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AI in the Era of Climate Change: Unveiling Patterns and Trends Through Bibliometric Analysis

Mohamed Ali Barre[1], Abdikadir Hussein Elmi[1*], Ibrahim Hassan Mohamud[2], Zakarie Abdi Warsame[3], Abdijalil Abdullahi Mohamed[1,4]

[1] Faculty of Computing, Department of Information Technology, SIMAD University, Mogadishu 2526, Somalia
[2] Faculty of Management Science, SIMAD University, Mogadishu JH09010, Somalia
[3] Faculty of Economics, SIMAD University, Mogadishu JH09010, Somalia
[4] National Advanced IPv6 Centre, Universiti Sains Malaysia, Penang 11800, Malaysia

Corresponding Author Email: gabowraage@gmail.com

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ABSTRACT

This study is to conduct a comprehensive bibliometric analysis of the evolving research landscape in the domain of artificial intelligence (AI) in the context of climate change, covering the period from 2017 to 2023. The analysis aimed to identify key trends, prolific contributors, and influential publications in the field. Our findings indicate a remarkable growth in research output, with the number of documents increasing from 60 in 2017 to 422 by 2023, reflecting a burgeoning interest in AI applications for climate change. In terms of geographic contribution, the United States and China emerged as leaders, with the United States producing the most documents and receiving the highest total citations. A keyword network analysis revealed five distinct clusters, highlighting focal areas such as 'Decision Support System', 'Machine Learning', and 'Climate Change'. Notably, journals like 'Science of the Total Environment' and 'Sustainability (Switzerland)' were identified as significant for their high citation counts, with the former achieving 807 citations from 25 documents. In contrast, journals such as 'Proceedings of SPIE' displayed a more niche presence with modest citation figures. These results illuminate the dynamic and expanding nature of AI research in addressing climate change, emphasizing both the growth and the diversification of the field.

1. INTRODUCTION

The escalating challenges posed by climate change necessitate innovative approaches to mitigate and adapt to its impacts. The advent of artificial intelligence (AI) offers unprecedented tools for analyzing complex environmental data, predicting climate patterns, and crafting solutions that were once beyond human capability [1]. In this context, the research paper "AI in the Era of Climate Change: Unveiling Patterns and Trends through Bibliometric Analysis" seeks to dissect the burgeoning nexus of AI and climate change research through a meticulous bibliometric examination [2].

AI, characterized by its capacity to autonomously learn and adapt from data, holds immense potential to revolutionize climate change mitigation and adaptation efforts. Through advanced data analytics, AI algorithms can discern intricate patterns within vast datasets, facilitating the identification of climate-related trends, vulnerabilities, and potential solutions. For instance, AI-driven climate models enable more accurate predictions of future climate scenarios, aiding policymakers in devising targeted mitigation strategies and enhancing resilience measures [3].

Moreover, AI-powered applications are increasingly deployed across diverse sectors to optimize resource utilization and reduce carbon emissions. In transportation, AI algorithms optimize traffic flow and logistics, leading to reductions in fuel consumption and greenhouse gas emissions [4]. Similarly, in agriculture, AI-driven precision farming techniques optimize irrigation schedules and crop management practices, thereby enhancing productivity while minimizing environmental impacts [5].

In this context, the significance of conducting a bibliometric analysis to unveil patterns and trends in AI research pertaining to climate change becomes apparent. By systematically analyzing scholarly publications, this study aims to elucidate the evolution of AI applications in addressing climate-related challenges, identify emerging research themes, and assess the global distribution of research efforts. Such insights are invaluable for guiding future research agendas, fostering interdisciplinary collaborations, and informing evidence-based policymaking in the realm of climate change mitigation and adaptation [6].

This study commences by delineating the prolific expansion of literature in this domain, as evidenced by the significant growth in the number of scholarly documents over recent years

[7]. The analysis reveals a discernible upward trajectory in research output, reflecting the escalating urgency for AI-driven climate solutions [8]. By harnessing bibliometric methodologies, we map out the collaborative networks and intellectual contours of this dynamic field, identifying key themes, seminal contributions, and emergent research clusters [9]. Through the lens of citation metrics and journal analyses, the paper elucidates the academic resonance and impact of published research, shedding light on the most influential journals and articles that are steering the academic discourse on AI applications in climate change mitigation and adaptation [10].

The multifaceted nature of this research landscape is further explored through the interconnections of various research clusters. Keywords such as 'decision support systems', 'machine learning', 'climate models', 'remote sensing', and 'human factors' serve as beacons that guide the investigation of the intricate web of research efforts [11]. These clusters not only underscore the diverse applications of AI but also reflect the interdisciplinary collaboration required to tackle the complex problems presented by climate change [12]. Moreover, the paper delves into the nuances of research dissemination and reception within the academic community, as evidenced by the citation analysis of various journals. The citation patterns observed in the journals' bibliometric data reflect not only the quantity of research being produced but also the qualitative influence these studies have on the wider scientific discourse [13]. For instance, the high citation rates of papers from journals like 'Science of the Total Environment' indicate a strong acceptance and utilization of the research findings within the field, suggesting that the studies published therein are of significant relevance to current climate change challenges and AI applications. On the contrary, the lower citation rates of other journals may imply a more nascent stage of development or a specialized focus within this interdisciplinary space [14].

The bibliometric analysis also brings forth the geographical and collaborative dimensions of the field, where the interconnectedness of researchers across nations and institutions is visualized and quantified. The authorship network reveals patterns of collaboration that transcend geographical boundaries, suggesting a global effort in the search for AI-driven climate solutions [15]. This collective endeavor, highlighted by the varying degrees of link strengths between authors from different countries, indicates a shared recognition of the global nature of climate change and the collective intelligence approach necessitated to address it. By scrutinizing these patterns, the paper not only reflects the current state of global cooperation but also identifies potential areas for further international and cross-disciplinary partnerships [16].

In essence, this introductory exploration sets the stage for a deeper dive into the intricate tapestry of AI and climate change research. It lays the groundwork for understanding how the flow of information and collaborative dynamics within this burgeoning field can inform future innovations and policy-making [17]. The study's bibliometric analysis serves as a foundational tool for understanding the current state of research, its historical evolution, and potential future directions. This paper aims to provide a comprehensive overview of the field, offering insights for researchers, policymakers, and practitioners invested in the intersection of AI and climate change [18].

2. LITERATURE REVIEW

The intersection of AI and climate change research is a rapidly evolving field marked by a diverse array of studies spanning technological innovations to socio-economic implications. The literature encapsulates advancements in AI that offer transformative potential for climate modeling, resource management, and policy development. It also critically examines the ethical considerations and collaborative dynamics that underpin the deployment of AI technologies in the global response to climate change.

Early works in the field, as highlighted by seminal papers from the late 2010s, laid the foundation by articulating the potential for AI to revolutionize climate change research [19]. Studies such as those published in 'Sustainability (Switzerland)' and 'Agricultural Water Management' emphasized the role of AI in enhancing the efficiency of resource use and in the precise monitoring of agricultural outputs under varying climatic conditions [20]. These works set the precedent for AI's application in optimizing water usage and in predicting crop yields, critical factors in climate resilience for the agricultural sector [21].

With the progression of the field, mid-decade literature began to focus on machine learning's predictive capabilities for climate modeling, as seen in contributions to 'Journal of Cleaner Production' and 'Science of the Total Environment' [22]. Here, the research began to address not only the direct applications of AI but also its integration with existing climate science methodologies, particularly in the realm of big data analytics and predictive modeling for climate phenomena [23]. The emphasis shifted to how machine learning algorithms could be applied to vast datasets for climate pattern recognition and forecasting [24].

Recent literature has expanded to consider the broader implications of AI in climate change, exploring the ethical, socio-economic, and policy dimensions [25]. Journals like 'Energies' and 'Water (Switzerland)' have contributed to the discourse around the governance of AI in the context of climate policy, and the implications of AI-driven interventions for sustainable development [26]. Moreover, studies have begun to delve into the human factors associated with AI applications in climate change, addressing issues such as equity, accessibility, and the redistribution of impacts across different populations [27].

Deep learning, as an advanced subset of machine learning, has been the focus of numerous articles within the 'Journal of Physics: Conference Series' and 'Lecture Notes in Computer Science' [28]. These publications have extensively discussed the application of neural networks in analyzing complex climate data and enhancing the accuracy of climate projections [29]. For instance, 'Lecture Notes in Computer Science' has provided a platform for discussing the development of convolutional neural networks that can process and interpret satellite imagery, contributing significantly to advancements in remote sensing for climate monitoring [30].

The role of AI in energy systems, as explored in 'Energies'. The journal has published works detailing how AI aids in the optimization of renewable energy sources, forecasting energy demands, and enhancing the efficiency of energy distribution networks [31]. This body of work reflects the critical importance of energy considerations within the climate change discourse and positions AI as an essential tool for achieving energy sustainability [6].

The influence of AI on policy-making and climate governance has also been a growing area of interest [26]. 'Sustainability (Switzerland)' has featured articles that explore the integration of AI into environmental policy frameworks, highlighting the technology's potential to inform more nuanced and responsive climate action strategies [28]. Moreover, research on decision support systems, particularly in 'Agricultural Water Management', has illuminated how AI can underpin policy decisions related to water resource allocation, crop irrigation strategies, and drought response planning [6].

3. METHODOLOGY

3.1 Data collection

This study has chosen the online Scopus database from 2017 to 26 November 2023 in food supply chain because it is the world's largest citation and abstract database of scholarly works from international publishers which provides a one-stop platform for scientific scholars [1]. Especially, compared to other databases like Web of Science (WoS), Google Scholar (GS), and PubMed (PubMed), Scopus has a wider variety of publications and helps with both keyword searches and bibliographic analysis [1]. Scopus has 20% higher coverage than WoS in terms of citation analysis, however, Google Scholar produces inconsistent results. PubMed is a database that is commonly utilized in scientific research [2]. Figure 1 shows the search strategy and detailed steps for the data collection for this study.

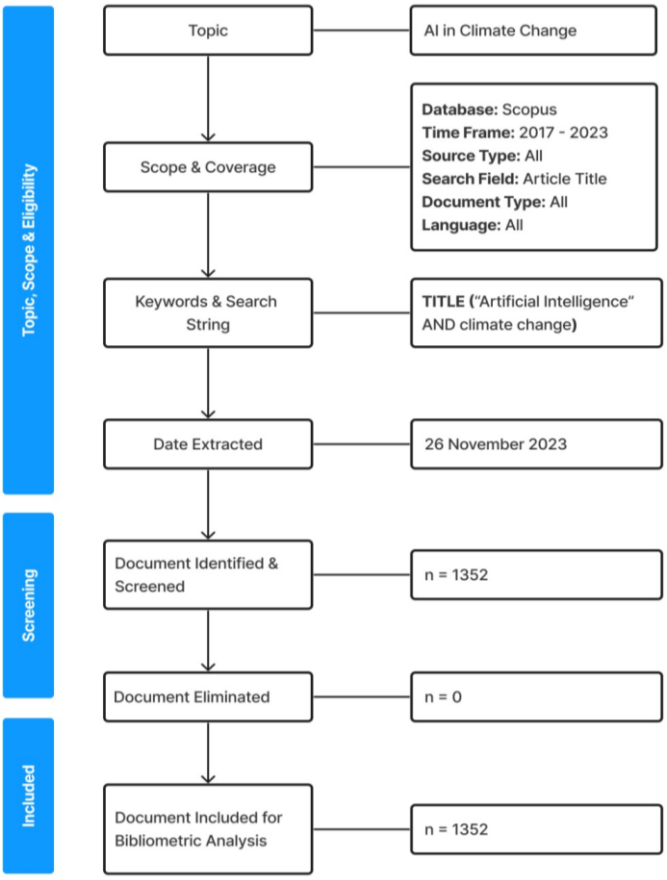

Figure 1. Flow diagram of article searching strategy of artificial intelligence and climate change documents

3.2 Search strategy

In a bibliometric study, it is important to choose the appropriate keywords. Based on the research questions, this study limited the search to two main title keywords: "food" and "supply chain". Therefore, this research encompassed two possible combination strings of keywords that are relevant to the study's topic. The title of an article should incorporate information that can be used to capture the attention of readers since it is the first element that readers will observe first [15]. Finally, this study comprises two search query strings TITLE ("AI") AND TITLE ("Climate Change"). A total of 1352 research documents between 1995 and 6 November 2022 were obtained from the Scopus database (Additional file 1). There were no excluded methods applied during the search of the document as shown in Figure 1.

3.3 Tools and data analysis

Numerous disciplines have adopted VOSviewer to perform bibliometric analysis, e.g., social media in knowledge management [31], Climate Change [32], presumption [33], business intelligence [34], health [25], and brand personality analysis [32]. To achieve the research objectives and research questions, this study adopted VOSviewer software to visualize the geographical distribution, authorship, citations, keywords, and collaboration among countries specifically on AI in Climate Change topics. The VOSviewer visualizes bibliometric maps in different methods to present various features of the literature structure. The VOSviewer employs an integrated approach to mapping and clustering that is constructed on the normalized term co-occurrence matrix and a similarity measure that determines the intensity of association between terms [1]. Based on citations and bibliographic coupling links, the VOSviewer creates clusters of authors' keywords, countries, and organizations. These clusters indicate the compactness of articles, keywords, countries, and organizations in specific research. In addition, Microsoft Excel 2013 software tools were used to analyze the primary data collected from Scopus (CSV format).

4. RESULT AND DISCUSSION

Figure 2 represents a bar chart depicting the number of documents against total citations from 2017 to 2023 in the context of AI and climate change research, distinct patterns emerge. The graph indicates a significant increase in the number of documents published from 2017 through 2019, beginning with 60 documents in 2017 and rising to 1,049 in 2018, followed by a more dramatic rise to 2,568 documents in 2019. This suggests a burgeoning interest and investment in research at the intersection of AI and climate change during these years. After 2019, there was an exceptional peak in 2020 with 2,829 documents. However, after this peak, there is a noticeable decline. In 2021, the number fell to 1,818 documents and continued to decrease to 1,639 documents in 2022, with a further drop to 422 documents in 2023. This downward trend could indicate a saturation of the topic, a shift in research priorities, or perhaps a consolidation phase in the research community where the focus may have moved from quantity to the quality of publications.

The total citations each year provide insight into the impact and recognition that the research has garnered within the

academic community. In 2017, there were only 75 citations, which grew modestly to 109 in 2018. The year 2019 saw a slight decrease to 172 citations, which is interesting considering the substantial increase in the number of documents published that year. This could suggest that a large number of new publications had not yet had the time to accumulate citations. The year 2020 had a small increase to 185 citations, despite being the year with the highest number of documents published, which could reflect a lag in the citation process or potentially lower citation rates per document. From 2021 onward, there's a clear decline in citations with 328 in 2021 and an even sharper drop to 163 citations in 2022. In 2023, the citations slightly increased to 422. This pattern might indicate that the documents from previous years are continuing to be cited, or that a few publications from recent years have gained particular prominence and are accruing citations rapidly.

The number of documents and citations do not always correlate directly year by year. A peak in publications does not necessarily result in an immediate increase in citations, which is evident in the lag seen in 2019 and 2020. The decline in both publications and citations after 2020 suggests a potential shift in the research landscape, possibly due to the maturation of the field, changes in funding, or emerging research directions. It is also worth noting that the citations in 2023 surpass the number of documents, indicating that although fewer papers are being published, the relevance and impact of existing research might be increasing.

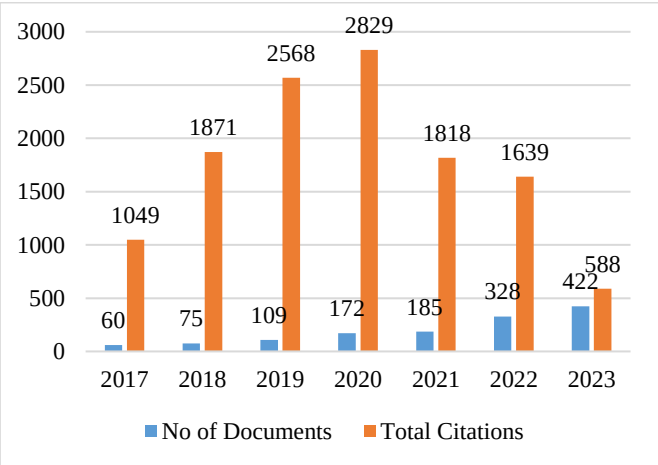

Figure 2. Publication by yearly

Figures 3 and 4 illustrate a comparative bibliometric analysis of the number of documents and total citations related to AI in climate change research across various countries. The bar and line graph compares the number of documents published and the total citations received by the top ten contributing countries in the field of AI and climate change research. This comparison gives us a layered understanding of each country's impact and influence in the domain.

France marks the beginning of this list, and the data points to an intriguing dynamic: while the number of documents is relatively low (60), the citations are considerably high (435). This indicates that the research output, though not voluminous, is of significant quality or importance, gaining considerable recognition within the academic community.

Moving to Australia, we see a slight increase in publications (62) compared to France, yet the citations are much lower (64). This suggests that the research produced by Australia is either less impactful or has not yet had the time to accumulate citations, which can be typical for newer research outputs.

Canada's figures (64 documents and 83 citations) suggest a scenario similar to Australia in terms of publications but with a higher citation impact, indicating Canadian research may be resonating more with the academic community or has been available for a longer period allowing for more citations.

As we progress to Spain and Germany, there's an observable increment in output and impact, especially for Germany, which has a higher citation count (1,056) relative to its publications (93). This disparity could be due to a number of seminal papers that have been widely recognized and cited, reflecting a robust and influential research environment.

Italy demonstrates a similar number of publications (97) to Germany but has a lower citation count (655), indicating that Italian contributions may not have the same level of influence or that the research is not as widely disseminated.

The United Kingdom displays a considerable increase in publication numbers (138) while also achieving a substantial citation count (890), suggesting a strong and impactful presence in the research community.

For India, the documents (169) outnumber those of the UK, yet the citations (274) are significantly lower, which might reflect a rapidly growing research output that has not yet had the opportunity to establish a strong citation record.

China shows a considerable volume of documents (1,760) with an even greater citation count (1,970), highlighting China as a dominant force in terms of both productivity and impact in this research field.

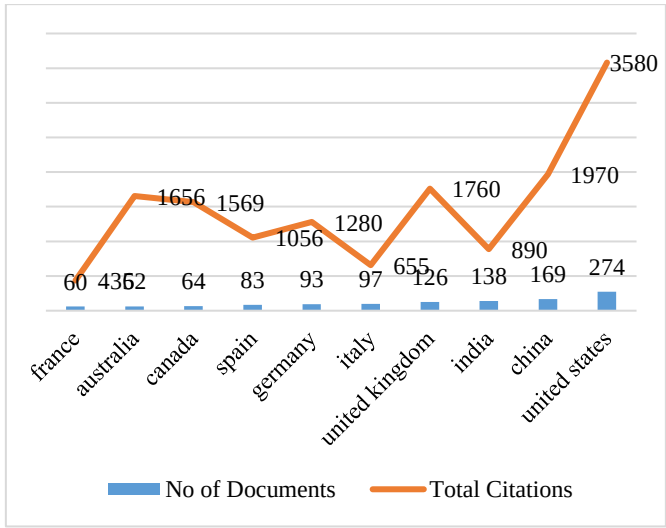

Figure 3. Contribution of numerous countries

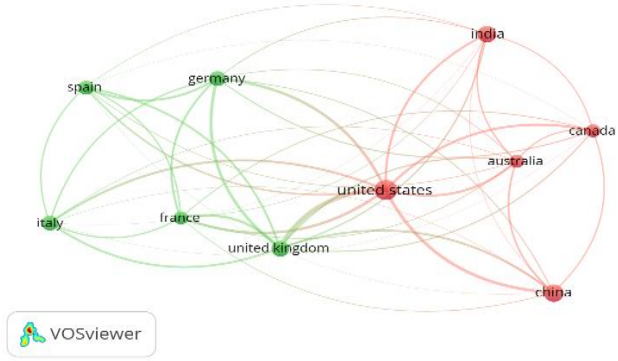

Figure 4. The contribution network of numerous countries

The United States stands out with the highest numbers in both categories – an impressive 3,580 citations for 274 documents. This indicates a highly influential role in AI and climate change research, with American publications being cited extensively, suggesting a combination of high-quality research, a large research community, and perhaps a longer publication history in this field.

The graph not only illustrates the quantitative contributions of each country but also suggests qualitative aspects of their research impact. The reasons behind these differences could be multifaceted, involving factors like the size and investment capacity of each country's research community, the maturity of AI and climate research within the country, and the country's overall strategy and priority in addressing climate change through technology.

Figure 5 provides bibliometric visualization, five distinct clusters illustrate the convergence of AI and climate change research. The first cluster, 'Decision Support System' (DSS), is densely connected within itself and to 'climate models' in the third cluster, suggesting a strong focus on integrating AI tools with climate forecasting. The second cluster, 'Machine Learning', exhibits robust intra-linkages, highlighting the role of AI in predictive analytics, and significant inter-cluster connections to 'Remote Sensing', emphasizing the use of AI in interpreting environmental data.

The central cluster, 'Climate Change', acts as a nexus, with extensive ties to all other clusters, indicating the overarching impact of climate change on AI research. In contrast, the 'Remote Sensing' cluster, despite its fewer outward connections, shows concentrated research on environmental monitoring. The 'Human' cluster, albeit less dense, links to 'economics' and 'sustainable development', pointing to an interdisciplinary approach to the socio-economic dimensions of climate change.

The strength and distribution of links within and between clusters highlight a multifaceted research landscape. Strong connections within clusters suggest established research domains, while the links between clusters reveal the interdisciplinary nature of AI applications in understanding and addressing climate change, with room for growth in exploring the human-centered aspects of the issue.

Figure 6 likely represents the collaboration network among a group of authors contributing to the field.

Each node (labeled with an author's name) represents an individual researcher, and the lines connecting the nodes (edges) represent co-authorship links between these researchers. The proximity of the nodes and the thickness of the edges usually indicate the strength of the collaborative relationships; closer nodes with thicker lines suggest frequent collaboration or a stronger co-authorship tie.

For the research paper at hand, this network map might be used to demonstrate the collaborative patterns among scientists working at the intersection of AI and climate change. It could show which researchers are central to the network, perhaps acting as key contributors or pivotal authors within this research community. The analysis might reveal how collaborative the field is, which could be indicative of the interdisciplinary nature of AI applications in climate change research. The map might also identify potential clusters of collaboration, which could represent sub-themes or specialized areas within the broader topic.

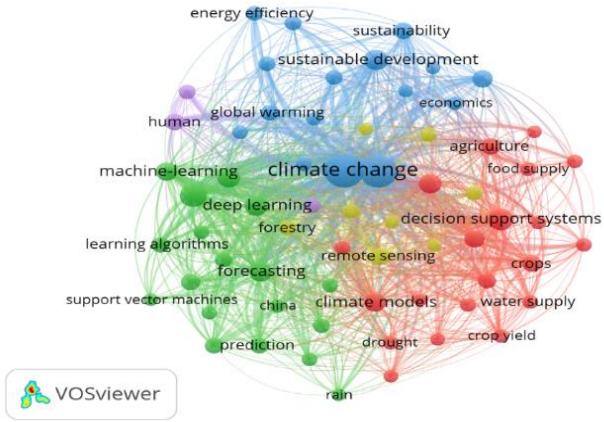

Figure 5. Matching network for the most common keywords

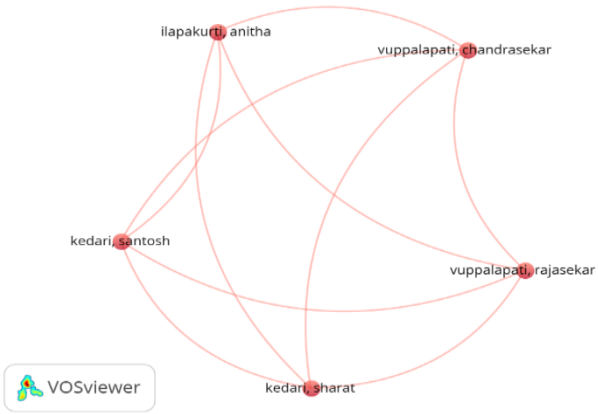

Figure 6. Co-authorship network among productive authors

Table 1. Most productive sources

Journals	No. of Doc.	Total Citations	Citation per Publication	Cite Score	SNIP	SJR
Agricultural Water Management	16	279	17.44	10.7	2.018	1.524
Energies	11	42	3.82	5.5	1.025	0.632
IFIP Advances in Information and Communication Technology	12	33	2.75	1.4	0.364	0.255
Journal of Cleaner Production	11	110	10	18.5	2.379	1.981
Journal of Physics: Conference Series	11	31	2.82	1	0.26	0.183
Lecture Notes in Computer Science (Including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)	19	37	1.95	2.2	0.542	0.32
Lecture Notes in Networks and Systems	18	9	0.5	0.7	0.19	0.151
Proceedings of SPIE - the International Society for Optical Engineering	11	4	0.36	0.7	0.235	0.166
Science of the Total Environment	25	807	32.28	16.8	2.026	1.946
Sustainability (Switzerland)	36	413	11.47	5.8	1.198	0.664
Water (Switzerland)	31	341	11	5.5	1.063	0.723

Table 1 represents the realm of AI and climate change research, the bibliometric data presented in the table provides a quantitative overview of journal performance. 'Science of the Total Environment' emerges as a leader with 25 documents amassing a total of 807 citations, translating to a remarkable average of 32.28 citations per publication. This journal's high Cite Score of 16.8, coupled with an impressive SNIP of 2.026 and an SJR of 1.946, underscores its authoritative presence in the field. In contrast, 'Proceedings of SPIE' appears more peripheral, with 11 documents garnering only 4 citations, a citation per publication rate of 0.36, and lower metric scores across the board (Cite Score of 0.7, SNIP of 0.235, and SJR of 0.166), indicating a niche or emerging status within the research landscape.

More specialized journals like 'IFIP Advances in Information and Communication Technology' with 12 documents and 'Lecture Notes in Networks and Systems' with 18 documents demonstrate modest total citations of 33 and 9, respectively. Their citation per publication figures (2.75 for IFIP Advances and 0.5 for Lecture Notes) and metric scores (SNIPs of 0.364 and 0.19, and SJRs of 0.255 and 0.151) reflect a focused but limited impact within the specific realms of information technology and network systems as they relate to climate change.

On the other end of the spectrum, 'Sustainability (Switzerland)' with 36 documents and 'Water (Switzerland)' with 31 documents show a more substantial influence, with total citations of 413 and 341, and citations per publication of 11.47 and 11, respectively. Their Cite Scores of 5.8 and 5.5, SNIPs of 1.198 and 1.063, and SJRs of 0.664 and 0.723 point to their important roles in disseminating research that intersects with sustainability and water resource management in the context of AI and climate change. These journals, through their focused yet impactful contributions, highlight the varied dimensions and the multi-disciplinary nature of this expanding field.

5. CONCLUSIONS

In this comprehensive bibliometric analysis, we have charted the dynamic expanse of research where AI intersects with climate change, revealing a pronounced surge in scholarly activities from 2017 to 2023. This amplification underscores AI's vital role in tackling the complex issues of climate change. The pre-eminence of the United States and China, manifest in both their prolific research outputs and high citation metrics, attests to the global impetus of these nations in steering the research community.

Our investigation has uncovered five pivotal research clusters, with 'Decision Support Systems' and 'Machine Learning' at the forefront, symbolizing the field’s rich and interdisciplinary fabric. This not only points to an expansion in research quantity but also a branching into new themes that range from predictive modeling to policy and socio-economic impact analysis.

Prominent journals such as 'Science of the Total Environment' and 'Sustainability (Switzerland)' have emerged as key platforms for propagating influential findings, as denoted by their citation frequencies. This accentuates the role of established journals as arbiters and disseminators of scholarly discourse. Conversely, the more specialized impact of 'Proceedings of SPIE' hints at burgeoning sectors or untapped facets of AI's application in climate change, which could be fertile ground for future exploration.

Reflecting on the study's findings, it becomes evident that AI's contribution to climate change is not just a topic of academic curiosity but a hotspot of vital, applied research. To advance this trajectory, we propose a multi-threaded approach for future research: bolstering data-driven methodologies, fostering cross-disciplinary alliances, and innovating in policy integration, to name a few. It is through such concerted efforts that academia and policymakers can glean practical insights and strategize effectively.

While our analysis provides a robust overview, we acknowledge certain limitations. The scope of journals reviewed, the rapidly changing landscape of AI technologies, and the evolution of climate change challenges call for continuous reassessment. Moreover, the impact of regional policies on research funding and focus areas remains an aspect that warrants deeper examination.

Finally, this study contributes uniquely by synthesizing a vast array of bibliometric data to unveil trends and patterns in AI-driven climate change research. It captures the zeitgeist of current academic endeavors and anticipates future scholarly currents. Our work serves not only as a scholarly compendium but also as a beacon, guiding ongoing research toward impactful and actionable science. As this field matures, it is our profound hope that the insights offered herein will help to inform and inspire the next wave of innovations at the nexus of AI and our global climate imperatives.

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