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Research Article

Pioneering Carbon Research: Unveiling a Decade of Academic Exploration through SCIE Highly Cited Papers

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ABSTRACT

This study addresses the critical need for understanding journal publication trends in carbon research, which plays a vital role in advancing the field, guiding research priorities, informing policy decisions, and assessing the sustainability of efforts to combat carbon-related challenges. The primary objective is to analyze 19,155 highly cited articles and review papers published globally between 2013 and 2022, indexed in the Science Citation Index-Expanded (SCIE) dataset of the Web of Science Core Collection. The study examines key aspects of publication platforms, including publishers, journal titles, affiliated categories, and open access status, to assess changes in publication dissemination. Text mining techniques were employed to analyze author keywords and abstracts, identifying emerging trends in carbon research across multiple academic disciplines. Additionally, the geographic distribution of researchers was studied to track shifts in the global landscape of expertise in this field. The study introduces an innovative 3-dimensional analysis system, categorizing research subjects into platform (x-axis), text (y-axis), and scholars (z-axis). Methodologies such as text mining, CiteSpace, and ArcGIS were applied to analyze the trends over the past decade, offering new insights into the evolution of carbon research. This approach provides a comprehensive framework for understanding the development of carbon research, offering valuable tools for scholars and institutions engaged in the field.

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INTRODUCTION

Profound content and Far-Reaching Significance of Carbon Research

Carbon, with the symbol 'C' and atomic number 6, is a versatile and abundant non-metallic element found in the Earth's crust, which has several allotropes, including graphite and diamond, each with unique properties. Carbon is the foundation of organic chemistry, forming the backbone of molecules in living organisms, as well as creating diverse compounds essential for life, such as proteins, carbohydrates, fats, and nucleic acids. Carbon finds extensive use in industries, from steel production using carbon as an alloying element to activated carbon in purification processes and carbon black in manufacturing various products like tires and ink. The carbon cycle involves the circulation of carbon through the atmosphere, oceans, soil, and living organisms. It encompasses processes like photosynthesis, respiration, decomposition, and fossil fuel combustion. Understanding carbon sequestration processes, such as natural storage in forests or engineered methods like Carbon Capture and Storage (CCS), is crucial for mitigating greenhouse gas emissions and climate change, which contributes to the development of carbon markets, incentivizing emission reductions and fostering financial mechanisms to address climate change. The significance of carbon research lies in its potential to drive sustainable development, combat climate change, promote innovation, and pave the way for a more resilient and environmentally conscious future.

WoS's Highly Cited Papers feature a curated selection of scholarly articles recognized for their exceptional impact and influence within their respective fields. These papers represent the pinnacle of impactful research, as they have received high citation counts,[1,2] indicating their significant contributions to advancing knowledge and shaping their fields.[3,4]

Definition of the Categorized Six Factors

Access Factor

WoS database encompasses various categories of publishers, covering a wide range of disciplines and specialties.[5,6] Categories of publishers, such as Medical Publishers, Social Sciences and Humanities Publishers, Multidisciplinary Publishers, Society Publishers, Technical Publishers, *et al.*, contribute to the diversity and depth of scholarly literature accessible through the WoS

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database, offering a comprehensive resource for researchers across various domains.

Categories Factor

WoS categorizes academic research into several dozen disciplinary fields to better organize and retrieve relevant literature. These disciplines cover a wide range of areas, including natural sciences, social sciences, engineering, technology, medicine, and health, whose specific number may vary over time due to updates, but typically encompasses several dozen or even more.

Keywords Factor

The keywords for articles included in WoS are typically provided by the authors or journal editors, which are used to describe the main topics, content, and key concepts of the articles, making it easier for readers to find relevant literature. The selection of keywords should accurately and comprehensively reflect the article's subject matter, aiding in retrieval and categorization, as well as being used within the WoS database to index and label articles, assisting users in finding relevant literature through keyword searches.

Abstract Factor

WoS defines an abstract as a brief summary of the article's content, typically provided by the authors, and utilizes abstracts to assist users in swiftly browsing and assessing a large volume of literature, making them crucial for literature retrieval and screening. The abstract covers the main points, research methods, results, and conclusions of the article, whose purpose is to offer readers an overview of the article's content, facilitating a quick understanding of the research's focus and significance, aiding in the decision of whether to delve further into the full text. Therefore, authors often strive to ensure that abstracts accurately and clearly convey the core information of the article.

Regions Factor

WoS introduces the feature of searching by the authors' affiliated country or region to facilitate users in retrieving and analyzing research outcomes specific to certain countries or regions, which allows users to filter results according to particular countries or regions, enabling exploration of literature published within those areas, thereby uncovering the research focus, developmental trends, and contributions within the region. This capability proves highly beneficial for international comparative research, tracking academic output in specific regions, and gaining insights into global research dynamics. Additionally, it assists researchers and policymakers in understanding the research levels, strengths, and trends across different regions and disciplines, thereby providing reference and support for decision-making. Hence, this search functionality based on authors' affiliated country or region holds significant importance within the framework of WoS.

Citations Factor

The display of citation counts and citing article information in WoS aims to provide insights into the impact and scholarly communication of the indexed papers, which could reveal how other academic articles reference a specific paper, indicating its influence and adoption within the academic community. This information is critical for assessing a paper's impact, significance, and academic contribution, by which researchers can discern which scholars, journals, or fields contribute to a specific research area, aiding in tracking the dissemination and reach of a particular research output. These data are widely used for academic assessments, comparative analyses of research outcomes, and evaluating the significance of specific papers within certain fields or disciplines.

Research Questions

In the realm of carbon research, it is crucial to understand the current state of knowledge and how it has evolved over the past decade. This study, "Pioneering Carbon Research: Unveiling a Decade of Academic Exploration through SCIE Highly Cited Papers," seeks to provide a comprehensive overview of the advancements in carbon research by analyzing highly cited publications indexed in SCIE. Through this exploration, the study aims to identify emerging trends, patterns, and significant achievements that have shaped the field. Additionally, the research delves into the interdisciplinary significance of carbon research, examining its far-reaching implications for both the environment and societal development. A critical objective of this work is to pinpoint existing knowledge gaps and prioritize areas where further research is needed to drive innovation and sustainability in carbon-related studies.

Analyzing the Development Trends and Significance of Carbon Research. This paper, for the first time, divides the six characteristics of the WoS -indexed papers mentioned above into an XYZ coordinate axis for research analysis. In a groundbreaking approach, this study introduces a novel method by mapping the 6 distinct attributes of the WoS-indexed papers into a tri-dimensional XYZ coordinate system. This innovative framework allocates the X-axis to denote the platform, the Y-axis to signify the textual elements, and the Z-axis to encapsulate the scholarly impact, thereby facilitating a comprehensive and multifaceted analysis of the research corpus.

Within the XYZ coordinate system, a sophisticated analytical framework is employed to classify the attributes of each WoS-indexed paper. The X-axis encompasses the publisher, journal, and the categorized discipline, amalgamating these elements to signify the platform on which the paper is published. The Y-axis is constructed by compiling the keywords and abstract content, which together form a representation of the paper's textual substance. Finally, the Z-axis aggregates the authors' affiliated country or region, citation count, and citation journal

details, providing a comprehensive measure of the scholarly influence exerted by the paper. This tridimensional approach provides a comprehensive and structured view of the research corpus, allowing for in-depth analysis and insights into the various facets of academic publishing.

METHOD IMPLEMENTATION AND DATA PROCESSING

Primary Application of Advanced Analysis Tools

Text mining, also known as text data mining or text analytics, extracts meaningful information from text data using techniques such as Natural Language Processing (NLP) and machine learning.[7] These techniques help identify significant words, phrases, and entities like names and organizations,[8] and can be applied for tasks such as sentiment analysis[9] and topic modeling.[10] Tools like SAS Text Miner, VOSViewer, XSTAT, and Apache OpenNLP are commonly used, depending on the project's requirements for scalability, ease of use, and integration with other software. CiteSpace is popular for analyzing scientific literature,[11] focusing on bibliometrics and visualizing research trends.[12] It identifies keyword co-occurrences and performs cluster analysis to uncover thematic clusters within a field.[13,14] VOSviewer, similarly, analyzes text within scientific literature using NLP techniques[15,16] and generates visual representations like word clouds to highlight relationships between terms.[17] ArcGIS is geographic information system software widely used for spatial analysis, mapping, and managing geospatial data across various industries.[18] GraphPad Prism is another versatile tool used for scientific graphing, statistical analysis, and data visualization, offering a user-friendly interface for researchers across different fields.[19,20]

Data Collection Query, Data Preprocessing And 3-Dimensional Analysis Strategies

This study searched the SCIE dataset of the WoS core database using the keyword 'carbon,' applying filters for 'article' and 'review article.' As a result, 19,155 highly cited papers published between 2013 and 2022 were retrieved. The publishers and journals (publication titles) of these papers, along with data regarding keywords, abstracts, authors' affiliated countries or regions, and citation counts, were downloaded and archived for analysis from the WoS database.

The research focuses on highly cited papers related to global carbon research published from 2013 to 2022, indexed in the WoS database (Table 1). The number of such papers has shown a steady upward trend, from 1,336 papers in 2013 to 2,557 papers in 2022. The largest increase occurred in 2019, with an 18.35% rise compared to 2018. The analysis covers eight main aspects: publisher, publication, sponsoring organization, subject classification, authors' affiliations, authors' institutions, h-index, and citation status. These eight items provide a broad measure of the influence of the papers (Table 2).

The XYZ coordinate system, constructed from six characteristics of the indexed papers, represents the academic landscape, covering publication platforms (publishers and open access), textual content (keywords and abstracts), and scholarly impact (regions and citations). The tools used for analysis are outlined in Table 3, offering a framework for examining the data.

RESULTS

Platform

From 1136 papers in 2013 to 2557 papers in 2022, the volume of highly cited papers in the field of carbon research nearly doubled. The significant 18.35% increase in global carbon-related papers indexed in the WoS Core Database from 2018 to 2019 can be attributed to several key factors. The release of the IPCC's Special Report on Global Warming of 1.5°C in 2018 heightened global awareness of the urgent need to address climate change, driving intensified research on carbon emissions and neutrality technologies. Simultaneously, policy drivers such as the European Union's 2050 Carbon Neutrality Strategy and China's low-carbon development plans spurred academic and industrial focus on carbon-related studies. Enhanced funding opportunities from programs like the EU's Horizon 2020 and China's National Natural Science Foundation further supported research in areas such as carbon capture and carbon markets. High-impact journals launched special issues and columns dedicated to carbon research during this period, attracting a surge of high-quality submissions. Additionally, the rapid development of interdisciplinary research, leveraging advanced technologies like AI and big data analytics, deepened collaborations and broadened the scope of studies in this field. Collectively, these factors contributed to the marked growth in carbon-related publications, reflecting a dynamic interplay of policy, technology, and academic innovation. This highlights the escalating attention directed towards the carbon research domain on a yearly basis. The varying annual growth rates of carbon-related highly cited publications in the WoS Core Collections SCIE Database from 2013 to 2022 can be attributed to several interconnected factors. Global awareness and policy

Table 1: Carbon related highly cited publications during 2013-2022 in WoS Core Collections SCIE Database.

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Carbon	Total pub	1336	1353	1472	1679	1787	1875	2219	2330	2547	2557
	Growth rate, %	-	1.27	8.80	14.06	6.43	4.92	18.35	5.00	9.31	0.39

Table 2: Characteristics of publications during 2013-2022.

Factors	Characters	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Publishers Record Count	Total	55	48	53	51	52	48	45	57	55	62
	Growth Rate, %	-	-12.73	10.42	-3.77	1.96	-7.69	-6.25	26.67	-3.51	12.73
Publications Record Count	Total	360	340	349	380	373	392	432	449	449	486
	Growth Rate, %	-	-5.56	2.65	8.88	-1.84	5.09	10.20	3.94	0.00	8.24
Regions Record Count	Total	84	80	87	85	85	93	99	115	106	98
	Growth Rate, %	-	-4.76	8.75	-2.30	0.00	9.41	6.45	16.16	-7.83	-7.55
WoS Categories Record Count	Total	112	108	114	102	99	106	114	117	116	124
	Growth Rate, %	-	-3.57	5.56	-10.53	-2.94	7.07	7.55	2.63	-0.85	6.90
Affiliations Record Count	Total	1633	1555	1766	2076	2031	2138	2554	2946	3089	3179
	Growth Rate, %	-	-4.78	13.57	17.55	-2.17	5.27	19.46	15.35	4.85	2.91
Affiliation with Department Record Count	Total	1533	1603	1863	2043	2121	2109	2613	2793	2781	2660
	Growth Rate, %	-	4.57	16.22	9.66	3.82	-0.57	23.90	6.89	-0.43	-4.35
Citation Record Count	Total	691392	660273	653185	689606	664934	600265	561438	453630	303581	143163
H-Index	Total	482	461	455	441	418	388	347	285	204	119

Table 3: XYZ coordinate system, analysis tools and applications of 3-Dimensional analysis strategies.

Tripartite axes	Factors of 3-Dimensional analysis	Distinct characteristics inherent in the indexed papers	Analysis tools
X	Platform	Publishers	XSTAT
		Open Access	GrapPad Prism
Y	Text	Keywords	CiteSpace
		Abstract	VOSviewer
Z	Scholar	Regions	ArcGIS
		Citations	WoS Report

developments, such as the 2015 Paris Agreement, often drive significant surges in research output, while years without groundbreaking initiatives see slower growth. Research funding cycles, with large programs like Horizon 2020 or China's National Natural Science Foundation, also play a crucial role, as funding announcements or renewals stimulate output, but delays in allocation can cause fluctuations. Technological advancements, such as AI and carbon capture technologies, periodically expand research scope, although their adoption often requires a lag period, influencing growth trends. Interdisciplinary collaborations across fields like chemistry, energy science, and environmental science bring new perspectives and increased output, but these efforts take time to develop and mature, leading to irregular growth rates. Lastly, external disruptions, such as the COVID-19 pandemic in 2020, can slow research productivity and publication processes. Together, these factors create a dynamic landscape that reflects the complex interplay of policy, funding, technology, collaboration, and global events in shaping academic research. The growth trajectory between publishers and publishing journals remained relatively consistent from 2013 to 2022. The growth trajectory remained relatively consistent due to several key factors. First, the annual growth rate fluctuations

for publishers and journals were relatively small, mostly staying within a ±10% range, indicating a stable trend. Second, the total numbers of publishers and journals showed steady increases over the decade, rising from 55 to 62 publishers and 360 to 486 journals, respectively, despite minor year-to-year variations. Third, the global publishing ecosystem for carbon research has matured, with major publishers consolidating their roles and maintaining consistent growth. Fourth, the close correlation between the growth of publishers and journals reflects a mutually reinforcing dynamic, where publishers support the expansion of the ecosystem by launching new journals or broadening existing ones. Lastly, the stable demand for carbon research, driven by global carbon neutrality policies and increased research funding, has ensured sustained publishing activity. Together, these factors underscore the robust and steady development of the publishing landscape in carbon research. The number of author affiliations by country and region also exhibited a steady rise, reaching its peak in 2020 and 2021. Over the past 10 years, the quantity of open-access publications among highly cited papers in the field of carbon research has shown a steady increase annually. This signifies that open access has become a major trend in global scholarly publishing. Among the 19,155 highly cited papers in the field of carbon research, the number of disciplines into which WoS classified these papers reached its peak in 2022, totaling 124 categories. Over the span of the last decade, the count generally remained above 100 disciplines, except for 2017, where it stood at 99 categories.

This study downloaded the open-access status of 19,155 papers and generated a heatmap spanning 10 years to analyze the trend in open-access availability of papers over the decade. Using the open-access status data obtained from WoS for these papers, the heatmap (Figure 1) was created with a ten-year timeframe along the horizontal axis and open-access types of publications along the vertical axis. The Open-Access (OA) heat map provides a detailed visualization of the distribution and trends of OA types across 19,155 highly cited papers over a decade, offering significant insights into open-access publishing. The horizontal axis represents the temporal progression from 2013 to 2022, highlighting the gradual increase in OA availability and reflecting global shifts towards OA mandates by funding agencies and institutions. The vertical axis categorizes publications into 7 OA types-Gold, Green, Hybrid, Bronze, Diamond, Closed, and Repository-based-allowing for comparative analysis of their prevalence and evolution over time. The color intensity of the map visually communicates the density of publications within each OA type, revealing patterns such as the dominance of Gold and Hybrid OA in recent years and the decline of non-OA publications. When combined with data from Tables S1 and S2, which detail the top 25 publishers and their publication metrics, the map illustrates the contributions of major publishers and their adoption of OA models. It also reflects the impact of global OA policies like Plan S and national mandates, with notable peaks in OA types corresponding to policy implementation. Overall, the heat map serves as a valuable tool for understanding OA trends, the strategic shifts by publishers, and the influence of global policies, offering actionable insights for researchers, policymakers, and publishers.

Attached Tables S1 and S2 list the top 25 publishers and the names of their publications, along with the number of publications and the percentage of their publications out of the total number of nearly 20,000 highly cited papers over the past decade. The inclusion of data on the top 25 publishers and their publications, along with the percentage of their contributions to nearly 20,000 highly cited carbon research papers, significantly enhances the paper's value. This comprehensive insight provides a detailed understanding of the leading publishers' roles, highlighting their alignment with global scientific priorities and establishing benchmarks for evaluating high-impact carbon research dissemination. The ranked list facilitates comparative analysis across a wide spectrum of publishing entities, enabling

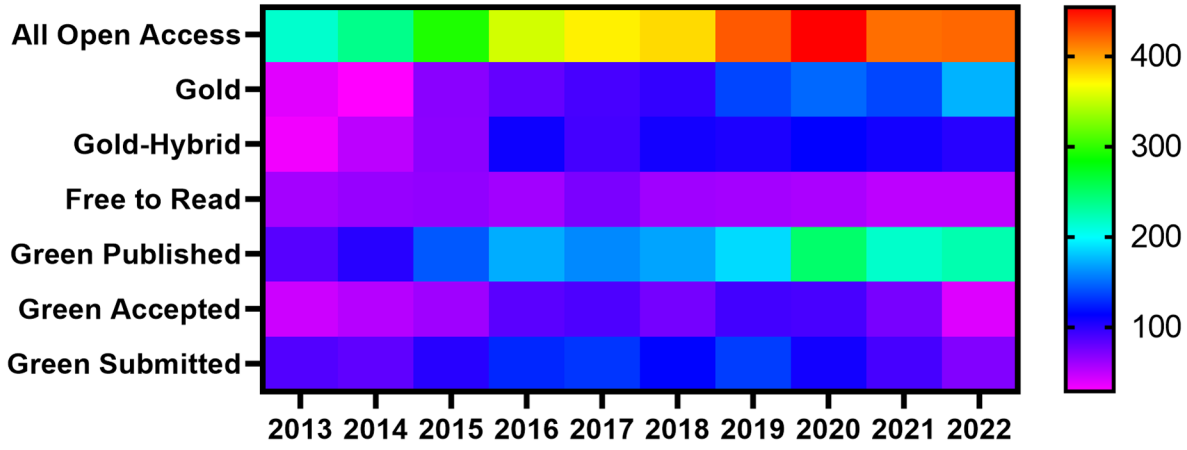

Figure 1: Open access heat map.

researchers, policymakers, and funding bodies to identify key contributors and potential collaborators. Moreover, emphasizing the publishers' share in highly cited papers underscores their role in promoting research accessibility and impact, encouraging the adoption of open-access practices. This data-driven evaluation supports strategic decision-making for academic institutions and researchers, helping them align their publishing strategies with prominent journals to maximize visibility and influence. Together, these aspects create a robust framework for understanding publication dynamics in carbon research, making the study an invaluable resource for the global academic and publishing community.

Text

The analysis of hot keywords in carbon research from 2013 to 2022 reveals dynamic trends, reflecting the evolving priorities within the field. Using tools like CiteSpace and VOSviewer, highly cited papers were examined to identify recurring terms in their abstracts, uncovering insights into the development of carbon science. Notably, the analysis found no consistent keywords across all years, highlighting the field's rapid evolution and diverse focus areas. Keywords such as 'emission,' 'soil,' 'electrode,' 'photocatalyst,' 'forest,' 'cancer,' and 'nanofluids' emerged as significant indicators of the interdisciplinary nature of carbon research. These terms encapsulate the multifaceted nature of the field, spanning environmental issues, technological advancements, and biomedical applications. For example, the presence of terms like 'emission' and 'soil' underscores the sustained focus on climate change and ecological conservation, while 'electrode' and 'photocatalyst' point to innovations in energy storage and conversion technologies. Additionally, keywords such as 'forest' and 'cancer' reveal the broad applicability of carbon research, highlighting its relevance to ecological studies and biomedical advancements. Terms like 'nanofluids' signify progress in nanotechnology and materials science, demonstrating carbon's role in developing cutting-edge solutions for energy and thermal management. This evolving landscape of keywords also reflects global efforts to address pressing challenges such as carbon neutrality and sustainability through innovative technologies. The visualized mapping of these terms provides valuable insights into emerging trends, interdisciplinary collaborations, and potential areas for future exploration. By understanding the co-occurrence and context of these keywords, researchers and stakeholders can better align their efforts with the evolving trajectory of carbon research, ensuring continued progress and impactful contributions to global challenges. This analysis not only captures the current focus areas within carbon research but also serves as a predictive tool for identifying new opportunities and directions in the field.

Paper keyword data spanning a decade was analyzed using CiteSpace and VOSviewer to visualize the dynamic trends and thematic evolution of carbon research. Figures S1 to S10 from CiteSpace illustrate annual keyword co-occurrence networks, revealing the evolving associations and significance of terms. Similarly, Figures S11 to S20, generated via VOSviewer, complement this analysis by visualizing abstract content trends, offering insights into broader thematic landscapes. This dual-visualization approach unveils the intellectual contours shaping carbon research, emphasizing the significance of keywords as indicators of prevailing scientific interests and emerging focal points. The analysis highlights five critical insights into the implications of these keywords in carbon research. Firstly, keywords serve as proxies for identifying shifts in research priorities, reflecting global responses to pressing issues such as climate change and carbon neutrality. Secondly, they demonstrate interdisciplinary integration, showcasing connections between carbon research and fields like materials science, environmental studies, and renewable energy. Thirdly, co-occurrence networks reveal collaborative and citation patterns, indicating influential authors, institutions, and regions driving innovation. Fourthly, temporal trends in keywords point to emerging technologies and methods, such as the rise of nanomaterials or advanced analytics, shaping the field's future. Lastly, the visualization fosters a meta-perspective on the progression of carbon research, offering researchers, policymakers, and industry stakeholders a clearer understanding of the field's developmental trajectory and impact. By focusing on these conceptual implications rather than methodological specifics, the study leverages keywords to provide a richer narrative of the scholarly discourse, demonstrating their utility as powerful tools for decoding scientific progress and guiding future research directions.

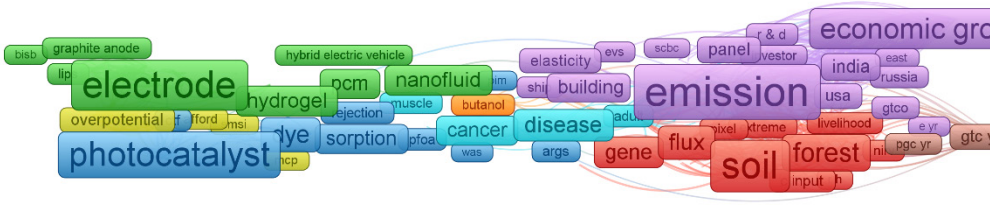

Figure 2: Abstract (VOSviewer).

Scholar

Information regarding the countries or regions of affiliation for the paper authors was downloaded. Within ArcGIS, country or regional data was imported to ensure the inclusion of spatial information related to author affiliations. Using the map-making capabilities of ArcGIS; a point-based map was created based on the data depicting the countries or regions of author affiliations, showcasing the geographic distribution of authors. Observations were made regarding the distribution patterns and related trends of author affiliations based on the visualized map and analytical outcomes (Figure 3). This aids in comprehending the geographical characteristics of author distribution and aspects related to international collaboration. Figures S21 to S30 in the Supplementary material illustrate the worldwide distribution of author regions for highly cited papers published annually across a decade. Table S3 catalogues the top 25 regions ranked by the volume of highly cited papers issued over the entire course of the past ten years. Tables S4 to S13 in the Supplementary section present detailed information on the top 10 highly cited papers published each year over a ten-year period.

DISCUSSION

Insights and Collaboration for Scientists and Experts

The surge in highly cited papers reflects increased global interest in carbon research, urging scientists to embrace interdisciplinary collaboration for innovation and address environmental challenges effectively. The nearly doubling of highly cited papers in research period indicates a significant rise in research activity and interest in the field of carbon research. Scientists can take this as a sign of the growing importance and recognition of their work, motivating them to contribute further. Additionally, the stable growth trajectory between publishers and publishing journals from 2013 to 2022 suggests a steady and reliable platform for disseminating research findings. Researchers can expect continued opportunities for publishing their work in reputable journals. The steady increase in the number of author affiliations by country and region, peaking in 2020 and 2021, reflects a trend towards greater international collaboration. Scientists should seek to leverage these global networks to enhance their research through diverse perspectives and resources. Furthermore, the peak in the number of disciplines classified by WoS in 2022, totaling 124 categories, highlights the interdisciplinary nature of carbon research. Researchers should consider engaging with different scientific disciplines to enrich their studies and foster innovation. Over the past decade, the classification of highly

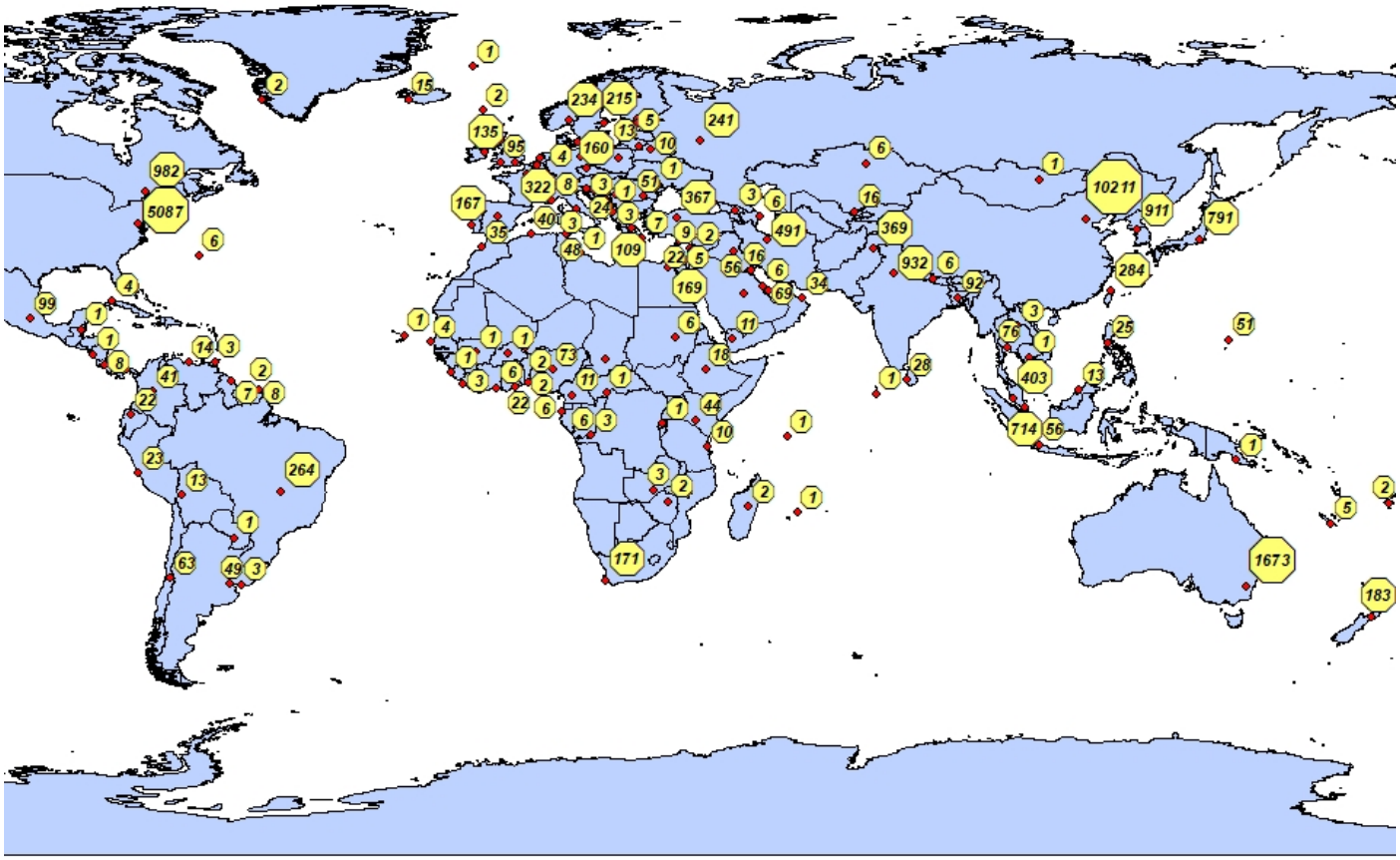

Figure 3: Regions (ArcGIS).

cited papers into over 100 disciplines, with only a slight dip in 2017, underscores the broad and diverse impact of carbon research. This trend emphasizes the importance of maintaining a wide-ranging approach and staying informed about developments across various fields. Overall, these insights encourage carbon research scientists to pursue interdisciplinary collaborations, take advantage of stable publication opportunities, and recognize the growing global interest and importance of their work. Through keyword analysis with VOSviewer, researchers gain a visual representation of key term frequency and interrelationships in abstracts, facilitating the identification of central themes and trends. Additionally, scholarly impact data highlights China and the United States as prolific contributors to academic publications in carbon research, aiding in the identification of leading research institutions and regions. Moreover, the interdisciplinary nature of highly cited papers underscores the importance of collaboration across diverse fields to address complex challenges and foster innovation. Overall, these insights empower experts to stay informed, identify key contributors and institutions, and foster interdisciplinary collaborations to advance knowledge and address pressing environmental issues in carbon research.

Key and Strategic Insights for Carbon Publishers

Publishers in carbon research must recognize influential players, prioritize rigorous peer review, promote innovation, foster strategic collaborations, invest in editorial teams and technology, embrace interdisciplinary research, and leverage visualization tools to enhance impact and facilitate collaboration, advancing the field. These conclusions offer several key insights for publishers dedicated to the field of carbon research. Firstly, they should recognize the leading influence held by publishing powerhouses such as Elsevier, Wiley, the American Chemical Society, Springer Nature, the Royal Society of Chemistry, NATURE PORTFOLIO, and the American Association for the Advancement of Science. Understanding the strategies and standards set by these organizations can enhance their own impact and visibility. Secondly, maintaining rigorous peer-review processes and supporting high-quality research are crucial for achieving recognition and citation rates akin to those of the top publishers, who collectively produce 90% of highly cited papers in the field. Thirdly, publishers must actively shape the narrative and boundaries of carbon research by promoting innovative studies that drive the field forward. Fourthly, strategic collaborations with top research institutions and scientists are invaluable for curating impactful content and staying competitive. Additionally, investment in robust editorial teams, advanced publication technologies, and comprehensive dissemination strategies is essential to emulate the success of leading publishers. Lastly, embracing interdisciplinary research is a key, as it broadens the scope and impact of journals in the carbon research domain. By focusing on these areas, publishers can strengthen their role, increase the impact of their publications, and contribute significantly to the advancement of carbon research. VOSviewer's visualization of keywords and their interrelationships within abstracts provides publishers with a deeper understanding of prevalent themes and trends. By analyzing distribution, color intensity, and associations within the heatmap, publishers can identify popular topics and areas of interest among researchers, informing editorial decisions to focus on content aligned with current trends. Understanding scholarly impact and affiliation patterns, particularly the significant contributions from China and the United States, guides publishers in targeting publications and marketing efforts, enhancing journal prestige and reach. Moreover, the interdisciplinary nature of highly cited papers highlights opportunities for publishers to encourage interdisciplinary collaboration and submissions. By fostering collaboration between researchers from different disciplines, publishers facilitate the dissemination of innovative research addressing complex challenges in carbon science. Overall, these insights empower publishers to strategically position their publications, attract high-quality submissions, and contribute to advancing knowledge in the field.

Open Access Trends and Interdisciplinary Perspectives

These findings offer significant insights for readers engaged in the field of carbon research. Firstly, the consistent uptick in the quantity of open-access publications among highly cited papers signals a notable trend in global scholarly publishing towards open access. This reflects an emerging acknowledgment among researchers and institutions of the advantages of disseminating research freely to the public. Secondly, the comprehensive heatmap analysis spanning a decade provides readers with a holistic understanding of the trajectory of open-access availability in carbon research. This analytical approach facilitates insight into the evolution of open access within the field and its implications for scholarly communication practices. Furthermore, the study exposes variations in different types of open access. While overall open-access paper numbers have steadily risen, the particularly notable growth rates of certain types, such as green published articles, highlight diverse pathways and models within open access publishing. However, concerns arise from the apparent stagnation in the quantity of free-to-read open access articles and the relatively unchanged number of gold-hybrid open access articles since 2016.

The rise of open-access publications, along with heatmap analysis and interdisciplinary collaboration, empowers readers to navigate trends and challenges in carbon research, fostering informed engagement and advancement in the field. These trends raise pertinent questions and suggest areas requiring further investigation to understand the dynamics and challenges of open access publishing in the carbon research domain. Through keyword analysis with VOSviewer, readers can visualize the interrelationships of keywords within abstracts, aiding in

understanding prevalent themes and trends. By observing the distribution, color intensity, and associations within the heatmap, readers can identify key topics and areas of interest, helping them stay updated on current research directions. Understanding scholarly impact and affiliation patterns, particularly contributions from China and the United States, allows readers to recognize leading contributors and institutions driving advancements in the field. This context aids in interpreting research findings and identifying potential collaborators or research partners. Additionally, the interdisciplinary nature of highly cited papers highlights the diverse fields and perspectives contributing to impactful research in carbon science, emphasizing the importance of interdisciplinary collaboration. Overall, these insights empower readers to stay informed, identify key contributors and institutions, and foster interdisciplinary collaborations to address pressing challenges and advance knowledge in the field of carbon research.

CONCLUSION

Widely used by academic institutions, researchers, librarians, and decision-makers, SCIE serves as a foundational tool for scholarly research, aiding in literature reviews, grant applications, and informed decision-making. Highly Cited Papers provide insights into research trends, identifying seminal works that have shaped the trajectory of scientific inquiry within various disciplines. This study, for the first time, categorizes six relevant elements of highly cited carbon research papers over a decade into the XYZ axes for a three-dimensional analysis. The platform information of research papers can better provide authors and readers with future selection criteria for submitting to publishers and journals. The textual content of research papers can better provide authors and readers with current hotspots in carbon research, and also establish future research directions and areas by laying the groundwork. The scholarly influence of research papers can better provide authors and readers with information about the research institution, its impact, and the significance of the thematic research. Analysis of these 19,155 highly cited papers in the field of carbon research over a decade reveals that the field of carbon research spans various disciplines and addresses critical global challenges related to climate change, materials science, energy, environmental sustainability, *et al*., and ongoing advancements in these areas are crucial for developing innovative solutions to global challenges associated with carbon emissions and their impact on the planet. Carbon research is crucial for advancing our understanding of carbon-related challenges, developing effective mitigation strategies, and working towards a more sustainable future. Collaboration across disciplines and sectors is essential to tackle carbon research gaps comprehensively.

The exploration of specific keywords aids in the efficient retrieval of pertinent articles while inspiring novel research avenues. Examining the abstracts of highly cited articles offers rapid insight into the core research content and methodological approaches utilized, fostering an in-depth understanding of pivotal contributions. This assessment helps researchers grasp the prevailing trends and areas of interest within their field, providing valuable guidance for future research directions. In research publishing, the careful selection of publishers and specific publications is of utmost importance, as it directly impacts how the researchers' scholarly contributions can be seen. The process of discerning suitable publishers and publication platforms is integral to establishing the credibility and reach of research findings. Besides, assessing how easily the research can be shared and cited is vital to understanding its impact in the academic community. By analyzing the extent to which research findings can be shared and referenced, researchers gain critical insights into the significance of their work.

Furthermore, understanding the national and institutional affiliations of authors of highly cited articles is instrumental in identifying opportunities for international collaboration and recognizing valuable research centers. This insight enables researchers to establish connections and partnerships with experts in the field, fostering a collaborative environment that promotes innovation and knowledge exchange. In summary, through a comprehensive analysis of these factors, researchers may gain a holistic understanding of the landscape of highly cited articles within the field of carbon research. This comprehensive understanding could serve as a guiding compass for their research endeavors, informs decisions related to the choice of suitable publication platforms, and facilitates the establishment of collaborative networks.

LIMITATIONS AND FUTURE RESEARCH

The limitations of this study include the reliance on highly cited carbon research papers, which may not fully represent emerging research trends or underrepresented areas in the field. Additionally, while the study provides valuable insights into research trends, platform information, and scholarly influence, it is constrained by the specific timeframe and data sources used, limiting its scope to a particular period and set of research papers. For future research, there is potential to expand the analysis by incorporating newer papers, exploring interdisciplinary collaborations more deeply, and considering broader global challenges beyond carbon research. Further exploration of keywords, abstracts, and institutional affiliations can enhance understanding of the field and foster international partnerships, guiding researchers in selecting publication platforms and advancing innovation in carbon research.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ABBREVIATIONS

SCIE: Science Citation Index-Expanded; **WoS:** Web of Science Core Collection; **CCS:** Carbon Capture and Storage; **NLP:** Natural Language Processing; **OA:** Open-Access.

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Table S1: Top 25 Publishers List 10 years.

Publishers	Record Count	% of 19,155
Elsevier	7960	41.556
Wiley	2796	14.597
Amer Chemical Soc	2299	12.002
Springer Nature	1571	8.202
Royal Soc Chemistry	1546	8.071
NATURE PORTFOLIO	630	3.289
Amer Assoc Advancement Science	356	1.859
Mdpi	239	1.248
Natl Acad Sciences	183	0.955
Frontiers Media Sa	147	0.767
Copernicus Gesellschaft Mbh	141	0.736
Oxford Univ Press	110	0.574
Taylor & Francis	108	0.564
Amer Geophysical Union	97	0.506
Tsinghua Univ Press	97	0.506
Annual Reviews	69	0.36
Iop Publishing Ltd	60	0.313
Shanghai Jiao Tong Univ Press	57	0.298
Science Press	55	0.287
Journal Mater Sci Technol	49	0.256
Keai Publishing Ltd	31	0.162
Public Library Science	29	0.151
Amer Physical Soc	24	0.125
IEEE	23	0.12
Techno-Press	22	0.115

Table S2: Top 25 Publication titles List 10 years.

Publication Titles	Record Count	% of 19,155
Chemical engineering journal	937	4.892
Angewandte chemie international edition	672	3.508
Advanced materials	646	3.372
Applied catalysis b environmental	527	2.751
Nature communications	504	2.631
Journal of the american chemical society	483	2.522
Chemical society reviews	364	1.9
Renewable sustainable energy reviews	358	1.869
Chemical reviews	353	1.843
Journal of cleaner production	351	1.832
Energy environmental science	342	1.785
Nature	297	1.551
ACS catalysis	294	1.535
Advanced functional materials	279	1.457
Advanced energy materials	270	1.41
Carbon	269	1.404
Science	265	1.383
Science of the total environment	265	1.383
Journal of hazardous materials	260	1.357
Acs nano	251	1.31
Nanoscale	240	1.253
Journal of materials chemistry a	196	1.023
Proceedings of the national academy of sciences of the united states of america	183	0.955
Accounts of chemical research	174	0.908
Applied Energy	170	0.887

Table S3: Top 25 Regions List 10 years.

Countries/Regions	Record Count	% of 19,155
PEOPLES R CHINA	10211	53.307
USA	5087	26.557
AUSTRALIA	1673	8.734
GERMANY	1560	8.144
ENGLAND	1428	7.455
CANADA	982	5.127
INDIA	932	4.866
SOUTH KOREA	911	4.756
FRANCE	852	4.448
JAPAN	791	4.129
SAUDI ARABIA	732	3.821
SINGAPORE	714	3.727
SPAIN	648	3.383
NETHERLANDS	625	3.263
SWITZERLAND	565	2.95
ITALY	554	2.892
IRAN	491	2.563
SWEDEN	441	2.302
MALAYSIA	403	2.104
PAKISTAN	369	1.926
TURKEY	367	1.916
BELGIUM	322	1.681
SCOTLAND	299	1.561
TAIWAN	284	1.483
DENMARK	276	1.441

Table S4: Top 10 Highly cited papers list 2013.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
The Chemistry and Applications of Metal-Organic Frameworks	Furukawa, Hiroyasu; Cordova, Kyle E.; O'Keeffe, Michael; Yaghi, Omar M.	SCIENCE	2013	10.1126/science.1230444	10758
Raman spectroscopy as a versatile tool for studying the properties of graphene	Ferrari, Andrea C.; Basko, Denis M.	NATURE NANOTECHNOLOGY	2013	10.1038/nnano.2013.46	5105
Carbon Nanotubes: Present and Future Commercial Applications	De Volder, Michael F. L.; Tawfick, Sameh H.; Baughman, Ray H.; Hart, A. John	SCIENCE	2013	10.1126/science.1222453	4010
Bounding the role of black carbon in the climate system: A scientific assessment	Bond, T. C.; Doherty, S. J.; Fahey, D. W.; Forster, P. M.; Berntsen, T.; DeAngelo, B. J.; Flanner, M. G.; Ghan, S.; Kaercher, B.; Koch, D.; Kinne, S.; Kondo, Y.; Quinn, P. K.; Sarofim, M. C.; Schultz, M. G.; Schulz, M.; Venkataraman, C.; Zhang, H.; Zhang, S.; Bellouin, N.; Guttikunda, S. K.; Hopke, P. K.; Jacobson, M. Z.; Kaiser, J. W.; Klimont, Z.; Lohmann, U.; Schwarz, J. P.; Shindell, D.; Storelvmo, T.; Warren, S. G.; Zender, C. S.	JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES	2013	10.1002/jgrd.50171	3813
Sodium-Ion Batteries	Slater, Michael D.; Kim, Donghan; Lee, Eungje; Johnson, Christopher S.	ADVANCED FUNCTIONAL MATERIALS	2013	10.1002/adfm.201200691	3651
Highly Photoluminescent Carbon Dots for Multicolor Patterning, Sensors, and Bioimaging	Zhu, Shoujun; Meng, Qingnan; Wang, Lei; Zhang, Junhu; Song, Yubin; Jin, Han; Zhang, Kai; Sun, Hongchen; Wang, Haiyu; Yang, Bai	ANGEWANDTE CHEMIE-INTERNATIONAL EDITION	2013	10.1002/anie.201300519	3234
Cation Intercalation and High Volumetric Capacitance of Two-Dimensional Titanium Carbide	Lukatskaya, Maria R.; Mashtalir, Olha; Ren, Chang E.; Dall'Agnese, Yohan; Rozier, Patrick; Taberna, Pierre Louis; Naguib, Michael; Simon, Patrice; Barsoum, Michel W.; Gogotsi, Yury	SCIENCE	2013	10.1126/science.1241488	2920
Covalent organic frameworks (COFs): from design to applications	Ding, San-Yuan; Wang, Wei	CHEMICAL SOCIETY REVIEWS	2013	10.1039/c2cs35072f	2590
Single-Atom Catalysts: A New Frontier in Heterogeneous Catalysis	Yang, Xiao-Feng; Wang, Aiqin; Qiao, Botao; Li, Jun; Liu, Jingyue; Zhang, Tao	ACCOUNTS OF CHEMICAL RESEARCH	2013	10.1021/ar300361m	2452
An Advanced Ni-Fe Layered Double Hydroxide Electrocatalyst for Water Oxidation	Gong, Ming; Li, Yanguang; Wang, Hailiang; Liang, Yongye; Wu, Justin Z.; Zhou, Jigang; Wang, Jian; Regier, Tom; Wei, Fei; Dai, Hongjie	JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	2013	10.1021/ja4027715	2227

Table S5: Top 10 Highly cited papers list 2014.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
25th Anniversary Article: MXenes: A New Family of Two-Dimensional Materials	Naguib, Michael; Mochalin, Vadym N.; Barsoum, Michel W.; Gogotsi, Yury	ADVANCED MATERIALS	2014	10.1002/adma.201304138	4047
Pseudocapacitive oxide materials for high-rate electrochemical energy storage	Augustyn, Veronica; Simon, Patrice; Dunn, Bruce	ENERGY & ENVIRONMENTAL SCIENCE	2014	10.1039/c3ee44164d	3793
Deep Eutectic Solvents (DESs) and Their Applications	Smith, Emma L.; Abbott, Andrew P.; Ryder, Karl S.	CHEMICAL REVIEWS	2014	10.1021/cr300162p	3767
Conductive two-dimensional titanium carbide 'clay' with high volumetric capacitance	Ghidiu, Michael; Lukatskaya, Maria R.; Zhao, Meng-Qiang; Gogotsi, Yury; Barsoum, Michel W.	NATURE	2014	10.1038/nature13970	3619
Metal Additive Manufacturing: A Review	Frazier, William E.	JOURNAL OF MATERIALS ENGINEERING AND PERFORMANCE	2014	10.1007/s11665-014-0958-z	3368
Lipid Peroxidation: Production, Metabolism, and Signaling Mechanisms of Malondialdehyde and 4-Hydroxy-2-Nonenal	Ayala, Antonio; Munoz, Mario F.; Argueelles, Sandro	OXIDATIVE MEDICINE AND CELLULAR LONGEVITY	2014	10.1155/2014/360438	3038
Semiconductor heterojunction photocatalysts: design, construction, and photocatalytic performances	Wang, Huanli; Zhang, Lisha; Chen, Zhigang; Hu, Junqing; Li, Shijie; Wang, Zhaohui; Liu, Jianshe; Wang, Xinchen	CHEMICAL SOCIETY REVIEWS	2014	10.1039/c4cs00126e	2930
Dye and its removal from aqueous solution by adsorption: A review	Yagub, Mustafa T.; Sen, Tushar Kanti; Afroze, Sharmeen; Ang, H. M.	ADVANCES IN COLLOID AND INTERFACE SCIENCE	2014	10.1016/j.cis.2014.04.002	2750
Biochar as a sorbent for contaminant management in soil and water: A review	Ahmad, Mahtab; Rajapaksha, Anushka Upamali; Lim, Jung Eun; Zhang, Ming; Bolan, Nanthi; Mohan, Dinesh; Vithanage, Meththika; Lee, Sang Soo; Ok, Yong Sik	CHEMOSPHERE	2014	10.1016/j.chemosphere.2013.10.071	2734
Lignin Valorization: Improving Lignin Processing in the Biorefinery	Ragauskas, Arthur J.; Beckham, Gregg T.; Biddy, Mary J.; Chandra, Richard; Chen, Fang; Davis, Mark F.; Davison, Brian H.; Dixon, Richard A.; Gilna, Paul; Keller, Martin; Langan, Paul; Naskar, Amit K.; Saddler, Jack N.; Tschaplinski, Timothy J.; Tuskan, Gerald A.; Wyman, Charles E.	SCIENCE	2014	10.1126/science.1246843	2647

Table S6: Top 10 Highly cited papers list 2015.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Towards greener and more sustainable batteries for electrical energy storage	Larcher, D.; Tarascon, J-M.	NATURE CHEMISTRY	2015	10.1038/NCHEM.2085	5142
Noble metal-free hydrogen evolution catalysts for water splitting	Zou, Xiaoxin; Zhang, Yu	CHEMICAL SOCIETY REVIEWS	2015	10.1039/c4cs00448e	4303
Metal-free efficient photocatalyst for stable visible water splitting via a two-electron pathway	Liu, Juan; Liu, Yang; Liu, Naiyun; Han, Yuzhi; Zhang, Xing; Huang, Hui; Lifshitz, Yeshayahu; Lee, Shuit-Tong; Zhong, Jun; Kang, Zhenhui	SCIENCE	2015	10.1126/science.aaa3145	3714
Carbon quantum dots and their applications	Lim, Shi Ying; Shen, Wei; Gao, Zhiqiang	CHEMICAL SOCIETY REVIEWS	2015	10.1039/c4cs00269e	3327
Polymeric Photocatalysts Based on Graphitic Carbon Nitride	Cao, Shaowen; Low, Jingxiang; Yu, Jiaguo; Jaroniec, Mietek	ADVANCED MATERIALS	2015	10.1002/adma.201500033	2790
A metal-free bifunctional electrocatalyst for oxygen reduction and oxygen evolution reactions	Zhang, Jintao; Zhao, Zhenghang; Xia, Zhenhai; Dai, Liming	NATURE NANOTECHNOLOGY	2015	10.1038/NNANO.2015.48	2489
A review of electrolyte materials and compositions for electrochemical supercapacitors	Zhong, Cheng; Deng, Yida; Hu, Wenbin; Qiao, Jinli; Zhang, Lei; Zhang, Jiujun	CHEMICAL SOCIETY REVIEWS	2015	10.1039/c5cs00303b	2341
Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems	Ferrari, Andrea C.; Bonaccorso, Francesco; Fal'ko, Vladimir; Novoselov, Konstantin S.; Roche, Stephan; Boggild, Peter; Borini, Stefano; Koppens, Frank H. L.; Palermo, Vincenzo; Pugno, Nicola; Garrido, Jose A.; Sordan, Roman; Bianco, Alberto; Ballerini, Laura; Prato, Maurizio; Lidorikis, Elefterios; Kivioja, Jani; Marinelli, Claudio; Ryhaenen, Tapani; Morpurgo, Alberto; Coleman, Jonathan N.; Nicolosi, Valeria; Colombo, Luigi; Fert, Albert; Garcia-Hernandez, Mar; Bachtold, Adrian; Schneider, Gregory F.; Guinea, Francisco; Dekker, Cees; Barbone, Matteo; Sun, Zhipei; Galiotis, Costas; Grigorenko, Alexander N.; Konstantatos, Gerasimos; Kis, Andras; Katsnelson, Mikhail; Vandersypen, Lieven; Loiseau, Annick; Morandi, Vittorio; Neumaier, Daniel; Treossi, Emanuele; Pellegrini, Vittorio; Polini, Marco; Tredicucci, Alessandro; Williams, Gareth M.; Hong, Byung Hee; Ahn, Jong-Hyun; Kim, Jong Min; Zirath, Herbert; van Wees, Bart J.; van der Zant, Herre; Occhipinti, Luigi; Di Matteo, Andrea; Kinloch, Ian A.; Seyller, Thomas; Quesnel, Etienne; Feng, Xinliang; Teo, Ken; Rupesinghe, Nalin; Hakonen, Pertti; Neil, Simon R. T.; Tannock, Quentin; Loefwander, Tomas; Kinaret, Jari	NANOSCALE	2015	10.1039/c4nr01600a	2125
The role of graphene for electrochemical energy storage	Raccichini, Rinaldo; Varzi, Alberto; Passerini, Stefano; Scrosati, Bruno	NATURE MATERIALS	2015	10.1038/nmat4170	1998
The contentious nature of soil organic matter	Lehmann, Johannes; Kleber, Markus	NATURE	2015	10.1038/nature16069	1979

Table S7: Top 10 Highly cited papers list 2016

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Graphitic Carbon Nitride ($g\text{-}C_3N_4$)-Based Photocatalysts for Artificial Photosynthesis and Environmental Remediation: Are We a Step Closer to Achieving Sustainability?	Ong, Wee-Jun; Tan, Lling-Lling; Ng, Yun Hau; Yong, Siek-Ting; Chai, Siang-Piao	CHEMICAL REVIEWS	2016	10.1021/acs.chemrev.6b00075	4938
Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization	Eyring, Veronika; Bony, Sandrine; Meehl, Gerald A.; Senior, Catherine A.; Stevens, Bjorn; Stouffer, Ronald J.; Taylor, Karl E.	GEOSCIENTIFIC MODEL DEVELOPMENT	2016	10.5194/gmd-9-1937-2016	4227
Active sites of nitrogen-doped carbon materials for oxygen reduction reaction clarified using model catalysts	Guo, Donghui; Shibuya, Riku; Akiba, Chisato; Saji, Shunsuke; Kondo, Takahiro; Nakamura, Junji	SCIENCE	2016	10.1126/science.aad0832	3123
Recent Advances in Electrocatalysts for Oxygen Reduction Reaction	Shao, Minhua; Chang, Qiaowan; Dodelet, Jean-Pol; Chenitz, Regis	CHEMICAL REVIEWS	2016	10.1021/acs.chemrev.5b00462	2901
Electrochemical capacitors: mechanism, materials, systems, characterization and applications	Wang, Yonggang; Song, Yanfang; Xia, Yongyao	CHEMICAL SOCIETY REVIEWS	2016	10.1039/c5cs00580a	2626
The ecoinvent database version 3 (part I): overview and methodology	Wernet, Gregor; Bauer, Christian; Steubing, Bernhard; Reinhard, Jurgen; Moreno-Ruiz, Emilia; Weidema, Bo	INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT	2016	10.1007/s11367-016-1087-8	2423
FUNGuild: An open annotation tool for parsing fungal community datasets by ecological guild	Nguyen, Nhu H.; Song, Zewei; Bates, Scott T.; Branco, Sara; Tedersoo, Leho; Menke, Jon; Schilling, Jonathan S.; Kennedy, Peter G.	FUNGAL ECOLOGY	2016	10.1016/j.funeco.2015.06.006	2139
High-power all-solid-state batteries using sulfide superionic conductors	Kato, Yuki; Hori, Satoshi; Saito, Toshiya; Suzuki, Kota; Hirayama, Masaaki; Mitsui, Akio; Yonemura, Masao; Iba, Hideki; Kanno, Ryoji	NATURE ENERGY	2016	10.1038/NENERGY.2016.30	2100
Stretchable, Skin-Mountable, and Wearable Strain Sensors and Their Potential Applications: A Review	Amjadi, Morteza; Kyung, Ki-Uk; Park, Inkyu; Sitti, Metin	ADVANCED FUNCTIONAL MATERIALS	2016	10.1002/adfm.201504755	2074
A metal-organic framework-derived bifunctional oxygen electrocatalyst	Xia, Bao Yu; Yan, Ya; Li, Nan; Wu, Hao Bin; Lou, Xiong Wen (David); Wang, Xin	NATURE ENERGY	2016	10.1038/NENERGY.2015.6	2046

Table S8: Top 10 Highly cited papers list 2017.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Combining theory and experiment in electrocatalysis: Insights into materials design	Seh, Zhi Wei; Kibsgaard, Jakob; Dickens, Colin F.; Chorkendorff, I. B.; Norskov, Jens K.; Jaramillo, Thomas F.	SCIENCE	2017	10.1126/science.aad4998	7087
Sodium-ion batteries: present and future	Hwang, Jang-Yeon; Myung, Seung-Taek; Sun, Yang-Kook	CHEMICAL SOCIETY REVIEWS	2017	10.1039/c6cs00776g	2920
The path towards sustainable energy	Chu, Steven; Cui, Yi; Liu, Nian	NATURE MATERIALS	2017	10.1038/nmat4834	2790
A review on g-C_3N_4-based photocatalysts	Wen, Jiuqing; Xie, Jun; Chen, Xiaobo; Li, Xin	APPLIED SURFACE SCIENCE	2017	10.1016/j.apsusc.2016.07.030	2091
Synthetic Organic Electrochemical Methods Since 2000: On the Verge of a Renaissance	Yan, Ming; Kawamata, Yu; Baran, Phil S.	CHEMICAL REVIEWS	2017	10.1021/acs.chemrev.7b00397	2051
SoilGrids250m: Global gridded soil information based on machine learning	Hengl, Tomislav; de Jesus, Jorge Mendes; Heuvelink, Gerard B. M.; Gonzalez, Maria Ruiperez; Kilibarda, Milan; Blagotic, Aleksandar; Shangguan, Wei; Wright, Marvin N.; Geng, Xiaoyuan; Bauer-Marschallinger, Bernhard; Guevara, Mario Antonio; Vargas, Rodrigo; MacMillan, Robert A.; Batjes, Niels H.; Leenaars, Johan G. B.; Ribeiro, Eloi; Wheeler, Ichsani; Mantel, Stephan; Kempen, Bas	PLOS ONE	2017	10.1371/journal.pone.0169748	1902
3D printing of polymer matrix composites: A review and prospective	Wang, Xin; Jiang, Man; Zhou, Zuowan; Gou, Jihua; Hui, David	COMPOSITES PART B-ENGINEERING	2017	10.1016/j.compositesb.2016.11.034	1846
Maximizing the right stuff: The trade-off between membrane permeability and selectivity	Park, Ho Bum; Kamcev, Jovan; Robeson, Lloyd M.; Elimelech, Menachem; Freeman, Benny D.	SCIENCE	2017	10.1126/science.aab0530	1759
Near-infrared fluorophores for biomedical imaging	Hong, Guosong; Antaris, Alexander L.; Dai, Hongjie	NATURE BIOMEDICAL ENGINEERING	2017	10.1038/s41551-016-0010	1693
The atom, the molecule, and the covalent organic framework	Diercks, Christian S.; Yaghi, Omar M.	SCIENCE	2017	10.1126/science.aal1585	1691

Table S9: Top 10 Highly cited papers list 2018.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Unconventional superconductivity in magic-angle graphene superlattices	Cao, Yuan; Fatemi, Valla; Fang, Shiang; Watanabe, Kenji; Taniguchi, Takashi; Kaxiras, Efthimios; Jarillo-Herrero, Pablo	NATURE	2018	10.1038/nature26160	4404
Additive manufacturing (3D printing): A review of materials, methods, applications and challenges	Ngo, Tuan D.; Kashani, Alireza; Imbalzano, Gabriele; Nguyen, Kate T. Q.; Hui, David	COMPOSITES PART B-ENGINEERING	2018	10.1016/j.compositesb.2018.02.012	3614
30 Years of Lithium-Ion Batteries	Li, Matthew; Lu, Jun; Chen, Zhongwei; Amine, Khalil	ADVANCED MATERIALS	2018	10.1002/adma.201800561	3000
Activation of Persulfate (PS) and Peroxymonosulfate (PMS) and application for the degradation of emerging contaminants	Wang, Jianlong; Wang, Shizong	CHEMICAL ENGINEERING JOURNAL	2018	10.1016/j.cej.2017.11.059	2094
Carbon Capture and Storage (CCS): the way forward	Bui, Mai; Adjiman, Claire S.; Bardow, Andre; Anthony, Edward J.; Boston, Andy; Brown, Solomon; Fennell, Paul S.; Fuss, Sabine; Galindo, Amparo; Hackett, Leigh A.; Hallett, Jason P.; Herzog, Howard J.; Jackson, George; Kemper, Jasmin; Krevor, Samuel; Maitland, Geoffrey C.; Matuszewski, Michael; Metcalfe, Ian S.; Petit, Camille; Puxty, Graeme; Reimer, Jeffrey; Reiner, David M.; Rubin, Edward S.; Scott, Stuart A.; Shah, Nilay; Smit, Berend; Trusler, J. P. Martin; Webley, Paul; Wilcox, Jennifer; Mac Dowell, Niall	ENERGY & ENVIRONMENTAL SCIENCE	2018	10.1039/c7ee02342a	1917
Stable Metal-Organic Frameworks: Design, Synthesis, and Applications	Yuan, Shuai; Feng, Liang; Wang, Kecheng; Pang, Jiandong; Bosch, Matheiu; Lollar, Christina; Sun, Yujia; Qin, Junsheng; Yang, Xinyu; Zhang, Peng; Wang, Qi; Zou, Lanfang; Zhang, Yingmu; Zhang, Liangliang; Fang, Yu; Li, Jialuo; Zhou, Hong-Cai	ADVANCED MATERIALS	2018	10.1002/adma.201704303	1844
g-C_3N_4-Based Heterostructured Photocatalysts	Fu, Junwei; Yu, Jiaguo; Jiang, Chuanjia; Cheng, Bei	ADVANCED ENERGY MATERIALS	2018	10.1002/aenm.201701503	1765
Batteries and fuel cells for emerging electric vehicle markets	Cano, Zachary P.; Banham, Dustin; Ye, Siyu; Hintennach, Andreas; Lu, Jun; Fowler, Michael; Chen, Zhongwei	NATURE ENERGY	2018	10.1038/s41560-018-0108-1	1596
A Practical Beginner's Guide to Cyclic Voltammetry	Elgrishi, Noemie; Rountree, Kelley J.; McCarthy, Brian D.; Rountree, Eric S.; Eisenhart, Thomas T.; Dempsey, Jillian L.	JOURNAL OF CHEMICAL EDUCATION	2018	10.1021/acs.jchemed.7b00361	1549
Evaluation of advanced oxidation processes for water and wastewater treatment - A critical review	Miklos, David B.; Remy, Christian; Jekel, Martin; Linden, Karl G.; Drewes, Joerg E.; Huebner, Uwe	WATER RESEARCH	2018	10.1016/j.watres.2018.03.042	1493

Table S10: Top 10 Highly cited papers list 2019.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Nanomaterials with enzyme-like characteristics (nanozymes): next-generation artificial enzymes (II)	Wu, Jiangjiexing; Wang, Xiaoyu; Wang, Quan; Lou, Zhangping; Li, Sirong; Zhu, Yunyao; Qin, Li; Wei, Hui	CHEMICAL SOCIETY REVIEWS	2019	10.1039/c8cs00457a	2462
Nanoparticles: Properties, applications and toxicities	Khan, Ibrahim; Saeed, Khalid; Khan, Idrees	ARABIAN JOURNAL OF CHEMISTRY	2019	10.1016/j.arabjc.2017.05.011	2412
Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications	Xue, Jiajia; Wu, Tong; Dai, Yunqian; Xia, Younan	CHEMICAL REVIEWS	2019	10.1021/acs.chemrev.8b00593	2192
Progress and Perspectives of Electrochemical CO_2 Reduction on Copper in Aqueous Electrolyte	Nitopi, Stephanie; Bertheussen, Erlend; Scott, Soren B.; Liu, Xinyan; Engstfeld, Albert K.; Horch, Sebastian; Seger, Brian; Stephens, Ifan E. L.; Chan, Karen; Hahn, Christopher; Norskov, Jens K.; Jaramillo, Thomas F.; Chorkendorff, Ib	CHEMICAL REVIEWS	2019	10.1021/acs.chemrev.8b00705	2046
The role of hydrogen and fuel cells in the global energy system	Staffell, Iain; Scamman, Daniel; Abad, Anthony Velazquez; Balcombe, Paul; Dodds, Paul E.; Ekins, Paul; Shah, Nilay; Ward, Kate R.	ENERGY & ENVIRONMENTAL SCIENCE	2019	10.1039/c8ee01157e	1785
The role of renewable energy in the global energy transformation	Gielen, Dolf; Boshell, Francisco; Saygin, Deger; Bazilian, Morgan D.; Wagner, Nicholas; Gorini, Ricardo	ENERGY STRATEGY REVIEWS	2019	10.1016/j.esr.2019.01.006	1652
Ultrathin 2D/2D WO_3/g-C_3N_4 step-scheme H_2-production photocatalyst	Fu, Junwei; Xu, Quanlong; Low, Jingxiang; Jiang, Chuanjia; Yu, Jiaguo	APPLIED CATALYSIS B-ENVIRONMENTAL	2019	10.1016/j.apcatb.2018.11.011	1637
Deep learning and process understanding for data-driven Earth system science	Reichstein, Markus; Camps-Valls, Gustau; Stevens, Bjorn; Jung, Martin; Denzler, Joachim; Carvalhais, Nuno; Prabhat	NATURE	2019	10.1038/s41586-019-0912-1	1605
Nanozymes: Classification, Catalytic Mechanisms, Activity Regulation, and Applications	Huang, Yanyan; Ren, Jinsong; Qu, Xiaogang	CHEMICAL REVIEWS	2019	10.1021/acs.chemrev.8b00672	1572
Carbon capture and conversion using metal-organic frameworks and MOF-based materials	Ding, Meili; Flaig, Robinson W.; Jiang, Hai-Long; Yaghi, Omar M.	CHEMICAL SOCIETY REVIEWS	2019	10.1039/c8cs00829a	1385

Table S11: Top 10 Highly cited papers list 2020.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
THE INTCAL20 NORTHERN HEMISPHERE RADIOCARBON AGE CALIBRATION CURVE (0-55 CAL KBP)	Reimer, Paula J.; Austin, William E. N.; Bard, Edouard; Bayliss, Alex; Blackwell, Paul G.; Ramsey, Christopher Bronk; Butzin, Martin; Cheng, Hai; Edwards, R. Lawrence; Friedrich, Michael; Grootes, Pieter M.; Guilderson, Thomas P.; Hajdas, Irka; Heaton, Timothy J.; Hogg, Alan G.; Hughen, Konrad A.; Kromer, Bernd; Manning, Sturt W.; Muscheler, Raimund; Palmer, Jonathan G.; Pearson, Charlotte; van der Plicht, Johannes; Reimer, Ron W.; Richards, David A.; Scott, E. Marian; Southon, John R.; Turney, Christian S. M.; Wacker, Lukas; Adolphi, Florian; Buentgen, Ulf; Capano, Manuela; Fahrni, Simon M.; Fogtmann-Schulz, Alexandra; Friedrich, Ronny; Koehler, Peter; Kudsk, Sabrina; Miyake, Fusa; Olsen, Jesper; Reinig, Frederick; Sakamoto, Minoru; Sookdeo, Adam; Talamo, Sahra	RADIOCARBON	2020	10.1017/RDC.2020.41	2670
Coastal Haze Pollution, Economic and Financial Performance, and Sustainable Transformation in Coastal Cities	Wang, Dongwu; Li, Jiao	JOURNAL OF COASTAL RESEARCH	2020	10.2112/JCR-SI109-001.1	1475
Covalent Organic Frameworks: Design, Synthesis, and Functions	Geng, Keyu; He, Ting; Liu, Ruoyang; Dalapati, Sasanka; Tan, Ke Tian; Li, Zhongping; Tao, Shanshan; Gong, Yifan; Jiang, Qiuhong; Jiang, Donglin	CHEMICAL REVIEWS	2020	10.1021/acs.chemrev.9b00550	1467
Recent Advances in Electrocatalytic Hydrogen Evolution Using Nanoparticles	Zhu, Jing; Hu, Liangsheng; Zhao, Pengxiang; Lee, Lawrence Yoon Suk; Wong, Kwok-Yin	CHEMICAL REVIEWS	2020	10.1021/acs.chemrev.9b00248	1375
Persulfate-Based Advanced Oxidation: Critical Assessment of Opportunities and Roadblocks	Lee, Jaesang; von Gunten, Urs; Kim, Jae-Hong	ENVIRONMENTAL SCIENCE & TECHNOLOGY	2020	10.1021/acs.est.9b07082	1337
Particulate Photocatalysts for Light-Driven Water Splitting: Mechanisms, Challenges, and Design Strategies	Wang, Qian; Domen, Kazunari	CHEMICAL REVIEWS	2020	10.1021/acs.chemrev.9b00201	1296
Environmental and Health Impacts of Air Pollution: A Review	Manisalidis, Ioannis; Stavropoulou, Elisavet; Stavropoulos, Agathangelos; Bezirtzoglou, Eugenia	FRONTIERS IN PUBLIC HEALTH	2020	10.3389/fpubh.2020.00014	1261

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
State of the Art and Prospects in Metal-Organic Framework (MOF)-Based and MOF-Derived Nanocatalysis	Wang, Qi; Astruc, Didier	CHEMICAL REVIEWS	2020	10.1021/acs.chemrev.9b00223	1237
Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement	Le Quere, Corinne; Jackson, Robert B.; Jones, Matthew W.; Smith, Adam J. P.; Abernethy, Sam; Andrew, Robbie M.; De-Gol, Anthony J.; Willis, David R.; Shan, Yuli; Canadell, Josep G.; Friedlingstein, Pierre; Creutzig, Felix; Peters, Glen P.	NATURE CLIMATE CHANGE	2020	10.1038/s41558-020-0797-x	1156
Guidelines for the use and interpretation of adsorption isotherm models: A review	Al-Ghouti, Mohammad A.; Da'ana, Dana A.	JOURNAL OF HAZARDOUS MATERIALS	2020	10.1016/j.jhazmat.2020.122383	1092

Table S12: Top 10 Highly cited papers list 2021.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Electronic cigarettes for smoking cessation	Hartmann-Boyce, Jamie; McRobbie, Hayden; Butler, Ailsa R.; Lindson, Nicola; Bullen, Chris; Begh, Rachna; Theodoulou, Annika; Notley, Caitlin; Rigotti, Nancy A.; Turner, Tari; Fanshawe, Thomas R.; Hajek, Peter	COCHRANE DATABASE OF SYSTEMATIC REVIEWS	2021	10.1002/14651858.CD010216.pub6	694
0D to 3D carbon-based networks combined with pseudocapacitive electrode material for high energy density supercapacitor: A review	Kumar, Sachin; Saeed, Ghuzanfar; Zhu, Ling; Hui, Kwun Nam; Kim, Nam Hoon; Lee, Joong Hee	CHEMICAL ENGINEERING JOURNAL	2021	10.1016/j.cej.2020.126352	641
Boron-doped nitrogen-deficient carbon nitride-based Z-scheme heterostructures for photocatalytic overall water splitting	Zhao, Daming; Wang, Yiqing; Dong, Chung-Li; Huang, Yu-Cheng; Chen, Jie; Xue, Fei; Shen, Shaohua; Guo, Liejin	NATURE ENERGY	2021	10.1038/s41560-021-00795-9	595
Clean and Affordable Hydrogen Fuel from Alkaline Water Splitting: Past, Recent Progress, and Future Prospects	Yu, Zi-You; Duan, Yu; Feng, Xing-Yu; Yu, Xingxing; Gao, Min-Rui; Yu, Shu-Hong	ADVANCED MATERIALS	2021	10.1002/adma.202007100	560
The global threat from plastic pollution	MacLeo, Matthew; Arp, Hans Peter H.; Tekman, Mine B.; Jahnke, Annika	SCIENCE	2021	10.1126/science.abg5433	551
Hollow Engineering to Co@N-Doped Carbon Nanocages via Synergistic Protecting-Etching Strategy for Ultrahigh Microwave Absorption	Liu, Panbo; Gao, Sai; Zhang, Guozheng; Huang, Ying; You, Wenbin; Che, Renchao	ADVANCED FUNCTIONAL MATERIALS	2021	10.1002/adfm.202102812	550

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Promises and Challenges of Next-Generation Beyond Li-ion Batteries for Electric Vehicles and Grid Decarbonization	Tian, Yaosen; Zeng, Guobo; Rutt, Ann; Shi, Tan; Kim, Haegyeom; Wang, Jingyang; Koettgen, Julius; Sun, Yingzhi; Ouyang, Bin; Chen, Tina; Lun, Zhengyan; Rong, Ziqin; Persson, Kristin; Ceder, Gerbrand	CHEMICAL REVIEWS	2021	10.1021/acs.chemrev.0c00767	540
Photocatalytic solar hydrogen production from water on a 100-m^2 scale	Nishiyama, Hiroshi; Yamada, Taro; Nakabayashi, Mamiko; Maehara, Yoshiki; Yamaguchi, Masaharu; Kuromiya, Yasuko; Nagatsuma, Yoshie; Tokudome, Hiromasa; Akiyama, Seiji; Watanabe, Tomoaki; Narushima, Ryoichi; Okunaka, Sayuri; Shibata, Naoya; Takata, Tsuyoshi; Hisatomi, Takashi; Domen, Kazunari	NATURE	2021	10.1038/s41586-021-03907-3	496
Removal of heavy metal ions from wastewater: a comprehensive and critical review	Qasem, Naef A. A.; Mohammed, Ramy H.; Lawal, Dahiru U.	NPJ CLEAN WATER	2021	10.1038/s41545-021-00127-0	483
Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations	Silva, Ana L. Patricio; Prata, Joana C.; Walker, Tony R.; Duarte, Armando C.; Ouyang, Wei; Barcelo, Damia; Rocha-Santos, Teresa	CHEMICAL ENGINEERING JOURNAL	2021	10.1016/j.cej.2020.126683	480

Figure S1: Keywords per year (citespace) 2013.

Table S13: Top 10 Highly cited papers list 2022.

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Emerging S-Scheme Photocatalyst	Zhang, Liuyang; Zhang, Jianjun; Yu, Huogen; Yu, Jiaguo	ADVANCED MATERIALS	2022	10.1002/adma.202107668	699
Global Carbon Budget 2021	Friedlingstein, Pierre; Jones, Matthew W.; O'Sullivan, Michael; Andrew, Robbie M.; Bakker, Dorothee C. E.; Hauck, Judith; Le Quere, Corinne; Peters, Glen P.; Peters, Wouter; Pongratz, Julia; Sitch, Stephen; Canadell, Josep G.; Ciais, Philippe; Jackson, Rob B.; Alin, Simone R.; Anthoni, Peter; Bates, Nicholas R.; Becker, Meike; Bellouin, Nicolas; Bopp, Laurent; Chau, Thi Tuyet Trang; Chevallier, Frederic; Chini, Louise P.; Cronin, Margot; Currie, Kim I.; Decharme, Bertrand; Djeutchouang, Laique M.; Dou, Xinyu; Evans, Wiley; Feely, Richard A.; Feng, Liang; Gasser, Thomas; Gilfillan, Dennis; Gkritzalis, Thanos; Grassi, Giacomo; Gregor, Luke; Gruber, Nicolas; Gurses, Ozgur; Harris, Ian; Houghton, Richard A.; Hurtt, George C.; Iida, Yosuke; Ilyina, Tatiana; Luijkx, Ingrid T.; Jain, Atul; Jones, Steve D.; Kato, Etsushi; Kennedy, Daniel; Klein Goldewijk, Kees; Knauer, Jurgen; Korsbakken, Jan Ivar; Kortzinger, Arne; Landschutzer, Peter; Lauvset, Siv K.; Lefevre, Nathalie; Lienert, Sebastian; Liu, Junjie; Marland, Gregg; McGuire, Patrick C.; Melton, Joe R.; Munro, David R.; Nabel, Julia E. M. S.; Nakaoka, Shin-Ichiro; Niwa, Yosuke; Ono, Tsuneo; Pierrot, Denis; Poulter, Benjamin; Rehder, Gregor; Resplandy, Laure; Robertson, Eddy; Rodenbeck, Christian; Rosan, Thais M.; Schwinger, Jorg; Schwingshackl, Clemens; Seferian, Roland; Sutton, Adrienne J.; Sweeney, Colm; Tanhua, Toste; Tans, Pieter P.; Tian, Hanqin; Tilbrook, Bronte; Tubiello, Francesco; van der Werf, Guido R.; Vuichard, Nicolas; Wada, Chisato; Wanninkhof, Rik; Watson, Andrew J.; Willis, David; Wiltshire, Andrew J.; Yuan, Wenping; Yue, Chao; Yue, Xu; Zaehle, Sonke; Zeng, Jiye	EARTH SYSTEM SCIENCE DATA	2022	10.5194/essd-14-1917-2022	472

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety	Al-Tohamy, Rania; Ali, Sameh S.; Li, Fanghua; Okasha, Kamal M.; Mahmoud, Yehia A. -G.; Elsamahy, Tamer; Jiao, Haixin; Fu, Yinyi; Sun, Jianzhong	ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY	2022	10.1016/j.ecoenv.2021.113160	446
Dimensional Design and Core-Shell Engineering of Nanomaterials for Electromagnetic Wave Absorption	Wu, Zhengchen; Cheng, Han-Wen; Jin, Chen; Yang, Bintong; Xu, Chunyang; Pei, Ke; Zhang, Huibin; Yang, Ziqi; Che, Renchao	ADVANCED MATERIALS	2022	10.1002/adma.202107538	347
Bioplastics for a circular economy	Rosenboom, Jan-Georg; Langer, Robert; Traverso, Giovanni	NATURE REVIEWS MATERIALS	2022	10.1038/s41578-021-00407-8	310
A green and sensitive guanine-based DNA biosensor for idarubicin anticancer monitoring in biological samples: A simple and fast strategy for control of health quality in chemotherapy procedure confirmed by docking investigation	Karimi-Maleh, Hassan; Khataee, Alireza; Karimi, Fatemeh; Baghayeri, Mehdi; Fu, Li; Rouhi, Jalal; Karaman, Ceren; Karaman, Onur; Boukherroub, Rabah	CHEMOSPHERE	2022	10.1016/j.chemosphere.2021.132928	302
Understanding the structure-performance relationship of active sites at atomic scale	Li, Runze; Wang, Dingsheng	NANO RESEARCH	2022	10.1007/s12274-022-4371-x	297
A review on heterogeneous photocatalysis for environmental remediation: From semiconductors to modification strategies	Wang, Huijie; Li, Xin; Zhao, Xiaoxue; Li, Chunyan; Song, Xianghai; Zhang, Peng; Huo, Pengwei; Li, Xin	CHINESE JOURNAL OF CATALYSIS	2022	10.1016/S1872-2067(21)63910-4	279
Engineering Dual Single-Atom Sites on 2D Ultrathin N-doped Carbon Nanosheets Attaining Ultra-Low-Temperature Zinc-Air Battery	Cui, Tingting; Wang, Yun-Peng; Ye, Tong; Wu, Jiao; Chen, Zhiqiang; Li, Jiong; Lei, Yongpeng; Wang, Dingsheng; Li, Yadong	ANGEWANDTE CHEMIE-INTERNATIONAL EDITION	2022	10.1002/anie.202115219	274

Article Titles	Authors	Publication Titles	Year	DOI	Total Citations
Review on Methylene Blue: Its Properties, Uses, Toxicity and Photodegradation	Khan, Idrees; Saeed, Khalid; Zekker, Ivar; Zhang, Baoliang; Hendi, Abdulmajeed H.; Ahmad, Ashfaq; Ahmad, Shujaat; Zada, Noor; Ahmad, Hanif; Shah, Luqman Ali; Shah, Tariq; Khan, Ibrahim	WATER	2022	10.3390/w14020242	266

Figure S2: Keywords per year (citespace) 2014.

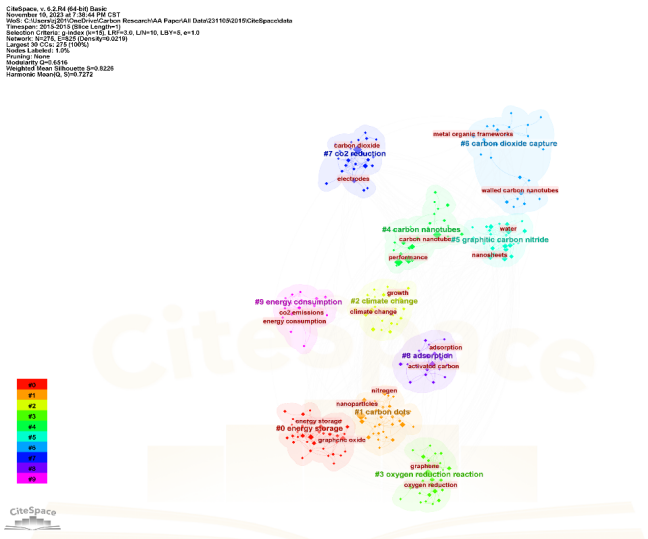


Figure S3: Keywords per year (citespace) 2015.

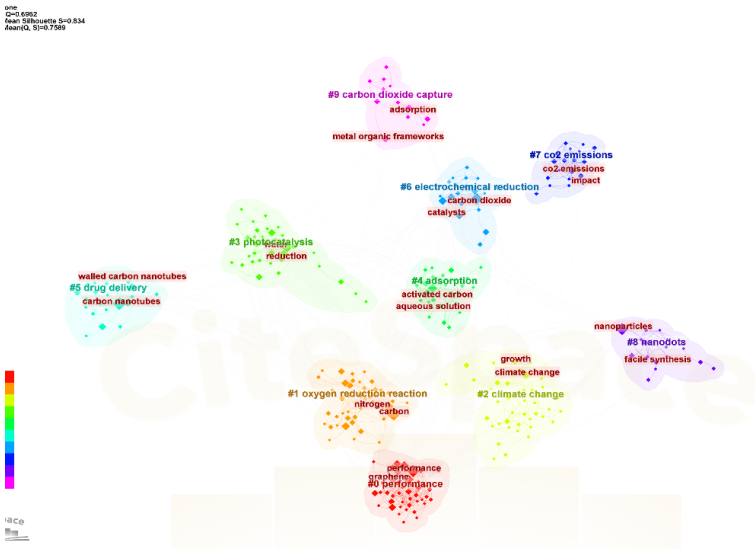


Figure S4: Keywords per year (citespace) 2016.

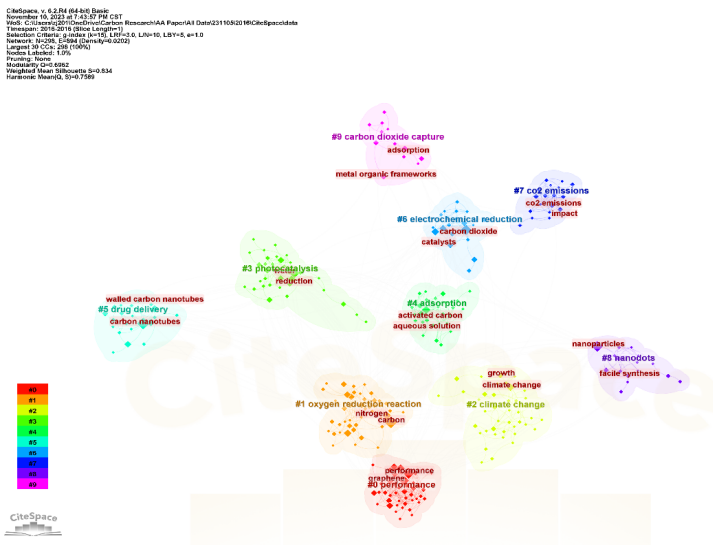


Figure S5: Keywords per year (citespace) 2017.

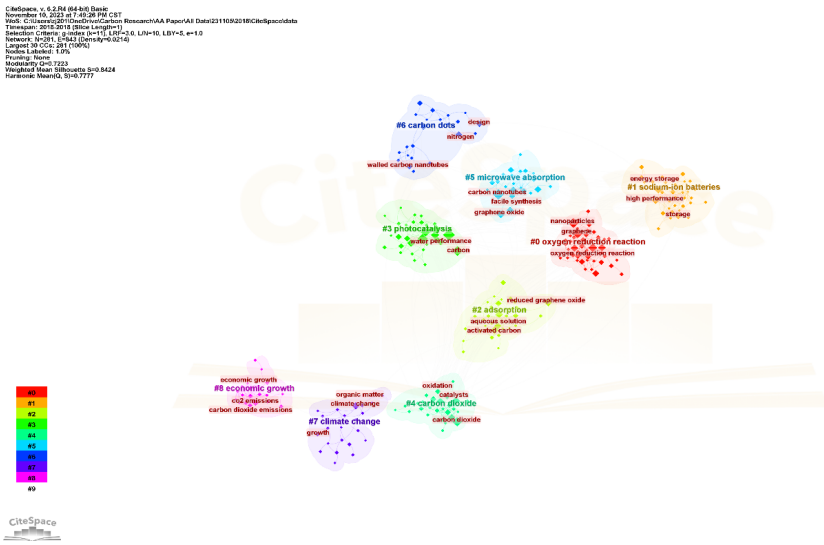


Figure S6: Keywords per year (citespace) 2018.

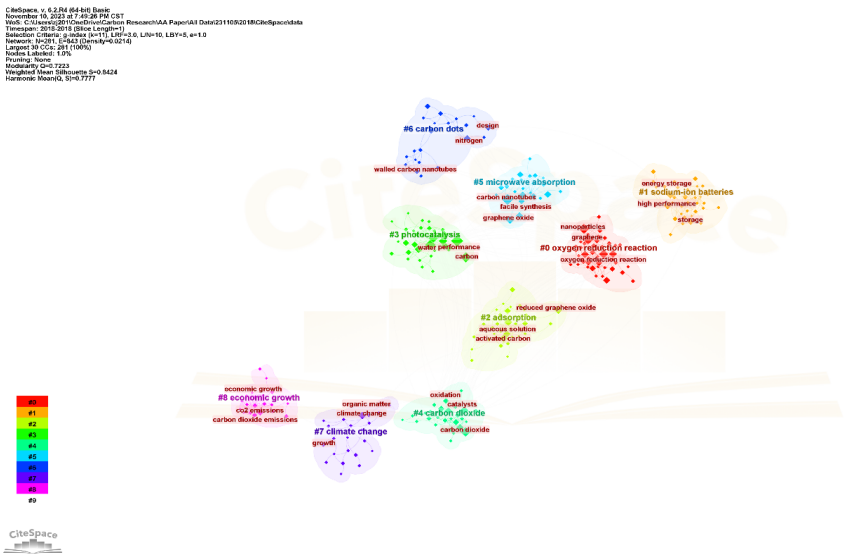


Figure S7: Keywords per year (citespace) 2019.

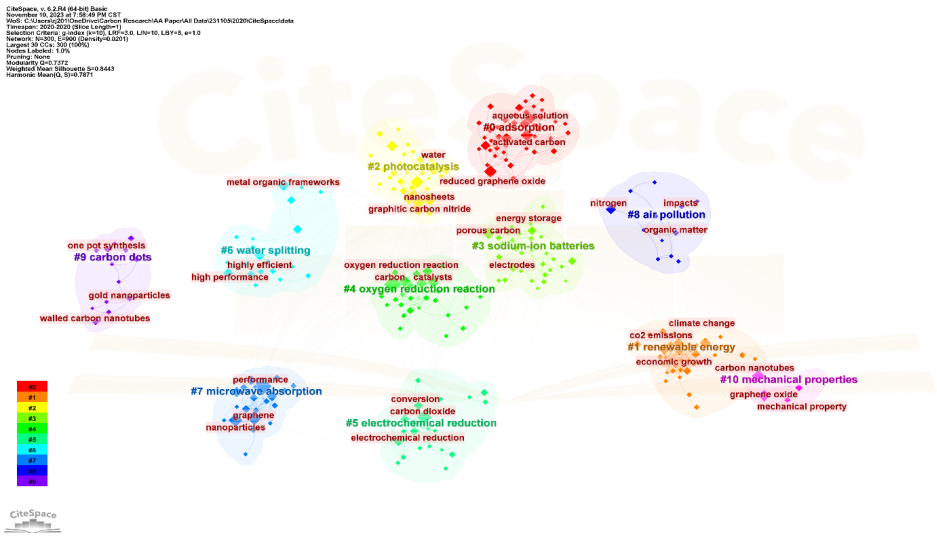


Figure S8: Keywords per year (citespace) 2020.

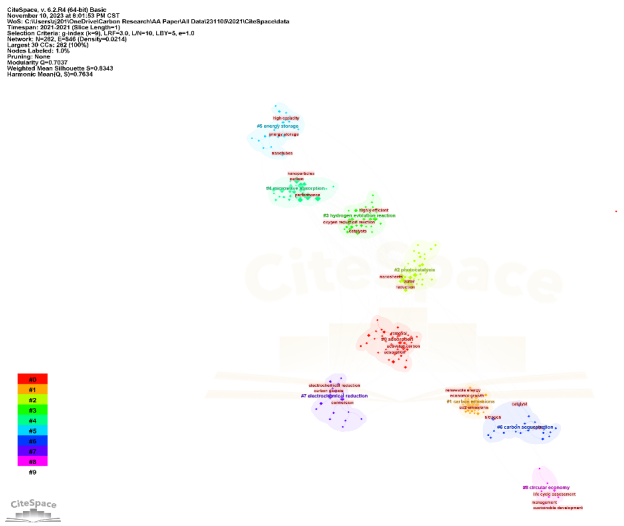


Figure S9: Keywords per year (citespace) 2021.

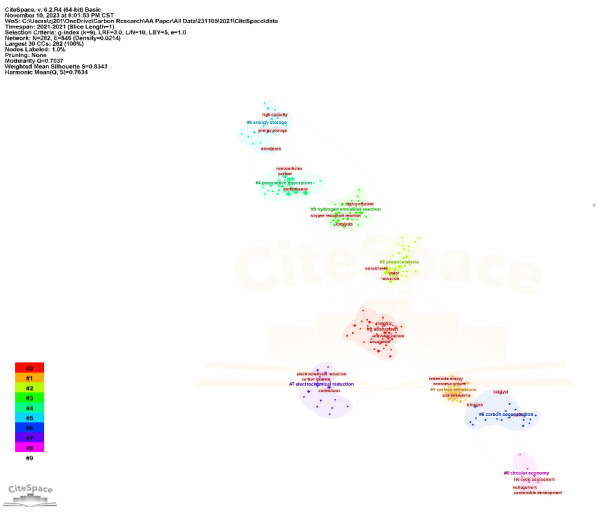


Figure S10: Keywords per year (citespace) 2022.

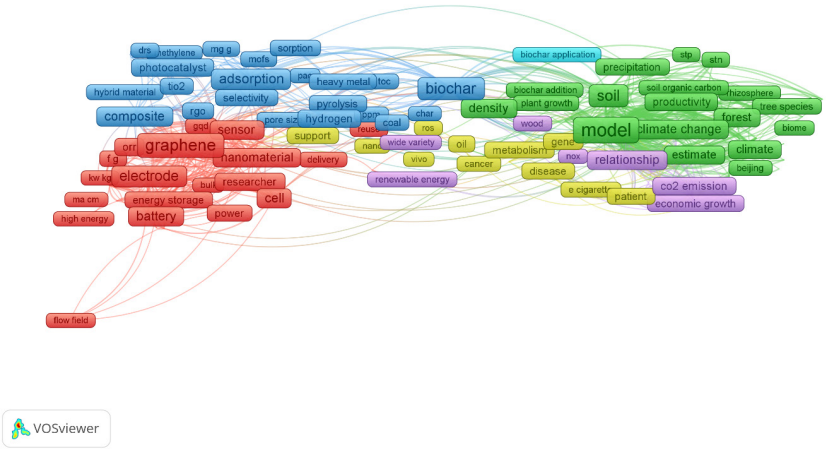


Figure S11: Abstract per year 2013.

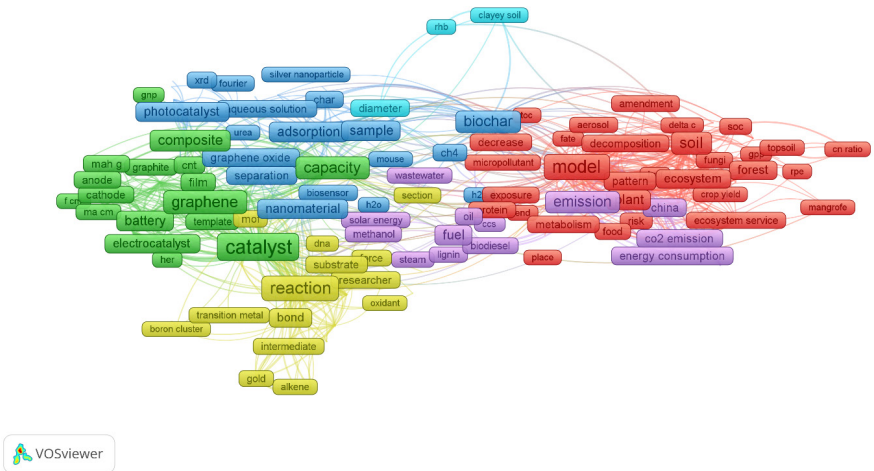


Figure S12: Abstract per year 2014.

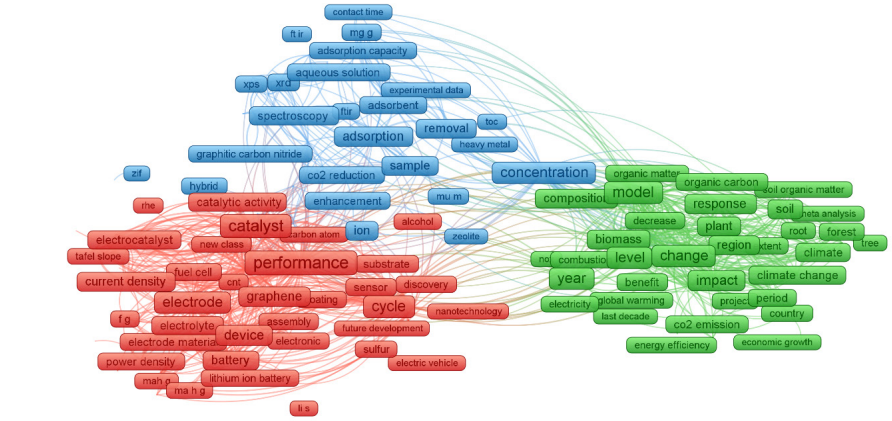


Figure S13: Abstract per year 2015.

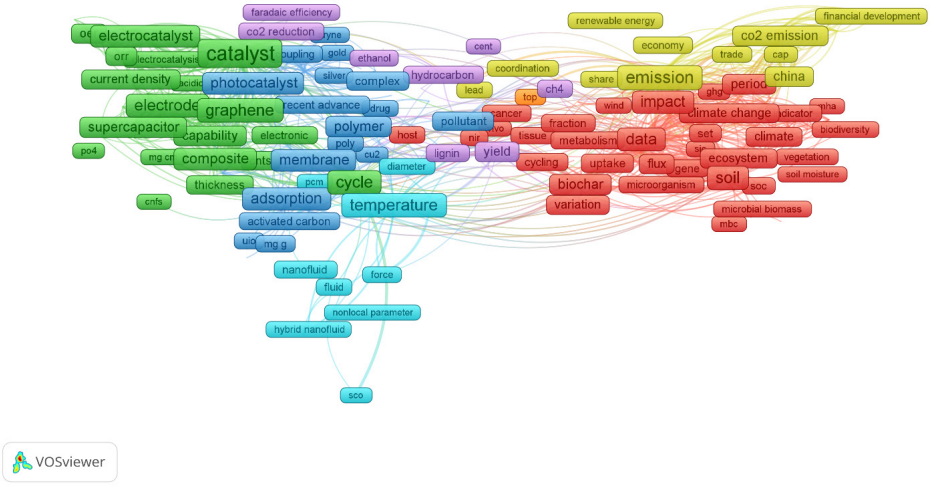


Figure S14: Abstract per year 2016.

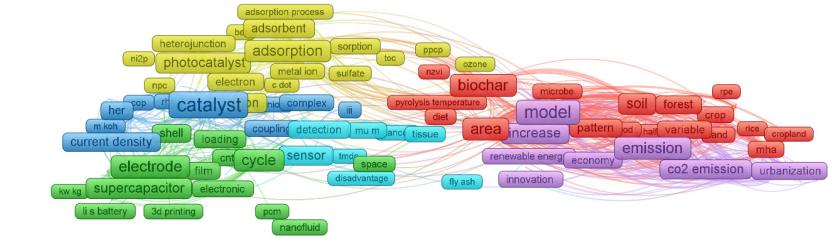
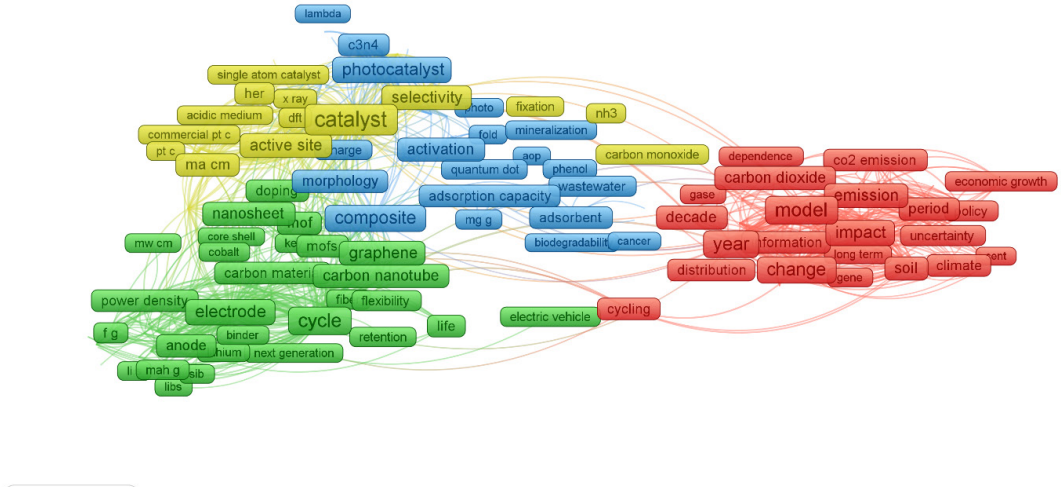


Figure S15: Abstract per year 2017.



VOSviewer

Figure S16: Abstract per year 2018.

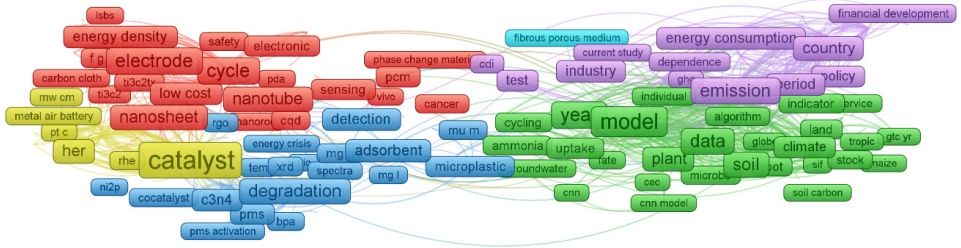


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Figure S17: Abstract per year 2019.

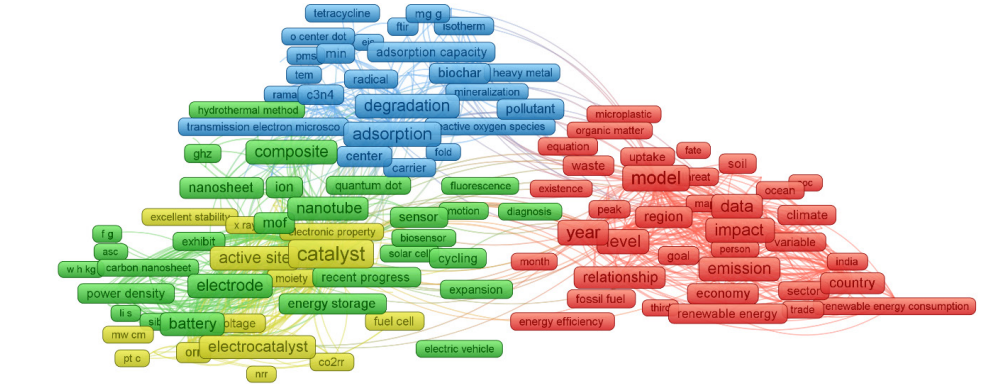

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Figure S18: Abstract per year 2020.

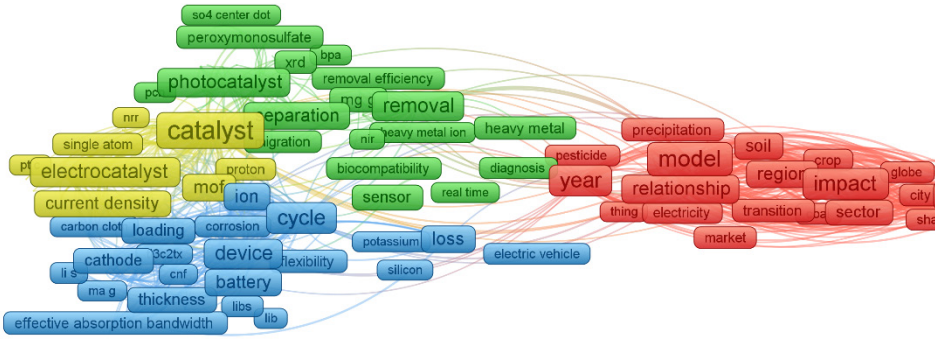
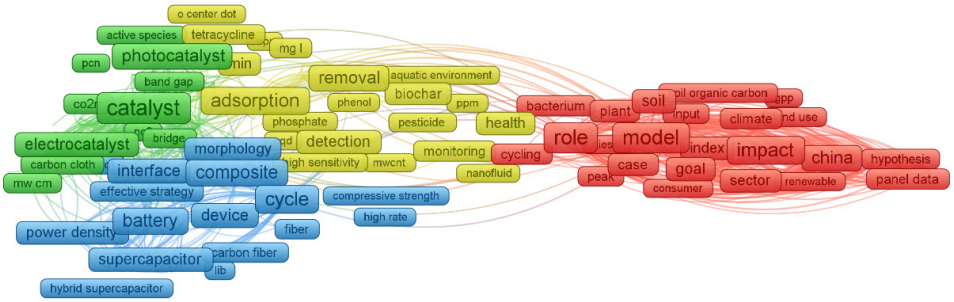


Figure S19: Abstract per year 2021.



VOSviewer

Figure S20: Abstract per year 2022.

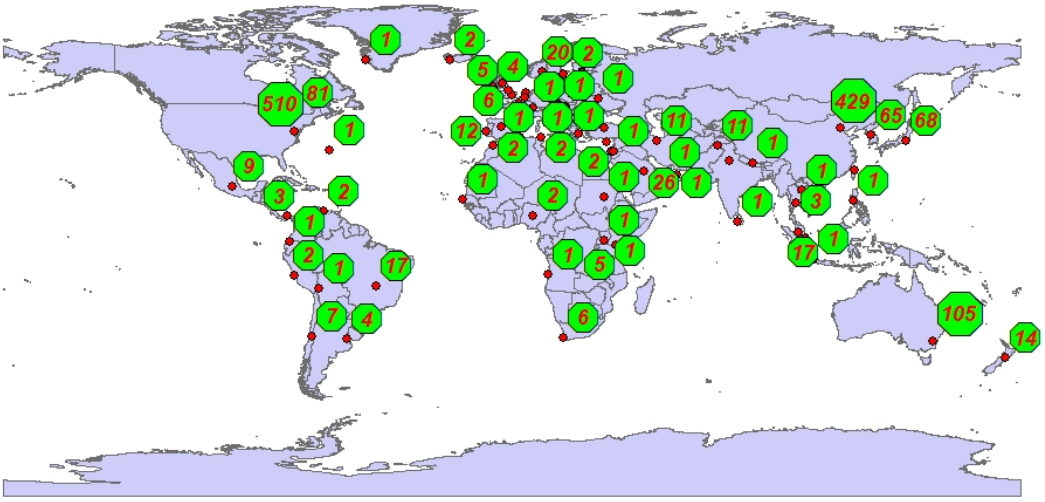


Figure S21: Regions per year (ArcGIS) 2013.

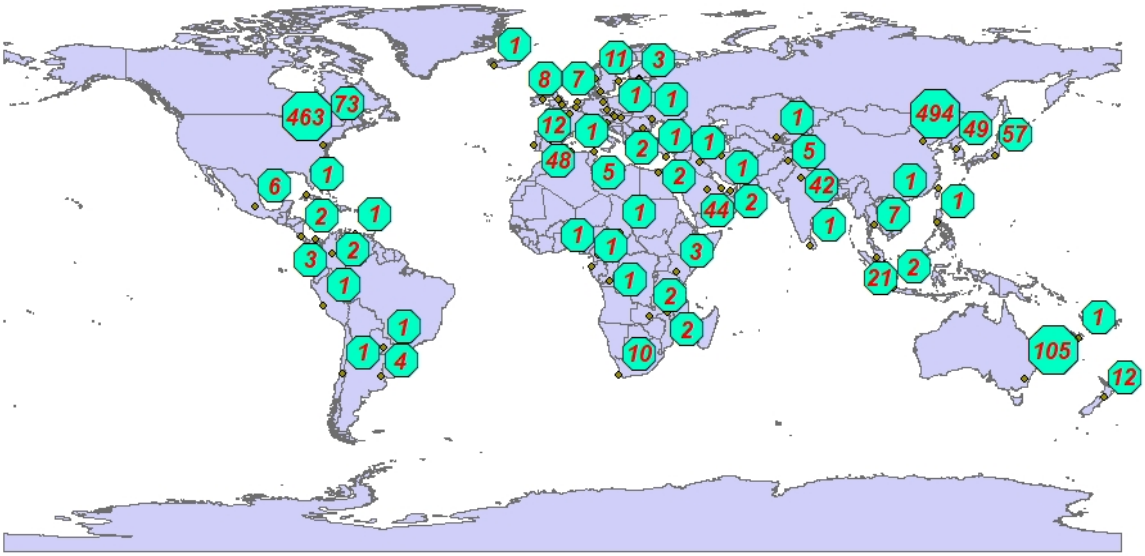


Figure S22: Regions per year (ArcGIS) 2014.

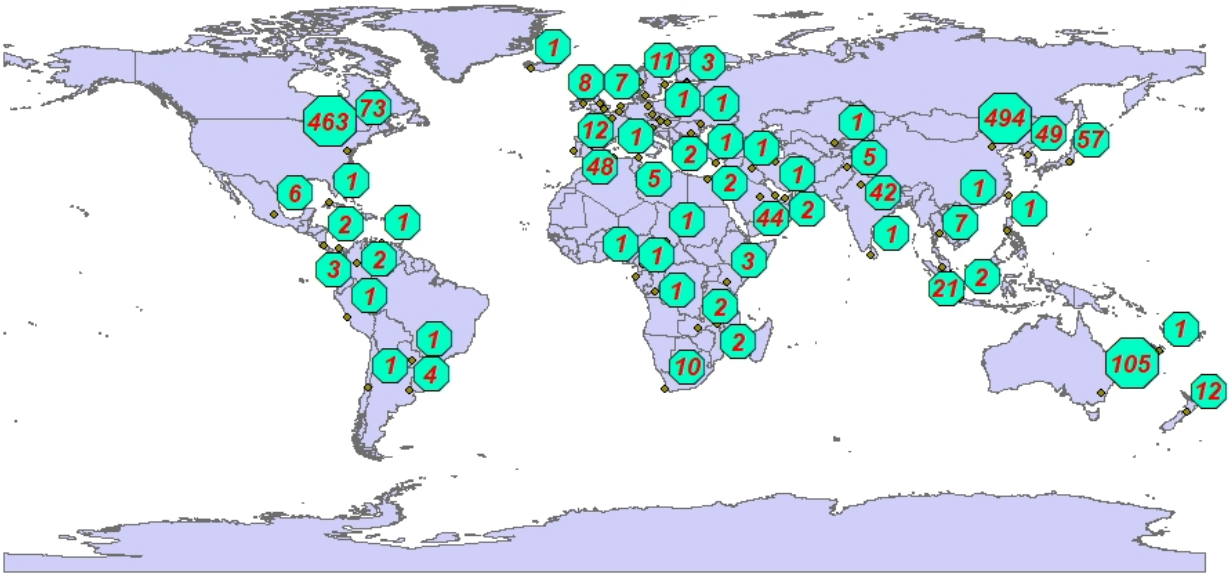


Figure S23: Regions per year (ArcGIS) 2015.

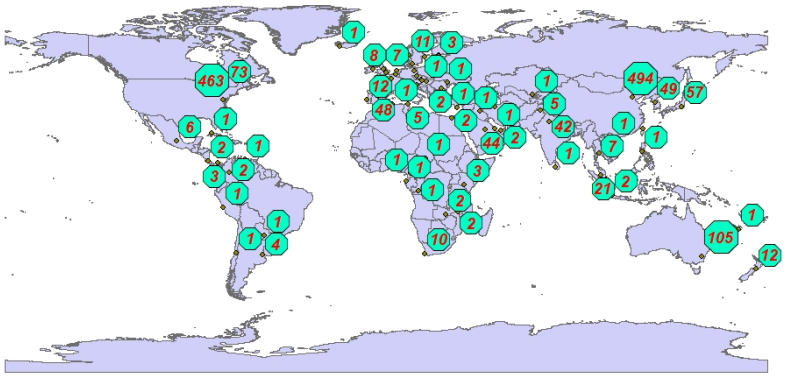


Figure S24: Regions per year (ArcGIS) 2016.

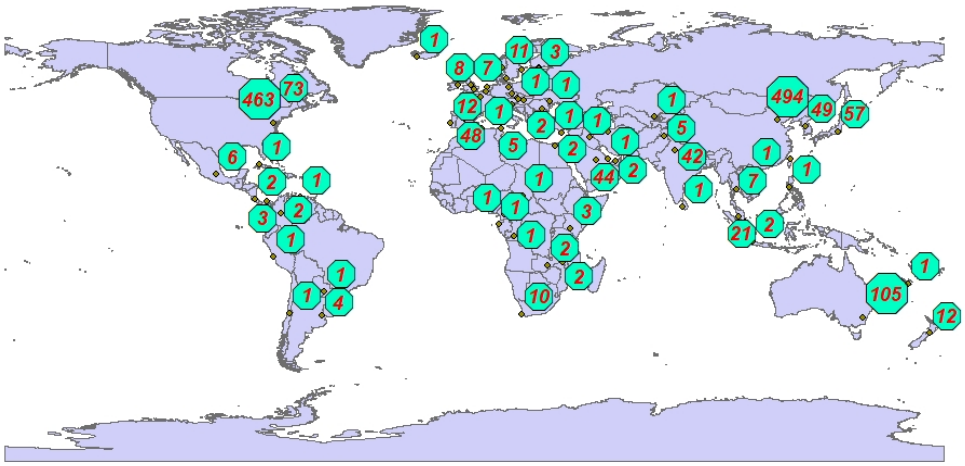


Figure S25: Regions per year (ArcGIS) 2017.

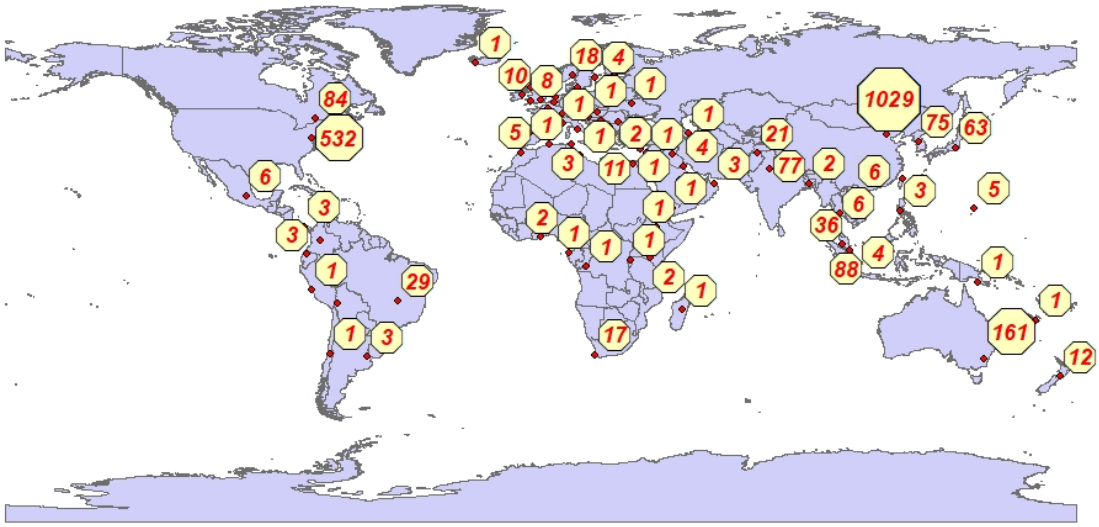


Figure S26: Regions per year (ArcGIS) 2018.

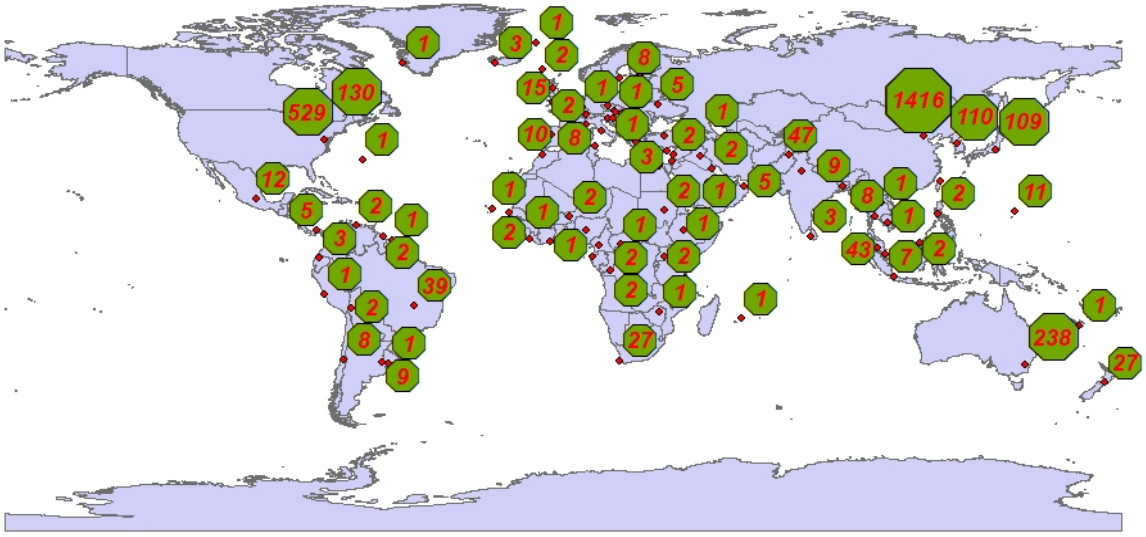


Figure S28: Regions per year (ArcGIS) 2020.

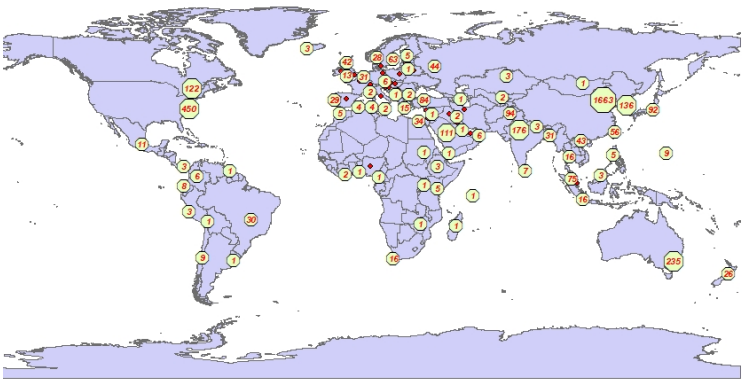


Figure S29: Regions per year (ArcGIS) 2021.

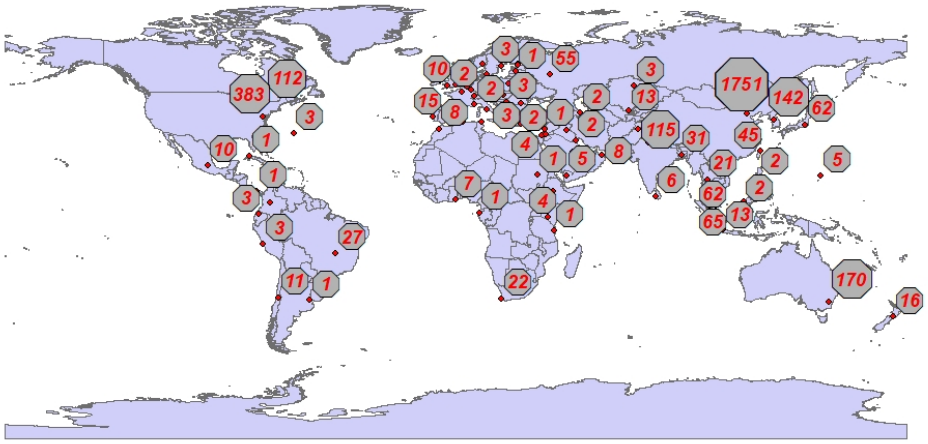


Figure S30: Regions per year (ArcGIS) 2022.