Review

How Can Industrial Parks Achieve Carbon Neutrality? Literature Review and Research Prospect Based on the CiteSpace Knowledge Map

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Abstract: Global responses to climate change have accomplished certain reductions in carbon emissions. However, current efforts are insufficient for reaching the worldwide objective of carbon neutralization. Industrial parks that integrate industrial and economic resources are priority entities concerning the achievement of national carbon mitigation. The implementation of carbon neutralization at an industrial park level is unclear. This paper used a bibliometric approach to analyze articles related to carbon emissions reduction in industrial parks. From 2001 to 2022, 114 publications were collected from the WoS database. Descriptive statistical analysis, network analysis, keyword co-occurrence network analysis, keyword clustering, co-citation analysis, and burst detection were employed to summarize the research hotspots and evolution trends in this field. The results showed that the research hotspots were energy management, industrial symbiosis, economics and development, and carbon emission assessments in industrial parks. Emerging trends are the management of integrated energy systems, circular economy, renewable energy, economic analysis, and the validation of various models. Based on these analyses, four challenges and prospects were proposed for the construction of zero-carbon industrial parks. Finally, this paper presents a systematic guidance framework for carbon neutralization in industrial parks, which provides important references for future theoretical and practical research on industrial parks.

Keywords: carbon neutralization; energy management; bibliometric analysis; industrial park; zero carbon; carbon emissions reduction; knowledge map; co-citation network

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC)’s fifth assessment report stated that human activities resulted in dramatic impacts on global ecosystems and the Earth’s climate system, which threatened the survival of human beings [1]. The Paris Agreement calls for participants to deliver net-zero greenhouse gas (GHG) emissions by the middle of the century to curb the magnitude of global warming by less than 2 °C compared to preindustrial levels [2]. Greenhouse gases in the atmosphere consist of H2O, CO2, N2O, CH4, and O3. Since CO2 contributes to the warming effect most, the CO2 equivalent is specified as the basic unit of measure of the greenhouse effect [3]. The intended nationally determined contributions (INDC) from covenant countries generally decreased GHG emissions. However, recent studies indicated that NDCs and national policies were insufficient to cover the temperature limits agreed upon in the Paris Agreement [4], which meant that the climate change actions required further strengthening [5].

Industrial parks are land-developed and divided into plots according to a comprehensive scheme to provide roads, transport, and other infrastructure facilities for a group of enterprises. Industrial parks are an essential carrier of industrial production, manufacturing and economic activities, and an area of significant population and commercial gathering [6]. The number of industrial parks worldwide is estimated to be between 12,000 and 20,000.
with construction rising in both developed and developing countries [7]. Nevertheless, industrial parks’ dynamic growth has also brought many challenges, including resource-intensive consumption, environmental emissions, and the increasing pressure of industrial production on climate change [8]. At the regional level, Asia has the highest level of carbon emissions in the world. Industrial parks in China accounted for 11% of national GHG emissions in 2015, while these parks accounted for 11% of the national GDP. Consequently, as the engine of regional economic growth, the economic and environmental benefits of carbon emissions reduction in industrial parks, involving the energy restructuring of the industrial sector and the promotion and application of renewable energy, can profoundly affect the sustainable development of the national economy [9]. However, considering carbon reduction strategies in industrial parks only from an energy consumption perspective is not comprehensive. Industrial parks include social, technological, and ecological factors, and the relationship between these factors must be analyzed and interpreted in greater depth [10]. In the context of the approaching carbon peak and carbon neutralization targets of countries around the world, better management of the environment has become an increasingly important factor in the green development and resource-saving “circular economy” business models. Industrial parks are under pressure to attract investment and provide greener services. Therefore, the interdisciplinary perspective of reducing carbon emissions in industrial parks is urgently needed.

Numerous industrial symbiosis (IS) cases have been performed to reduce carbon emissions in industrial parks in many countries. For example, the Ulsan Eco-Industrial Park in Korea tested a practical approach to quantify total and allocated GHG emissions from IS exchanges. This study suggested GHG reduction credits achieved by IS exchanges should be issued to IS exchanges companies through stakeholder negotiations based on their contribution to the IS exchanges [11]. As one of the first and the best-known eco-town projects, Kawasaki Eco-town [12] adopted a life cycle CO2 analysis method to calculate the total CO2 emission in various scenarios. Their findings were that material exchanges between enterprises and the surrounding area could further reduce GHG emissions. While the studies mentioned above focused on carbon audits in industrial parks and the association between IS and the environment, it is also essential to investigate carbon reduction in industrial parks from a broader, integrated strategic perspective for such a complicated and extensive project [13]. The research to date has tended to use methods including carbon emission monitoring and carbon accounting to assess a variety of innovative carbon reduction strategies for IPs. The concepts of IS, eco-industrial parks (EIP), and low-carbon industrial parks (LCIP) have been widely applied [14]. However, few studies discussed the systematic design of carbon neutralization from the perspective of integrating carbon absorption and emission. The impact of carbon trade, carbon management, and other measures on reducing carbon emissions in IP is also seldom mentioned [15]. As a catalyst for industrial development, industrial parks can also facilitate socially and environmentally responsible industrialization and have the potential to demonstrate to the rest of the country that they can make an essential contribution to benchmarking sustainable development goals. For this reason, the status of research around carbon emissions reduction in industrial parks needs to be clearly sorted out and critically examined to identify the gap between the real demands of sustainable development and current academic research.

Furthermore, to obtain a comprehensive understanding of the field of IPs, a couple of studies have been undertaken to synthesize different aspects of industrial park development. Marianne Boix et al. [16] described several types of cooperative networks in EIPs, combined with a study of optimization methods to solve each problem. Their study included that current EIPs require multi-objective optimization studies, the formulation of social objectives, and the flexibility to organize EIP activities from an operational perspective. GAF Barrera et al. [17] used bibliometric analysis to analyze the evolution of IP research topics and research fields from a systematic perspective. Their research showed that industrial ecology (IE), IS, and circular economy (CE) were the keywords with the highest frequency, indicating that IP research focused on the exchange of byproducts from
these perspectives. Current systematic methods of analysis are evaluating IP performance and environmental impact through carbon footprint, emergy analysis, and life cycle analysis (LCA). Up to now, the systematic bibliometric investigation of how to realize carbon emissions reduction at the IP level remains to be enhanced. Many reviews on industrial parks have analyzed related topics from a more macro point of view. There is a requirement for more research that focuses on carbon emissions reduction in industrial parks, and bibliometric tools are ideal for collecting and evaluating studies on this topic [18]. Specifically, the quantitative analysis of bibliometrics on the current status of research can effectively illustrate the focus and development trend of associated studies [19], thus highlighting the gaps and potential development of present studies and enabling the proposal of valuable suggestions for future research.

This study uses bibliometrics and knowledge mapping, with the help of CiteSpace software, to analyze research hotspots and emerging trends of carbon emissions reduction research on IPs worldwide, based on the Web of Science database. Challenges and prospects related to research into reducing carbon emissions from industrial parks are presented. To further explore development opportunities for industrial parks, this paper proposes a systematic design framework to guide its top-level planning, identifying the intricate social, economic, and technological components needed to achieve the objective of carbon neutralization.

2. Methodology
2.1. Methods

This article conducts an insightful review of the literature on carbon emissions reduction in IPs using bibliometric analysis to build a knowledge graph with CiteSpace software. Bibliometrics is a statistical method adopted to evaluate a specific academic field [20], which is theoretically based on the distribution of authors revealed by Price’s law and the spread of specific disciplines across journals described by Bradford’s law. This method is widely used to evaluate scientific results, capture scientific developments, build the structure of scientific knowledge maps, and identify emerging trends in a given field [21]. A comprehensive network of concepts, knowledge, and social structures in a given area can be constructed and visualized via the analysis of scientific literature using bibliometric methods. This complex knowledge network comprises a selection of nodes, such as authors, terms or keywords, cited literature and journals, subject areas, etc. [22]. The CiteSpace software, designed by Professor Chaomei Chen of Drexel University, USA, incorporates bibliometric and information visualization principles and describes the evolution of scientific knowledge and structural relationships via graphics. It is an essential tool for generating knowledge maps [23].

2.2. Data Sources

This article used CiteSpace version 5.7.R5 (64-bit) to visually analyze the literature related to carbon emission reductions in IPs and chose Web of Science (WoS) as the data source. WoS is considered one of the largest and most used databases in the bibliometric analysis [24]. The query for searching is shown in Table 1. To search the relevant literature as comprehensively as possible, we adopted various terms related to carbon emissions reduction extracted from previous studies such as those by Elizabeth J. Abraham et al. [25] and Xiang Yu et al. [26]. The date of data retrieval was 25 October 2022. The “Article or Review Article” and “English Language” option in the results was selected, and a total of 191 articles were obtained. The records of articles were saved from WoS in plain text format, set to include all records and cited references. To optimize the efficiency of the bibliometric analysis results, documents that did not match the subject were removed after manual screening. The duplicate data were eliminated, and other pre-processing manipulations were performed. Finally, 114 valid documents were obtained.
2.3. Framework of This Study

The structure of this article is as follows, as shown in Figure 1. Section 2 describes the methodology used in this research for selecting the database and the keywords, including the methods of bibliometric analysis. Section 3 demonstrates the results of the scientific mapping, including the following work: (1) descriptive statistical analysis, covering the annual number of publications, and the distribution of high-output journals and subject areas, aiming to paint a panoramic view of the field; (2) network analysis, incorporating national cooperation networks, institutional cooperation networks, and author cooperation networks, aiming to analyze the cooperation links between them; (3) research hotspots, employing keyword co-occurrence network analysis and keyword clustering to analyze the current research hotspots of carbon emission reduction in industrial parks; (4) timeline co-citation and burst detection analysis, dividing the research themes into three stages from the time dimension, then analyzing the evolution of research frontiers and summarizing the critical literature. Section 4 presents the challenges and prospects for the construction of zero-carbon industrial parks. Section 5 proposes a systematic design framework for carbon neutralization in industrial parks. Finally, Section 6 concludes the contributions and limitations of this paper.

![Figure 1. The framework of this study.](image)

### Table 1. Publication extraction protocol.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Input Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web of Science</td>
<td>(TS = (“industrial park” OR “eco-industrial park”)) AND TS = (“carbon emission” OR “carbon dioxide emission” OR “greenhouse gas” emission” OR “GHG emission” OR “greenhouse gas mitigation” OR “CO₂ emission” OR “carbon discharge” OR “carbon footprint” OR “carbon absor” OR “carbon fixation” OR “carbon sink” OR “carbon neutral” OR “zero carbon”) AND TI = “Publication extraction protocol.”</td>
</tr>
<tr>
<td>Limiters</td>
<td>“Article or Review Article”, “English”</td>
</tr>
</tbody>
</table>

Note: * refers to any character group, including null characters.

3. Results

3.1. Descriptive Statistical Analysis

Analyzing the annual variation number of publications within a selected research domain enables the assessment of the current status of research in the field and the prediction of future trends [27]. As seen in Figure 2, the number of articles published in the area of carbon emission reductions in industrial parks increased exponentially over the past two decades, implying that the field is in a rapid development phase and that new theories and technologies are emerging [28]. In the period spanning 2001 to 2008, fewer than 10 articles were published on carbon emissions reduction in industrial parks, indicating that the
significance of achieving carbon emissions reduction at the industrial park level had yet to be taken seriously during this period. From 2011 to 2013, a relatively increasing rate of publications occurred in this area. Then, there was a decline between 2013 and 2015. From 2016 to 2018, the number of publications increased moderately. However, from 2019 onwards, the number of papers increased swiftly. In 2021, the number of publications reached 20 for the first time. By November 2022, the number of publications in this field reached 10 in the year 2022. The exponential line of the publications of recent years, whose R-squared value is 0.6603, represented its reliability. The closer the R-squared value is to 1, the better the fit of the exponential line to the figures. In summary, the development of the field related to carbon emissions reduction in IPs is accelerating.

![Figure 2. The annual trends of publications.](image)

Articles related to carbon emission reduction in industrial parks are distributed among 30 subject categories in WoS. More than half of the articles were published in "Environmental Sciences" (63, 55.26%), followed by "Energy Fuels" (42, 36.84%), "Engineering Environmental" (42, 36.84%), "Green Sustainable Science Technology" (41, 35.97%), "Engineering Chemical" (15, 13.16%). Figure 3 lists the top three most published subject categories and shows the change in the number of articles published annually under each category. The number of articles published in the “Energy Fuels” category has increased steadily since 2001 and expanded explosively in 2021. The category “Engineering Environmental” experienced consistent growth in the number of articles since 2008 but encountered a decline from 2018 onwards. Finally, the “Economics” and “Multidisciplinary Sciences” categories represented a handful of novel articles published from 2013 to 2021, signifying promising directions for future research, with themes focused on IE, sustainable development (SD), circular economy (CE), etc.

An overview of the distribution of journals for research related to carbon emission reduction in industrial parks reveals the allocation of disciplines in the field and the profile and preference of core journals. To illustrate the distribution of journals, Table 2 lists the top 10 high-impact journals in terms of the percentage of articles published. According to WoS, the 114 papers in this field were distributed in 49 journals. “Journal of Cleaner Production” (23, 20.18%), “Energy” (8, 7.02%), “Applied Energy” (7, 6.14%), “Energy Policy” (6, 5.26%), “Resources, Conservation and Recycling” (6, 5.26%) were the top five most published research journals in this field, accounting for nearly 50% of the total number of articles published. Such a high proportion demonstrates that this field constituted a coherent community of journals within which research articles in this area are concentrated. Notably, “Journal of Cleaner Production” contributed 20.18% of overall publications, making it the
most influential core journal in its field. In addition, regarding their impact factors, these journals are authoritative in the environment and energy fields, located in Q1 or Q2 of the WoS’ division. They are pivotal knowledge aggregation and dissemination platforms in the area of carbon emissions reduction in industrial parks.

Figure 3. WoS subject categories with the top three number of publications.

Table 2. Key journals distribution.

<table>
<thead>
<tr>
<th>Number</th>
<th>Journal</th>
<th>TP</th>
<th>Percentage</th>
<th>IF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Journal of Cleaner Production</td>
<td>23</td>
<td>20.18%</td>
<td>11.072</td>
</tr>
<tr>
<td>2</td>
<td>Energy</td>
<td>8</td>
<td>7.02%</td>
<td>8.857</td>
</tr>
<tr>
<td>3</td>
<td>Applied Energy</td>
<td>7</td>
<td>6.14%</td>
<td>11.446</td>
</tr>
<tr>
<td>4</td>
<td>Energy Policy</td>
<td>6</td>
<td>5.26%</td>
<td>7.576</td>
</tr>
<tr>
<td>5</td>
<td>Resources, Conservation and Recycling</td>
<td>6</td>
<td>5.26%</td>
<td>13.716</td>
</tr>
<tr>
<td>6</td>
<td>Journal of Industrial Ecology</td>
<td>5</td>
<td>4.39%</td>
<td>7.202</td>
</tr>
<tr>
<td>7</td>
<td>Environmental Science &amp; Technology</td>
<td>4</td>
<td>3.51%</td>
<td>11.357</td>
</tr>
<tr>
<td>8</td>
<td>Renewable &amp; Sustainable Energy Reviews</td>
<td>4</td>
<td>3.51%</td>
<td>16.799</td>
</tr>
<tr>
<td>9</td>
<td>International Journal of Energy Research</td>
<td>3</td>
<td>2.63%</td>
<td>4.672</td>
</tr>
<tr>
<td>10</td>
<td>Sustainability</td>
<td>3</td>
<td>2.63%</td>
<td>3.889</td>
</tr>
</tbody>
</table>

Note: TP = number of publications; IF = 2021 journal impact factor.

3.2. Network Analysis

3.2.1. National Cooperation Network

Based on the national cooperation network in Figure 4, there was relatively intimate cooperation between countries on carbon emissions reduction in industrial parks. There were 29 nodes in the collaborative network and 35 links with a network density of 0.0862. The node’s size reflected the number of articles published by the country. The larger the node, the more articles are published by that country. The top five countries and regions in terms of the number of papers published were China (65), Japan (11), the USA (10), South Korea (7), and Taiwan (7), which the size of the nodes visualize, indicating that China is dominant in terms of the number of publications. Centrality denotes the value of the
country in the research field. The higher the centrality, the greater the country’s contribution to the research field. The nodes marked by pink circles have a centrality exceeding 0.1 and constitute the more critical nodes. In this study, China had the highest centrality at 0.59, followed by Korea (0.34), the UK (0.28), India (0.2), and Italy (0.2). The links between the nodes indicated the existence of a partnership between the two countries, with warmer colors signaling a more recent collaboration and cooler colors showing an earlier association. The graph shows that Canada and the USA were the first to establish partnerships, Korea and Japan, Singapore and the UK, and Pakistan and Saudi Arabia also collaborated at an earlier stage. In recent years, China has partnered with Iran, Sweden, Japan, Pakistan, Saudi Arabia, Germany, the USA, and Canada. Portugal, Colombia and Sweden, Ethiopia, and other countries have also developed cooperation with other countries recently, and various countries are proactively participating in this field of research.

Figure 4. National cooperation network.

3.2.2. Institutional Cooperation Network

From the cooperative network of institutions, Figure 5 shows a total of 165 nodes with 214 connections, with a network density of 0.0158, which is a high value and represents a solid aggregation of the overall network formation. Tsinghua University was the most published institution with 14 articles, followed by Beijing Normal University (5), the Chinese Academy of Sciences (5), National Institute for Environmental Studies (5), and Chinese Academy of Social Sciences (4). Dalhousie University, North China Electric Power University, Texas A&M University in Qatar, and the University of Tokyo also achieved some progress in the realm of carbon emissions reduction in industrial parks. Concerning partnerships, the Chinese Academy of Sciences, National Institute for Environmental Studies, Dalhousie University, and Shanghai Jiao Tong University proactively foster interinstitutional coordination. From the point of view of the period of cooperation, Beijing Normal University, Dalhousie University, and the University of Ulsan and other research institutions established collaboration at an earlier stage, while the Chinese Academy of Sciences,
Chinese Academy of Social Sciences, Hohai University, and The University of Maryland have developed many new partnerships in more recent years. From the perspective of centrality, the Chinese Academy of Sciences (0.11), National Institute for Environmental Studies (0.08), Xi An Jiao Tong University (0.06), and Beijing Normal University (0.06) were comparatively more central, and these institutions became critical nodes in the cooperative network. These institutions are vital bridges in this collaborative network.

Figure 5. Institutional cooperation network.

3.2.3. Co-Authorship Network

According to Figure 6, a collaborative network of scholars was generated with a density of 0.0124, 268 nodes, and 445 links. Overall, the density of these collaborative networks is relatively high, and many scholars established substantial collaborative networks. Jinping Tian from Tsinghua University (Beijing, China) constituted a significant cluster of authors. He has published 12 papers in this field. His research topics have included the construction of GHG emission inventories in eco-industrial parks, the analysis of the eco-efficiency of cogeneration in industrial parks, the impact of energy infrastructure configuration on GHG emissions in industrial parks, etc. He has analyzed the characteristics of GHG emissions by different energy-consuming facilities in industrial parks and received many citations. His partnership with Lujun Chen, the second-most published author, was initiated earlier. The two authors have recently collaborated with Yang Guo, the third most published author. In addition, a large group of authors formed around Tsuyoshi Fujita (National Institute for Environmental Studies, Tsukuba, Japan), whose research focused on assessing the carbon footprint of industrial parks, the impact of industrial symbiosis on CO\textsubscript{2} reduction in industrial parks, and the analysis of carbon emissions and economic benefits of industrial parks and urban symbiotic networks. Together with Minoru Fujii (Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), Tsukuba City, Japan), Liang Dong (Institute of Environmental Studies (CML), Leiden University, The Netherlands), Hungsuck Park (Department of Civil and Environmental Engineering, University of Ulsan, Ulsan, Republic of Korea), Tsuyoshi Fujita and his associated group constituted the largest group of authors in the field.
3.3. Research Hotspots

3.3.1. Keyword Co-Occurrence Network Analysis

Keywords are a high-profile distillation of subject matter in the literature. They can be used to investigate hot topics and vital research issues in a given subject area based on high-frequency keywords. In CiteSpace, we set the network node types to “Keyword”, then chose pruning options “Pathfinder” and “Pruning the merged network” to obtain the keyword co-occurrence network and perform synonym merger and node adjustment. The bigger the node in the network, the higher the frequency of its occurrence. High-frequency keywords represented research hotspots in the field. As some keywords were used to retrieve the literature presented in this paper, these high-frequency keywords were removed, as shown in Figure 7. Table 3 illustrates the top 20 high-frequency keywords in the keyword co-occurrence network. The top five high-frequency keywords for studies on carbon emissions reduction in industrial parks are China, energy, system, management, and design. The analysis of these high-frequency keywords revealed that many studies on carbon emissions reduction in industrial parks use industrial parks in China as a case study, and that their authors were usually from China, which indicated that Chinese academics attach high priority to research on carbon emissions reduction in industrial parks and are in the leading position globally. A series of innovative approaches have been developed to evaluate the carbon footprint of industrial parks in China, such as a life-cycle approach, a framework for tracking carbon metabolic processes based on ecological network analysis, and an eco-efficiency assessment of cogeneration in industrial parks. Furthermore, research on carbon emissions reduction in industrial parks focused on energy consumption (coal combustion, microgrid planning, natural gas, etc.), the systematic management of park elements (management and strategic systems, CO\(_2\) integration solutions, integrated energy systems, etc.), IP system design and planning (design of low-cost integrated carbon network systems, design of integrated projects within parks, park layout design, etc.).
integration solutions, integrated energy systems, etc.), IP system design and planning (design of low-cost integrated carbon network systems, design of integrated projects within parks, park layout design, etc.).

Figure 7. Keyword co-occurrence network.

Table 3. Top 20 high-frequency keywords.

<table>
<thead>
<tr>
<th>Number</th>
<th>Frequency</th>
<th>Centrality</th>
<th>Keyword</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.29</td>
<td>China</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>0.39</td>
<td>energy</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>0.3</td>
<td>system</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>0.08</td>
<td>management</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>0.07</td>
<td>design</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>0.12</td>
<td>city</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>0.03</td>
<td>life cycle assessment</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>0.21</td>
<td>symbiosis</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>0.03</td>
<td>performance</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>0.03</td>
<td>industrial symbiosis</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>0.07</td>
<td>consumption</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>0.09</td>
<td>model</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>0.01</td>
<td>mitigation</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>0.05</td>
<td>ecology</td>
</tr>
<tr>
<td>15</td>
<td>5</td>
<td>0.18</td>
<td>energy efficiency</td>
</tr>
<tr>
<td>16</td>
<td>5</td>
<td>0.01</td>
<td>industrial ecology</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>0.02</td>
<td>efficiency</td>
</tr>
<tr>
<td>18</td>
<td>5</td>
<td>0.06</td>
<td>climate change</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>0.04</td>
<td>integrated energy system</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>0.01</td>
<td>optimal design</td>
</tr>
</tbody>
</table>

However, not all high-frequency keywords have high centrality, and high-frequency keywords cannot be relied on to capture the complete picture of research hotspots in the field. In CiteSpace, keywords with high centrality (Centrality ≥ 0.1) can be regarded as the inflection point of the keyword frequency knowledge graph and, to a certain extent, represent research hotspots in the field as well. “Industrial symbiosis” is one of the hot topics in industrial park research, emphasizing differentiated low-carbon project portfolio strategies. “Optimizations” models are used to determine the best approach between the various options within an industrial park and play a vital role in integrating energy solutions and designing CO₂ emission solutions in industrial parks. Optimizing the energy
mix and improving energy efficiency have been critical components in developing zero-carbon industrial parks. In addition, the use of carbon capture technologies in industrial parks and the interaction between industrial parks and cities have scarcely been studied and appear infrequently. The high centrality of these two research themes indicates that they are also crucial topics in the field of carbon emissions reduction in industrial parks.

3.3.2. Keyword Clustering

Keyword clustering investigates network clusters formed by keywords with similar research topics. Keyword clustering enables an overview of the current research topics in the domain. Keyword clustering is done by selecting the clustering function in CiteSpace, selecting keyword clustering, and then selecting the LLR algorithm to cluster the keywords into 11 categories. The smaller the serial number of the clusters, the more keywords they contain. The modularity Q value is 0.7684 (>0.3), which means that the obtained network structure is remarkable. The weighted mean silhouette S value is 0.9341 (>0.4), and a value approaching 1 means that the average homogeneity of the network is high and the clustering results are reasonable. Table 4 shows the labels of the 11 keyword clusters and the corresponding keywords after collation and removing duplicates.

Table 4. Keyword clustering.

<table>
<thead>
<tr>
<th>Cluster ID</th>
<th>Cluster Label</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>low carbon</td>
<td>low carbon; climate change; hybrid lca; structural decomposition</td>
</tr>
<tr>
<td>1</td>
<td>industrial ecology</td>
<td>industrial ecology; eco-industrial development; environmental co-benefits</td>
</tr>
<tr>
<td>2</td>
<td>strategy</td>
<td>strategy; small and medium enterprises; carbon metabolism; embodied carbon emissions; des/chp</td>
</tr>
<tr>
<td>3</td>
<td>combined heat and power</td>
<td>combined heat and power; CO₂ footprint; uncertainty analysis; eco-efficiency; energy efficiency</td>
</tr>
<tr>
<td>4</td>
<td>industrial layout adjustment</td>
<td>industrial layout adjustment; industrial land reallocation; industrial land development cost</td>
</tr>
<tr>
<td>5</td>
<td>system integration</td>
<td>system integration; bioeconomy; urban ecology; bioenergy; chp; industrial energy symbiosis</td>
</tr>
<tr>
<td>6</td>
<td>carbon neutral</td>
<td>carbon neutral; multi-level modelling and optimization; carbon negative; carbon capture</td>
</tr>
<tr>
<td>7</td>
<td>techno-economic analysis</td>
<td>techno-economic analysis; pv; wind; grid-connected systems; industrial symbiosis</td>
</tr>
<tr>
<td>8</td>
<td>optimization</td>
<td>optimization; eco-industrial development strategies; carbon capture and storage (ecs); system; ghg management</td>
</tr>
<tr>
<td>9</td>
<td>energy infrastructure</td>
<td>energy infrastructure; infrastructure stock; industrial park infrastructure; economic assessment</td>
</tr>
<tr>
<td>10</td>
<td>renewable energy</td>
<td>renewable energy; energy consumption; solar pv; wind power; zero carbon emission</td>
</tr>
</tbody>
</table>

According to the clustering analysis of keywords, the most highly cited articles are grouped under the clustered keywords, and the clustered topics are summarized and classified. The research subjects for carbon emission reduction in industrial parks are to be mainly focused on the following.

1. Research on energy management in industrial parks.

The reduction of the carbon intensity of energy infrastructures and the improvement of water-use efficiency are priorities of the sustainable development goals set out by the United Nations. Evaluating and refining the environmental performance of energy systems paves a solid path to low-carbon development [29]. Yang Guo et al. [30] employed a slacks-based data envelopment analysis (DEA) model to evaluate the eco-efficiencies of 44 coal-fired combined heat and power (CHP) plants. The inputs to the model were coal consumption, freshwater consumption, capital depreciation, and operating costs, and the outputs were electricity, heat, and GHG emissions. The results showed that the eco-efficiency and thermal energy efficiencies of CHP plants vary considerably and that annual operating time is the most dominant factor affecting eco-efficiency. For IPs, the more energy-intensive their industries were, the less eco-efficient the CHP was. Nan Yu et al. [31] developed an efficient multi-objective optimization model for robust microgrid planning based on an economic robustness measure applied to Taichung IP in Taiwan. The study’s outcome indicated that the most concentrated solution was the costliest, i.e., 45% of the gas engine and 47% of the photovoltaic panel. M.A. Butturi et al. [32] explored the energy symbiosis options in EIPs and concentrated on urban–industrial energy symbiosis solutions, including design and optimization models, technologies used, and organizational strategies. The study also demonstrated viable alternatives for boosting the use of renewable energy in IPs. Creating strategies between companies in IPs to enable them to use and share
renewable energy efficiently effectively reduces carbon emissions at an industrial level. The uncertainty and intermittency of renewable energy generation can undermine the effectiveness of energy use and the supply flexibility of the integrated energy system (IES). Hang Liu et al. [33] analyzed the combined supply of cooling, heating, and power (CCHP)’s influence on system efficiency compared to the traditional IES. They adopted the fuzzy c-mean-clustering comprehensive quality (FCM-CCQ) algorithm to control the system’s operational risk, which was improved to be reliable. A growing number of industrial parks are currently pursuing sustainability strategies at the feasibility stage. Energy planning and management are becoming an integral part of industrial park planning and development as industrial parks, in particular, offer opportunities for the sustainable use of low-carbon energy and shared infrastructure.

2. Research on industrial symbiosis (IS) in industrial parks.

Industrial symbiosis is an eco-industrial model for the sustainable development of industrial parks through the exchange of byproducts [34]. Most of the studies referred to IS in IPs focused on the industrial ecology (IE), the urban–industrial symbiosis, and the byproduct exchange among IPs. Laura Sokka et al. [35] argued that the considerable contribution of upstream processes to total GHG emissions suggested that the studied systems were reliant on their surroundings. Independent study of IS in isolation from its surroundings might yield a divergent picture of environmental impact. Thus, upstream production processes and their effects on the environment should be considered when recommending how to develop a specific IS. Hui Zhang et al. [36] used substance flow analysis (SFA) to evaluate three standard iron and steel industry technologies, including coke dry quenching (CDQ), combined cycle power plant (CCPP), and CO₂ capture by slag carbonization (CCSC), in terms of carbon mitigation potential and unit reduction cost. They concluded that IPs applying those three techniques effectively reduced net carbon emissions compared with business as usual (BAU). At the same time, the unit costs for the three technologies were so high they demanded national financial support.

In the energy-consuming industrial sector, only a fraction of the high-grade waste heat generated by industrial processes is utilized by other methods through the industrial symbiosis network in industrial parks. A significant amount of low-grade waste heat is discharged into the environment. Hyeong-Woo Kim et al. [37] systematically constructed industrial–urban symbiosis (I–US) through a technical evaluation of the energy balance between the industrial park’s waste heat source and the heat sink in the urban area and carried out a co-benefit analysis in four scenarios. The outputs demonstrated that symbiotic networks were capable of achieving CO₂ reductions and fuel cost savings. Yun Zhang et al. [34] assessed an industrial park chain’s material substitution and environmental impact using a life cycle assessment method. The results indicated significant ecological benefits generated by the shared byproducts, which meant that industrial symbiosis is an invaluable way for the Chinese government to achieve its environmental goals and promote this eco-industrial model.

3. Research on economics and development of industrial parks.

Industrial parks can provide a favorable business environment for the development of manufacturing. A competitive manufacturing sector plays a crucial role in economic growth and socioeconomic transformation. Industrial parks can also create links backwards and forwards, with raw materials and supplies flowing from savings to parks for processing. Xin Nie et al. [38] used the staggered difference-in-difference method to organize a quasi-natural experiment to evaluate the impact of national-level EIPs on low-carbon development. Their findings demonstrated that the EIPs lowered the carbon intensity of the pilot cities by 7.2%, promoted technological innovation, stimulated the Porter effect, and upgraded the industrial structure. Regional heterogeneity analysis also revealed that EIPs are conducive to low-carbon development in pilot cities in southern China, cities along the coast, and cities east of the Hu line. Haifei Gu et al. [39] proposed a bilevel optimal low-carbon economic dispatch model for an IP considering multi-energy price incentives. The model facilitated
multi-energy users (MEU) to proactively obtain retail energy price signals and determine the best multi-energy use strategy, engaging proactively in the integrated demand response (IDR) plan. This model and methodology contributed to optimizing the price of energy sold and electricity used by IDR, increasing the Integrated Energy Service Agency (IESA)’s net revenue. Supply chain management is not only a core aspect of a company’s competitive strength but can also substantially contribute to reducing a company’s environmental impact. Raymond P. Côté et al. [40] investigated the supply chains of three small and medium enterprises (SME) operating in the Burnside IP in Nova Scotia, Canada, to explore the chances of enhancing the environmental performance of SMEs linked in supply chains. This study confirmed that the opportunities for reducing GHG emissions and solid waste emissions that could be achieved by implementing any individual actions in the supply chains explored in the study are small. Still, the cumulative benefits that could be realized within supply chains and industrial parks are significant, given the number of SMEs.

4. Research on evaluations of carbon emissions in industrial parks.

The carbon footprint quantification is crucial in an industrial park’s strategy to reduce emissions. Huijuan Dong et al. [41] chose the hybrid LCA method to assess a specific comprehensive IP in China. Their findings detailed the complete life-cycle carbon footprint of the industrial estate, including direct, upstream, and downstream carbon footprints, which could be instrumental in decision-making on emission reduction policies. Ning Wang et al. [42] employed a life cycle model to build an emissions matrix for the carbon footprint (CF) of coal-fueled power generation in China’s coal-fueled power circular economy (CE) parks. They concluded that carbon emissions from coal-fired power generation in China’s IPs are consistent with trends in raw coal production and consumption, with direct carbon emissions accounting for over 86% of them. Life-cycle carbon emissions should be mitigated through energy substitution and the implementation of emission controls. Jian Zhang et al. [43] established the CO₂ emissions inventory, including energy consumption, industrial process, and waste disposal. At the same time, they built an uncertainty analysis framework considering scope 1, 2, and 3 emissions. Their research contributed to the establishment of GHG accounting standards for Chinese IPs. Dhayia M. Al-Mohannadi et al. [44] presented the approach to the systematic design of low-cost carbon integration networks for IPs through a comprehensive analysis of sources, utilization, and storage options, which was helpful for designers and policymakers in investigating carbon footprint reduction solutions. Zhe Liu et al. [45] stated that life cycle and emergy analysis are both effective methods for environmental management, but both have their limitations. They consequently elaborated a hybrid model that integrated LCA into an emergy analysis framework to assess the co-benefits achieved by an eco-strategy for IPs. The reduction of GHG emissions is one of the environmental benefits obtained. The study recommended that the management of industrial parks required the consideration of the transfer of excess waste heat to potential users.

3.4. Research Topic Evolution Analysis

3.4.1. Timeline View of Co-Citation Analysis

In our timeline view, documents of the same clusters are placed on the same horizontal line. The publication time of the literature is located at the top of the graph. Timeline view provides a clear picture of the amount of the literature in each cluster. The greater the representation of the literature in a cluster, the more critical the resulting cluster area is. The period of the literature in each cluster is also obtained with the cluster’s rise, boom, and decline. Co-citation of literature means that two pieces of literature are cited by one or more pieces of literature at the same time, indicating that they share a common research theme [46]. The co-citation of the literature provides insight into the relevant research topics’ knowledge base and research frontiers.

The development and characteristics of research related to carbon emissions reduction in industrial parks are shown in Figure 8. CiteSpace’s literature co-citation analysis groups similar literature and identifies clustering themes [47], sorting them and visualizing the
historical span of clustered themes and the links between clustered themes. The horizontal axis of Figure 8 shows the publication date, and the vertical axis shows the 10 clustered themes sorted by cluster size. The plot includes 420 nodes, 1308 links, and a co-citation network with a density of 0.0149. The modularity Q value is 0.8934 (>0.3), which indicates that the study topics have clear boundaries. The weighted mean silhouette S value is 0.9526 (>0.4), indicating substantial homogeneity within the clustered themes. The size of the nodes represents the frequency of co-citations in the literature, and the color of the cluster theme font corresponds to when the co-citation first appeared. A warm color indicates a co-citation approximately close to the present time. A cool color suggests an earlier time. Cross-sectionally, the period of the clustering themes varies considerably; number 3, sustainable carbon and number 2, Chinese eco-industrial park, have a more significant time span, developing from 2012 to the present. Number 9, urban–industrial symbiosis, and number 14, managing energy infrastructure, were popular themes for research between 2015 and 2018, but no new literature has been published in recent years. The top-ranked number 1, low-carbon pilot spanned from 2011 to 2017, and no contemporary literature has been produced since. However, number 10, cycle-based multicriteria sustainability evaluation and number 4, greenhouse gas emission, which started earlier, have not been published since 2014. The rise and fall of the above clustering themes suggest that these studies may have produced mature results or have shifted to new research paths following the emergence of mutational influences. Number 6, carbon peak (2017-), and number 13, eco-industrial energy system design (2018-), span a smaller period but remain very active to date and represent a new direction in the development of carbon emissions reduction in industrial parks.

Vertically, the connecting lines between the different clustered themes represent their intrinsic links. The two earlier clustering themes, number 4, greenhouse gas emission, and number 10, cycle-based multicriteria sustainability evaluation, are strongly linked to number 1, low-carbon Pilot, number 2, Chinese eco-industrial park, and number 3, sustainable carbon, suggesting a deep connection between these five clusters. Number 14, managing energy infrastructure, is more connected to the first three clustering themes and less to the other clustering themes.
Table 5 presents the top ten significant articles and their metrics regarding total citations within these clustered themes. Prominence represents the cutting edge of the article in the research field, and centrality is defined as the strength of the article’s connection to other articles. As the field of research on carbon emissions reduction in industrial estates is still in a developmental stage; only the top-ranked article has a suddenness of 3.67. These high-frequency cited articles are mainly distributed in the number 1, low-carbon pilot, and number 2, Chinese eco-industrial park, clusters. Articles by Yang Guo et al. [48] in 2018 had the highest centrality and citation frequency, representing solid research relevance to articles within and outside the clustering theme and a cutting-edge position in the field of carbon reduction in industrial parks. Their article revealed the direct and indirect energy-related GHG emissions of 213 Chinese national industrial parks, which accounted for 11% of China’s GHG emissions, and models five GHG emission mitigation measures for energy consumption. Meanwhile, another article by Yang Guo et al. [49] also had high citation frequency and a centrality of 0.05, implying their crucial position in the field of carbon emissions reduction in industrial parks. Their study examined the evolution of energy infrastructure units available in 608 Chinese national eco-industrial parks by year, fuel type, energy output, and technology of cogeneration units. The direct GHG emissions of the energy infrastructure and the parks were assessed, and the characteristics and drivers of energy infrastructure development in the EIPs were identified.

Table 5. Major articles distributed in clusters (numbers 1, 2, 3, 4, 6, 9, 14).

<table>
<thead>
<tr>
<th>Centrality</th>
<th>First Author</th>
<th>Year</th>
<th>Article</th>
<th>Journal</th>
<th>Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>Guo Y</td>
<td>2018</td>
<td>The Role of Industrial Parks in Mitigating Greenhouse Gas Emissions from China</td>
<td>ENVIRON SCI TECHNOL</td>
<td>6</td>
</tr>
<tr>
<td>0.04</td>
<td>Maes T</td>
<td>2011</td>
<td>Energy Management on Industrial Parks in Flanders</td>
<td>RENEW SUST ENERG REV</td>
<td>4</td>
</tr>
<tr>
<td>0.09</td>
<td>Dong HJ</td>
<td>2013</td>
<td>Carbon Footprint Evaluation at Industrial Park Level: A Hybrid Life Cycle Assessment Approach</td>
<td>ENERG POLICY</td>
<td>2</td>
</tr>
<tr>
<td>0.05</td>
<td>Guo Y</td>
<td>2018</td>
<td>Exploring Greenhouse Gas-Mitigation Strategies in Chinese Eco-Industrial Parks by Targeting Energy Infrastructure Stocks</td>
<td>J IND ECOL</td>
<td>2</td>
</tr>
<tr>
<td>0.08</td>
<td>Boix M</td>
<td>2015</td>
<td>Investigation of Ions Hydration Using Molecular Modeling</td>
<td>J CLEAN PROD</td>
<td>1</td>
</tr>
<tr>
<td>0.05</td>
<td>Dong HJ</td>
<td>2014</td>
<td>Achieving Carbon Emission Reduction Through Industrial &amp; Urban Symbiosis: A Case of Kawasaki</td>
<td>ENERGY</td>
<td>1</td>
</tr>
<tr>
<td>0.01</td>
<td>Guo Y</td>
<td>2016</td>
<td>Greenhouse Gas Mitigation in Chinese Eco-Industrial Parks by Targeting Energy Infrastructure: A Vintage Stock Model</td>
<td>ENVIRON SCI TECHNOL</td>
<td>14</td>
</tr>
<tr>
<td>0.09</td>
<td>Feng JC</td>
<td>2018</td>
<td>Case Study of an Industrial Park toward Zero Carbon Emission</td>
<td>APPL ENERG</td>
<td>9</td>
</tr>
<tr>
<td>0.09</td>
<td>Butturi MA</td>
<td>2019</td>
<td>Renewable Energy in Eco-Industrial Parks and Urban-Industrial Symbiosis: A Literature Review and a Conceptual Synthesis</td>
<td>APPL ENERG</td>
<td>3</td>
</tr>
<tr>
<td>0.01</td>
<td>Liu W</td>
<td>2014</td>
<td>Greenhouse Gas Emissions in China’s Eco-Industrial Parks: A Case Study of the Beijing Economic Technological Development Area</td>
<td>J CLEAN PROD</td>
<td>2</td>
</tr>
</tbody>
</table>

To better understand the evolution of research themes related to carbon emissions reduction in industrial parks, we have divided them into three stages of development.

- Phase I (2007–2011): Initial exploration of energy management and carbon neutralization concepts in industrial parks. Research on carbon emissions reduction in industrial parks was only in its infancy during this period, with only three articles having high centrality and the rest with relatively low citation frequency. The issues of global climate change and environmental pollution had not received sufficient attention during this period, and theories and ideas on environmental performance at the industrial park level had yet to be established. The main findings of this period were all produced in 2011. Tom Maes et al. [50] explored the literature on industrial symbiosis and eco-industrial parks, starting with the Flanders’ poor control of greenhouse gas emissions from industrial parks. They argued that energy management in industrial parks can be integrated into the overall development process as well as the direction of the park. Maximizing efficiency is an extremely promising local optimization problem and enhancing the flexibility and stability of energy management in industrial
parks requires further research. Mirko Z. Stijepovic et al. [51] presented a systematic approach to targeting the potential of waste heat recovery and designed the best reuse scenario at a plant in an industrial area. The method first considered the distances between the individual plants and determined the available waste heat’s mass and the feasibility of reuse. An objective optimization problem was solved to establish the maximum possible waste heat recovery for the industrial area. Then, a design optimization problem was solved for a concrete waste heat recovery scheme considering economic objectives. C. Block et al. [52] made a park-wide inventory for 2007 of the CO\(_2\) emissions due to energy consumption (electricity and fossil fuel) and waste incineration, as well as an inventory of the existing renewable electricity and heat generation of the Herdersbrug IP. Flanders’ carbon emissions were less than the carbon dioxide emissions avoided from renewable energy generation and therefore met the local government’s criteria for carbon neutralization. However, they did not consider the carbon dioxide emissions from fossil fuels used for heating. Overall, the articles in this period presented the concept of carbon neutralization in industrial estates and made initial explorations of carbon reduction from the perspective of energy management and waste heat recovery.

- Phase II (2012–2016), a period of theoretical and methodological development of carbon emissions reduction in industrial parks. This period was a boom period for carbon reduction research in industrial parks. Many studies began to employ models to quantify the carbon footprint and greenhouse gas emission potential within industrial parks and to reach certain conclusions. In addition, several gaps in the research were identified, such as spatial planning of industrial parks, the integration of emission reduction projects within parks, and social and business perspectives. Huijuan Dong et al. [41] argued that industrial parks were the main areas of greenhouse gas emissions. Therefore, it was essential to quantify the carbon footprint of industrial parks to suggest appropriate policies for reducing emissions. They applied a hybrid LCA model and obtained specific carbon footprint data for industrial parks, concluding that the chemical industry and specialized machinery manufacturing sector were the two sectors with the most prominent life-cycle carbon footprint. Marianne Boix et al. [16] retrieved articles in the form of reviews on “industrial symbiosis” (or “eco-industrial park”, or “inter plant integration”) and “optimization”, then detailed several EIP network types. They suggested that the problems with previous research were the need for multi-objective optimization studies, more flexibility in considering EIP’s from a business perspective, and the need to explore the objective social factor. Yang Guo et al. [53] developed a vintage stock model to quantify the GHG mitigation potential and cost-effectiveness of Chinese eco-industrial parks by targeting energy infrastructure with five key measures. The results showed that two actions (conversion of coal-fired boilers to natural gas-fired boilers and replacement of coal-fired units with natural gas-fire-combined cycle units) had significant potential for GHG reductions (42–46%) compared to the baseline scenario. In most cases, significant economic benefits could also be achieved through GHG emission reductions. Industrial parks in Korea are also one of the country’s primary sources of CO\(_2\) emissions. To assess the performance of commercial eco-industrial park projects in mitigating climate change, Yong Un Ban et al. [54] analyzed the direct CO\(_2\) emission reductions from 41 eco-industrial park projects implemented in Korea between 2005 and 2012. The results showed that after the start of the eco-industrial park projects, CO\(_2\) emissions from the industrial sector in Korea decreased by 0.48% in 2004. Most of the projects were effectively implemented through networks that shared and exchanged energy and resources. Spatial development planning is therefore needed to establish relationships between nodes in the network effectively. Their study also found that the performance and limitations of eco-industrial park projects vary depending on the amount of fuel and waste reduction, the byproducts and waste recovered, and the location of the eco-industrial park. Therefore, eco-industrial park projects should integrate with
other projects that reduce CO₂ emissions from other sources, as eco-industrial park projects alone do not reduce CO₂ emissions. Furthermore, local governments should cooperate in implementing city and regional projects to achieve environmentally and economically sustainable development. Catharine A. Kastner et al. [55] reviewed the quantitative tools and methods developed to identify and cultivate symbiotic industrial exchanges in existing industrial parks to minimize overall energy and material consumption. They highlighted the introduction of new topics such as infrastructure transformation, network analysis, company motivation, and confidentiality.

- Phase III (2017–2020) In-depth exploration of the industrial symbiosis approach and the initial proposal of a zero-carbon industrial park. The economic analysis of carbon reduction in industrial parks is gradually increasing, and energy management methods are becoming more abundant. Research on zero-carbon parks began to emerge at this stage. In addition, the study of industrial symbiosis extends from within industrial parks to the industrial symbiosis between parks and cities. Yang Guo et al. [48,49], the critical authors of this phase, were described in the preceding section, and their summary and assessment of carbon emissions in China’s national industrial parks, as well as that of the development of energy infrastructure within China’s national industrial parks, is of great relevance to future research. Jing-Chun Feng et al. [56] conducted a scenario analysis of the Traditional Chinese Medicine Industrial Park in Zhongshan City, Guangdong Province, China, to achieve zero carbon emissions. The results showed that all three scenarios could achieve zero carbon emissions. The economic assessment found that purchasing carbon offsets is the least cost-effective under current market conditions. Sensitivity analysis showed that the carbon price and the rate of reduction in the cost of solar energy significantly impacted the cost-effectiveness of carbon emission reductions. At the same time, with the current 90% reduction in the price of solar energy, the large-scale application of renewable energy, which generates more carbon offsets, could reap more economic and carbon reduction benefits. Xu Zhu et al. [57] proposed a regional integrated energy systems (RIES) energy management strategy based on energy stepped utilization to minimize the daily cost further and fully use the power. Finally, the simulation analysis showed that their proposed RIES energy management approach allowed for more flexible scheduling of gas turbine combinations and equipment output and could provide a more economical scheduling solution. Zhe Liu et al. [58] argued that there is currently more research required on achieving comprehensive development of industrial symbiosis with the aim of greenhouse gas emission reduction. They analyzed the challenges of lack of indicators, survey methods, and regional differences, and they detailed the opportunities for mitigating greenhouse gas emissions through the comprehensive development of industrial symbiosis. M.A. Butturi et al. [32] highlighted four main ways of achieving energy strategies and demonstrated possible solutions to increase renewable energy uptake at an industrial level. In addition, research gaps were identified, revealing that energy symbiosis networks between industrial and urban areas that integrate renewable energy systems remained to be adequately studied.

The evolution of research themes in these three stages showed that research related to carbon reduction in industrial parks moved from a shallow to a deeper perspective, from a single viewpoint to a systematic one. Initially, industrial parks were designed to promote vigorous national and regional economic development, and as spatial aggregates of production and innovation factors, they became engines of economic growth. The first phase of research raised the need for integrated energy management in industrial parks, which has remained the focus of research to date. The concept of carbon neutralization has been proposed but has yet to be studied in detail. During the second phase, the audit of carbon emissions in industrial parks received unprecedented attention, and the application of industrial coproduction in industrial parks blossomed. A range of complex models and quantitative tools have been proposed and implemented. In the third stage, research on reducing carbon emissions in industrial parks became more systematic, and
scenario analysis and sensitivity analysis were integrated into carbon accounting. The symbiosis between industrial parks, towns, and surrounding areas has also received the attention of researchers. The concept of zero-carbon industrial parks has been proposed and implemented, but the number of studies is still lacking. All the studies were validated experimentally and with results in specific parks, and this field of research is very relevant and practical.

3.4.2. Burst Detection

A research frontier is an active direction or theme in the development of a discipline, which is derived from the discipline’s knowledge base. Burst detection can identify emerging or upcoming research frontiers [59]. By analyzing burst detection, we can specify periods and dynamic changes in the intensity of keyword emergence, thus reflecting the cutting-edge situation and trends in the research field [60]. Table 6 shows the first 20 keywords regarding emergence frequency, their emergence intensity, and the start and end years. The keyword with the highest intensity of occurrence is “system”, with an intensity value of 3.16, which has attracted extensive research in academia. The longest occurrence is “sustainability”, which has been an active theme from 2015 to 2020. The changing frontiers of research in the field can be divided into three phases based on keyword “burst detection”.

Table 6. Top 20 Keywords with the Strongest Citation Bursts.

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Strength</th>
<th>Begin</th>
<th>End</th>
<th>2001–2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>emission reduction</td>
<td>1.89</td>
<td>2013</td>
<td>2013</td>
<td></td>
</tr>
<tr>
<td>carbon dioxide</td>
<td>2.64</td>
<td>2014</td>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>sustainability</td>
<td>2.39</td>
<td>2015</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>system</td>
<td>3.16</td>
<td>2016</td>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>design</td>
<td>2.93</td>
<td>2016</td>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>ghg emission</td>
<td>1.87</td>
<td>2016</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>sensitivity analysis</td>
<td>2.33</td>
<td>2017</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>life cycle assessment</td>
<td>2.1</td>
<td>2017</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>performance</td>
<td>2.03</td>
<td>2017</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>mitigation</td>
<td>2.42</td>
<td>2018</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>management</td>
<td>2.13</td>
<td>2018</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>energy efficiency</td>
<td>2.28</td>
<td>2018</td>
<td>2019</td>
<td></td>
</tr>
<tr>
<td>optimal design</td>
<td>2.98</td>
<td>2019</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>circular economy</td>
<td>2.95</td>
<td>2019</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>renewable energy</td>
<td>2.25</td>
<td>2019</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>model</td>
<td>1.87</td>
<td>2019</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>energy</td>
<td>2.14</td>
<td>2020</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>economic development</td>
<td>2.48</td>
<td>2021</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>integrated energy system</td>
<td>2.31</td>
<td>2021</td>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>carbon peak</td>
<td>1.98</td>
<td>2021</td>
<td>2022</td>
<td></td>
</tr>
</tbody>
</table>

From 2013 to 2016, keywords representing the research frontiers in this period are “emission reduction”, “carbon dioxide”, “sustainability”, “system”, and “design”. The studies on GHG emissions in IPs have seen a tremendous increase, and carbon emissions reduction attracted the attention of researchers in this period. The study of energy systems in industrial parks and the study of the preferential design of emission reduction schemes in parks have become hotspots, and scholars have judged the carbon emission reduction benefits of industrial parks from the perspective of carbon emission audits. Chuan Zhang et al. [61] proposed a methodology to assess the opportunities for waste heat recovery (WHR) in EIPs at a park level. Single and multi-objective optimization approaches were used. They concluded that multi-objective optimization can provide a trade-off between different objective functions and that waste heat discontinuities severely affect the optimization of waste heat recovery networks. Delin Fang et al. [62] established an embodied carbon accounting framework based on energy to identify the industrial park’s input–output structure and embodied carbon emission flows. A case study of a typical industrial park in Beijing shows that the implied carbon emissions of the whole process are mainly concentrated in three segments: external inputs, waste management, and water recycling, with the implied carbon emissions of external inputs being less intensive than those of waste management and water recycling. Qun Guo et al. [63] focused on the
coordinated operation of industrial energy parks (IEP) with various thermal, electrical, and cooling loads to satisfy economic and environmental benefits. They proposed a combined cooling, heat, and power (CCHP)-based energy industrial park equipped with multiple energy conversion facilities, such as absorption and electric chiller, power-to-heat facility, and multi-energy storage. In this phase, scholars paid more attention to determining carbon emission sources of energy infrastructure in industrial parks, constructing a carbon accounting framework, and comparing carbon emissions. The research horizon was centered on energy infrastructure planning and multiple energy conversion methods. However, the research on the optimization and transformation of the comprehensive energy structure of industrial parks, its carbon emission reduction effect, and the utilization of renewable energy has yet to be comprehensively conceived.

From 2017 to 2018, keywords representing the research frontiers are “sensitivity analysis”, “life cycle assessment”, “performance”, “mitigation”, “energy efficiency”, and “optimal design”. More assessment tools are being used to measure the evaluation and decision-making of carbon reduction options for industrial parks. Elements such as sensitivity analysis in economics have been used to assess the environmental performance of industrial parks, life cycle assessment methods to innovative multi-level designs, and research related to carbon reduction in industrial parks have been further expanded. Tefera Mekonnen Azerefegn et al. [64] examined the feasibility of integrating PV/wind power systems into existing unreliable grid/diesel generator systems for supplying the critical loads of industrial parks in three different regions of Ethiopia. The results show that the grid/diesel/photovoltaic/battery system is technically, economically, and environmentally feasible for all three climatic regions. Xiaokai Xing et al. [65] established a multi-objective mathematical programming (MOMP) model to minimize each industrial park’s total construction investment and operation costs considering emission, energy balance, and other technical constraints. The augmented ε-constraint method was used to determine the optimal configuration, operation strategy, and economic and emission performance of the distributed energy system in each industrial park. As an example, the model was validated using the design of distributed energy systems in three industrial parks in Jinan City. Murat Yeşilkaya et al. [66] proposed a theoretical industrial symbiosis network in an eco-industrial park hosting companies focused on the forest industry. The life cycle assessment (LCA) method was used to establish the network. Their data from the LCA made it possible to determine the amount and type of potential byproducts, waste, and energy that could be exchanged in this network. At this stage, the design of energy systems in industrial parks had been innovatively developed, and their optimal configuration and economic benefits were included in the assessment of the green transformation of the industrial parks. Nonetheless, the interactions between the ecological environment and industrial parks have yet to be further discussed regarding other elements within industrial parks, such as the driving force of stakeholders and the influence of national and local policies.

Since 2019, keywords representing the research frontiers have been “management”, “circular economy”, “renewable energy”, “economic development”, “model”, and “integrated energy system”. These keywords represent themes that have become more active in research in recent years. Xin Cao et al. [67] introduced an urban ecosystem that transformed the cement industry into an effective complement to the environmental infrastructure. Their approach included proposing technologies for developing efficient urban ecosystems centered around cement plants; evaluating their environmental and economic performance; identifying barriers to their development; and proposing supportive policies. The results showed that the city’s waste recycling rate increased from 50% to 70%, saving 0.6 Mt/a of equivalent coal and reducing carbon dioxide emissions by approximately 3.0 Mt/a. Aldric S. Tumilar et al. [68] introduced a new modeling framework capable of designing and evaluating materials and energy exchanges within an industrial ecosystem. In this scalable model, an algorithm was developed to balance material and energy exchange and determine optimal inputs and outputs based on industrial symbiosis objectives and participating industries. Xiang Yu et al. [69] examined a sample of 171 green industrial parks certified by
China’s Ministry of Industry and Information Technology (MIIT). Using the Tapio decoupling model, we conducted decoupling analyses at the national and regional scales of their economic growth and environmental conservation for three consecutive years. Embracing the gradual expansion of the disciplinary vision of carbon emission research in industrial parks, the current frontier themes of academic research revolve around the circular economy, integrated energy systems, and renewable energy utilization. The decoupling state of the carbon economy and the synergistic effect of environmental protection has gained the attention of scholars. These research themes have been the frontier of progress on carbon emissions research in industrial parks in recent years with a certain continuity.

4. Challenges and Prospects for the Zero Carbon Industrial Parks

There is a massive expansion of related research on carbon neutralization in the world [70]. Discussions on achieving carbon neutrality at varying levels are ongoing in energy, architecture, and engineering disciplines [71]. Towards carbon neutralization, the restructuring and transformation of traditional fossil energy sources are the primary focus of academia’s considerations. Integrated energy planning from a social perspective has yet to be abundant but is attracting further attention [72]. At a micro-level, there has been a great deal of exploration in the design and assessment of zero-carbon buildings [73,74]. There has also been a considerable amount of research into the modeling and verifying of zero-carbon community planning from a systematic standpoint [75]. From a more macro-level, studies on energy demand and CO$_2$ emissions in cities [76] have addressed the assessment of carbon emissions from renewable energy sources in cities, natural carbon sinks in cities, and projections of the timing of achieving carbon neutralization in cities [77]. Furthermore, on a societal level, previous studies have applied input–output models, spatial systems, geographic information system maps, light detection, and ranging techniques to map carbon emissions. Decarbonization technologies, negative carbon technologies, carbon trading, and carbon taxes have also been mentioned [78].

Nevertheless, as national and regional engines of economic growth [79] and highly aggregated units of social production and life [80], the study of carbon emissions from industrial parks could be broadened further. Increasingly, planning discussions on EIPs are taking a systematic approach to frame, incorporating stakeholders such as society’s policies, businesses, and people’s wellbeing into consideration [81]. Technologies are always one of the fundamental driving forces in carbon neutralization [82]. Social issues have received strong academic interest. The development of relevant policies, laws, and regulations, as well as the active participation of enterprises, can contribute to achieving carbon neutralization at different levels. A multilayered systemic framework can also promote the development of zero-carbon parks [83]. According to the research previously in this paper, there are still gaps and challenges in the research field of carbon emissions reduction in IPs. Incorporating the research mentioned above and the hotspots and research frontier trends in the area of carbon emission reduction in industrial parks, this paper summarizes the gaps in the current research on carbon emissions reduction in IPs as well as the potential directions for future research exploration. Thus, we propose the following challenges and prospects for the construction of zero carbon industrial parks:

1. The carbon neutralization objective for IPs has not been established. There have been many studies focusing on how to reduce carbon emissions in industrial parks through measures such as integrated management solutions, but few case studies have started with the goal of achieving carbon neutralization in industrial parks as a construction and operational objective [84]. Apart from that, research on industrial parks has remained focused on planning EIPs, calculating and monitoring carbon emissions from established EIP resources [85], consolidating and repositioning energy infrastructure, and industrial symbiosis projects [86]. The transition from EIP to zero-carbon industrial park (ZCIP) or the methods and practices of how to build a ZCIP have received scant mention. It is vital to clarify the goal of carbon reduction in industrial parks. A ZCIP must have carbon neutralization as its primary vision [87].
Therefore, its construction goal and operational management throughout its life cycle can be coordinated to achieve zero carbon emissions by working together, significantly increasing the efficiency of carbon emissions reduction [88]. Within such a macro goal, energy management, production logistics, economic efficiency, and human-centered concepts need to be integrated into the system framework of a zero-carbon park [89]. Carbon neutralization is the essential feature that distinguishes a ZCIP from a traditional industrial park. It is also the principal basis for developing strategies in a park’s construction process. The ZCIP system’s design should be based on this vision to build a management and operation system and a human-centered intelligent service platform, and carbon emission and absorption are one of the evaluation criteria of the ZCIP system.

Absence of integrated exploration of carbon absorption and emissions. The current study focused on measuring the sources of carbon emissions in industrial parks, with direct and indirect emissions. Electricity consumption and renewable energy offsets were all taken into account [90]. There are some challenges in measuring the carbon emissions side of the industry, such as the comprehensive inclusion of Scope 1, 2, and 3, for which data are not readily available. Whether upstream and downstream carbon emissions need to be included in the carbon accounting criteria needs further exploration [91]. Carbon emissions from transport and renewable energy-powered street lighting in parks also need to be discussed. Beyond this, little research has been conducted on carbon sequestration [92]. The achievement of carbon neutralization relies on carbon sequestration measures such as bioenergy with carbon capture and storage (BECCS) and carbon capture, utilization, and sequestration (CCUS), in addition to renewable energy offsets [93]. The critical role of vegetation planting for carbon sequestration in industrial estates has rarely been mentioned, but carbon sequestration is an essential part of achieving carbon neutrality. There are two main paths to achieving carbon neutrality in a ZCIP: controlling carbon emissions and increasing carbon sequestration, establishing a carbon trading market, and strengthening intelligent control [94], primarily utilizing renewable energy sources such as solar, wind, biomass fuels, nuclear, and other primary energy sources. Meanwhile, the development and large-scale application of hydrogen energy storage are being strengthened [95]. From an energy use point of view, energy saving and emissions reduction are mainly from the energy, production, transportation, building, and living aspects of parks [96]. We must optimize industrial production patterns, develop low-carbon and carbon-negative technologies, and promote zero-carbon transport and living. In addition, an integrated energy system must be established, combined with an intelligent grid, to form an all-in-one energy plan with multiple energy sources complementing each other. Furthermore, at the carbon sequestration end, the development of ecological carbon sinks, such as vegetation planting and pocket parks, as well as industrial carbon capture and sequestration capture technologies must be implemented. In addition, establishing a carbon trading market to optimize the allocation of carbon emission rights can further promote the upgrading of enterprises.

Lack of a systematic review of social and environmental factor integration. The zero-carbon upgrade of many traditional parks is a significant aspect in constructing zero-carbon parks. Currently, the infrastructure of traditional parks, such as power systems, network systems, service systems, and data centers, is aging and lacks connectivity. The embedding of intelligent technologies urgently requires infrastructural upgrade and transformation, with a high demand for innovative design of physical systems and information systems [97]. Traditional Park design is based on fragmented and functional construction, with each sector relatively isolated and difficult to interoperate information with. The lack of system design thinking can lead to difficulties in obtaining sustainable benefits and smooth iterative system updates [98], and there is particular neglect of social and ecological factors surrounding the park, thus lacking the resilience to develop in the ever-changing economic and social environments. In
addition, the concepts of carbon pricing, carbon trading markets, and carbon taxes are rarely mentioned [99]. An industrial park is a socioeconomic and ecological system formed by the interaction of multiple stakeholders, including the park, government, enterprises, and the public [100]. For industrial parks, their environmental management demands the participation of multiple parties. When considering environmental issues in industrial parks, researchers often base their research on the park, the government, or the enterprises, lacking the perspective of multiple subjects [101]. Public facilities and services, social consumption levels, tax policies, openness, regional industrial structure, and technological innovation capacity all have a significant impact on the output efficiency of industrial parks [93]. In the social dimension, the direct guiding role of national policies and the combined role of strategies with other dimensions need to be taken into account [102]. The design of a ZCIP system needs to consider the interests and needs of decisionmakers, managers, technical staff [103], resident enterprises, and residential users, and establish a decision model for the zero carbon park system [104]. Rationalize the weighting of different stakeholders’ decisions under the carbon neutralization target to motivate people to respond to the park’s policies and become a potent force for improving a park’s operational efficiency in the social dimension [105]. Ecologically, it is appropriate to exploit the strengths of local natural resources to promote the carbon neutralization level of IPs [106]. On the one hand, making good use of local natural resources such as wind, solar, and hydropower can solve most of the park’s energy supply needs, while other energy needs can be supplemented by utilizing intelligent grids or the presence of power generation, can achieve zero-carbon energy in IPs [107]. On the other hand, ecological carbon sinks can create small eco-climatic zones in IPs, designed and distributed in accordance with the carbon emissions of the buildings, creating gardening in the park and attracting households to participate in the maintenance and operation of the ecological carbon sink facilities.

4 Insufficient uptake of emerging technologies and theories. The digital transformation of society has permeated all aspects of industrial production. Industrial parks integrate various resources inside and outside the parks, but little research has yet addressed the flexible use of emerging technologies in industrial parks. The application of emerging technologies such as 5G, IoT, digital twin, artificial intelligence, and cloud computing has not been studied in depth in the current articles on carbon reduction in industrial estates [108]. The traditional IP mainly relies on human resources management, which wastes many human resources. Handling these problems is a passive response, failing to provide intelligent and proactive services and lacking user experience design [109]. The various monitoring and management systems in parks fail to integrate and control the data collected and present it visually to park personnel [110], resulting in low operational efficiency. Data from various departments within the traditional IP lack effective sharing and interoperability [111]. A park’s real-time monitoring data needs to be processed and optimized by applying intelligent algorithms for data mining and analysis and filtering out critical information. To better achieve the goal of carbon neutrality, a park’s smart governance must be an innovative transformation of the entire park system for real-time carbon monitoring and management [112]. Digital empowerment is the key to building a zero-carbon park. While technology development for renewable energy and smart power systems plays a key role [113], the full integration of digitalization can drive the growth of zero-carbon park technology even more strongly. Firstly, zero carbon parks can be digitally managed to improve operational efficiency. Secondly, digitalization can also drive technological innovation in both directions, promoting the development, promotion, and commercialization of zero-carbon, carbon-reducing, and carbon-negative technologies. Thirdly, digitization helps to build a carbon monitoring system to achieve a real-time panoramic picture of a park’s carbon emissions [114]. In addition, digitalization is also a strong support for the operation of the carbon accounting system, which involves social entities from
central to local, government to enterprise, and other cross-sectoral levels. The source of data, calculation methods, calculation scope, and other complex factors require digital monitoring to ensure accuracy.

5. A Systematic Design Framework to Construct Zero-Carbon Industrial Parks

Driven by the urgency of the global carbon neutralization target, industrial parks are undergoing transformation and development, evolving toward ZCIPs. Many achievements have been made in the research on carbon emissions reduction in industrial parks. However, the current research needs to advance toward carbon neutralization or even negative carbon emissions to better promote the development of a circular economy. Traditional park design lacks system thinking and is based on the construction of single-point functions, with a lack of deep integration between technology and people. Current industrial park research seldom includes equally critical social and ecological factors in its planning consideration, which leads to the isolation of the park system and the inadequacy of management and service and makes it challenging to meet the growing and diversified needs of people in production and life. This paper proposes a generalized ZCIP system design framework for future research. The composition of the ZCIP system’s design elements can be summarized as one objective, two sides, three dimensions, and one services platform, as shown in Figure 9.

**Figure 9. A systematic design framework to construct zero-carbon industrial parks.**

1. **One objective: carbon neutralization**
   
   This objective is the primary principle of ZCIP construction and the principal basis for developing strategies at all levels of the IP construction process. ZCIP system design is based on this vision to build a management and operation system and a people-oriented intelligent service platform. When building a ZCIP or upgrading traditional parks, establishing this construction goal enables the control of carbon to be integrated into the system design of ZCIPs.

2. **Two sides: carbon emission and carbon absorption**
   
   The realization of carbon neutralization in zero-carbon parks starts on two main paths, controlling carbon emissions and increasing carbon absorption. A carbon trading market is also established to facilitate the flow of carbon credits. On the carbon emission side, renewable energy sources, such as solar and wind power, are combined with distributed...
energy systems of complementary performance. On the carbon absorption side, ecological carbon sinks and replicable CCUS technologies are developed.

3 Three dimensions: social, technical, and ecological dimensions

The complex factors inside and outside ZCIPs can be categorized into three dimensions. Current research on ZCIP system design is mainly technology-centered, focusing on hydrogen production technology, carbon capture, utilization, and storage (CCUS), information and communications technology (ICT), zero-carbon buildings, and zero-carbon transportation. In an increasingly complex global climate, and an economic and political development context, a single-technology orientation is no longer sufficient to maximize the overall effectiveness of a zero-carbon park. Establishing social–technological–ecological thinking in ZCIP system design can expand the vision of park strategy development.

In the social dimension, ZCIP system design needs to consider the interests and needs of decisionmakers, managers, technical staff, resident companies, and residential users. Managers need to establish a decision model for the ZCIP system and assign reasonable decision weights to different stakeholders under the goal of carbon neutralization to motivate people to respond and cooperate with government policies.

In the technical dimension, digital empowerment is the way to build a zero carbon park. The application of IoT and digital twin technologies is crucial to developing renewable energy and intelligent power system technologies. At the same time, the full integration of digitalization can more strongly promote the development of zero-carbon park technologies. Zero-carbon parks can improve operational efficiency through digital management.

In the ecological dimension, ZCIPs must take advantage of local natural resources according to local conditions. On the one hand, using local natural resources such as wind, solar, and hydropower can solve most of a park’s energy supply needs. Other energy needs can be supplemented by a smart grid or presence power generation, which can realize the zero-carbon energy of the park.

4 The carbon-neutral smart services platform

This platform, with built-in control, supports a ZCIP’s business and activities and enables the implementation of smart governance. Technologies such as IoT, big data, and artificial intelligence can help track and monitor resident enterprises’ relevant data. A user-friendly visualization system is designed to show the park management and decisionmakers a real-time carbon-neutral and dynamic picture of the park. This platform can realize the digital transformation of the park in terms of living services, medical appointments, catering services, transportation, etc., expanding the scope of information sharing and improving the park’s governance.

6. Conclusions

Based on the 114 papers in the WoS database from 2001 to 2022, this paper investigated research hotspots and evolving research frontiers in the field of carbon emissions reduction in industrial parks using CiteSpace and bibliometric analysis. According to the descriptive statistical analysis, the number of articles gradually increased and had a tendency to increase over time. These articles were primarily distributed in the environmental and energy disciplines while concentrated in specific vital journals. An analysis of the cooperation network showed that research in this field is centered in China, with immense contribution from Chinese institutions and scholars. Four research hotspots were identified through keyword co-occurrence network analysis and keyword clustering: energy management, industrial symbiosis, economic development, and carbon emission assessment methods. A timeline view of the co-citation analysis was used to categorize the research findings into three phases of development and summarize the evolution of knowledge at each stage. Employing burst detection, this paper concluded that future research would focus on the systematic direction of industrial parks, the complementary application of integrated energy sources, the carbon offsetting of renewable energy sources, and the further development of economic analysis. In the end, this paper summarized the
current research gaps in this area and the challenges of building ZCIPs: the ambiguity of the carbon neutralization objective of IPs, the absence of integrated exploration of carbon absorption and emissions, the lack of a systematic review of social and environmental factor integration, and the insufficient uptake of emerging technologies and theories. With the aim of achieving carbon neutralization in IPs, this paper proposed a systematic guidance framework for building ZCIPs, which provides important references for the theoretical and practical research of industrial park builders and scholars. In future research, different data sources and knowledge-mapping tools should be incorporated to enrich the data source for more comprehensive discussion and analysis of the research topic.

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