

Evolution of Global Climate Change Related Research: Bibliometric Analysis

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Abstract. The burgeoning interest in addressing climate change has catalyzed a significant increase in related research, necessitating a comprehensive review to understand the evolution of the field, emergent research areas, and geographical contributions. By employing a bibliometric methodology to analyze a wide array of scientific publications, this study aims to map out the dynamics of global research on climate change, focusing on publication growth, international collaborations, thematic trends, and citation impact. Our findings reveal not only a substantial rise in the volume of research and international collaborations, reflecting the global consensus on climate change challenges, but also a diversification of topics, indicating a shift towards more integrative and interdisciplinary approaches. The citation analysis further highlights the growing influence and importance of climate change research in scientific discourse and policy-making. Overall, this work underscores the dynamic evolution of climate change research, offering valuable insights into its progress, changing priorities, and the future challenges and opportunities, thereby contributing to a deeper understanding of the scientific landscape and informing future studies and policy development.

Keywords. Climate Change Research, Bibliometric Analysis, Scientific Publications Trends, International Collaborations, Research Impact and Evolution.

1 Introduction

Climate change represents one of the greatest threats to the global environment, human societies and economies worldwide [1-3]. Mainly induced by human activities, this phenomenon is leading to profound and rapid changes in the earth's climate, affecting ecosystems, communities and lifestyles [4-7]. The urgency of the situation is underlined by increasingly frequent and intense extreme weather events, such as heat waves, droughts, floods and hurricanes, threatening food security, public health and geopolitical stability [8-13]. In the face of this crisis, scientific research plays a crucial role. It enables us not only to understand the complex mechanisms of climate change, but also to assess its impacts on various natural and human systems.

One of the primary effects of climate change on water resources is the alteration of hydrological cycles [14-19]. Changes in temperature and precipitation patterns influence the amount, timing, and intensity of rainfall. Some areas might experience increased rainfall, leading to higher incidences of flooding, while others may see a decrease in precipitation, resulting in prolonged droughts [8, 20-26]. This variability in water availability makes it increasingly difficult to manage water resources effectively, impacting agriculture, drinking water supplies, and energy production. Furthermore, the melting of glaciers and ice caps contributes to rising sea levels, which can lead to the salinization of freshwater resources [19, 27-29]. This process reduces the availability of potable water and can harm agricultural lands, making them less fertile and

reducing crop yields [30-32]. Coastal communities are especially vulnerable to these changes, facing increased risks of flooding and loss of habitat [12, 33].

Climate change also affects water quality. Higher temperatures can lead to increased rates of evaporation, concentrating pollutants in water bodies [34, 35]. Additionally, extreme weather events, such as heavy rains and floods, can overwhelm storm water systems and lead to the contamination of water supplies with pathogens, chemicals, and sediments [36-38]. Such events pose serious risks to human health and aquatic ecosystems, requiring significant investments in water treatment and infrastructure to ensure safe water for consumption and use [39, 40].

Climate change poses significant threats to human populations through a variety of direct and indirect effects that impact health, food and water security, livelihoods, and displacement [41, 42]. Rising temperatures and extreme weather events lead to increased heat-related illnesses, cardiovascular and respiratory conditions, and a broader spread of vector-borne diseases [43, 44]. Agricultural productivity faces disruptions from altered precipitation patterns and extreme weather, threatening food security and elevating food prices [45, 46]. Economically, those dependent on natural resources for their livelihoods, such as farmers and fishers, experience heightened vulnerabilities, while escalating environmental degradation and resource scarcity drive displacement and climate-induced migration [47]. Furthermore, the social and cultural fabric of communities, especially those of indigenous and rural populations, is under threat as traditional ways of life become untenable.

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Addressing these multifaceted challenges requires comprehensive adaptation and mitigation efforts, global cooperation, and a commitment to sustainable development to protect human well-being in the face of climate change.

Science offers the tools needed to develop effective adaptation and mitigation strategies, proposing innovative solutions to reduce greenhouse gas emissions, protect vulnerable ecosystems, and support affected communities [48-51]. Scientific research also fuels public debate and informs political decisions, providing a solid basis for the development of ambitious, evidence-based climate policies [52, 53].

In this context, bibliometrics, the quantitative study of scientific literature, is emerging as a valuable tool for assessing and understanding the evolution of climate change research [54-57]. Bibliometric analysis enables us to map the scientific landscape of the field, identifying publication trends, key contributors (researchers, institutions, and countries), collaborative networks and emerging research themes [58, 59].

This approach provides an overview of the global scientific effort dedicated to climate change, highlighting advances made, gaps in current knowledge, and potential future directions for research. In this way, bibliometric analysis constitutes an invaluable resource for researchers, policy-makers and stakeholders involved in the fight against climate change, providing them with key insights to guide future efforts and maximize the impact of scientific research on this global challenge.

2 Methodology

To carry out this bibliometric analysis of the evolution of climate change research, we opted to use several leading bibliometric databases and tools. These include Web of Science, Scopus and Google Scholar, each offering comprehensive access to a wide range of scientific publications [54]. These platforms were chosen for their extensive coverage of scientific disciplines, their ability to provide detailed publication data, and their recognition in the academic world for the quality and reliability of the information provided [56, 57]. Our methodology for collecting and analyzing data on climate change research is based on a defined search strategy for extracting relevant publications from academic databases. We have targeted publications that incorporate the keywords "global", "climate", "change", and "models" in their title, abstract, or keywords, and that were published between the years 2013 and 2023. The search criteria outlined focus on scholarly articles published in English within the journal category, specifically targeting the environmental science (ENVI) subject area. The primary focus is on global climate change models, excluding articles with specific keywords such as "Article," "China," "Animal/Animals," "Economic and Social Effects," "Economics," "Europe," "Human/Human Activity/Humans," "India," "Lakes," "Nonhuman," "North America," "Population Distribution," "Population Statistics," "Physiology," and "Phenology."

This refined search aims to isolate research that precisely addresses climate change models without the influence of the excluded themes, ensuring a focused examination of the topic within the specified timeframe and subject area. The bibliometric indicators selected for analysis were chosen to provide an in-depth understanding of the dynamics of research in this field. These indicators include publication volume, revealing the growth or decline of scientific interest in climate change; citation counts, indicating the impact and resonance of research work within the scientific community; keyword analysis, identifying dominant and emerging research themes; co-authorship patterns, reflecting scientific collaboration and networks; and the identification of the most active institutions and countries, showing the geographical distribution of climate change research. Together, these indicators provide a comprehensive and nuanced overview of the current state and evolution of climate change research. Table 1 presents the aim informations of this study.

Table 1. Main informations.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2013:2023
Sources (Journals, Books, etc)	836
Documents	12301
Annual Growth Rate %	10.02
Document Average Age	4.59
Average citations per doc	26.79
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	23006
Author's Keywords (DE)	23458
AUTHORS	
Authors	37102
Authors of single-authored docs	504
AUTHORS COLLABORATION	
Single-authored docs	606
Co-Authors per Doc	5.6
International co-authorships %	42.97
DOCUMENT TYPES	
article	11404
conference paper	49
data paper	5
editorial	23
erratum	22
letter	42
note	39
retracted	10
review	694
short survey	13

3 Evolution of climate change research

3.1 Publication and citation trends by year

Table 2 shows publications and citations by year for research related to global climate change. Between 2013 and 2023, there is a significant increase in the number of papers published, from 8 in 2013 to 146 in 2023. At the same time, the average number of citations per article (Mean TC per Art) and per year (Mean TC per Year) is gradually decreasing, indicating that although the amount of research is increasing, the impact or recognition of each article, as measured by citations, is decreasing. In 2013, an article received an average of 221.12 citations, while in 2023, this number has fallen to 2.55. This trend may reflect the saturation of the field with a rapid increase in publications, making it harder for individual works to stand out. Citable years, also decreasing, show that the body of research is expanding over time, but with decreasing recognition per publication.

Table 2. Publications and citations per year.

Year	Documents	Mean TC per Art	Mean TC per Year	Citable Years
2013	8	221.12	18.43	12
2014	15	131.8	11.98	11
2015	29	96.07	9.61	10
2016	25	103.36	11.48	9
2017	27	71.3	8.91	8
2018	55	63.24	9.03	7
2019	70	66.64	11.11	6
2020	91	43.75	8.75	5
2021	117	24.82	6.2	4
2022	156	13.83	4.61	3
2023	146	2.55	1.27	2

3.2 Co-occurrence of keywords

Figure 1 shows a lattice map visualizing keyword occurrences in searches related to global climate change. Keywords are proportional in size to their frequency of appearance, with "climate change" being the most predominant, accounting for 22% of occurrences.

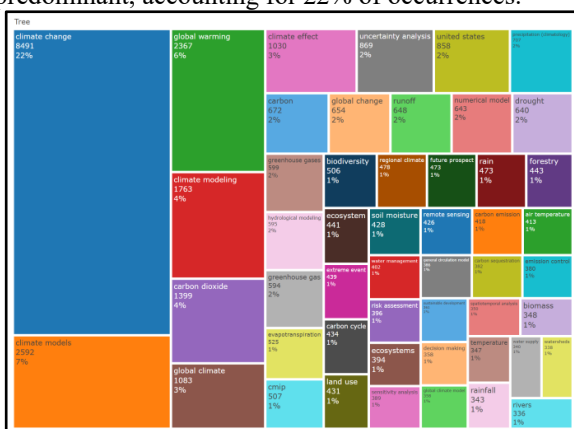


Fig. 1. Keywords occurrences.

Other important terms include "global warming" and "climate models", indicating specific focal points in the

search. More specific topics, such as "carbon dioxide", "climate effect", "uncertainty analysis", and "United States" are also present, but with a lower frequency, showing the diversity of the sub-themes studied. It is also interesting to note the inclusion of terms such as "biodiversity", "ecosystems", and "rainfall", which underline the interdisciplinary nature of the field of climate change research. The variety of colors and block sizes underlines the complexity and richness of the topics addressed in this branch of science.

This co-occurrence map, created by VOSviewer, illustrates the links between keywords used in climate change-related searches (Fig. 2). Keywords such as "climate change", "global warming" and "climate models" are visibly at the heart of searches, indicated by their larger size and central position. Around these terms are a multitude of related concepts such as "carbon dioxide", "greenhouse gases" and "climate modeling", forming clusters of interconnected topics. The shades of color probably indicate distinct thematic clusters, reflecting the diversity and interdisciplinarity of the field: red for emissions and pollution, green for ecology and biodiversity, blue for hydrology and oceans, etc. The density of links between keywords reflects the complexity of interactions between different aspects of climate change.

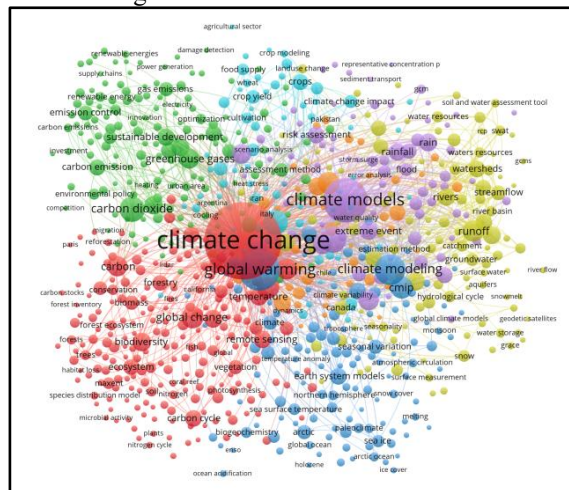


Fig. 2. Co-occurrence of keywords.

3.3 Thematic Evolution

This thematic map (Figure 3) represents the classification of climate change-related research topics according to their degree of development (density) and their degree of relevance (centrality). Basic themes such as "climate change", "global warming" and "global climate" are located in the lower right-hand quadrant, showing that they are well established and central to climate change research. At the top right, "climate models", "climate modeling" and "climate effect" are identified as driving themes, indicating that they are both well-developed and influential in the field. In the upper left quadrant, niche themes such as "carbon dioxide", "global change" and "greenhouse gases" have a high density but lower centrality, suggesting that they are specific and developed but less connected to other research fields. Finally, emerging or declining themes

such as "atmospheric temperature", "sea level change" and "pacific ocean" are found in the lower left quadrant, reflecting their increasing or decreasing relevance and less dense development in current literature.

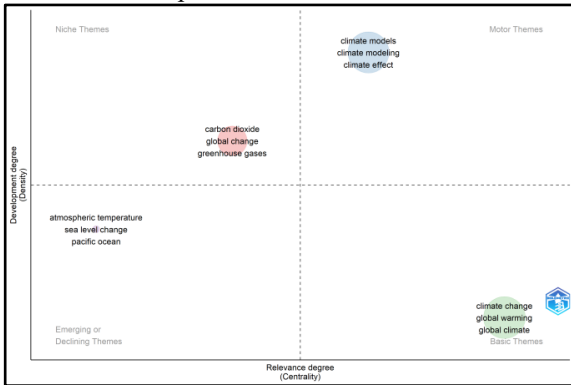


Fig. 3. Thematic map.

Figure 4 presents the thematic evolution map illustrating the progression and transformation of the main climate change research topics from 2013 to 2023. Between 2013 and 2017, the dominant themes were "climate change", "carbon dioxide" and "sea level change". From 2018 to 2020, the focus remains on "climate change" and "carbon dioxide", but also introduces "hydrological modelling" and "atmospheric temperature", reflecting a diversification of the topics studied. In the 2021-2022 periods, "runoff" and "ecosystem" emerge as new themes, indicating a growing focus on hydrological and ecological impacts.

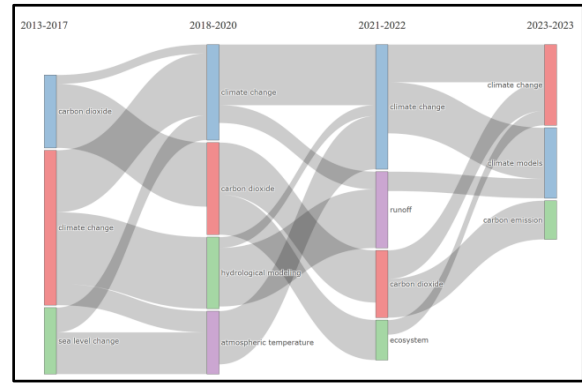


Fig. 4. Evolution map.

Finally, for the years 2023-2024, "climate models" and "carbon emission" stand out, which may suggest an increased interest in climate modeling tools and a renewed focus on carbon emissions? The flows between the columns show the evolution and persistence of the themes over time, with "climate change" remaining a constant thread throughout the decade.

4 Main players and contributions

4.1 Most relevant authors

Figure 5 shows the most relevant authors in the field of climate change research, ranked by number of papers published.

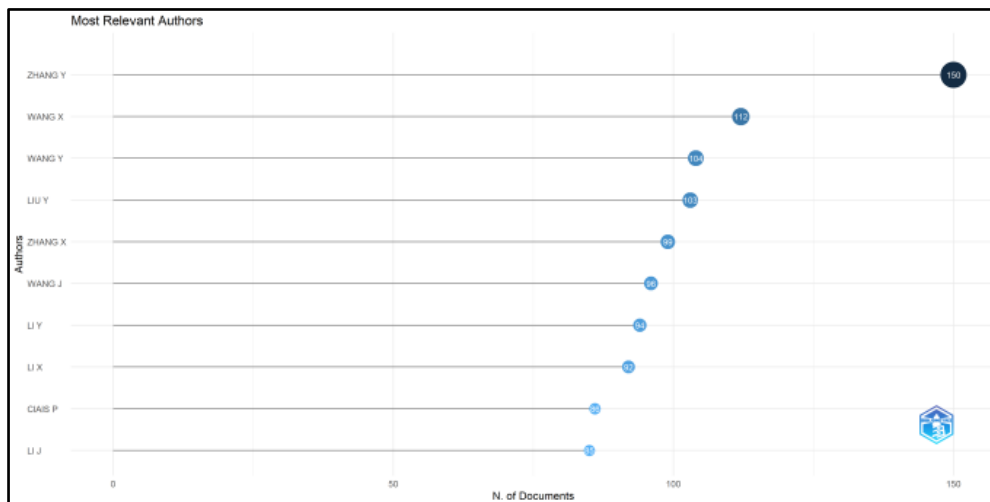


Fig. 5. Most relevant authors.

The most productive author is "ZHANG Y" with 150 papers, followed by "WANG X" with 112 and "WANG Y" with 104. Authors "LIU Y", "ZHANG X", "WANG J", "LI Y", "LI X", "CIAIS P", and "LI J" also show a significant contribution with a number of publications ranging from 85 to 103. The size of the bubbles indicates

the volume of publications, and the position on the horizontal axis reflects the total number of papers attributed to each author. This distribution suggests a concentration of significant research around a few individuals, possibly reflecting their expertise and influence in the field of climate change.

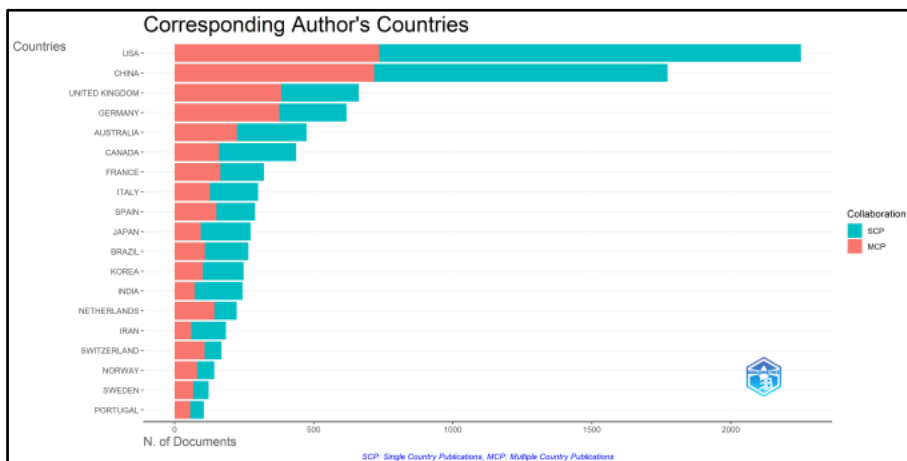


Fig. 6. Most relevant countries.

4.2 Countries and Affiliations with the highest productivity

This bar chart illustrates the countries corresponding to the most prolific authors in the field of climate change research (Figure 6). The USA leads with the highest number of papers published, closely followed by China and the UK. Germany, Australia and Canada are also significant contributors. The bars are divided into two colors: blue represents publications from a single country (SCP), while red indicates publications from collaborations between several countries (MCP). This pattern suggests not only a high volume of research produced by these countries, but also a trend towards international collaboration. Collaborations are particularly notable for countries such as Germany and the UK, indicating a strong commitment to cross-border research projects on climate change.

Figure 7 shows the most relevant affiliations in the field of climate change research, ranked by the number of articles published.

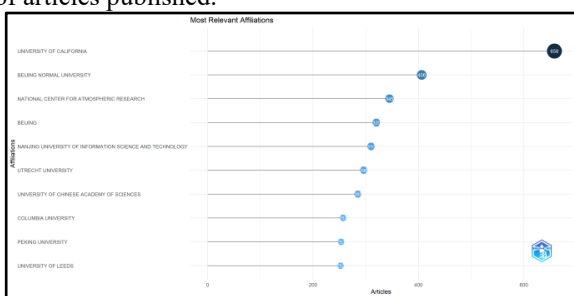


Fig. 7. Most relevant affiliations.

The University of California stands out as the most prolific institution, with 658 articles. It is followed by Peking University and the National Center for Atmospheric Research, with 406 and 345 articles respectively. Other important institutions include Peking Normal University, Nanjing University of Information Science and Technology, and Utrecht University, all contributing significantly to the literature on climate change. The University of Chinese Sciences, Columbia University, Peking University and the University of Leeds also feature on the list, underlining the global contribution to research in this field. The size of the bubbles reflects the volume of scientific output,

indicating the weight of each institution in global climate research.

4.3 Highest productive journals

Figure 8 shows a scatter plot of the most relevant sources related to global climate change research. The journal "Environmental Research Letters" clearly dominates with 655 papers, followed by "Global Change Biology" and "Water (Switzerland)" with 386 and 379 publications respectively. Other journals such as "Climatic Change", "Sustainability (Switzerland)", "Earth's Future", and "Journal of Hydrology" also present a significant number of contributions to this field of research. The logo at bottom right indicates that the data probably come from the "Bibliometrix" platform, a bibliometric analysis tool.

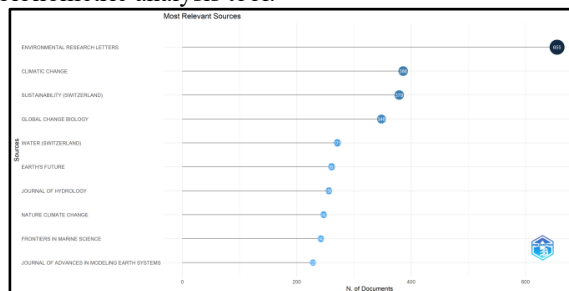


Fig. 8. Most relevant sources.

Figure 9 lists the most cited documents worldwide in the field of climate change research. Documents are listed on the y-axis with author names, year of publication and journal abbreviation.

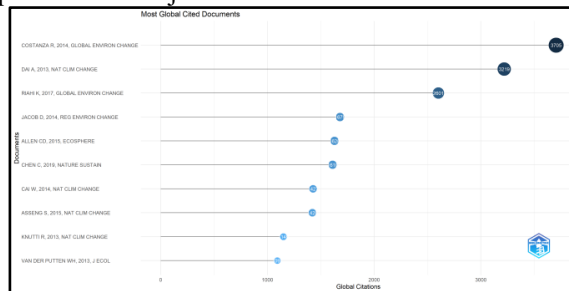


Fig. 9. Most globally cited documents.

The x-axis shows the number of overall citations received by each paper. Costanza R.'s paper, published

in 2014 in "Global Environmental Change", stands out as the most cited with 3705 citations. It is followed by a paper by Dai A., published in 2013 in "Nature Climate Change", with 3219 citations. Several other papers, notably those published in "Nature Climate Change" and "Nature Sustainability", also show a high number of citations, indicating their influence and importance in the field of climate change. The "Bibliometrix" logo suggests that this data has been analyzed using this bibliometric tool.

5 Discussions

Firstly, the significant upward trend in publications between 2013 and 2023, from 8 to 146 papers, underlines the intensification of interest and research efforts in this crucial field. However, this increase is accompanied by a decrease in average recognition per paper, as evidenced by the drop in average citations per paper from 221.12 in 2013 to 2.55 in 2023. This trend may indicate saturation in the climate change research field, making it more difficult for individual works to stand out within a growing mass of literature. This dynamic reflects the growing challenge for researchers to maintain the impact and visibility of their work in a rapidly expanding field.

Analysis of keyword co-occurrence reveals the predominant themes and their interconnection within climate change research. Terms such as "climate change", "global warming" and "climate models" take center stage, surrounded by a multitude of related concepts that form thematic clusters, indicating the diverse aspects and interdisciplinarity of the field. These thematic clusters, ranging from ecology to hydrology, demonstrate the richness and complexity of the subjects addressed in this branch of science.

The thematic evolution of research highlights a shift from a focus on themes such as "climate change" and "carbon dioxide" to a diversification towards topics such as "hydrological modelling" and "ecological impact", underlining an increasingly holistic and integrated approach to the impacts of climate change. This thematic progression suggests an on-going adaptation of research in the face of emerging challenges, and an evolution towards the exploration of more complex solutions and modelling.

The identification of the main players, in terms of authors, countries, affiliations and journals, underlines the concentration of expertise and the importance of international collaboration in climate change research. The predominance of certain institutions and countries in the volume of publications reflects not only their research capacity, but also their commitment to in-depth understanding and action on climate change. International collaborations, in particular, play a crucial role in the advancement of research, fostering the exchange of knowledge and the integration of diverse perspectives to tackle this global issue.

These bibliometric results reveal an evolving research dynamic, marked by significant quantitative and thematic expansion. However, they also highlight the challenges of research saturation and visibility in a

rapidly expanding field. The importance of international collaborations and the concentration of contributions around certain key players reaffirm the need for a collaborative and integrated approach to meeting the challenges of climate change. These findings should encourage researchers to pursue their efforts with a renewed focus on impact, innovation and interdisciplinary, in order to make a significant contribution to the fight against climate change.

6 Conclusion

Our bibliometric analysis reveals the dynamic evolution of global climate change research, showing an exponential increase in publications from 2013 to 2023 alongside a decline in average citations per article, suggesting field saturation and challenges for individual works to gain prominence. The diversity and interdisciplinarity of research themes underscore the complexity of addressing climate change. Key implications include the need for robust knowledge evaluation mechanisms, promotion of impactful research over quantity, and enhanced interdisciplinary collaboration.

Future research should focus on deepening interdisciplinary approaches, innovating methodologies for literature synthesis, prioritizing studies with practical applications, and strengthening international collaborations. This approach aims to advance a more coordinated and impactful responses to climate change, emphasizing the importance of comprehensive strategies in research and policy-making to effectively combat this global challenge.

This study's unique value lies in its comprehensive analysis and strategic insights, which not only enrich the existing body of literature but also chart a path forward for the scientific community to address climate change more effectively. By highlighting the importance of innovation, application, and collaboration, our analysis underscores the critical need for a holistic and impactful research paradigm to meet the challenges posed by climate change.

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