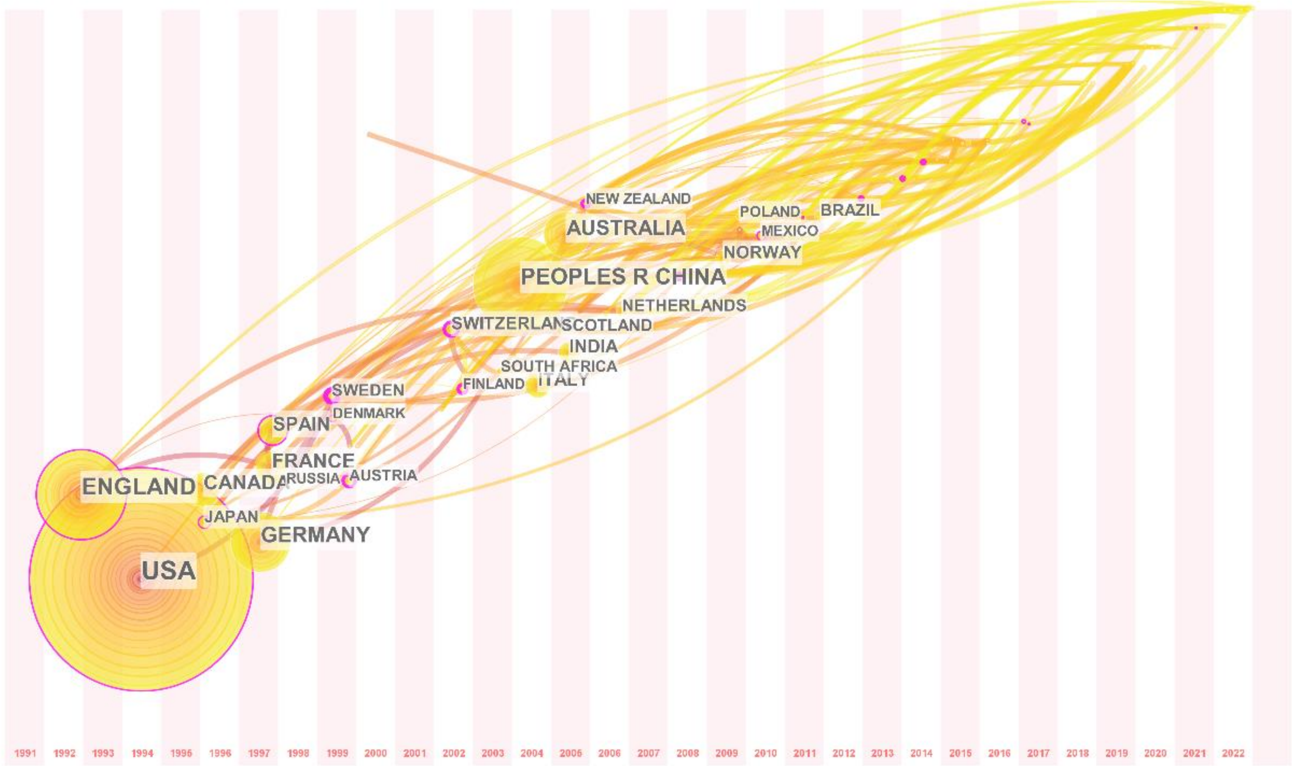

Figure 5. National time zonal mapping for RCHSCC.

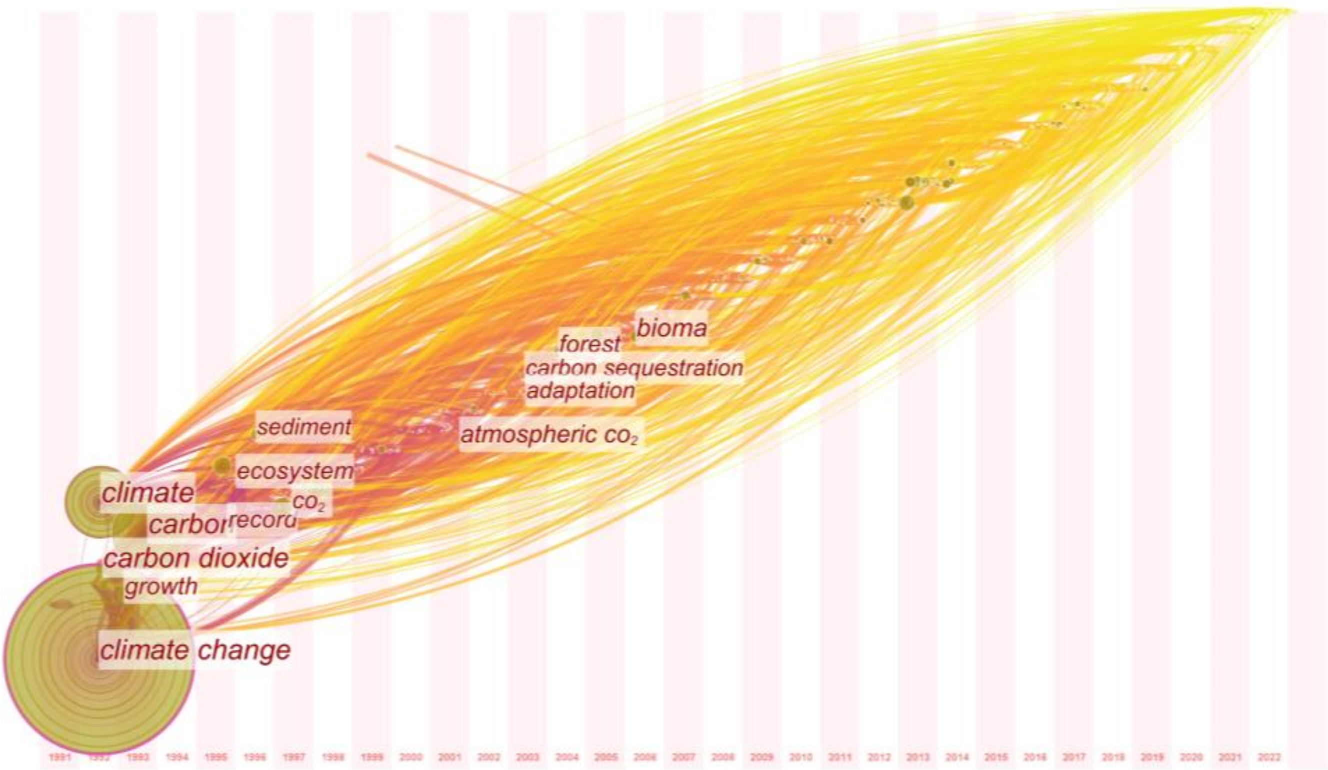

Figure 6. Distribution map of RCHSCC hotspot keywords.

Table 2. Centrality and frequency of RCHSCC high-frequency keywords.

Phase	Year	Frequency	Keyword	Centrality *
1991–2001	1992	281	Climate change	0.23
	1993	29	Land use	0.05
	1995	16	Ecosystem	0.06
	1996	9	Reconstruction	0
	1997	28	CO_2	0.05
	1998	20	Environmental change	0.03
	2001	21	Biodiversity	0.04
2002–2009	2003	21	Adaptation	0.04
	2003	22	Carbon sequestration	0.05
	2003	17	Carbon storage	0.04
	2004	28	Forest	0.06
	2005	10	Diversity	0.02
	2005	22	Management	0.02
	2009	21	Air pollution	0.03
2010–2016	2010	14	Black carbon	0.02
	2012	13	Evolution	0
	2012	10	Land use change	0.02
	2012	25	Variability	0.02
	2013	23	CO_2 emission	0.01
	2013	24	Ecosystem service	0.03
	2013	14	Sustainable development	0.01
	2014	13	Drought	0
	2016	17	Ocean acidification	0.02
	2016	8	Pollution	0
	2017	12	Consumption	0
2017 to date	2017	3	GI	0
	2017	9	Global warming	0
	2017	3	Risk	0
	2018	5	Governance	0.01
	2018	2	Land cover	0
	2018	3	Urbanization	0
	2019	4	Carbon accumulation	0.01
	2019	2	Energy efficiency	0
	2019	8	Health	0
	2019	5	Land cover change	0
	2020	4	Blue carbon	0.02
	2020	2	Heat island	0
	2021	2	Environmental Kuznets curve	0
	2022	2	Farming system	0
	2022	2	Renewable energy	0

* Centrality represents the importance of the nodes in the clusters, and nodes with centrality over 0.1 are called core keywords. The larger the value of centrality, the more significant the role that it plays in the clustering theme [30].

3.2.1. Early Exploration Stage (1991–2001): The Rise of Multidisciplinary Research and Models

Research on the greenhouse effect was conducted earlier [35]. The 1997 Kyoto Protocol proposed to limit greenhouse gas emissions to curb global warming [36]. The high-frequency keywords in the early stage include climate change (281 times), land use (29 times), ecosystem (16 times), environmental change (20 times) and biodiversity (21 times) (Table 1), among which climate change and ecosystem centrality are significant (0.23 and 0.06), being the hotspots of research at that time. This indicates that the early studies mainly focused on the integration of ecology, palaeoclimatology and other multidisciplinary studies, and some scholars also focused on carbon cycle models in the climate, but the literature that explicitly discussed RCHSCC had not yet appeared.

Research has primarily focused on the relationship between the role of plants and carbon in human settlements. Boston found that aquatic animals can provide carbon to plants in carbon-poor environments [37], similarly to McElwain et al. [38]. It was found that forests [39], vegetation [40,41] and shrubs [42] are essential factors in improving atmospheric carbon concentrations and increasing carbon sinks. Experiments by Jarvis et al. found that forests are important carbon sinks and significantly impact global atmospheric CO_2 concentrations, but the expansion of forest resources has little effect on CO_2 concentrations [39].

Many scholarly studies have found a close relationship between climate change and the carbon cycle. Barnola et al. studied the atmospheric CO_2 records for the past 160,000 years and found that CO_2 is directly and closely linked to climate change and shows a cyclic pattern of change [43]. Berner revised the long-term Earth carbon cycle model (GEOCARB I) and found that the CO_2 greenhouse effect plays a significant role in global climate due to a combination of geological, biological and astronomical factors [44]. Climate change can affect the global carbon cycle by influencing net primary productivity and, thus, the global carbon cycle [45].

In general, the amount of literature published at this stage is small (3.9% of the total), and the attention of the academic community is not significant.

The research objects mainly focus on ecology and palaeoclimatology, and the articles primarily study the effects of forest and plant elements on carbon in human settlements and the long-term interaction between carbon and climate. The exploration of the research system of the environmental response to climate change in human settlements has not yet emerged, and it can be said to be the early exploration stage of the research.

3.2.2. Relationship Building Phase (2002–2009): In-Depth Research and Theory Construction

Following the establishment of the UNFCCC in 2002, the IPCC Global Climate Assessment Report and the gradual increase in the international community's awareness of the impacts of climate change, the Earth's climate is being affected by the accumulation of greenhouse gases, such as carbon dioxide, caused by human activities. People have realized the importance of human settlements in climate change and carbon reduction. From the total citations of the literature, the research has also gradually changed from the study of the impact of human settlements on carbon to the specific study of improving carbon storage and then adapting to climate change, and also gradually considering the impact of climate issues on human settlements. The high-frequency keywords in this phase include adaptation (21 times), carbon storage (22 times), forest (28 times), water (15 times) and air pollution (Table 1), among which forest and carbon sequestration have high centrality (0.06 and 0.05) and are the hotspots of research at this time.

Carbon sequestration is an excellent way to mitigate climate change and improve the environment. Pacala proposed seven actions, including carbon capture energy and geological carbon sequestration, to solve the climate problem in the next 50 years [46]. Topics such as carbon management and human settlements are included in future planning [47]. The currently feasible carbon sequestration pools include geological, marine and terrestrial. There is also the potential for converting CO_2 into stable minerals. For oceanic carbon sequestration, Moore found that marshes have a carbon sequestration effect and are strongly influenced by climate change [48]. Kurihara et al. found that CO_2 sequestration in the ocean can mitigate the increase in atmospheric CO_2, but it can also reduce the hatching rate of copepods [49]. However, it has also been found that excess CO_2 will cause ocean acidification and affect the availability of nutrients for phytoplankton growth [50], which in turn affects the ecosystem [51]. Compared to ocean carbon sequestration, land-based carbon sequestration is a win–win strategy that is less costly and increases food security, in addition to mitigating climate change and improving the environment [52]. It is also valid for forest carbon sequestration [53].

At this stage, people have realized the importance of human settlements in climate change and carbon reduction. Le Quéré et al. analyzed global trends in CO_2 sources and sinks and found that increased climate change would cause a decrease in the uptake of CO_2 by carbon sinks, which in turn would increase the proportion of CO_2 emissions remaining in the atmosphere by 5% per year, suggesting that controlling climate change requires the stabilization of atmospheric CO_2 concentrations [54]. Kennedy et al. found that geophysical factors, such as climate, and technological factors, such as urban design, combine to influence city carbon emissions [55]. Grimm et al. proposed that urban development needs to consider environmental impacts and analyze the responses of cities and other regions to climate and carbon emissions in the context of the global environment [56].

In general, the role of human settlements in the evolution of the biosphere and the global carbon cycle has been considered at this stage, and the relationship between the forms and patterns of human settlements' development and the carbon cycle has been argued to be crucial not only for climate change mitigation but also for modeling future changes in atmospheric greenhouse gas concentrations [57].

During this period, the RCHSCC literature began to increase (12.3% of the overall), and academic interest continued to rise. The research content and methods were further expanded, the research on the impact of carbon was further deepened, and human settlement-related studies also appeared. However, the RCHSCC element's exploration and strategy development had not yet appeared; thus, this can be considered the relationship-building stage of the research.

3.2.3. Integrated Development Phase (2010–2016): Factor Exploration and Strategy Validation

The research on RCHSCC was further advanced by the adoption of two resolutions (UNFCCC and Kyoto Protocol Phase II Commitment) to address climate change at the Cancun Climate Conference in 2010. The IPCC notes that the human impact on the climate system is increasing, and it is urgently necessary to reduce carbon emissions and implement stringent mitigation activities. The main keywords in this phase are black carbon (14 times), land use change (10 times), CO_2 emission (23 times), ecosystem services (24 times) and sustainable development (14 times). It also focuses on evolution, consumption, management and other technical means, among which ecosystem services (0.03) and land use change (0.02) have a high central position and are the research focus in this phase.

In this phase, the research object of RCHSCC is further deepened, and the study focuses on the effects of land use change, the fossil fuel mix and the urban scale on climate change in human settlements, explains the effects of changes in human settlement elements on carbon emissions and then proposes carbon reduction strategies and conducts theoretical studies on the issue.

In their study, Goldewijk et al. analyzed global land use change over the past 12,000 years and found that land use change has long-term and sustained effects on biogeochemical cycles and global climate change [58]. Houghton et al. statistically found that from 1990 to 2010, net carbon fluxes from land use and land cover change (LULCC) accounted for 12.5% of anthropogenic carbon emissions [59]. Niemelä et al. found that vegetation in urban areas can play a role in CO_2 sequestration and help to mitigate climate change. He suggested that governments could increase carbon sinks and reduce CO_2 through proper land use planning of emissions [60]. Fragkias et al. analyzed the relationship between city size and CO_2 emissions and found that large cities are not as emitting but are more efficient than small cities, and perhaps city size can be used as a climate change mitigation strategy [61]. The same view is shared by Glaeser et al., who found a strong negative correlation between CO_2 emissions and land use, and that emissions from cities are usually lower than in the suburbs [62]. Le Quéré et al. combined data on energy statistics, land cover change, fire activity in deforested areas and ocean models to calculate the global carbon budget to understand the global carbon cycle, support the climate policy process and predict future climate change [63]. Some scholars have also continued to focus on the effects of ocean acidification from the previous phase of ocean carbon sequestration, analyzing its effects on communities in the ecosystem and predicting the impact of CO_2 emissions on the Earth's ecosystem [64].

At this stage, scholars have already proposed strategies to combat climate change and reduce carbon in human settlements, based on the studies mentioned above regarding economic, social, ecological and technological aspects. Andres, R. J. found that continued increases in total global fossil fuel CO_2 emissions will be a significant driver of the modern climate change problem and called for the control of CO_2 emissions through economic instruments, improved infrastructure and better population distribution [65]. Zaehle et al. used anthropogenic nitrogen inputs to increase the net uptake of carbon by the terrestrial biosphere and found that carbon sequestration due to nitrogen deposition has reduced the current CO_2 radiation by 96 ± 14 mW m^{-2} [66]. Balaban argued that urban actions have great potential to address climate issues, mainly urban policies that can transition from carbon-emitting vulnerable cities to low-carbon and resilient cities [67]. Schandl used a new approach combining economic and environmental modeling to evaluate resource use for carbon emission differences. Decarbonization does not reduces human well-being and living standards., but also makes cities and human settlements more resilient.

This period saw a gradual increase in the number of publications (32.3% of the total) compared to the previous period (Figure 1), indicating an increase in RCHSCC topics, further extension of research objects compared to the previous period and the emergence of response strategies to RCHSCC; this can be considered as a comprehensive research development stage.

3.2.4. Deepening Collaboration Phase (2017–Present): New Technology Application and Multi-Perspective Collaboration

The acceleration of global urbanization and the outbreak of COVID-19 [68] have brought new impacts on climate change, and RCHSCC has gradually focused on applying new technologies and multi-perspective cooperation based on the previous phase. This phase of research focuses on the application of new technologies and multi-perspective collaboration, with important keywords such as health (8 times), global warming (9 times) and governance (5 times). New technologies and models, such as the environmental Kuznets curve and carbon accumulation, are also utilized in RCHSCC. The research aims to pay more attention to diversification to improve the quality and solutions of human settlements to cope with carbon and the climate and to propose corresponding innovative strategies and tools.

In terms of keywords, the terms blue carbon (0.02), carbon accumulation (0.01) and governance (0.01) are highly centered and represent the focus of research in this phase, which is concerned with proposing new techniques and concepts for RCHSCC based on estimating carbon accumulation and further expanding carbon mitigation strategies to enhance the carbon benefits of responding to climate through governance mechanisms. Macreadie et al. advocated for the promotion of blue carbon sequestration through coastal watershed management, proposing three potential management strategies to optimize coastal blue carbon sequestration based on ways to protect and restore coastal vegetation (seagrasses, tidal marshes and mangroves) to sequester blue carbon [69]

Many new techniques and measures have been proposed for RCHSCC. Liu et al. (2017) found that social development affected human settlements and concluded that climate change and policy implementation significantly impact regional ecosystem service changes, based on an analysis of land use and ecosystem service changes under multiple scenario simulations [70]. Otto et al. proposed six social tipping interventions, such as building carbon-neutral human settlements, to understand the potential of using socio-ecological dynamics to mitigate climate change and to advance the rapid global transition to a carbon-neutral society [71].

At this stage, RCHSCC strategies are not limited to land use change, fossil fuel combustion, forested land area [72,73], forest investment [74,75] and the urban scale, but elements such as personal habits [76] and the shared economy [77] are also incorporated. Sustainable governance actions [78], such as carbon governance [78], are also proposed as effective mitigation strategies to further narrow climate change's impacts and mitigate the climate mitigation gap. Moreover, the benefits of climate-resilient carbon strategies, such as human health [79,80] and food security, have also been progressively considered.

Research in this period entered a phase of rapid growth (51.5% of the total), its research scope and methods were further expanded, its publication volume showed explosive growth, and research results continued to increase (Figure 1), with research on architectural, technological and socioeconomic elements, health objectives and model simulations in the human settlements. A diversified research direction has been formed; thus, this can be considered a collaborative research development stage.

4. RCHSCC Hotspots and Trends

4.1. Analysis of RCHSCC Hotspots

4.1.1. Distribution of RCHSCC Hotspots Based on Keyword Clustering

The keywords of the literature are the authors' refinement and summarization of the main contents of the article, and the word frequency analysis of keywords is often used in bibliometry to reveal the distribution of research hotspots [34]. VOSviewer indicates the connection between each key node and research hotspot by the node size, color and distance of connecting line thickness and density, which can reflect the relationship between each important node, topic and keyword more intuitively [31]. Moreover, the clustering of keyword co-occurrence mapping is more precise and better graphically represented.

The data were imported into VOSviewer for keyword co-occurrence analysis to present the distribution characteristics of RCHSCC hotspots. The minimum threshold of word frequency statistics was set to 40 in VOSviewer, and the top 90 high-frequency keywords were selected to draw the RCHSCC keyword co-occurrence network map (Figure 7) and annual overlap map (Figure 8). Several keywords with a high word frequency were environment (690 times), change (372 times), climate change (355 times) and carbon (279 times), which represented the main hotspots of RCHSCC research.

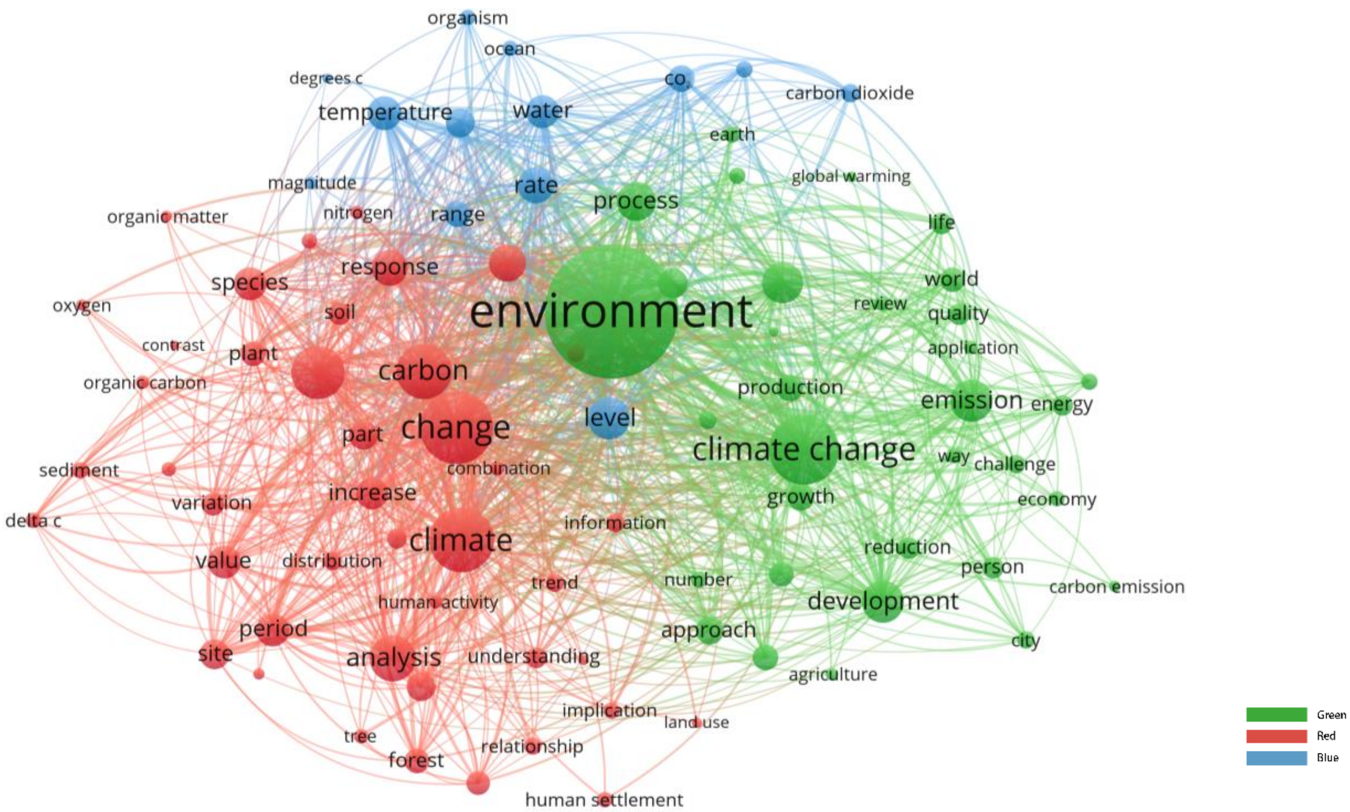

Figure 7. RCHSCC keyword co-occurrence network mapping.

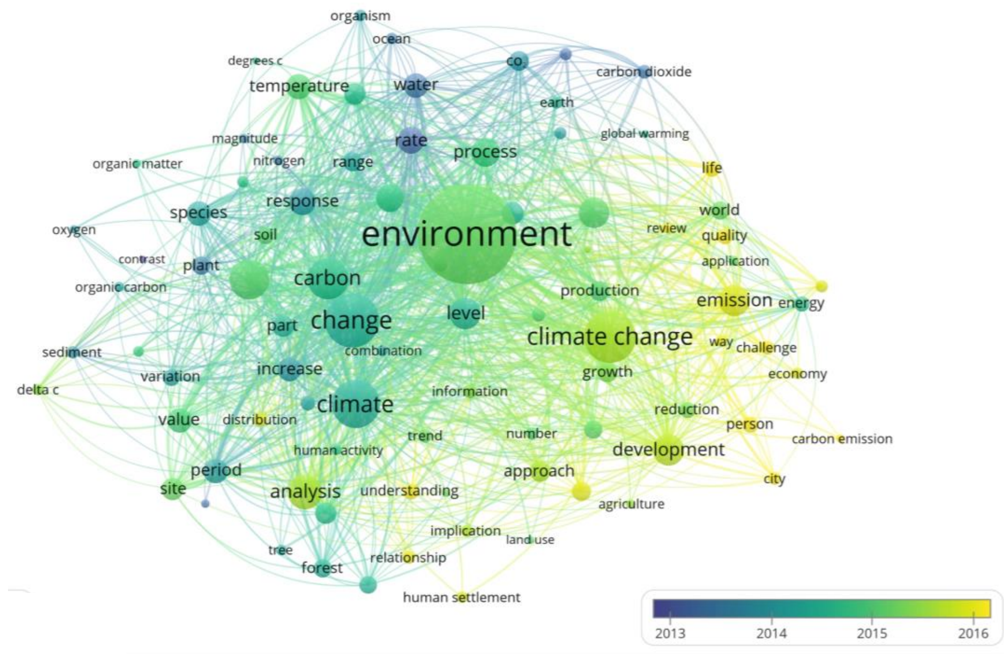

Figure 8. RCHSCC keyword annual overlap mapping.

In the keyword co-occurrence network view (Figure 6), environment (690 times) and climate change (355 times) had the most significant word nodes and highest word frequency and represent the research context of RCHSCC, and the remaining words with high relevance are carbon emission, delta c, building, technology and lake. Around these core concepts, based on the co-occurrence relationship, the study presents three main research clusters, which are as follows. (1) Red cluster: The clustered high-frequency words include climate, carbon, condition, analysis and ecosystem, to study environmental changes in ecosystems such as forests and plants and land use, carbon and other related research. From the word frequency, the research object focuses on ecological aspects, exploring the environmental change caused by carbon in forests, plants and soils. The research purpose mainly focuses on land use and human activity. (2) Green cluster: The study of the impact of climate change and global warming on carbon emissions. The high-frequency words are environment, climate change, development, emission and system. From the word frequency, the research background is related to global warming, and the research purposes are the quality of biodiversity, energy growth and economical technology. The research method involves an application strategy. (3) Blue cluster: The high-frequency words are rate, temperature and water. The main focus is on the level of carbon dioxide in the ocean and other organisms, and the research involves carbon dioxide's range, speed and concentration.

Different nodes and connecting lines in Figure 7 indicate high-frequency words in different time dimensions, presenting the evolutionary characteristics of different research content in the time dimension. Although the RCHSCC originated earlier in the year analysis, the high-frequency words mainly appeared in recent years (2013–2016). The high-frequency words that appeared slightly earlier include rate, water, carbon dioxide, atmosphere and plant, indicating that the early studies focused on research related to the deposition of carbon dioxide emissions and ecosystem factors such as plants and water sources, and primarily focused on the impact of carbon sinks and ecosystems. As the research progressed, RCHSCC considered climate change, energy and temperate land. After 2015, the research objects and content were further expanded, and the research focused on the changes in carbon dioxide and carbon sink from the early stage of resource consumption. The elements related to human settlements, such as economy, urbanization and biodiversity, were gradually considered; the high-frequency words such as diversity, and new concepts and technologies, were gradually applied.

4.1.2. Evolution of RCHSCC Hotspots Based on Annual Overlap

The temporally partitioned mapping of keyword co-occurrence and literature co-citation that CiteSpace can achieve helps to further analyze the evolutionary path of research hotspots. The time view function of CiteSpace that enables the visual analysis of evolutionary paths [34] helps to identify research frontiers by discovering the turning time points of research and the important literature in the corresponding period [30]. In this paper, we use CiteSpace's keyword analysis, set the time slice to 1 year, analyze the keywords of RCHSCC during 1991–2022 and plot the time-partitioned axes of research in different periods (Figure 9). The top 10 categories are #0 climate change, #1 sustainability, #2 blue carbon, #3 aerosol, #4 carbon dioxide, #5 climate warming, #6 bronze age, #7 biogeochemical modeling, #8 biogeochemical cycles and #9 atmospheric CO_2. It shows many aspects of future and long-term trends in urban structure, land cover change, carbon cycles and urban systems. As seen in Figure 8, the warming category is a major category of research because of its early origin, greater importance and stronger relationship with the rest of the categories. The wide coverage of its keywords again verifies the multidisciplinary nature of RCHSCC, and there are obvious differences in the research focus and major topics at different stages.

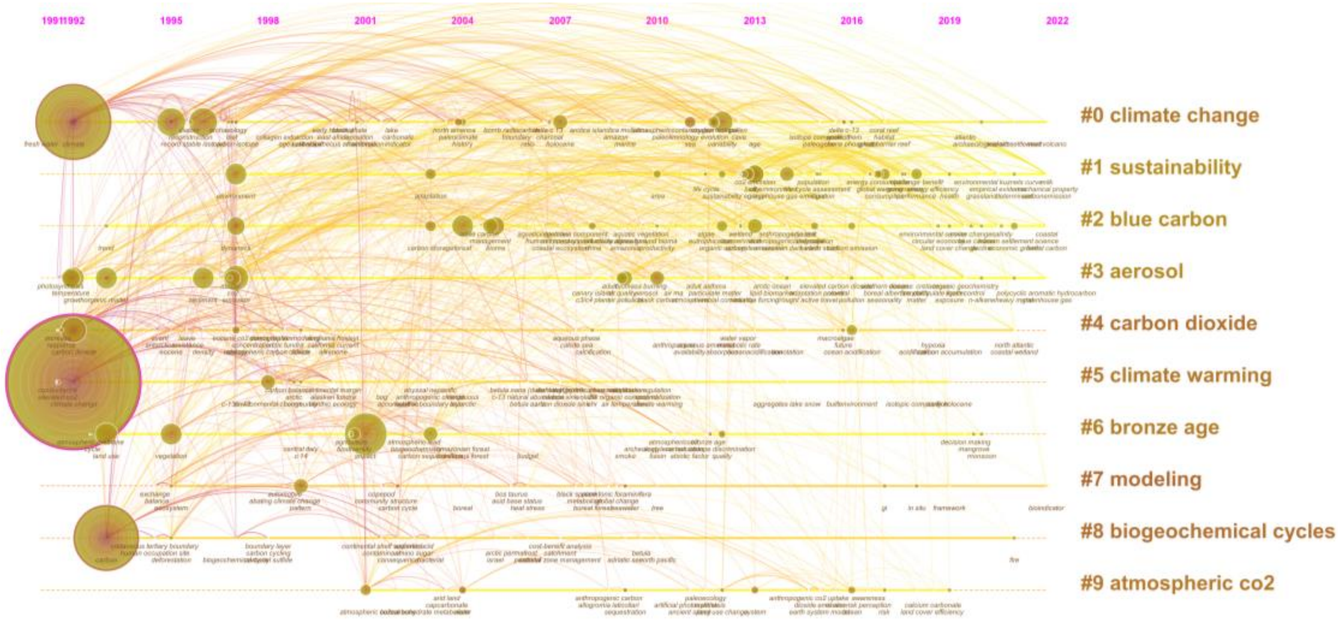

Figure 9. RCHSCC time-zoned axial mapping (top 10 categories).

4.1.3. Keyword Burst of RCHSCC Hotspots

Keyword burst detection can detect changes in the frequency of keywords in a research field over a certain period, thus reflecting changes in research hotspots during that period, and these "burst" keywords have specific development potential and research value in this research period [34]. From the 50 burst words that appeared in the RCHSCC field from 1991 to 2022, this paper selected the 25 most frequent keywords for analysis (Table 2). In Table 3, keywords represent the outbreak words, intensity represents the importance of the burst keyword, start represents the start year of the keyword, end represents the end year of the keyword, and the red line represents the burst duration. At different stages, RCHSCC has apparent differences in research focus and hotspot areas. Before 2010, burst keywords focused on ecological directions such as atmospheric carbon dioxide, ocean, water and soil, with no evident research targeting human settlements. From 2011 to 2013, burst keyword research expanded to land use change, emissions and sustainable development, gradually focusing on urban carbon emissions, land use change, other land use processes and sustainable development goals. From 2014 to 2017, the research keywords gradually increased, as well as research objects and research purposes. Research gradually expanded on global warming and other backgrounds, as well as on the management of pollution, energy consumption and other response methods and future predictions. From 2017 to the present, relevant research has focused more on human settlements under land cover change in response to climate change governance, where the management of ecosystem services, health evolution and sustainability have become major topics.

Table 3. Top 25 burst keywords for RCHSCC, 1991–2022.

Keywords	Intensity	Start	End	1991 2022 *
Atmospheric CO_2	2.944	2001	2004	
Marine	2.8636	2009	2016	
Water	5.4565	2010	2015	
Soil	2.5817	2010	2012	
Land use change	4.4121	2012	2016	
Environment	4.3493	2013	2015	
Emission	3.4814	2013	2017	
Transport	4.8195	2013	2018	
Sustainable development	4.1334	2013	2014	
City	3.3863	2013	2016	
Built environment	2.8956	2014	2017	
Plant	4.0268	2014	2019	
Energy	2.8923	2015	2019	
Pollution	3.0838	2016	2017	
Ocean acidification	2.8526	2016	2018	
Global warming	2.9349	2017	2019	
Management	4.3068	2017	2020	
Consumption	2.5528	2017	2022	
Governance	2.7529	2018	2019	
Ecosystem service	4.4562	2019	2022	
Land cover change	2.5964	2019	2020	
Health	3.3304	2019	2022	
Evolution	2.635	2019	2022	
Variability	4.1765	2019	2022	
Decline	2.4755	2020	2022	

* The blue line indicates the period examined, 1991–2022, with each small segment representing one year; the red thickened line indicates the period of sudden growth of the corresponding keyword, with the red appearing and ending positions representing its starting and ending years, and the longer the red line is, the longer the sudden growth of the keyword is maintained.

The bibliometric analysis is mainly conducted based on citations and cross-references among the historical literature, and the cross-citation data of the literature published in recent years can only be reflected in the future. This paper aimed to study the RCHSCC trends better and predict the research trends in this field. Therefore, in this paper, we use the burst keywords that emerged in the last 5 years (2017–2022) and the intensity and timing of the emergence obtained from the CiteSpace keyword emergence analysis in order to analyze more precisely the research trends regarding the climate change response in human settlements under carbon orientation. As shown in Table 4, transportation, resilience, environmental change, governance, biodiversity, variability and decline have been novel topics in recent years.

Table 4. Burst keywords highlighting intensity and timing of RCHSCC in 2017–2022.

Keywords	Intensity	Start	End	2017 2022 *
Transport	2.9057	2017	2018	
Resilience	1.6559	2017	2018	
Environmental change	2.1815	2018	2019	
Governance	1.9814	2018	2019	
Biodiversity	1.9704	2018	2020	
Variability	1.8639	2019	2022	
Decline	1.4038	2020	2022	

* The blue line indicates the period from 2017 to 2022, with each small segment representing one year; the red thickened line indicates the period of sudden growth of the corresponding keyword, with the red appearing and ending positions representing its starting and ending years, and the longer the red line, the longer the sudden growth of the keyword is maintained.

The keyword clustering mapping is combined with the statistical method of clustering based on co-occurrence analysis to reduce the co-occurrence network relationships to a relatively small number of clusters. In this paper, the log-likelihood ratio algorithm is chosen to label each cluster, and the top 10 clusters are listed. CiteSpace provides two metrics, the module value (Q value) and the average profile value (S value), based on the network structure and the clarity of the clusters, as a basis for us to judge the effectiveness of the mapping. The Q value is generally in the interval [0, 1]; Q > 0.3 means that the delineated modules are significant, and the clustering is convincing when the S value is 0.7. The cluster module value (Q value) of RCHSCC is 0.70 > 0.3, and the average profile value (S value) is 0.83 > 0.7, indicating that the clustering is within the confidence interval and the clustering quality is high. The specific clustering contents are shown in Table 5 and Figure 10.

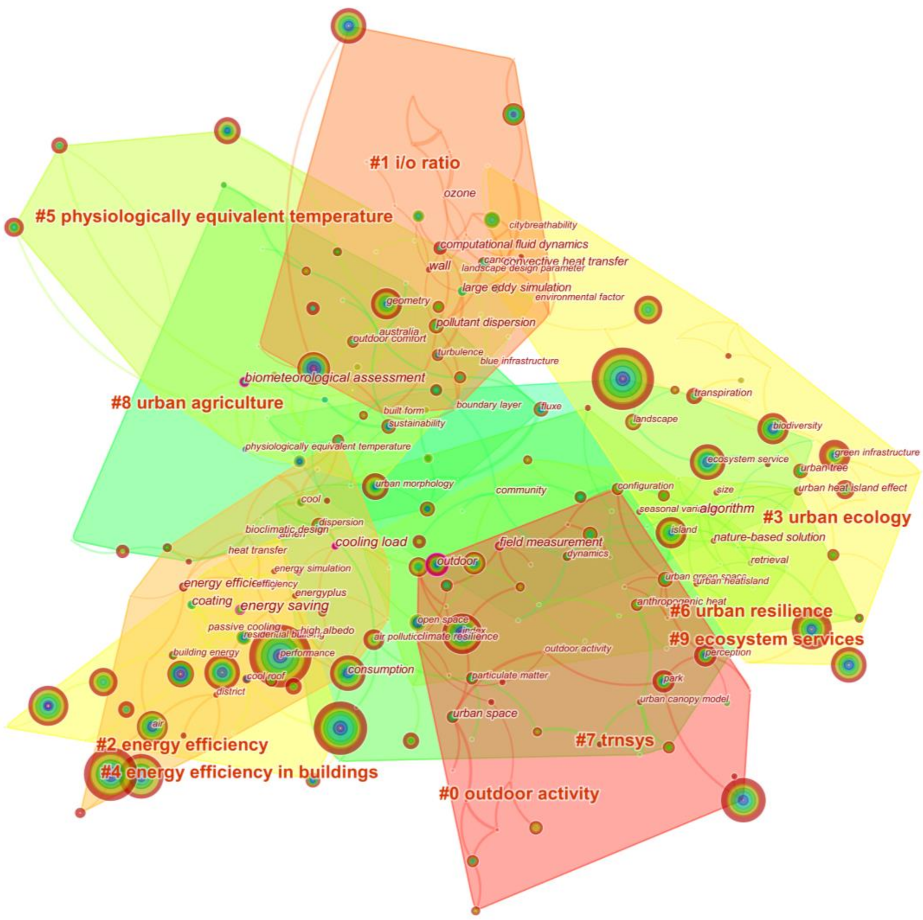

Figure 10. Cluster mapping of RCHSCC keywords, 2017–2022.

Table 5. Keyword clustering of RCHSCC in the last five years.

Cluster Name	Size	Profile Value	Year	Main Keywords
0. Climate change mitigation	25	0.849	2019	carbon; blue carbon; climate change; warming; decarbonization; Paris agreement; urban air pollutants; urban heat island; large trees; greenhouse gas emissions;
1. Carbon sequestration	24	0.878	2018	geoecological factors; bioproductivity; sustainable urban development; water limitation; satellite remote sensing; decarbonization; sustainable land management;
2. Methane	22	0.848	2018	energy; extinction; greenhouse gas; fossil fuel; land transformation; natural selection; adaptation; optimization; biodiversity; global change driver; decline; agriculture; soil health;
3. Temperature	21	0.708	2018	variability; ocean acidification; growth; saturation state; carbon storage; ecological sustainable development; mitigation; risk perception; value; carbon cycle;
4. Soil	21	0.899	2018	freshwater; resilience components; soil organic matter; El Nino; palaeoclimatology; temperate forests; hydroclimate; mortality; emission of carbon dioxide; carbon cycle;
5. Aktun ha cenote	20	0.785	2019	stable isotope; biomarkers; soil carbonate; ecological restoration; drought; ecosystem; degradation; land use; ocean acidification; global warming; climate; environment;
6. Energy efficiency	20	0.844	2018	wastes; sustainable; governance; regional livability; gas treating; low carbon cities; urban environment; soil sealing; process intensification; economic development; urban planning; green infrastructure;
7. Sustainability	19	0.923	2020	life cycle assessment; solar planning; sustainable development; biochar; carbon footprint; global warming; heat stress; ecosystem services; temperature; agriculture; carbon isotopes;
8. Complex	19	0.899	2020	land classification types; uncertainty; large-scale infrastructure construction; environmental safety; urban heat island ratio index; carbon isotope event; ecosystem carbon;
9. Urban form	17	0.969	2018	urban form; fourth industrial revolution; constructed wetland; local economic development; emerging technology; environmental Kuznets curve; structural equation model sem; nature-based solutions;

Among them, those with a high frequency (more than 20 times) are climate change, climate, carbon, land use, ecosystem service, ecosystem service, energy, stable isotope, variability and sediment. The strong centrality (more than 0.15) of ecosystem service, growth, environmental impact, consumption, forest, ocean acidification and pollution is noted. It shows that the future RCHSCC will focus more on the fourth industrial revolution. In the future, RCHSCC research will try to build an adaptive climate governance system to reduce the vulnerability of cities to climate change risks and improve urban climate sustainability by using technologies such as carbon sequestration in a diversified context to cope with climate change.

4.2. RCHSCC Trend Forecast

Based on the emerging word strength and keyword clustering analysis for the past 5 years, the future trend of RCHSCC is predicted to focus on the following three areas.

4.2.1. Trends in Climate Risk Governance Research

From the bibliometric results presented in Section 4.1, it can be seen that climate change-related research, such as climate change mitigation (2019), pollution (2016), sustainable urban development (2018), risk perception (2018) and others, which emerged after 2019, was one of the major research trends in recent years.

Since the industrial revolution, greenhouse gas emissions have continued to accumulate, and forest resources have been decreasing, contributing to a significant increase in the frequency and extent of climate change phenomena such as sea level rise, temperature rise, soil erosion and their derived disasters. In contrast, strong climate governance can contribute to the political interpretation of urban climate risk vulnerability and the construction of analytical models for per capita environmental risk management [81]. Intelligent tools can facilitate urban governance for climate adaptation and risk reduction [82]. Ni'mah analyzed urban governance research on climate change adaptation for disaster risk reduction [83]. Effective disaster risk management is an essential component of urban adaptation to climate change; therefore, it is necessary to build adaptive risk governance systems to reduce the vulnerability of human settlements to carbon and climate change.

4.2.2. Trends in Carbon Technology Upgrading Research

From the bibliometric results presented in Section 4.1, it can be seen that carbon technology and carbon governance-related research, such as blue carbon, decarbonization (2019), decarbonization (2018), carbon footprint (2020) and nascent technology (2018), which emerged after 2018, was one of the major research trends in recent years.

Human settlements are an essential source of greenhouse gas (GHG) emissions globally [15], and approximately 70~80% of CO_2 emissions globally come from urban human settlements. Consequently, climate change, caused by significant GHG emissions, poses a great challenge to the sustainable development of human settlements [76]. Scholars have studied the interrelationships between carbon technologies and climate governance, economic development and market transactions, such as carbon control in climate governance policies [24–26], carbon performance and carbon economy at the response outcome level [27,28,84], quantity-based mechanisms (e.g., carbon trading) and price-based mechanisms (e.g., carbon taxes) [85], as well as influencing factors [86] and the modeling of carbon emissions themselves [87]. Carbon orientation, as the primary goal of research on the climate change response in human settlements, should be considered in the future to enhance the research on carbon technologies and develop and apply diversified carbon technologies to assist in human settlement climate analysis, simulation and multidisciplinary fields for collaboration.

4.2.3. Trends in Urban Security Resilience Research

From the bibliometric results presented in Section 4.1, it is clear that studies related to urban safety and resilience, such as resilience (2018), ecological sustainability (2018) and health (2019), which emerged after 2018, reflect some of the major research trends in recent years. Human settlements, as hotspots affected by climate warming or exacerbated by climate warming, must consider climate adaptation strategies [88] in future construction to improve their resilience and mitigate the climate impacts of rapid urbanization. The principles of good land governance are an essential part of urban security rehabilitative thinking and action [89], and the RCHSCC field should pay more attention to poor groups [90] in informal settlements [91] and implement more comprehensive, appropriate and effective security and rehabilitation measures in the future. Specific adaptation measures can be developed regarding prevention criteria, risk assessment and the emergency response to promote an understanding of climate resilience and sustainability. The climate resilience of human settlement ecosystems, built environment systems and infrastructure systems should be developed to enhance the prevention and mitigation of climate change's adverse impacts and risks.

5. Discussion

Based on the findings of the literature distribution characteristics, development stages and major trends of RCHSCC, the following three aspects can be focused on in RCHSCC research in the future.

The first aspect is establishing and improving the theoretical system of RCHSCC. From the literature distribution characteristics and development stages, it is seen that the origin of RCHSCC occurred early (1991); the early research mainly focused on multidisciplinary studies such as ecology, and the research on the theoretical system of RCHSCC did not appear until after 2010 in terms of RCHSCC strategies, including infrastructure improvement, population distribution optimization [61] and low-carbon city policies [63]. The future research should consider establishing a perfect theoretical system of RCHSCC, which has assessed, classified and scored studies on the response to climate change in human settlements under different carbon targets based on carbon potential, carbon cost and other factors. In response to the systematic construction and improvement of the theoretical system of RCHSCC, the results brought about by different types of carbon targets should be explored in order to effectively respond to the actual climate change problems, such as extreme weather events (e.g., hurricanes, droughts, heat waves) and chronic climate change (e.g., sea level rise, desertification, glacier retreat, land degradation, ocean acidification and salinization).

The second aspect is exploring climate risk governance mechanisms and strategies, including research topics on climate risk management, ecological and environmental protection and climate adaptation planning. The uncertainties of climate change and urban development may form new coupled risks, so it is necessary to develop climate risk mechanisms and strategies to provide forward guidance for RCHSCC and strengthen the research on climate risk management assessment and governance countermeasures for RCHSCC, especially the countermeasures for the environmental protection of the habitat environment. Therefore, future RCHSCC research should include ecological risk response and climate adaptation planning, efficient use of resources, protection against ecological risks and the development of countermeasures, such as investments in weather warning systems, cultivation of drought-resistant food varieties to ensure food supply and promotion of low-carbon living.

The third aspect focuses on the implementation and enforcement of RCHSCC. (1) Investment aspects. Addressing climate change requires financial resources and sound investments to reduce emissions, promote adaptation to the impacts that have already occurred and increase resilience. Investments targeting carbon and climate are sustainable and effective [68]. (2) Implementation efficiency aspects. The future RCHSCC work should focus on the efficiency of its implementation process, which requires rapid and resilient development to improve habitat re-adaptation in the face of climate change, such as promoting clean energy use, increasing sustainable energy production to mitigate climate risks, reforming or investing in solar energy and creating green economy systems. The implementation of RCHSCC will not only reduce carbon emissions but will also help habitats to become resilient to the impacts of climate change, to cope with the catastrophic losses and damages that have already occurred and will become more severe and ultimately create inclusive, productive, healthy and harmonious habitats.

6. Conclusions

As RCHSCC has gradually been emphasized, the research literature continues to increase, and research results have received attention from all walks of life. Based on the bibliometric data analysis of CiteSpace and VOSviewer, this paper analyzes the distribution characteristics of the RCHSCC literature in different periods, disciplines and countries. It visualizes the characteristics of research hotspots and development trends based on keyword co-occurrence and literature co-citation. Moreover, it draws the following conclusions.

(1) The literature of RCHSCC has shown a fluctuating upward trend, and the distribution of its literature is characterized by a continuous increase in the number of studies, a combination of disciplines, a focus on ecology and sustainable development elements and a predominance of developed countries in the study area.

(2) RCHSCC can be divided into four stages: early exploration, relationship building, integrated development and deepening collaboration. In terms of the literature and discipline distribution, research hotspots and focus, they show “the emergence of multidisciplinary research and modeling”, “in-depth research and theory exploration”,

"factor exploration and strategy validation", "new technology application" and "new technology application".

(3) From the knowledge mapping characteristics of research hotspots based on keyword clustering, annual overlap and keyword highlighting, it is clear that the governance of human settlements under land cover change in response to climate change is important, where the management of ecosystem services, health evolution and sustainability have become major topics. In the context of multiple changes, such as resilient city construction, new crown epidemic outbreaks and industrial revolution 4.0, the future RCHSCC field will display three major trends: climate risk governance, carbon technology enhancement and security and resilience target research.

In the future, RCHSCC researchers should strengthen the development and implementation of urban climate risk governance mechanisms and strategies while introducing new technologies, policies and models for carbon emissions. Based on the resilient city framework and urban security resilience, we will build an effective human settlement model to cope with climate change and achieve the goal of carbon neutrality.

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Nomenclature

COVID-19	Coronavirus Disease 2019
IPCC	The Intergovernmental Panel on Climate Change
RCHSCC	Research on carbon-oriented human settlements for climate change
UNEP	United Nations Environment Programme
VOS	VOSviewer
WOS	Web of Science

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