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Review

Carbon Peak and Carbon Neutrality in the Building Sector: A Bibliometric Review

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Abstract: Due to large energy consumption and carbon emissions (ECCE) in the building sector, there is huge potential for carbon emission reduction, and this will strongly influence peak carbon emissions and carbon neutrality in the future. To get a better sense of the current research situation and future trends and to provide a valuable reference and guidance for subsequent research, this study presents a summary of carbon peak and carbon neutrality (CPCN) in buildings using a bibliometric approach. Three areas are addressed in the review through the analysis of 364 articles published from 1990–2021: (1) Which countries, institutions, and individuals have conducted extensive and in-depth research on CPCN in buildings, and what is the status quo of their collaboration and contributions? (2) What subjects and topics have aroused wide interest and enthusiasm among scholars, and what are their time trajectories? (3) What journals and authors have grabbed the attention of many scholars, and what are the research directions related to them? Moreover, we propose future research directions. Filling these gaps will enrich the research body of CPCN and overcome current limitations by developing more methods and exploring other practical applications.

Keywords: building energy; carbon peak; carbon neutrality; bibliometric study

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1. Introduction

The building and construction industries, as well as the policies and standards promulgated therein, not only affect social and economic development [1], but are also closely related to environmental protection [2,3]. When it meets people's needs through buildings [4], it will inevitably impact the environment throughout the entire lifecycle of a building [5]. The building sector, one of the three major sectors in terms of energy consumption (i.e., industry, transportation, construction) and one of the main areas of responsibility for direct and indirect carbon emissions, accounted for 36% of the final energy consumption and 38% of the total carbon emissions in 2019 [6]. With the development of cities and rapid economic growth worldwide, the rapid growth of energy consumption and carbon emissions (ECCE) in the building sector has attracted more and more attention from countries around the world [7–11]. Due to the huge ECCE of the building sector, the carbon emission abatement potential of the construction industry will significantly influence the carbon peak and carbon neutrality (CPCN) in the future [12], aroused great attention from academics and industry practitioners.

The existence of a carbon emissions peak means that there will be a steady decline in carbon emissions after reaching a plateau [13]. Carbon neutrality refers to the total amount of greenhouse gas emissions produced by an enterprise, organization, or individual within a certain amount of time and the realization of a zero-carbon emissions status by offsetting these carbon emissions through forest planting, energy saving, and emission reduction [14,15]. Developed countries and major economies have developed their own targets to curb greenhouse gas emissions and are trying to do their part [16–20]. For example, China, a major emitter of greenhouse gases, has made a commitment to reach its carbon emissions peak by 2030 and to achieve a carbon neutral status by 2060 [21]. The United States aims to decrease its carbon dioxide emissions by 17% by 2020 and by 83% by 2050 compared with 2005 levels [22]. The UK has set the objective of cutting greenhouse gas emissions by at least 20% by 2050 compared with 1990 levels [23].

From 1990 to 2021, research on CPCN in the building sector was diverse and active. Since the CPCN of the building sector should be considered from the perspective of the lifecycle, research in this area either covers a single phase (design, construction, and operation) or the entire lifecycle. For example, You et al. calculated the overall carbon dioxide emissions of residential buildings through their lifecycles [24]. Zhang et al. discussed the trends in ECCE in China's building sector from 2000 to 2016 using the China Building Construction Model based on the life cycle assessment method [25]. Danatzko et al. analyzed energy use by structural parts made up of different materials throughout the life cycle to achieve sustainable design [26]. Sozer et al. changed the building envelope during the design phase to improve energy efficiency [27]. Lam et al. revealed that the participation of stakeholders impacts other factors through the implementation of green codes in the construction phase [28]. Chen et al. investigated the changes in carbon emissions on different emission scales during the operation phase of civil buildings from 30 provinces of China [29]. Research on CENCN in buildings can also focus on commercial buildings and residential buildings [30,31]. For example, Ma et al. measured carbon emission abatement in commercial buildings in China based on the Kaya-LMDI method [32,33]. Hong et al. studied the energy efficiency of small commercial buildings using an energy analysis tool [34]. Zhang et al. analyzed the road map of carbon neutrality in the operation stage of commercial buildings and made a comparison between China and the United States [35,36]. Tian et al. investigated the status quo of near (net) zero-energy residential buildings in Beijing [37]. Zheng, Wei, and Wang et al. conducted a household survey on the energy consumption characteristics of Chinese residents [38]. In addition to the CPCN study on urban buildings, Yao et al. and Zhang et al. analyzed the reduction of ECCE in rural buildings and found that the energy use of rural residents has significantly shifted from non-commercial energy to commercial energy [39,40].

In the existing literature, there are various reviews on the research of CPCN in buildings, but these tend to focus on a limited part of the method [41–44], technologies [45–50], or on the macro research subjects of systems and laws [8,51–56]. For instance, Ali and Xiao reviewed the method for estimating building embodied carbon and the strategy for reducing it [57]; Ma, Cai, and Wu reviewed the implementation of the China Act on the Energy Efficiency of Civil Buildings (2008) over the past decade [58]. Chau et al. reviewed the research progress on the assessment of energy and carbon emissions during a building's lifecycle [59]. However, to the best of our knowledge, few studies have outlined the research trend and cooperation network for CPCN in the building sector, and most review articles have determined research topics from a subjective point of view. To get a better sense of the current research situation and future trends and to provide a valuable reference and guidance for subsequent research, we needed to address three problems.

- Which countries, institutions, and individuals have conducted extensive and in-depth research on CPCN in buildings, and what is the status quo of their cooperation and contributions?
- What subjects and topics have aroused wide interest and enthusiasm among scholars, and what are their time trajectories?
- What journals and authors have grabbed the attention of many scholars, and what are the research directions related to them?

Bibliometrics can be used to observe the state of technology and science during the overall production of scientific literature [60], and citation analysis is a common method used in bibliometrics to visualize the results of the analysis and map knowledge fields, so as to master the research frontiers hidden in the literature knowledge [5]. The research results presented in this article summarize the current situation in this area of research, identify the hot spots and knowledge gaps in the literature, and indicate potential future research directions.

The rest of the paper is presented as follows: Section 2 contains the data retrieved and describes the data processing methods used. Section 3 is the main part of this paper. Section 3.1 explains the changes in the number of annual publications for the top ten countries and the trend for the cumulative number of publications. Section 3.2 contains three parts, presented in Sections 3.2.1–3.2.3: the cooperative relationships and contributions of the authors, research institutions, and countries are analyzed. Section 3.3 describes the disciplines and topics related to CPCN in buildings. This section consists of Section 3.3.1 (subject category co-occurrence network) and Section 3.3.2 (keywords co-occurrence analysis). The last part (i.e., Section 3.4) of Section 3, which describes the intellectual structure of CPCN in buildings, is also subdivided into three parts, Section 3.4.1, Section 3.4.2, and Section 3.4.3, which present a co-citation analysis of journals, documents, and author. Section 4 discusses the current research gaps and future research. Section 5 presents the conclusions.

2. Materials and Methods

2.1. Data Retrieved

Through a comparative analysis of the statistics retrieved from the Scopus and Web of Science (WOS) databases, it was determined that the articles and references retrieved by these two databases were highly similar [61]. Since the core set of WOS databases contains high-quality data, groundbreaking content, and a longer history than Scopus, we chose the 'Science Citation Index Expanded (SCI-EXPANDED)' and 'Social Sciences Citation Index (SSCI)' of the core set of WOS databases to retrieve the data originally used for analysis [62]. Since journal articles usually provide deeper research and higher quality information than other types of publications [5], the literature types chosen were research articles and review articles. The language was set as English. The time period of the articles was set to 1990–2021, as the focus of this research was on the development of this topic following the adoption of the United Nations Framework Convention on Climate Change in 1992. We expected our data to reveal the trends that have emerged in the past 30 years.

The input data we reviewed were generated from a combination of the results of multiple subject search queries on WOS (Table 1). First, literature in research fields and topics was retrieved through different retrieval queries, and the results are shown as Set #1–Set #5 in Table 1. According to the WOS database retrieval rules, '*' and 'TS' stand for fuzzy search and publication article topics, respectively. Then, through the Boolean operation "And" operation symbol to locate the four topics to the research field, the results Set #6–Set #9 were obtained. The amount of literature in Set #6 and Set #7 shows that many scholars have conducted studies on ECCE in the field of buildings. Based on the research on ECCE in the building sector, this review focused on the research topic of CPCN in buildings, so finally, Set #8 and Set #9 were combined by the "OR" operation symbol. Hence, a list of 364 publication records was gathered for the review analysis, including 328 research articles and 36 review papers. Each record consisted of the author, affiliate, country/region, year of publication, source journal, title, abstract, keywords, and references.

Table 1. Topic search queries used for data collection.

Set	Search Queries	Time Span	Publications	Articles	Reviews
#1	TS = (building OR construction)	1990–2021	1,198,060	1,142,270	55,790
#2	TS = ("energy consumption *" OR "energy demand *" OR "energy use *")	1990–2021	116,712	109,202	7510
#3	TS = ("carbon emission *" OR "CO_2 emission *")	1990–2021	48,553	45,656	2897
#4	TS = ("carbon emission * peak" OR "energy demand * peak" OR "energy peak" OR "carbon peak" OR "CO_2 peak")	1990–2021	2014	1995	19
#5	TS = ("carbon neutrality" OR "carbon neutral" OR "net zero emission" OR "nearly zero emission")	1990–2021	2150	1793	357
#6	#2 AND #1	1990–2021	22,949	21,433	1516
#7	#3 AND #1	1990–2021	7042	6522	520
#8	#4 AND #1	1990–2021	100	99	1
#9	#5 AND #1	1990–2021	270	235	35
#10	#9 OR #8	1990–2021	364	328	36

Note: * means fuzzy search.

2.2. Data Processing Methods

In the Bibliometrics field, different types of knowledge mapping software (Publish or Perish, CiteSpace, VOSviewer, HistCite, and BibExcel, etc.) have different features and limitations [63]. Since VOSviewer (version 1.6.16, Nees Jan van Eck and Ludo Waltman, Leiden University, Leiden, Netherlands). performs well in the visualization of contributions and cooperation, it was used to analyze the contributions and cooperation of institutions and authors. At the same time, CiteSpace software can be used to carry out co-occurrence and co-citation analyses and can be used to visualize the knowledge field of bibliographic records [64]. Thus, it can be used to analyze the co-occurrence of keywords and subjects as well as the co-citation of journals, documents, and authors. It is worth noting that compared with manual reviews, bibliometric reviews can draw more objective conclusions by examining the quantitative and unbiased links between different studies. They can supplement manual reviews but cannot replace them [65].

3. Results

3.1. The Publication Trends

The annual distribution of CPCN in the building sector reflects the development speed and knowledge accumulation status of this field [63]. According to the data in Set #10 retrieved from the "Web of Science Core Collection", and as shown in Figure 1, the annual publication volume has increased year-by-year. Initially, steady growth began in 2005 through publications from England and Australia. Publications began to increase rapidly in 2015, indicating that the Paris Agreement for energy saving and emission reduction policies in various countries around the world had a significant impact and caused experts and scholars in various countries to conduct research in the field of CPCN in buildings [66–68]. In 2020, the growth rate of literature publishing accelerated significantly in line with the occurrence of the 2020 Climate Ambition Summit initiated by the United Nations and relevant countries to commemorate the fifth anniversary of the Paris Agreement. It is clear that the 2020 Climate Ambition Summit further mobilized the international community to strengthen climate action and advance the multilateral process [69].

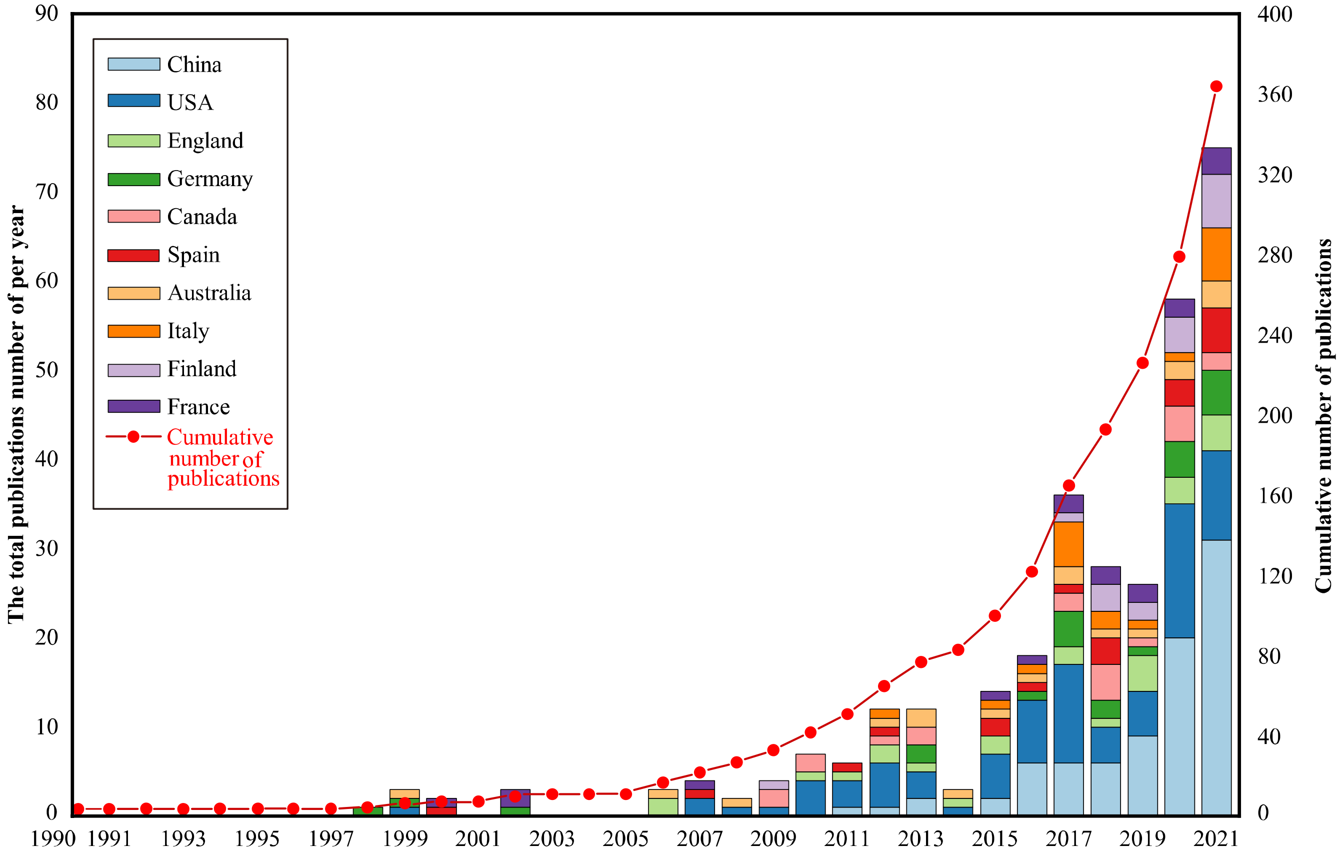

Figure 1. Annual change curves for articles published in the field of CPCN in buildings (1990–2021).

Figure 1 also shows the annual publication changes for the top ten countries. What is noteworthy in terms of publication volume is that among the top 10 countries the only developing country is China, while the rest are all developed countries. However, global sustainable development needs joint effort from all countries, so this means that developing countries need to conduct more cooperative research with developed countries, and developed countries should provide more help to developing countries. Publications from China have maintained rapid growth, especially in 2016. This trend is also consistent with the development of the "Thirteenth Five-Year Plan for Controlling Greenhouse Gas Emissions" issued by the State Council of China in 2016 [70,71]. Publications on CPCN in buildings from the USA, England, Italy, Germany, Canada, France, Australia, India, and Spain have generally shown an upward trend. In addition, the cumulative number of publications has increased exponentially.

3.2. Contributions and Cooperation from Three Aspects: Author, Institution, and Country

3.2.1. Author Contributions and Collaboration

The analysis of the author's cooperation and contributions to the CPCN in the building sector can provide some guidance for scholars seeking cooperation in similar fields. Table 2 lists the top 10 authors who have published the most articles in the field of CPCN in buildings. We can see that the number of articles published by authors in this field is relatively small. Prof. Cai Weiguang from Chongqing University has published six articles in this field and ranks first both in terms of the number of papers and the total number of citations. He is followed by Ma Minda from Tsinghua University, who has published four papers on the subject and is ranked first in citations per paper. It is worth noting that the first, second, fifth, and seventh authors in the top 10 are from China, two are from Australia, and two are from Finland.

Table 2. Top 15 authors with the most publications on CPCN in buildings.

Rank	Author	Country	Organization	Documents	Citations	TLS [a]	CPP [b]
1	Cai, Weiguang	China	Chongqing University	6	267	17	44.50
2	Ma, Minda	China	Tsinghua University	4	262	8	65.50
3	Pullen, Stephen	Australia	University of South Australia	3	99	8	33.00
4	Junnila, Seppo	Finland	Aalto University	3	13	10	4.33
5	Cai, Wei	China	Southwest University	2	121	6	60.50
6	Bogdanov, Dmitrii	Finland	Lappeenranta University of Technology	2	120	11	60.00
7	Dong, Liang	China	City University of Hong Kong	2	113	10	56.50
8	Meil, Jamie	Canada	Athena Sustainable Materials Institute	2	106	3	53.00
9	Zuo, Jian	Australia	The University of Adelaide	2	75	11	37.50
10	Georges, Laurent	Norway	Norwegian University of Science and Technology	2	75	11	37.50

Note: [a] Total Link Strength; [b] Citations Per Paper.

The total link strength (TLS), analyzed with the VOSviewer software, reveals the frequency of cooperation between cooperating authors, institutions, and countries based on available publications. The TLS shown in Table 2 indicates preliminary cooperation among scholars, but the frequency of cooperation is relatively low. This also can be observed in Figure 2.

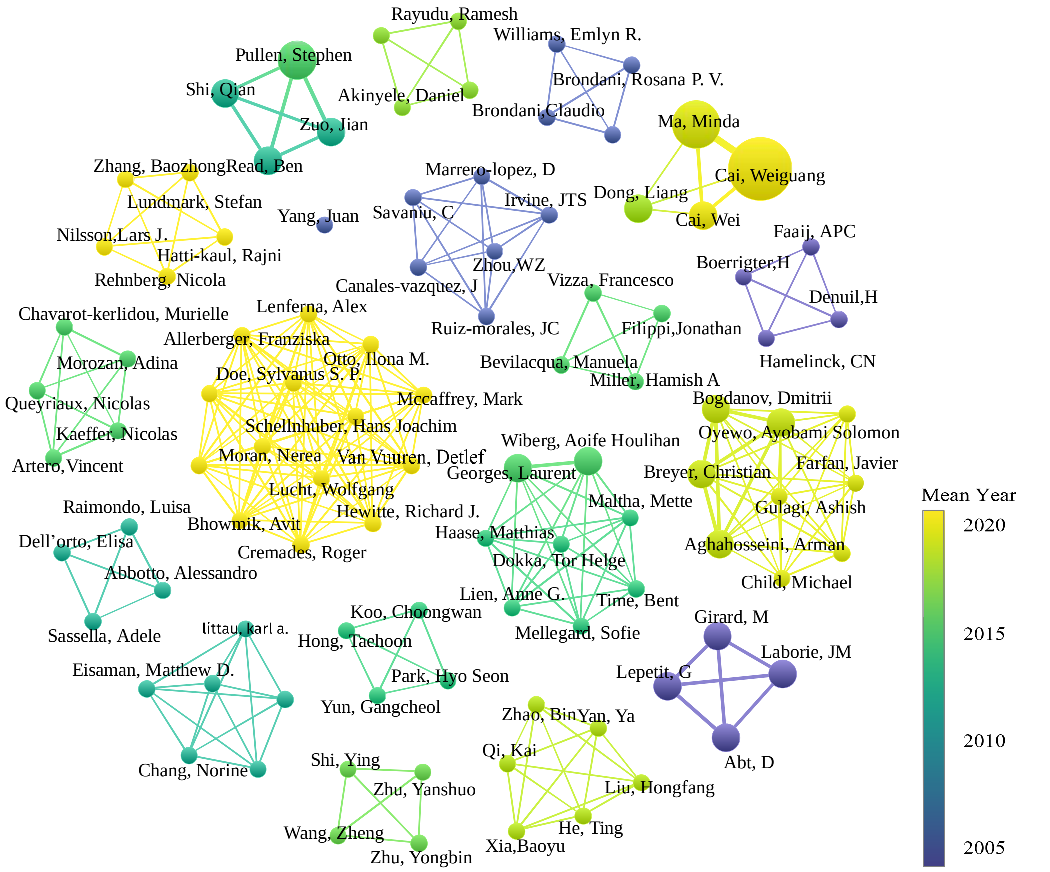

Figure 2. Overlay visualization map of co-authors.

VOSviewer software was used to carry out overlay visual mapping for the TLS of the top 100 authors. In Figure 2, the node size represents the number of co-authored articles. The links between nodes represent collaboration, and a larger link width indicates closer collaboration between authors [63]. In Figure 2, we can see the contribution and cooperation degrees of experts more intuitively than in Table 2. Different nodes come together to form a cluster, with frequent cooperation within a cluster but less cooperation between clusters.

Different node colors in the figure represent the different average publication times for an author's articles. The warmer the node color, the closer the publication time of the author's article. This indicates whether an author is currently active in this research field, with active authors including Prof. Cai Weiguang and Cai Wei. On the contrary, the colder the node, the longer the publication time of the author's article. A cold node indicates that the authors have done preliminary basic research for the development of this field, for example, Prof. Girard M., Laborie J.M., Lepetit G., and Abt, D.

3.2.2. The Most Influential and Productive Institutions

Table 3 lists the top 15 research institutions in terms of the number of articles published. Chongqing University ranks first for the total number of published articles and the total number of citations, with the number of published articles accounting for 2.20% of the total number. The Chinese Academy of Sciences has also published eight articles, while the National University of Singapore and the Aalto University have published seven articles each. It is worth noting that in terms of the average number of citations, the University of Washington ranks first with 47 citations per article.

Table 3. Top 15 institutions with the most publications on CPCN in buildings.

Rank	Institution	Country	Publications	Percentage	Citations	TLS [a]	CPP [b]
1	Chongqing University	China	8	2.20%	308	15	38.50
2	Chinese Academy of Sciences	China	8	2.20%	137	13	17.13
3	National University of Singapore	Singapore	7	1.92%	61	5	8.71
4	Aalto University	Finland	7	1.92%	19	0	2.71
5	Tsinghua University	China	6	1.65%	162	24	27.00
6	Lawrence Berkeley National Laboratory	USA	5	1.37%	178	21	35.60
7	The Hong Kong Polytechnic University	China	5	1.37%	130	7	26.00
8	Southeast University	China	5	1.37%	44	5	8.80
9	North China Electric Power University	China	5	1.37%	14	0	2.80
10	University of Washington	USA	4	1.10%	188	20	47.00
11	Stockholm University	Sweden	4	1.10%	92	20	23.00
12	National Institute for Environmental Studies	Japan	4	1.10%	89	9	22.25
13	Swiss Federal Institute of Technology	Switzerland	4	1.10%	71	3	17.75
14	The University of Tennessee	USA	4	1.10%	61	12	15.25
15	The University of Michigan	USA	4	1.10%	54	6	13.50

Note: [a] Total Link Strength; [b] Citations Per Paper.

Figure 3 shows the number of articles published by institutions and the partnerships between institutions. Each circular node represents a research institution, and the node size represents the number of articles issued by the institution. The links between nodes represent cooperation. The wider the link width, the closer the cooperation between institutions [63]. Different colors indicate different clusters of institution cooperation. Nodes of the same color belong to the same cluster, which means that the kinship between these nodes is stronger. In Figure 3, there are seven clusters altogether. Although Cluster #5 has only three main items, Tsinghua University has the highest total link strength. Lawrence Berkeley National Laboratory follows Tsinghua University with a total link strength of 21, and it is shown to cooperate relatively frequently with Chongqing University and the Chinese Academy of Sciences.

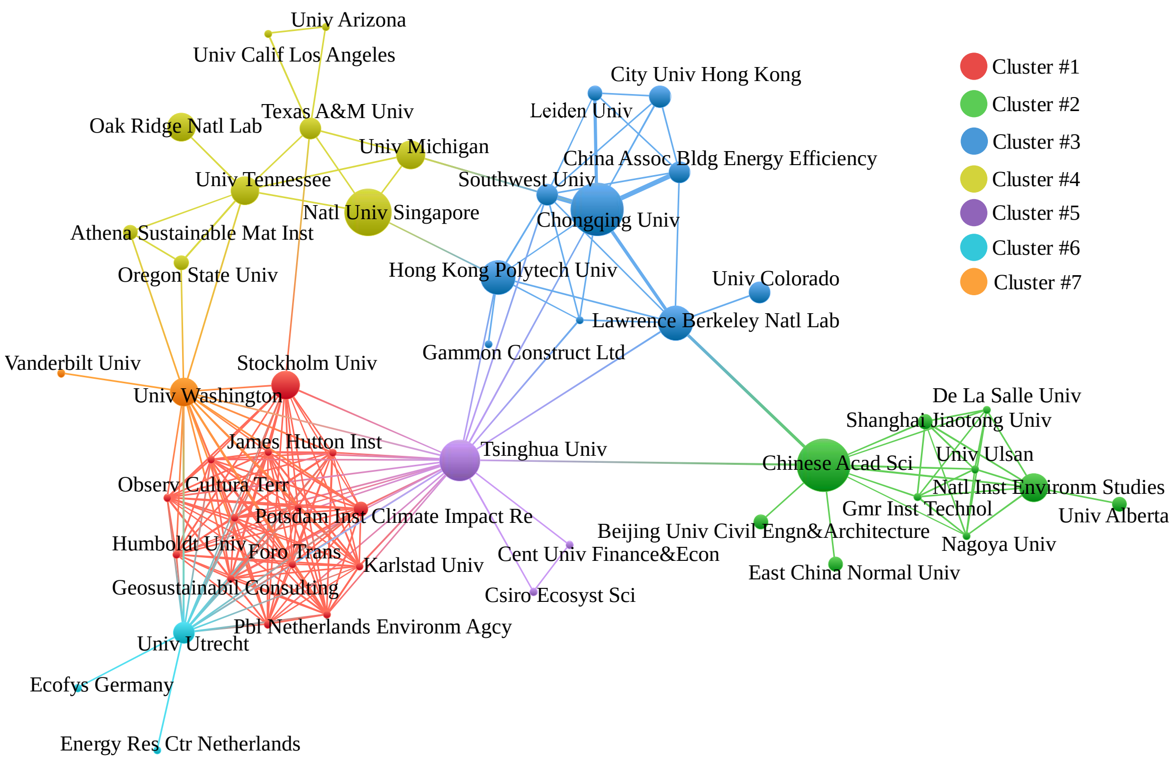

Figure 3. Knowledge domain map of institutional contributions and collaboration.

3.2.3. The Most Influential and Productive Countries

Table 4 lists the 20 countries with the most published articles. The numbers of articles published and of citations are significantly higher in China and the USA than in other countries. Similarly, China and the United States are also in the top two in terms of total link strength, indicating that both countries are actively engaged in collaborative research with other countries.

Table 4. Top 20 countries with the most publications on CPCN in buildings.

No.	Country	Start Year	Publications	Centrality	Citations	Citations Per Paper	Total Link Strength
1	China	2011	84	0.05	1656	19.71	48
2	USA	1999	77	0.27	1401	18.19	53
3	England	2006	24	0.16	745	31.04	15
4	Germany	1998	22	0.43	760	34.55	30
5	Canada	2009	20	0.12	534	26.70	9
6	Spain	2000	19	0.58	193	10.16	22
7	Australia	1999	18	0.3	424	23.56	13
8	Italy	2012	18	0.05	312	17.33	16
9	France	2000	17	0.05	291	17.12	17
10	Finland	2009	17	0.11	189	11.12	8
11	Netherlands	2004	12	0	669	55.75	16
12	Japan	1993	12	0.05	139	11.58	7
13	Sweden	2001	11	0	183	16.64	18
14	India	2010	10	0.16	255	25.50	8
15	Scotland	2006	9	0.6	477	53.00	15
16	Norway	2009	8	0	180	22.50	3
17	South Korea	2014	8	0.05	132	16.50	11
18	Belgium	2002	8	0.11	97	12.13	10
19	Switzerland	2017	8	0	93	11.63	12
20	Singapore	2010	7	0	61	8.71	5

Each individual knowledge network is composed of publications produced over a period of time, which is called a time slice. These independent networks were integrated by CiteSpace to form an overview to express how the field of science has evolved over time [72]. In Figure 4, the corresponding 3-year slice, 1990–2021, shows the networks of the 100 countries with the most publications. CiteSpace describes the changing trends and patterns that are emerging in such networks using various visual attributes [72]. In Figure 4, the node size represents the number of articles produced by a country. The number of articles published in the time slice of each country is described by the citation tree ring: the thicker the citation tree-ring, the greater the number of articles published in that time period. The structural attributes of the nodes are represented by purple rings. The thickness of the purple ring indicates its degree of betweenness centrality (BC). BC is a measure related to the transformational potential of scientific contributions. Nodes with a purple ring often connect different phases of the development of a scientific field.

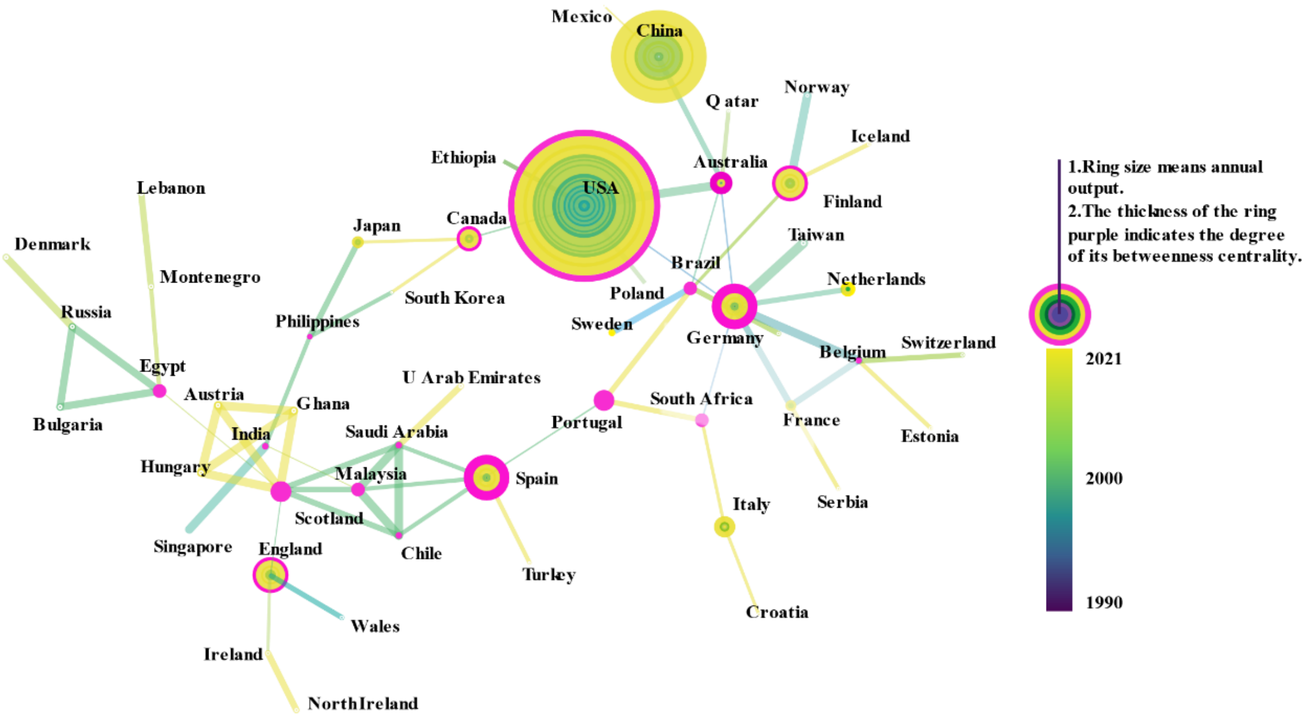

Figure 4. Mapping knowledge domains of coauthoring countries.

It can be seen intuitively from Figure 4 that Scotland (BC = 0.6), Spain (BC = 0.58), Germany (BC = 0.43), Australia (BC = 0.3), and the USA (BC = 0.27) have thick purple rings, which indicates that research articles published by these countries are of high value. This conclusion is also consistent with the data presented in Table 4.

3.3. Disciplines and Topics Involved in CPCN in Buildings

In 1990–2021, different research themes and topics related to CPCN in buildings were explored. Co-occurrence analysis not only detects research hotspots and trends for an item, it can also explain the affinities relationship between different items. We used the co-occurrence analysis module from CiteSpace to generate category and keyword co-occurrence knowledge maps for the data extracted from the WOS database.

3.3.1. Subject Category Co-Occurrence Network

Which disciplines are involved in CPCN in buildings? In the WOS database, each article belongs to at least one subject category [5]. A co-occurrence network of subject categories in CPCN in buildings was generated to show the research trends in and relationships between different subject categories. In terms of the attributes of the CiteSpace co-occurrence analysis module, we set the time slice as 3 years, conducted data visualization for the top 100 subjects in each time slice, and set a threshold of 100 in the knowledge graph to display the node label. Figure 5 shows a network with 88 nodes and 365 links, demonstrating that this research topic covers at least 88 subject categories and involves interdisciplinary research. The size of the node represents the number of articles contained in the category. The most common categories are 'Environmental Sciences & Ecology', 'Energy & Fuels', 'Engineering', and 'Environmental Sciences'. Although 'Materials Science', 'Urban Studies' and 'Architecture', etc., are much smaller than the other categories, they are also marked for reference. Table 5 lists the top 20 subject categories by the number of articles. The years in Table 5 represent when the first article on this research topic was published in each subject category. Research in the 'Materials Science', 'Physics', and 'Materials Science, and Multidisciplinary' fields began earlier than other disciplines, while papers on 'Environmental Sciences & Ecology', 'Environmental Science', 'Science & technology', and 'Green & Sustainable Science & Technology' were published relatively late, but these areas have developed rapidly.

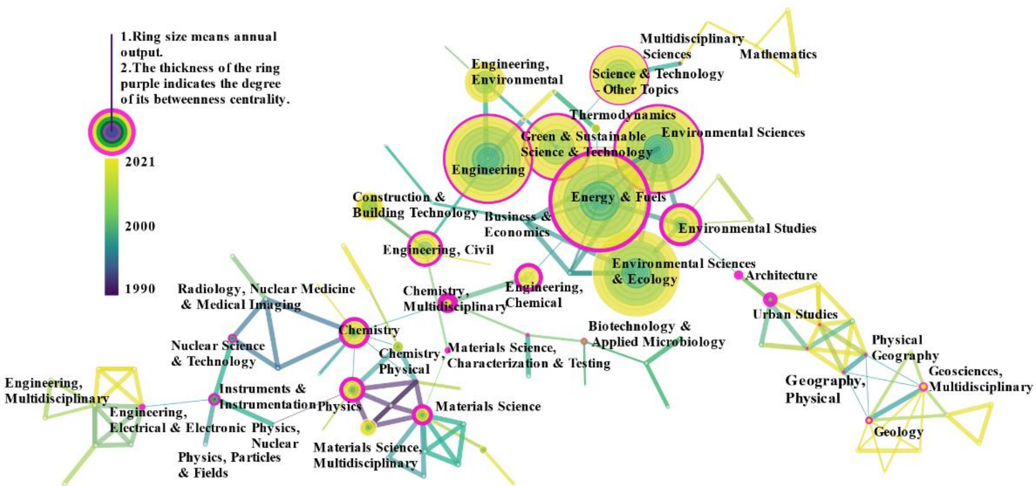

Figure 5. Subject categories involved in CPCN in buildings.

Table 5. Top 20 subject categories with the most publications on CPCN in buildings.

Rank	Subject Categories	Years	Count	Centrality
1	Environmental Sciences & Ecology	2007	124	0.01
2	Energy & Fuels	1999	118	0.56
3	Engineering	2001	118	0.23
4	Environmental Sciences	2007	107	0.26
5	Science & Technology—other Topics	2006	97	0.16
6	Green & Sustainable Science & Technology	2009	82	0.34
7	Environmental Studies	2007	59	0.54
8	Engineering, Environmental	2009	48	0.03
9	Construction &Building Technology	2011	42	0
10	Engineering, Civil	2011	39	0.25
11	Chemistry	2000	35	0.57
12	Materials Science	1993	28	0.38
13	Physics	1993	27	0.34
14	Engineering Chemical	2006	24	0.52
15	Materials Science, Multidisciplinary	1993	23	0
16	Nuclear science & technology	2000	20	0.13
17	Thermodynamics	1999	18	0.03
18	Instruments & Instrumentation	2002	17	0.3
19	Chemistry, Physical	2007	14	0.07
20	Physics, Nuclear	1998	14	0.2

In Figure 5, a purple circle means that the node has a high degree of BC, for example, Chemistry (BC = 0.57), Energy & Fuels (BC = 0.56), Environmental Studies (BC = 0.54), Engineering Chemical (BC = 0.52). This represents the turning points that connect different stages of research and have key impacts on the development of CPCN in buildings. The colors of link and node rings (form cold color to warm color) correspond to the years from 1990 to 2021. Figure 5 illustrates that the number of articles published in most disciplines has increased significantly since start of the 21st century.

CiteSpace divides the co-occurrence network of subject categories into clusters so that subject categories are closely linked in the same cluster but loosely connected between different clusters. As shown in Figure 6, the most common subject categories are mainly covered by Cluster #1 and Cluster #3, which indicates that using the log-likelihood ratio test method (LLR), the research content from 'Engineering', 'Green & Sustainable Science & Technology', 'Engineering Environmental', and 'Engineering Civil' can be extracted and summarized as 'Recycled Aggregate', and the research content from 'Environmental Studies', 'Environmental Sciences', 'Energy & Fuels', and 'Environmental Sciences & Ecology' can be extracted and summarized as 'Greenhouse Gas Emissions'.

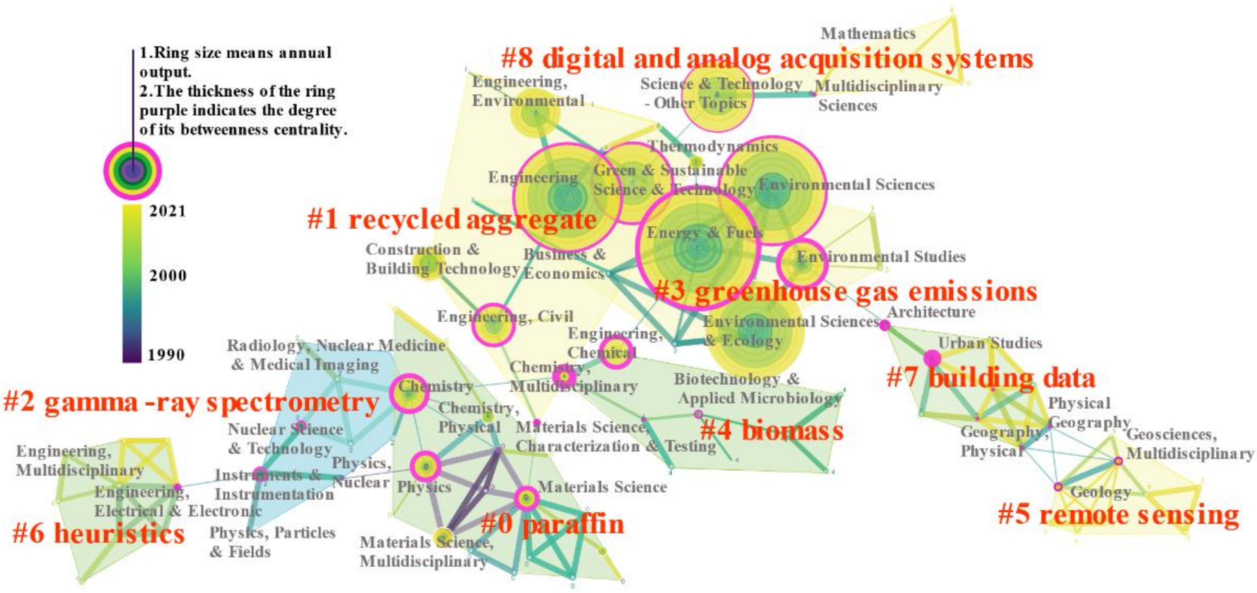

Figure 6. Cluster map of the co-occurrence of subject categories.

3.3.2. Keyword Co-Occurrence Analysis

Topics related to CPCN in the building sector can be described using keywords assigned to each article in the data set. The WOS database contains two types of keywords: the 'author keywords' provided by the author and the 'keywords plus' provided by the journals [5]. We used two sets of keywords from 364 records to make a timeline view using CiteSpace software. Figure 7 shows the research progress for each cluster, and this can be used to understand the changes in research topics. Each cluster is composed of several keywords, among which the clustering keywords are ranked on the right side of the Figure 7, and the time when the keywords first appear is presented at the top. The curved line in Figure 7 indicates the co-occurrence of different keywords. The thickness of the line shows the frequency of co-occurrence: the larger the cross node, the higher the intensity of the keyword bursts. It can be seen from Figure 7 that node 'System' (Cluster #0), node 'Life Cycle Assessment' (Cluster #1), node 'Energy consumption' (Cluster #2), node 'CO_2 emission' (Cluster #2), node 'Energy consumption' (Cluster #2), node 'Energy' (Cluster #4), node 'Performance' (Cluster #4), and node 'Impact' (Cluster #6) have strong bursts. This shows that these topics have been widely studied by scholars, and this can be more accurately understood from Table 6. It is worth noting that a large number of keywords appeared in 2010 and continue to be studied so far. This shows that although the United Nations Climate Change Conference held in Copenhagen in December 2009 failed to produce the new international legal framework for man-made climate change [73], the Copenhagen Accord that resulted from the conference successfully promoted scientific research, and research in the field of buildings has been a positive response to the Copenhagen Accord.

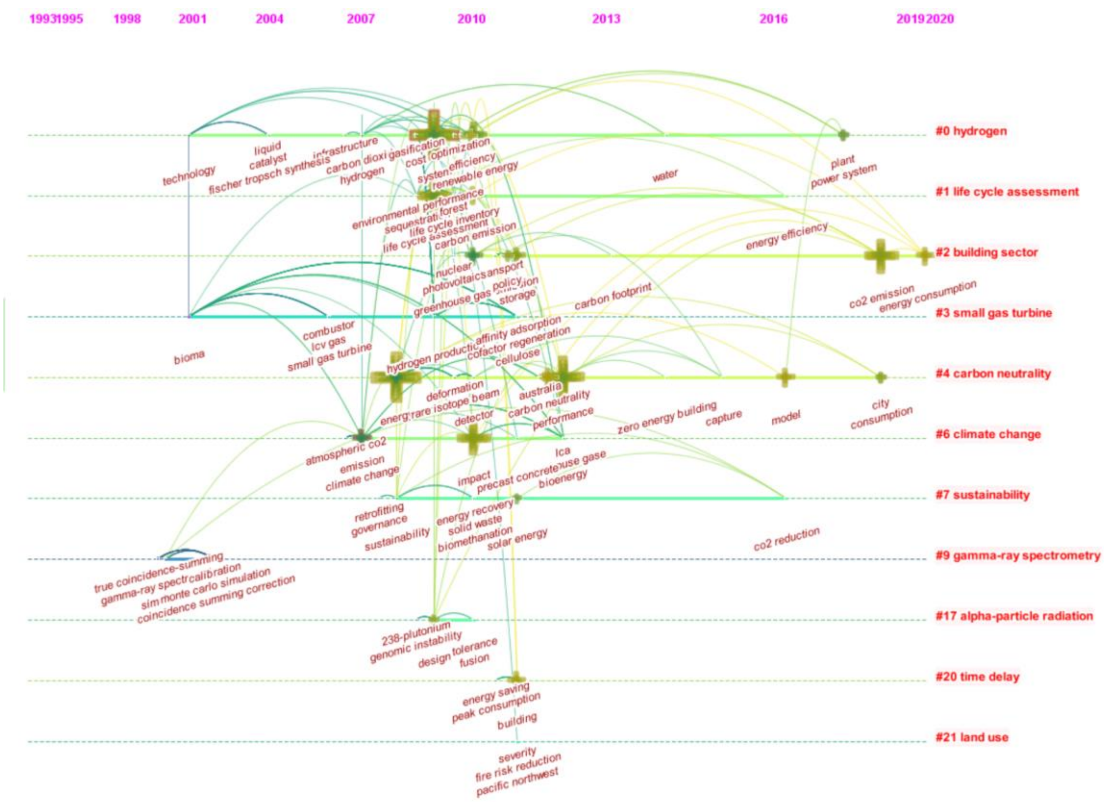

Figure 7. Keyword co-occurrence timeline view.

Table 6. Top 17 keywords with the strongest co-occurrence bursts for CPCN in buildings.

No.	Keywords	Strength	Begin	End	1990–2021
1	Emission	4.19	2012	2017	
2	Greenhouse gas emission	3.78	2012	2019	
3	Climate change	3.48	2012	2017	
4	System	7.92	2014	2021	
5	Performance	6.58	2014	2021	
6	Energy	6.02	2016	2021	
7	Life cycle assessment	5.52	2016	2021	
8	Renewable energy	4.52	2016	2019	
9	Design	3.9	2016	2019	
10	Impact	7.9	2018	2021	
11	CO_2 emission	7.68	2018	2021	
12	Energy consumption	5.36	2020	2021	
13	Building	5.19	2020	2021	
14	Carbon emission	4.65	2020	2021	
15	Efficiency	4.65	2020	2021	
16	Carbon neutrality	4.32	2020	2021	
17	Model	4.16	2020	2021	

Table 6 lists the top 17 keywords with the strongest co-occurrence bursts (Red line segment represents the year of co-occurrence bursts), among which 'System', 'Impact', and 'CO_2 emission' rank as the top three. 'Emission', 'Greenhouse gas emission', and 'Climate change' appeared relatively early. In 2020, the topics of 'Energy consumption', 'Building', 'Carbon emission', 'Efficiency', 'Carbon emission', and 'Model' have attracted wide attention from scholars. It is particularly noteworthy that although 'Impact' and 'CO_2 emission' appeared in 2018, they have high co-occurrence bursts, which indicates that these topics have caught the eye of many scholars in the last three years.

3.4. The Intellectual Structure of CPCN in Buildings

In 1973, Small, an intelligence scientist from the United States, first proposed the concept of using co-citations to measure the relationship degree between documents [74]. At the same time that Small came up with this idea, Soviet intelligence scientist Marshakova had a similar idea.

When two articles/journals are frequently cited together, it is obvious that the two articles/journals are related in some respects. It has been proven that the network created in this method of co-citation can identify the research priorities of the scientific community, and the citation burst is a valuable means to track the development trend of research priorities [72].

3.4.1. Journal Co-Citation Analysis

The intensity and duration of the burst state are two important attributes of citation bursts. Table 7 lists the strongest citation burst journals for the entire dataset from 1990 to 2021 (Red line segment represents the year of co-citation bursts). 'P. Natl. Acad. Sci. Usa' and 'Energ. Environ. Sci.' are not only the earliest journals with citation bursts but also have lasted for the longest: 12 years. Although 'Sustainability' appeared late in the citation surge, the citation intensity was high, reaching 11.36 and producing the highest intensity of citation bursts, indicating that high-quality articles appeared in the journal. In the last two years, the journals 'Energies', 'Energy Proced.', 'Energ. Econ.' and 'Appl. Energ.' have had the strongest citation bursts, showing that relevant articles in these journals are worth referring to.

Table 7. Top 20 Cited Journals with the Strongest Citation Bursts.

No.	Cited Journals	Strength	Begin	End	1990–2021
1	P. Natl. Acad. Sci. Usa	9.04	2008	2019	
2	Energ. Environ. Sci.	8.30	2008	2019	
3	Int. J. Hydrogen Energ.	6.65	2008	2016	
4	Biomass Bioenerg.	5.32	2008	2013	
5	Bioresource Technol.	4.63	2008	2013	
6	Environ. Sci. Technol.	4.36	2008	2016	
7	J. Am. Chem. Soc.	4.87	2011	2016	
8	Environ. Res. Lett.	4.73	2011	2019	
9	Climate Change	3.79	2011	2013	
10	Sol. Energy	7.04	2014	2019	
11	Build. Res. Inf.	4.93	2014	2016	
12	Phys. Chem. Chem. Phys.	3.62	2014	2016	
13	Chem. Rev.	3.62	2014	2016	
14	Energ. Buildings	3.57	2014	2019	
15	Sustainability	11.36	2017	2021	
16	Energies	8.28	2017	2021	
17	Nat. Clim. Change	6.12	2017	2019	
18	Energy Proced.	4.98	2017	2021	
19	Energ. Econ.	4.48	2017	2021	
20	Appl. Energ.	4.37	2017	2021	

3.4.2. Document Co-Citation Analysis

A research article usually quotes many references. The document co-citation analysis can not only determine the potential knowledge structure of a knowledge field, but it can also prove the number and authority of the cited documents. In order to determine the distribution of documents on CPCN in the building sector, we used CiteSpace to collect the top 10 documents with the most frequent co-citations in the references. Meanwhile, we obtained the number of citations from these 10 documents according to the WOS database, and this is presented in Table 8.

Table 8. The top 10 most co-cited articles.

Rank	Cited References	Year	Co-Citation Times	Times Cited	Centrality
	Author, Year, Journal, Volume, Page, Doi				
1	Zhou N., 2018, Nat. Energy, V3, P978, doi:10.1038/s41560-018-0253-6	2018	6	85	0
2	Ma M.D, 2017, J. Clean. Prod., V143, P784, doi:10.1016/j.jclepro.2016.12.046	2017	5	93	0
3	Tan X.C., 2018, Energ. Policy, V118, P429, doi:10.1016/j.enpol.2018.03.072	2018	5	55	0
4	Fargione J., 2008, Science, V319, P1235, doi:10.1126/science.1152747	2008	4	2434	0
5	Sartori I., 2012, Energ. Buildings, V48, P220, doi:10.1016/j.enbuild.2012.01.032	2012	4	442	0
6	Dong K.Y., 2018, Renew. Sust. Energ. Rev., V94, P419, doi:10.1016/j.rser.2018.06.026	2018	4	94	0
7	Ma M.D., 2018, Sci. Total Environ., V634, P884, doi:10.1016/j.scitotenv.2018.04.043	2018	4	75	0
8	Lin B.Q., 2015, Build. Environ., V92, P418, doi: 10.1016/j.buildenv.2015.05.020	2015	4	61	0
9	McNeil M.A., 2016, Energ. Policy, V97, P532, doi:10.1016/j.enpol.2016.07.033	2016	4	49	0
10	Wu C.B., 2018, J. Clean. Prod., V172, P466, doi:10.1016/j.jclepro.2017.10.216	2018	4	46	0

It can be seen from Table 8 that 8 of the top 10 highly cited papers have been published since 2015, indicating that research on CPCN in buildings has developed rapidly in the past five years. Specifically, research articles by Zhou N. (2018), Ma M.D. (2017), and Tan X.C. (2009) received six, five, and five co-citations, respectively, placing these articles in the top three. Zhou N. et al. (2018) explored the ECCE of China's building sector in 2050 through four scenarios with different application degrees of new energy efficiency or renewable energy policies and predicted the peak times of different scenarios. Moreover, it is pointed out that the focus of energy savings and carbon emission abatement in the building sector should be on a system that can achieve energy efficiency rather than on technology, and the impact of individual policies should be assessed in future studies. Further, the behavior of human and occupants should be given extra consideration [75]. We searched 85 papers citing this article through WOS (Table A1 in the Appendix A) and found 3 papers with high numbers of citations: Ma M.D. (2019) with 104 citations, Liang Y. (2019) with 73 citations, and Ma M.D. (2020) with 70 citations. In terms of the three highly cited papers, Ma M.D. et al. (2019) analyzed the factors mitigating the carbon dioxide (CO_2) intensity in China based on a household scale through decomposition and found that the housing price–income ratio, housing purchasing power, and population size per household are three housing economic indicators linked to a significantly reduced CO_2 intensity [76]. Liang Y. et al. (2019) used decomposition and decoupling methods to determine the decoupling effect of residential buildings in China and explored the decoupling modes of four megacities by mapping the carbon Kuznets curves of residential buildings [77]. The third article, also from Ma M.D. (2020), through the construction of China's energy and emission peak historical carbon emission reduction assessment and simulation, showed that residential construction will produce peak carbon emissions in 2037, and through a sensitivity analysis, concluded that, per capita, building area and urban residential building energy consumption have the most significant impacts on the emissions peak of uncertainty [7].

Considering that it is difficult to quantify the factors affecting the national building energy savings (NBES), Ma M.D. et al. (2017), the author of the second article presented in Table 8, proposed a method that combines the IPAT model and LMDI decomposition (Logarithmic Mean Divisia Index, LMDI) to calculate the national building energy savings. By comparing the China's calculated NBES with the official plan, it was found that China has exceeded its building energy-efficiency target [44]. On this basis, Ma M.D. et al. (2017) (i.e., the seventh article in Table 8) decomposed five driving forces of Chinese commercial building carbon emissions (CCBCE) to assess carbon abatement in Chinese commercial building value in 2001–2015, further breaking down the research from NBES to CCBCE [78].

In the third article from 'Energ. Policy' presented in Table 8, Tan X.C. et al. (2018) developed a bottom-up model to predict the future carbon emissions trend for China's building sector. This shows that, under the policy scenario, the low-carbon policy of the construction industry can only slow down but not completely curb carbon dioxide emissions. Research shows that coordinated emission reduction between sectors has a better effect than coordinated emission reduction by one sector [79].

From the 4th to the 10th articles in Table 8, although there were four co-citations in total, the total citation times differed greatly. The 4th article by Fargione J. (2008) from 'SCIENCE' was cited 2434 times, while that by Sartori I. (2012) from 'Energ. Buildings' was cited 50 times. Fargione J. et al. (2008) proposed that although biofuels are a potential low-carbon energy source, different production methods determine whether biofuels can save carbon [80]. Sartori I. et al. (2012) proposed a consistent definition framework that includes five standards and corresponding sub-standards to describe the characteristics of net zero energy buildings [81]. Lin B.Q. et al. (2015) conducted empirical research on the determinants of carbon dioxide emissions in relation to building energy and evaluated the carbon dioxide emission reduction potential of buildings [82]. The 9th article is also from the 'Energ. Policy'. McNeil M.A. et al. (2016) quantified the potential impact of energy efficiency projects in China's building sector on energy saving and emission reduction by using a bottom-up modeling framework [83].

3.4.3. Author Co-Citation Analysis

If an author has a high number of co-citations, we consider their research to be of high value. In order to further understand the scholars in this field who have attracted attention, we analyzed their strongest citation bursts, as shown in Table 9 (Red line segment represents the year of co-citation bursts). Professor Metz B. and Professor Lewis N.S. had the longest citation burst duration of five years, followed by Sartori I. It is noteworthy that Zhang Y. had the highest burst intensity, although the burst state only lasted for two years. The citation outbreak years of the four authors were all after 2010, which indicates that the articles of these four authors have played important reference value in the past decade and have aroused the interest of other scholars.

Table 9. Top 4 Cited Authors with the Strongest Citation Bursts.

No.	Cited Authors	Strength	Begin	End	1990–2021
1	Metz B.	3.8	2011	2016	
2	Lewis N.S.	3.68	2011	2016	
3	Sartori I.	3.61	2014	2019	
4	Zhang Y.	4.47	2017	2019	

We also selected the top 10 co-cited authors, with co-citations ranging from eight to six (Table 10). The top four cited authors with the strongest citation bursts all appear in Table 10, ranking 9th, 8th, 5th and 1st according to the number of co-citations. For the articles retrieved from the subject search, there were five articles by five authors. Notably, Chen X. (1st author) and Zhang Y. (2020) topped the list. By working together at the sectoral level, the two scholars predicted emission peaks for four carbon pillar industries: industry, construction, transport, and agriculture. Compared with the Chinese government's commitment for CO_2 emissions to peak around 2030 [84], they found that the peak time was six years later, and it was concluded that the delay was mainly due to the industrial, building, and transportation sectors. This research provides a reference for us to further determine the time of peak carbon emissions in the building sector [85].

Table 10. Top 10 most co-cited Authors.

Rank	Author	Year	Co-Citations	Title	Times Cited
1	Zhang Y.	2017	8	Analysis on the carbon emission peaks of China's industrial, building, transport, and agricultural sectors	44
2	Chen X.	2020	8	Analysis on the carbon emission peaks of China's industrial, building, transport, and agricultural sectors	44
3	Zhou N.	2020	8	Exploring potential pathways towards urban greenhouse gas peaks: A case study of Guangzhou, China	9
4	Lin B.Q.	2020	8	/	0
5	Sartori I.	2014	7	/	0
6	Wang J.	2020	7	Energy demand and carbon emission peak forecasting of Beijing based on leap energy simulation method	0
7	Wang Y.	2020	7	Feasibility assessment of the carbon emissions peak in China's construction industry: Factor decomposition and peak forecast	14
				Feasibility of peaking carbon emissions of the power sector in China's eight regions: decomposition, decoupling, and prediction analysis	7
8	Lewis N.S.	2011	6	/	0
9	Metz B.	2011	6	/	0
10	Zhang Y.J.	2020	6	/	0

Compared to the research on the potential of energy efficiency and carbon dioxide emissions in the Chinese building sector conducted by Zhou N. et al. (2018), which was mentioned in the previous section, Zhou N. et al. (2019) took Guangzhou as an example to study the potential pathway of the urban greenhouse gas peak from the city level. The research revealed that, in the long run, the energy-saving strategy of the construction industry will be very important to Guangzhou [86]. Similarly, Wang J. et al. (2020) predicted the energy demand and peak carbon emissions for Beijing and found that enhancing the energy efficiency of the tertiary industry and improving the industrial structure is an effective way to decrease energy use and carbon emissions [87].

Two articles by Wang Y. analyzed the factors leading to peak carbon emissions production by China's building industry and the feasibility of reaching peak carbon emissions in the eight major regions of China's power industry. The results show that GDP has the highest cumulative contribution to carbon emissions in the building sector in China [88] and is also the main factor affecting the carbon emissions of the power industry in eight regions [89].

4. Discussion

This study reviewed literature on CPCN in buildings from 1990 to 2021 and summarized current research hotspots. It should be pointed out that the above research content was determined through an objective analysis and does not cover all topics that need to be researched.

At present, research on CPCN in the building sector is mainly focused on developed countries and major economies [90–94], and further cooperation between authors, institutions, and countries is needed to keep the global temperature rise to below 1.5 °C above pre-industrial levels [95]. Take China, for example, the reduction of the ECCE potential of China's building sector has been estimated under various scenarios [7,75,79,96,97]. India is one of the top three emitters worldwide, and its energy demand increases obviously with the rapid growth of economy and population [98]. In the upcoming two decades, India's CO_2 emissions are expected to increase by 50%, and buildings are one of the main drivers. The building sector in India accounted for 24% of the nationwide CO_2 emissions in 2019, and the indirect emissions released by the building sector nearly tripled from 2000 to 2017. India's urbanization level aims to reach 40% in the next one decade, which will promote the increase of ECCE in the building sector significantly at the same time [99]. As the ECCE of non-developed countries in the world will experience the levels of their predecessors with economic and population growth, research on CPCN in the building sector of developing countries cannot be ignored [96,100]. So, by expanding the data set, especially the future ECCE research in developing countries [101], the research scope can be extended from the country to the world, and the civil building peak carbon emission under different emission standards in different countries can be researched from a global perspective.

At the provincial and municipal building sector level, potential paths for urban CPCN have also been extensively explored [102–105], and further detailed research on CPCN has been carried out for commercial and residential buildings [52,106–108]. For example, Wu et al. conducted a modeling analysis on Qingdao's future CO_2 emissions (including the number of emission peaks and the time of occurrence) using the STIRPAT model [109]. Huang et al. calculated the carbon footprint of Xiamen city and conducted a low-carbon scenario analysis [110]. Li et al. took Jiangsu Province as an example to analyze how to achieve the carbon emission peak for the provincial building sector [111]. Goomi et al. [112], Farzaneh et al. [113], and Jing et al. [114] developed low-carbon development models for different cities to evaluate low-carbon development scenarios in the city system. With the growth of economy and population, the construction area of the county seat has grown steadily [115]. Based on the data from the China Statistical Yearbook, we illustrated the changes of construction area and population size in county seat in China (see Figure 8) [116]. It shows the growth of population and construction area have the same trend, which means the decrease of ECCE in the county seat faces the huge challenge. Most of the existing studies on CPCN in the building sector focused on the city level, and study with case area focused on the county level has been barely discussed [117]. The potential of energy saving and emission abatement in county seat is worth researching.

The thermal integrity of residential buildings in rural areas is poor [118,119], and the comfort level is not as good as that of cities [120,121]. In China, the energy use of rural residential buildings accounts for nearly 14% of the total building energy consumption [122]. According to the China Statistical Yearbook, in 2020, stock of China's rural residential buildings reached 26.6 billion m^2, which is the equivalent of constructing an entire New York City every month for over three decades [116]. Besides, the floor area per capita in rural residential buildings increased from 24.8 m^2 in 2000 to 47.3 m^2 in 2018 [123].With the implementation of the rural revitalization plan issued by the Chinese government [124], the ECCE of rural residential buildings will keep the increase to meet the demand of rural household and also to obtain a goal of thermal comfort in the future [125–129]. Since research on the CPCN of rural residential buildings is scarce at present, it will become necessary in the future.

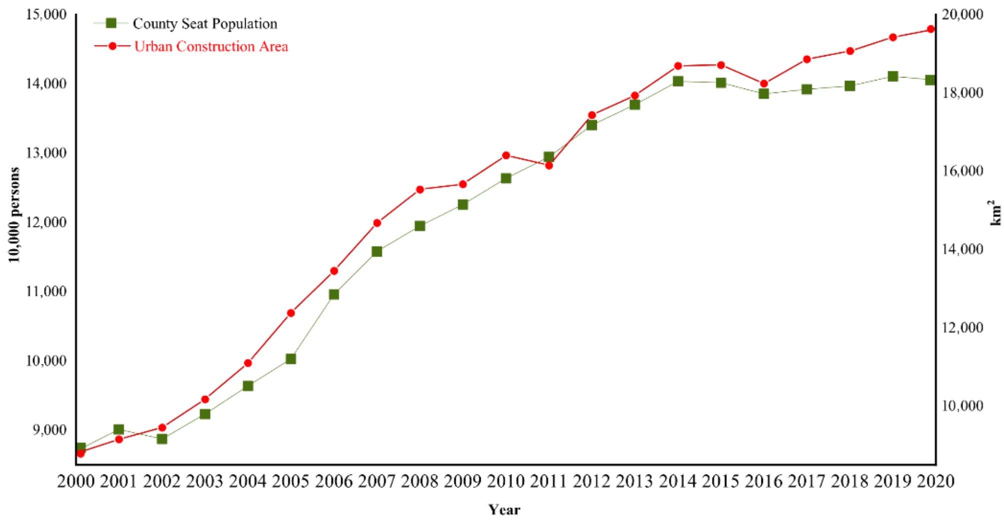

Figure 8. Changes of population size and construction area of county seat in China (2000–2020).

Based on the existing review and analysis, in order to further refine the work on CPCN in the building sector, this review paper proposes the above three future research directions.

5. Conclusions

This paper conducted a bibliometric analysis on literature published on CPCN in the building sector. Knowledge maps were obtained through information visualization techniques. This paper presents the research hotspots and development trends on CPCN in buildings and provides references for researchers to explore further.

By analyzing the contributions of and cooperation among authors, institutions, and countries as well as the trend of published articles, we can conclude that although the number of articles is relatively small at present, it has grown rapidly since 2005, especially in developed countries and China. The United States and China cooperate the most with other countries, and other countries cooperate less with each other. Collaboration among most institutions and authors is relatively rare and non-extensive.

The co-occurrence analysis on disciplines and themes revealed that the most common disciplines are 'Environmental Sciences & Ecology', 'Energy & Fuels', 'Engineering', 'Environmental Sciences and Materials Science, Physics', and' Materials Science'. Multidisciplinary research in this field started earlier than other disciplines, while the environmental science and science technology areas were introduced to this field relatively late but have developed rapidly. The 'Chemistry', 'Energy & Fuels', 'Environmental Studies', and 'Engineering Chemical' areas have high centrality, indicating that they are turning points connecting different years of research and have greatly influenced the development of CPCN in buildings. Through a cluster analysis of disciplines, the 'Green & Sustainable', 'Science & Technology', 'Engineering', 'Engineering Civil', and 'Engineering Environmental' research content can be extracted and summarized as Recycled Aggregate, and the 'Energy & Fuels', 'Environmental Studies', 'Environmental Sciences', and 'Environmental Sciences & Ecology' research content can be extracted and summarized as Greenhouse Gas Emissions.

As indicated by the analysis of keyword co-occurrence, a large number of keywords appeared in 2010 and continue to be studied. 'System', 'Life Cycle Assessment', 'Energy consumption', 'CO_2 emission', 'Energy consumption', 'Energy consumption', 'Energy consumption', 'Performance', and 'Impact' have strong co-occurrence bursts. This shows that these topics have been widely studied by scholars, and although 'Impact' and 'CO_2

emission' appeared in 2018, they showed high co-occurrence bursts, which indicates that these topics have attracted significant attention among scholars in the past three years.

In terms of aspects of the intellectual structure of CPCN in buildings, the analysis of journal co-citations showed that 'P. Natl. Acad Sci. Usa' and 'Energ. Environ. Sci.' are not only the earliest journals with citation bursts but also have lasted the longest: 12 years. Although the citation surge for 'Sustainability' appeared late, the citation intensity was high. This journal had the highest intensity of citation bursts, indicating that high-quality articles appeared in the journal. In the last two years, the journals 'Energies', 'Energy Proced.', 'Energ. Econ.', and 'Appl. Energ.' had the strongest citation bursts, which shows that the relevant articles in these journals are worth referring to. Through further analysis of article co-citations, we found that these authors and their articles have aroused the interest of other scholars: Zhou N. (2018), Ma M.D. (2017), and Tan X.C. (2009) received six, five, and five co-citations, respectively, ranking them within the top three. These were followed by Fargione J (2008), Sartori I (2012), Lin B.Q. (2015), and McNeil M.A. (2016). In addition, the analysis of the authors' strongest citation bursts found that the citation bursts of Professors Metz B. and Lewis N.S. lasted the longest, followed by that of Professor Sartori. The citation outbreak years of the four authors are all after 2010, which indicates that the articles by these four authors have had important reference value in the past decade and have aroused the interest of other scholars.

This article provides practitioners and researchers with a comprehensive overview of the current situation, future agenda, and research gaps of CPCN in the building sector. Researchers should fill in the knowledge gaps according to the recommended directions, thereby expanding the research body of CPCN in the building sector.

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Abbreviations

BC	betweenness centrality
CPCN	Carbon peak and carbon neutrality
CCBCE	Chinese commercial building carbon emissions
ECCE	Energy consumption and carbon emissions
IPAT	I = Human Impact, P = Population, A = Affluence, T = Technology
LMDI	Logarithmic Mean Divisia Index
NBES	National building energy savings
TLS	Total link strength

Appendix A

Table A1. Citing articles of 'Zhou N., 2018, NAT. ENERGY, V3, P978, doi:10.1038/s41560-018-0253-6'.

Rank	Citing Articles	Type	Times Cited	Reference
	Author, Year, Journal, Volume, Page/Article Number, doi			
1	Ma M.D., 2019, Energ. Convers. Manage., V198, Article No.111915, doi:10.1016/j.enconman.2019.111915	Article	104	[76]
2	Liang Y., 2019, Sci. Total Environ., V677, P315–327, doi:10.1016/j.scitotenv.2019.04.289	Article	73	[77]
3	Ma M.D., 2020, Appl. Energ., V273, Article No.115247, doi:10.1016/j.apenergy.2020.115247	Article	70	[7]
4	Liu W., 2019, J. Energy Chem., V1, Article No. 100008, doi:10.1016/j.enchem.2019.100008	Review	40	[130]
5	Langevin J., 2019, Joule, V3, P2403–2424, doi:10.1016/j.joule.2019.07.013	Article	27	[131]
6	Zhang X.G., 2019, J. Co_2 Util., V33, P394–404, doi:10.1016/j.jcou.2019.06.019	Article	27	[132]
7	Jiang J.J., 2019, Renew. Sust. Energ. Rev., V112, P813–833, doi:10.1016/j.rser.2019.06.024	Review	23	[133]
8	Zhang X., 2020, Appl. Energ., V261, Article No. 114353, doi:10.1016/j.apenergy.2019.114353	Article	22	[134]
9	Khanna N., 2020, Appl. Energ., V242, P12–26, doi:10.1016/j.apenergy.2019.03.116	Article	21	[135]
10	Li B., 2019, Sci. Total Environ., V706, Article No.135716, doi:10.1016/j.scitotenv.2019.135716	Article	20	[88]
11	Cao Z., 2019, Appl. Energ., V238, P 442–452, doi:10.1016/j.apenergy.2019.01.106	Article	19	[136]
12	Pan Y., 2020, Appl. Energ., V268, Article No.114965, doi:10.1016/j.apenergy.2020.114965	Article	16	[137]
13	Dai B.M., 2020, Energ. Convers. Manage., V209, Article No.112594, doi:10.1016/j.enconman.2020.112594	Article	15	[138]
14	Guo S.Y., 2021, Energy, V214, Article No.119063, doi:10.1016/j.energy.2020.119063	Article	13	[92]
15	Duan H.M., 2020, J. Clean. Prod., V260, Article No.120929, doi:10.1016/j.jclepro.2020.120929	Article	12	[139]
16	Xian Y.J., 2019, J. Clean. Prod., V221, P457–468, doi:10.1016/j.jclepro.2019.02.266	Article	10	[140]
17	Wang Y.S., 2020, J. Clean. Prod., V251, Article No. 119637, doi:10.1016/j.jclepro.2019.119637	Article	9	[141]
18	Li W., 2019, J. Mater. Chem. A, V7, P25010–25019, doi:10.1039/c9ta09227g	Article	9	[142]
19	Chen Y.X., 2020, Energ. Buildings, V222, Article No.110100, doi:10.1016/j.enbuild.2020.110100	Article	8	[143]
20	Zhang S.C., 2021, Energ. Buildings, V241, Article No.110938, doi:10.1016/j.enbuild.2021.110938	Article	7	[144]

Table A1. *Count*.

Rank	Citing Articles Author, Year, Journal, Volume, Page/Article Number, doi	Type	Times Cited	Reference
21	Mata E., 2020, Environ. Res. Lett., V15, Article No.113003, doi:10.1088/1748-9326/abb69f	Review	7	[145]
22	Zhu W.N., 2020, J. Clean. Prod., V269, Article No. 122438, doi:10.1016/j.jclepro.2020.122438	Article	7	[146]
23	Liu W., 2019, Energ. Convers. Manage., V199, Article No. 111943, doi:10.1016/j.enconman.2019.111915	Article	7	[147]
24	Deb C., 2021, Renew. Sust. Energ. Rev., V144, Article No.110990, doi:10.1016/j.rser.2021.110990	Review	6	[148]
25	Zhang S.C., 2020, Energy, V213, Article No. 118792, doi:10.1016/j.energy.2020.118792	Article	6	[149]
26	Memon S., 2020, Energ. Buildings, V227, Article No. 110430, doi:10.1016/j.enbuild.2020.110430	Article	6	[150]
27	Liu Q.B., 2020, Energ. Buildings, V224, Article No. 110242, doi:10.1016/j.enbuild.2020.110242	Article	6	[151]
28	Yu B.Y., 2020, Ecol. Econ., V13, Article No.3210, doi:10.1016/j.ecolecon.2020.106706	Article	6	[152]
29	Ding C., 2021, Energies, V14, Article No. 7461, doi:10.3390/en13123210	Article	6	[153]
30	Li H.M., 2021, Energ. Buildings, V244, Article No. 111011, doi:10.1016/j.enbuild.2021.111011	Article	5	[154]
31	Li H.R., 2021, Energ. Convers. Manage., V231, Article No. 113648, doi:10.1016/j.enconman.2020.113648	Article	5	[155]
32	Liu P., 2020, Appl. Energ., V277, Article No. 115546, doi:10.1016/j.apenergy.2020.115546	Article	5	[156]
33	Zhang L.H., 2020, J. Clean. Prod., V271, Article No.122696, doi:10.1016/j.jclepro.2020.122696	Article	5	[157]
34	Mathew D., 2020, IET Power Electron., V13, P1487–1499, doi:10.1049/iet-pel.2019.1237	Review	5	[158]
35	Li L.X., 2021, Energy, V227, Article No. 120460, doi:10.1016/j.energy.2021.120460	Article	4	[159]
36	Mahapatra B., 2021, Energy, V227, Article No. 120485, doi:10.1016/j.energy.2021.120485	Article	4	[160]
37	Nematchoua M.K., 2020, Renew. Energ., V162, P81–97, doi:10.1016/j.renene.2020.07.141	Article	4	[161]
38	Levesque A., 2021, Environ. Res. Lett., V16, Article No. 054071, doi:10.1088/1748-9326/abdf07	Article	3	[162]
39	Yan B., 2021, Renew. Energ., V54, P 2193–2220, doi:10.1007/s10462-020-09902-w	Review	3	[163]
40	Shi Q.W., 2020, Sustainability, V12, Article No. 2695, doi:10.3390/su12072695	Article	3	[164]
41	Wu W.T., 2020, Renew. Sust. Energ. Rev., V117, Article No. 109516, doi:10.1016/j.rser.2019.109516	Article	3	[165]

Table A1. *Count.*

Rank	Citing Articles Author, Year, Journal, Volume, Page/Article Number, doi	Type	Times Cited	Reference
42	Yu L., 2021, Ieee Internet Things, V8, P 12046–12063, doi:10.1109/JIOT.2021.3078462	Review	2	[166]
43	Zhong X.Y., 2021, J. Clean. Prod., V305, Article No.127098, doi:10.1016/j.jclepro.2021.127098	Article	2	[167]
44	Nam E., 2021, J. Clean. Prod., V300, Article No.126962, doi:10.1016/j.jclepro.2021.126962	Article	2	[168]
45	Wang S.Y., 2021, Build. Environ., V195, Article No. 107777, doi:10.1016/j.buildenv.2021.107777	Article	2	[169]
46	Malek M., 2021, Materials, V14, Article No.1888, doi:10.3390/ma14081888	Article	2	[170]
47	Zhang T., 2021, Resour. Conserv. Recy., V164, Article No.105124, doi:10.1016/j.resconrec.2020.105124	Article	2	[171]
48	Lin J., 2019, Sci. Rep-uk, V9, Article No. 16095, doi:10.1038/s41598-019-52653-0	Article	2	[172]
49	Shimoda Y., 2021, Appl. Energ., V303, Article No. 117510, doi:10.1016/j.apenergy.2021.117510	Article	1	[173]
50	Li W., 2021, Therm. Sci. Eng. Prog., V25, Article No. 101033, doi:10.1016/j.tsep.2021.101033	Article	1	[174]
51	Tang B.J., 2021, Appl. Energ., V298, Article No. 117213, doi:10.1016/j.apenergy.2021.117213	Article	1	[12]
52	Edelenbosch O.Y., 2021, Technol. Forecast Soc. Change, V170, Article No. 120887, doi:10.1016/j.techfore.2021.120887	Article	1	[175]
53	Tang B.J., 2021, J. Clean. Prod., V 307, Article No. 127206, doi:10.1016/j.jclepro.2021.127206	Article	1	[176]
54	Zhao Y.J., 2021, Renew. Sust. Energ. Rev., V 145, Article No. 111091, doi:10.1016/j.rser.2021.111091	Article	1	[177]
55	Yue H., 2021, J. Clean. Prod., V 301, Article No. 126978, doi:10.1016/j.jclepro.2021.126978	Article	1	[178]
56	Nibedita B., 2021, Environ. Sci. Pollut. R., V28, P56938–56954, doi:10.1007/s11356-021-14642-7	Article	1	[179]
57	Cao X.Y., 2021, Energ. Buildings, V 236, Article No. 110767, doi:10.1016/j.enbuild.2021.110767	Article	1	[180]
58	Meuer J., 2021, Energ. Buildings, V 235, Article No. 110710, doi:10.1016/j.enbuild.2020.110710	Article	1	[181]
59	Cheng S.L., 2021, Environ. Sci. Technol., V55, P 813–822, doi:10.1021/acs.est.0c04026	Article	1	[182]
60	Shi Q.W., 2020, Sustainability, V12, Article No.10432, doi:10.3390/su122410432	Article	1	[183]
61	Zhang L.H., 2020, J. Clean. Prod., V272, Article No. 122760, doi:10.1016/j.jclepro.2020.122760	Article	1	[184]
62	Liu Y.S., 2022, Renew. Sust. Energ. Rev., V154, Article No. 111811, doi:10.1016/j.rser.2021.111811	Article	0	[185]

Table A1. *Count.*

Rank	Citing Articles Author, Year, Journal, Volume, Page/Article Number, doi	Type	Times Cited	Reference
63	Li K., 2022, Appl. Energ., V306, Article No. 118098, doi:10.1016/j.apenergy.2021.118098	Article	0	[117]
64	Meng M., 2022, Energy, V239, Article No. 121912, doi:10.1016/j.energy.2021.121912	Article	0	[186]
65	Yamaguchi Y., 2022, Appl. Energ., V306, Article No. 117907, doi:10.1016/j.apenergy.2021.117907	Article	0	[187]
66	Al Shawa B., 2021, Energ. Buildings, V254, Article No.111634, doi:10.1016/j.enbuild.2021.111634	Review	0	[188]
67	Lin J., 2021, Appl. Energ., V304, Article No. 117741, doi:10.1016/j.apenergy.2021.117741	Article	0	[189]
68	Zhang S.C., 2021, Energ. Policy, V159, Article No. 112661, doi:10.1016/j.enpol.2021.112661	Article	0	[190]
69	Su C., 2021, Energies, V14, Article No. 7461, doi:10.3390/en14227461	Article	0	[191]
70	Zhong X.Y., 2021, Nat. Commun., V12, Article No. 6126, doi:10.1038/s41467-021-26212-z	Article	0	[192]
71	Fan G.J., 2021, Front. Earth Sci., V9, Article No. 694729, doi:10.3389/feart.2021.694729	Article	0	[193]
72	Jia J.J., 2021, Energ. Effic., V14, Article No. 65, doi:10.1007/s12053-021-09974-9	Article	0	[194]
73	Liu J.L., 2021, Renew. Sust. Energ. Rev., V149, Article No. 111336, doi:10.1016/j.rser.2021.111336	Article	0	[195]
74	Wang L., 2021, Appl. Energ., V299, Article No. 117303, doi:10.1016/j.apenergy.2021.117303	Article	0	[196]
75	Zhang S.C., 2021, Adv. Clim. Chang. Res., V12, P734–743, doi:10.1016/j.accre.2021.07.004	Article	0	[197]
76	Chi F.A., 2021, Sol. Energy, V225, P1026–1047, doi:10.1016/j.solener.2021.08.020	Article	0	[198]
77	Liu Q.C., 2021, J. Ind. Ecol., doi:10.1111/jiec.13182	Article	0	[199]
78	Yang X.Y., 2021, Int. J. Life Cycle Ass., V26, P1721–1734, doi:10.1007/s11367-021-01960-8	Article	0	[200]
79	Yue H., 2021, Energ. Effic., V14, Article No. 60, doi:10.1007/s12053-021-09979-4	Review	0	[201]
80	Vand B., 2021, Energ. Convers. Manage., Article No. 114178, doi:10.1016/j.enconman.2021.114178	Article	0	[202]
81	Jiang J.J., 2021, Environ. Sci. Technol., V55, P7225–7236, doi:10.1021/acs.est.0c06952	Article	0	[203]
82	Tong H., 2019, J. Clean. Prod., V45, P10989–10996, doi:10.1039/d1nj01464a	Review	0	[204]
83	Gou S.W., 2021, Arab. J. Geosci., V14, Article No. 803, doi:10.1007/s12517-021-07104-4	Article	0	[205]

Table A1. *Count.*

Rank	Citing Articles Author, Year, Journal, Volume, Page/Article Number, doi	Type	Times Cited	Reference
84	Fan G.J., 2021, Oil Gas Sci. Technol., V76, Article No. 30, doi:10.2516/ogst/2021007	Article	0	[206]
85	Yue H., 2021, Appl. Energ., V282, Article No. 116241, doi:10.1016/j.apenergy.2020.116241	Article	0	[207]

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