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Exploring the Climate Change-AI Nexus: A Bibliometric and Scientometric Study[1]

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Abstract. *The intersection between artificial intelligence (AI) and climate change mitigation has received increased attention as a result of pressing global environmental concerns and technological advancements. This paper will cover key scientific literature about the development and implementation of AI in tackling climate change challenge. Methodologically, bibliometric and scientometric analyses, including co-occurrence and co-citation analysis, were employed to systematically examine research trends and patterns. The major research question focuses on tracing the evolution of AI research in relation to climate change, investigating important drivers of interest and identifying influential works and research groups. The data find a considerable increase in AI and climate change papers after 2015, demonstrating a growing appreciation for AI's potential to provide novel solutions. Implications of this trend include the use of AI technologies for environmental monitoring, prediction, and policy makers. Moreover, interdisciplinary collaborations on AI and climate change between experts from various fields shown the importance of global climate issues. This paper provides a new idea for the study on AI in climate change, highlighting opportunities for further exploration and collaboration.*

Keywords: artificial intelligence, climate change, renewable energy, machine learning, bibliometric analysis

Introduction

With its capacity to simulate future climatic scenarios, identify sensitive areas, and evaluate risks and opportunities for various industries, artificial intelligence (AI) has emerged as a viable tool for climate change adaptation. By analyzing large datasets derived from climate models, satellite imagery, and other sources, AI facilitates valuable insights crucial for informed decision-making and preparedness for climate change impacts. (Jain et al., 2023).

Artificial intelligence (AI) describes a machine's capacity to learn from the past experiences, adapt to new situations and carry out jobs that humans would normally complete. Artificial intelligence and its subset of machine and lifelong learning have attracted widespread attention in recent decades. The impact of such innovative technologies on people has increased due to recent improvements, namely: much faster connectivity, increased processor speed and increased data storage capacity.

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Artificial intelligence is often used in many related fields, such as renewable energy and ocean dynamics, environmental quality control, healthcare and transportation, education, construction industry etc. At present, artificial intelligence has the greatest impact on the global economy (T.Z. Ang et al., 2022).

To develop effective adaptation programs, governments and communities must have access to accurate and relevant information on the specific hazards that each region faces. Artificial intelligence has the potential to help governments and communities meet this challenge by analyzing large amounts of data, such as climate models, satellite images and weather patterns, to develop specific adaptation plans (Arrieta et al., 2020).

Climate change adaptation strategies based on artificial intelligence have the power to modify the way we deal with and react to climate change. Artificial intelligence can help with decision-making by identifying weaknesses in infrastructure and communities and by providing more accurate information or warning systems to react to severe weather events.

AI-based methods for adjusting to the changing environment are still developing as new technologies are created for dealing with the complicated and quickly changing nature of climate change.

Literature review

The utilization of artificial intelligence (AI) in addressing climate change presents a significant avenue for positive impact. This makes it a useful tool for identifying regions vulnerable to climate change impacts, such as those at risk of floods, landslides or drought (Akter et al., 2021).

AI can be conceptualized as a collection of versatile tools and methodologies devised to replicate and/or enhance processes that would typically require human intelligence (McCarthy et al., 2006). AI has capacities such as classification, prediction, and decision-making. These skills are used industries such healthcare, transportation, and communication. By applying AI's problem-solving capabilities to the challenges of climate change, significant advantages can be yield, mainly by providing understanding of the issue and facilitating effective responses.

AI's capability to swiftly and accurately analyze vast datasets proves invaluable in identifying areas vulnerable to climate change impacts such as floods, landslides, and droughts (Nost and Colven, 2022). Governments and communities can create specific adaption plans by using AI to assess data from diverse sources such as climate models and satellite imagery, addressing specific hazards in each area. However, it is imperative to address ethical concerns and biases associated with AI-driven climate change adaptation to ensure inclusivity, transparency, and equitable outcomes (Leal Filho et al., 2022; Griffin et al., 2023).

AI offers a potential solution by analyzing large information to develop targeted adaptation plans, assisting governments and communities in addressing climate change challenges (Chen et al., 2023).

Additionally, a range of AI models such as general linear models, decision trees, support vector machines and artificial neural networks are gaining prominence (Shrestha and Mahmood, 2019; Şerban and Lytras, 2020). Subfields like natural computing explore algorithm optimization using biophysical materials, while expert systems leverage AI capabilities to address complex natural world issues such as climate change impacts (Nishant et al., 2020).

Multi-sensor-driven AI tools and blockchain platforms offer potential in optimizing circular economy loops, reducing carbon footprint, and enhancing resource efficiency (Kouhizadeh and Sarkis, 2018; Adebiyi-Abiola et al., 2019). Moreover, AI-driven initiatives hold promise in

mitigating climate change risks, preserving ecosystems, and fostering sustainable urban planning (Şerban and Lytras, 2020).

From eradicating poverty and hunger to promoting gender equality and sustainable energy sources for the preservation and conservation of biodiversity, artificial intelligence unquestionably plays a crucial role in attaining environmental sustainability.

Sustainable development goals are divided into three categories: social, economic and environmental. This division makes it possible to provide an overview of the areas where artificial intelligence is having an impact. There areas include waste management, wildlife protection, pollution control, conservation of natural resources etc. (G . Dubois et al., 2019). In addition, energy systems with lower carbon footprints and higher energy efficiency, which are essential given the current state of climate change, are supported by artificial intelligence.

The integration of AI has become a revolutionary force in the pursuit of sustainable solutions to address climate change, especially in optimizing energy use in various industries. AI algorithms, with their capacity to process vast amounts of data and learn from patterns, have revolutionized energy management practices in buildings, industries, and transportation systems (Stecula et al., 2023; Lyu and Jiu, 2021).

Reducing carbon emissions has become a worldwide priority. Several case studies highlight the potential of artificial intelligence is optimizing energy efficiency in multiple sectors when it comes to technological innovation aimed at lowering carbon emissions (Ahmad et al., 2021; Mehmood et al., 2019; Chen et al., 2022).

At forefront of climate science, predictive climate modeling uses innovative methods to predict future climatic conditions and foresee natural calamities. With the advent of artificial intelligence (AI), there has been a paradigm shift in climate modeling, revolutionizing its predictive capabilities through the analysis of vast datasets and intricate environmental factors (Huntingford et al., 2019).

Conventional climate models frequently struggle with the intricacy of environmental relationships and the enormous amount of data needed for thorough study. Artificial intelligence (AI) methods, such machine learning algorithms and neural networks, are particularly good at identifying complex patterns in data, which makes it possible to anticipate climate phenomena with more accuracy. Climate scientists may integrate several datasets that cover atmospheric conditions, oceanic dynamics, land surface features, and anthropogenic influences through the use of artificial intelligence (AI). This allows for a comprehensive understanding of climate dynamics. (Karanth et al., 2023; Yang et al., 2017; Torky et al., 2023; Dewitte et al., 2021).

Sustainable resource management has emerged as a critical imperative in the face of escalating environmental challenges. Innovative approaches and technology are required to address the intricate interactions between ecological systems and human activity. In this context, Artificial Intelligence (AI) has emerged as a potent tool for optimizing resource management practices and fostering sustainability across various domains (Kamyab et al., 2023; Nishant et al., 2020).

Global agriculture is facing previously unheard-of difficulties as a result of climate change, including uncertainty over crop productivity, water availability, and pest control. A paradigm change toward climate-informed agriculture is necessary to overcome these issues. Harnessing the capabilities of artificial intelligence (AI) offers a promising avenue to empower farmers with real-time insights and precision techniques, thereby optimizing resource management and enhancing resilience against climatic variability (Shaikh et al., 2022; Chaterji, 2020).

AI-driven precision agriculture optimizes farming operations by utilizing cutting-edge technology like machine learning, remote sensing, and Internet of Things (IoT). By integrating

data from various sources including satellite imagery, weather stations, and soil sensors, AI enables farmers to make informed decisions tailored to specific field conditions (Ameer et al., 2024). Through predictive analytics and optimization algorithms, AI assists in precise irrigation scheduling, fertilization, and pest control, leading to enhanced crop yields and resource efficiency (Kumar, 2022; Redhu et al., 2022).

However, the widespread adoption of AI for environmental sustainability faces challenges, including energy-intensive infrastructures and cybersecurity risks (Kaplan and Haenlein, 2020; Nishant et al., 2020). Addressing these challenges requires holistic metrics for AI performance evaluation, enhanced public awareness of AI risks, and regulatory frameworks to ensure ethical and transparent AI deployment (Vinuesa et al., 2020).

As with any technology, ethical considerations and potential favoritism must be addressed when implementing AI-based climate change adaptation strategies. When artificial intelligence systems use a lot of data to generate predictions and recommendations, this is known as data bias.

However, if the data used to train an AI model is subjective, subjective results may occur. For example, the experiences of different groups might not be accurately reflected in the historical data used to train an AI system if the data includes only historical data from certain regions or particular populations. This can lead to inaccurate predictions and recommendations that have a disproportionate impact on vulnerable groups (Issa et. al, 2022).

Large volumes of data, especially sensitive personal data, are necessary for the ethical use of AI systems data. Protecting privacy and preventing the misuse of personal information requires the ethical use of information.

As for the lack of transparency, AI systems can be multifaceted and difficult to understand, and not showing the algorithms used to develop and train AI models can make it difficult to identify potential biases or even errors. Developing efficient adaptation techniques to mitigate the risks of climate change is one of the main difficulties in the fight against (Arrieta et. al, 2020).

This study aims to use both bibliometric and scientometric analysis to find the most viable answers to the following research questions underlying our hypothesis:

RQ1: What are the most relevant keywords of studies that address both climate change and artificial intelligence?

RQ2: What are the countries of origin of the authors of the selected studies?

RQ3: What are the most cited papers and what are the fields of the publications?

RQ4: What are the future trends of publications on studies with an economic background that address climate change from the perspective of artificial intelligence?

Our goal to better understand the complexity through which artificial intelligence plays a significant role in the energy transition process. Brian Davis (2021) claims that digitization facilitates the development of new energy systems, with AI being implemented to optimize energy efficiency and support the decarbonization process.

Methodology

To achieve our objective, we conducted a comprehensive search of academic publications using the Clarivate - Web of Science online database. We used a methodical approach, using a scientific mapping process that was specifically designed for the suggested investigation. The study employed several methodologies, including network construction and mapping, data collecting and selection, and bibliometric analysis with the VoS Viewer tool.

The initial step involved the extraction of relevant publications from the Web of Science Core Collection. Understanding the value of multidisciplinary viewpoints, we concentrated on papers that were relevant to the nexus between artificial intelligence and climate change. Keywords such as "artificial intelligence" and "climate change" were utilized to narrow down the search within fields including Environmental Sciences, Green Sustainable Science Technology, Environmental Studies, Computer Science Artificial Intelligence, Multidisciplinary Sciences, Business, Management, among others.

After applying a rigorous selection process, we were able to identify 648 papers that were considered appropriate for our research. These articles provide as the basis for our investigation into how artificial intelligence is developing in relation to mitigating climate change. The ideas from these articles will be examined in more detail in the next sections, which will highlight important themes, new trends, and topics that need more investigation and focus.

Scientometrics seeks to establish multidisciplinary or intradisciplinary connections and define a field's scientific foundations in order to produce representations in the form of maps or indicators. Scientometrics is the generalization of bibliometrics, a tool for measuring scientific output, with the aim of characterizing and identifying the key players in a subject. The relationship between the two concepts creates the fact that bibliometric analysis was developed within the discipline of scientometrics using quantitative tools such as: the number of publications in a field in a certain period of time, the relationship between participants and countries of authors; but it also considers the use of qualitative elements such as keywords, theme, title, magazines, etc. (Ristea et al., 2017). The evaluation of scientific influence and contribution, management of funding programs by research organizations, and performance assessments in a particular literary field can all be aided by the utilization of bibliometric data.

All publications were exported containing the authors, the title, the year of publication, the number of citations, the address of the authors, the keywords and the abstract, thus we were able to determine as indicators: which are the keywords used in the papers to be able to analyze them by themes and form clusters in depending on the field, the countries from which the authors who researched the field come, the most cited articles.

The relationship between climate change, artificial intelligence (AI), and sustainability has gained increased attention in scientific literature. Bracarense et al. (2022) contribute to this discourse through a meticulous bibliometric analysis, drawing upon a dataset of 3887 documents sourced from the Web of Science core collection. Their work clarifies important themes and research paths in this field, highlighting significant gaps as well as current trends in the body of literature. Critical gaps are revealed by the analysis, even while it emphasizes the importance of focusing on issues like energy efficiency and renewable energy. Among these gaps are the lack of studies that look at how people can respond to initiatives to mitigate the climate issue and the lack of studies that look at the negative environmental effects of AI development.

Dhamija and Bag (2020) conduct a thorough examination of the role of artificial intelligence (AI) in operations management, particularly within manufacturing, employing a bibliometric analysis to augment their review. Their research highlights the potential of AI to improve decision-making processes and emphasizes the significance of AI in addressing sustainability issues.

Jrad (2023) illustrates the transformational power of AI technologies through a bibliometric examination, especially when it comes to tackling modern issues like climate change. This analysis emphasizes how AI promotes sustainability, efficiency, and productivity and shows how technology has the potential to improve economies all across the world. Jrad's research also

highlights how crucial it is to take ethical issues into account and provide everyone with equal access to AI technologies in order to maximize its advantages across a range of economic environments.

Results and discussions

Academic publications relevant to our objective of mapping the trend of artificial intelligence development in relation to climate change were extracted from the Clarivate - Web of Science online database. We used a systematic methodology, adopting a scientific mapping approach to carry out the proposed analyses. As a methodological process, we selected 648 publications from the Web of Science Core Collection for the keywords artificial intelligence; climate change, from fields related to research, such as Environmental Sciences, Green Sustainable Science Technology, Environmental Studies, Computer Science Artificial Intelligence, Multidisciplinary Sciences, Business, Management, etc., represented in Figure 1, depending on the number of articles in each field.

Figure 1. TreeMap diagram - Web of Science categories by the number of articles in each domain
Source: Web of Science statistics (https://www.webofscience.com/wos/woscc/analyze-results/b3a32ea9-b634-4b3b-a3fb-19932a84a1e9-ce3b8cf2)

Regarding the number of publications marked in a certain period of time, we selected as the interval the period between 1994 and 2024. In Figure 2 we can see the increased interest in this field starting from 2015, and the largest number of articles indexed in this international database in the year 2023.

There are a few important reasons for this increased interest. First, people all throughout the world are becoming more concerned about the severity of climate change. This has led to a search for creative adjustments, with artificial intelligence being one potential path. Second, substantial advancements in AI technology, particularly in machine learning and data analytics, have made it possible to construct sophisticated tools that can address environmental challenges. Thirdly, because data is widely available, researchers can now utilize AI to evaluate large datasets and obtain crucial insights about climate change. Furthermore, interest in investigating AI's ability

to guide policy decisions, optimize resource allocation, and promote sustainable development has increased in response to growing demand from governments, corporations, and civil society to take urgent action on climate change. Lastly, interdisciplinary cooperation between experts from different fields has aided research and publications. As indicated by the rise of papers indexed in international databases, these variables collectively lead to the growing trend of studies addressing the interface of AI and climate change.

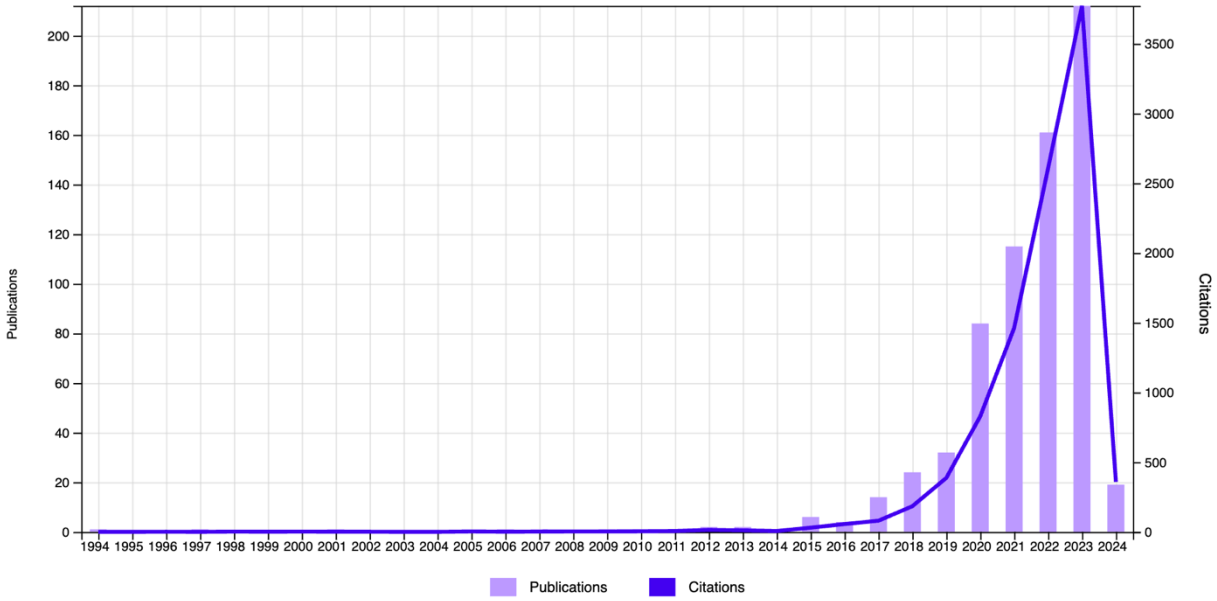

Figure 2. Times Cited and Publications Over Time between 1994 and 2024

Source: Web of Science statistics (https://www.webofscience.com/wos/woscc/citation-report/96ecbd90-2602-4b02-a0c3-3200abe8a75c-ce3e559f)

Keywords reflect the general content of the paper and express the researched area within the scope of the field (Ghaleb, 2022). The software used in this study for bibliometric analysis is VOSviewer. Keyword co-occurrence analysis generates networks based on the data where the space between words indicates the strength of the relationship between the keywords used. Smaller distance indicates a stronger relationship between keywords, and the size of the circle is directly proportional to the number of words used in the documents. This type of tool, VOSviewer, groups related keywords from the same domain by color, clusters. In Figure 3 we find the most used keywords: artificial intelligence, climate change, sustainability, model, prediction, performance, trends, impact, evolution. Clustering is also observed here, the specific groupings of words such as climate change associated with renewable energy, efficiency, carbon footprint; the green color goes to trends brought by artificial intelligence, with keywords such as prediction, impacts, adaptation; and the red color to the economic environment through circular economy, smart city, industry 4.0, etc.

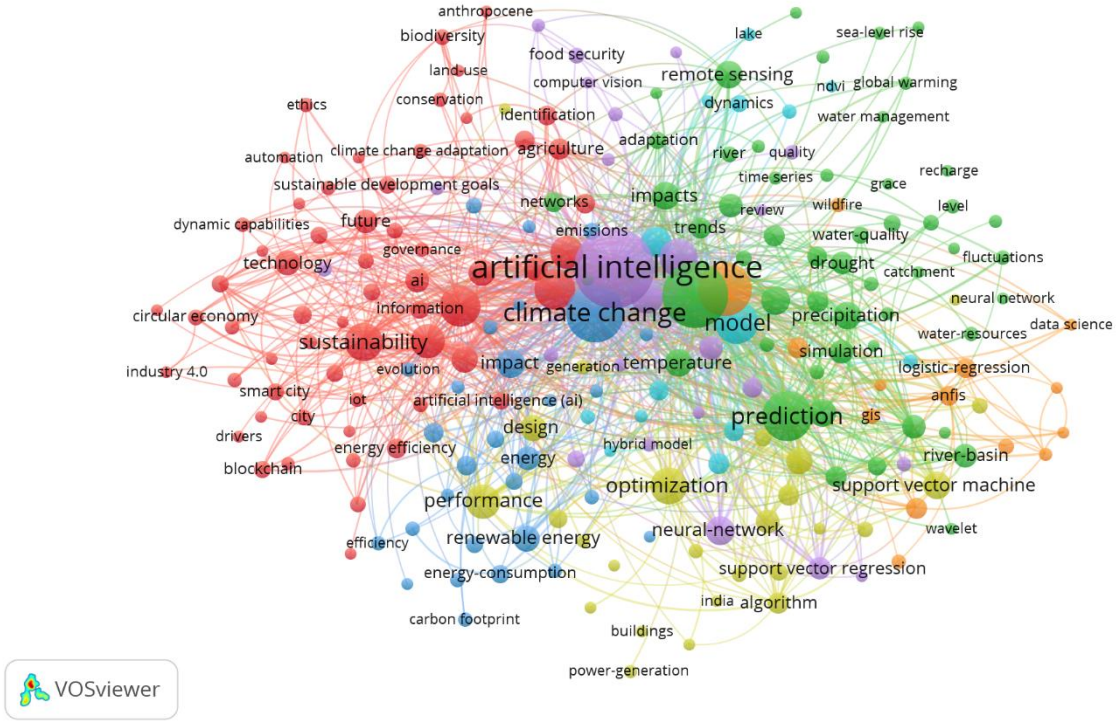

Figure 3. Overlay visualization of keywords

Source: Web of Science database, Authors` computation using VOS Viewer.

In our research, key sustainability topics are classified into distinct clusters, hereafter referred to as clusters, which provide essential information about the interconnectedness of terms used in the literature, highlighting critical areas of interest for both the scientific community and public policy making.

The cluster comprising terms in the thematic area of climate change and renewable energy highlights the major problem present and underlines an imperative transition towards green energy sources. Numerous studies in the literature mark the importance of mitigating climate change through the effectiveness of renewable energy transition technologies, with effects in reducing greenhouse gas emissions and promoting long-term sustainable policies (Suman, 2021).

Artificial intelligence presents opportunities for environmental management through the use of specific forecasting techniques in climate change impact analysis. AI-based models facilitate more accurate climate projections that can be a real help for future public policy strategies, but also allow for real-time monitoring of environmental variables (Feng et al., 2019).

The third cluster, containing the keywords identified in red in Figure 3, is at the intersection of sustainability and economic development, with a focus on concepts supporting the circular economy and Industry 4.0. The literature reveals the potential of circular economy models in sustainable societal growth and resource efficiency, and smart city initiatives are considered to be catalysts for sustainable economic growth (Lakatos et al., 2021).

The co-citation network is based on the number of citations an author or first author has in other published scientific documents. The top-ranked author is Das with a 2018 paper that has

accumulated 535 citations (Das et al., 2017) exploring the interplay between Ai and climate change, highlighting ways in which AI technologies can address environmental issues such as temperature monitoring, climate modeling and optimization of energy resources, but also cautions that there are risks and limitations associated with large-scale implementation.

In Figure 4, the countries of the authors who have researched the most in the field, using both AI and climate change in their work, are marked. The USA authors are ranked first in the number of publications in the mentioned period, namely 113 articles between the years 1994 and 2024. Also in a period of 30 years, authors from China published 90 articles addressing this theme. In third place in terms of number of published articles are India authors with 53 publications. The 3 states mentioned above are at the top of the ranking due to the resources and infrastructure allocated to the reign of science and technology, as the biggest economic powers of the world. They have been involved in the development and implementation of AI technologies, as well as in the management of environmental issues considering economic, geographical and geographical dimensions. A strong commitment to research is also held by authors from countries such as Great Britain, Germany, Canada, Italy.

Due to their advanced technological capabilities, access to vast data resources, particular climate challenges, supportive policy environments, and global influence as major economic powers and significant contributors to greenhouse gas emissions, the United States, India, and China are at the forefront of artificial intelligence and climate change research.

Guo et al.'s (2022) bibliometric analysis explores research trends in air pollution to further explore the emerging convergence of artificial intelligence (AI) and climate change. According to their analysis, there has been a notable increase in publications since 2017, with China and the US emerging as the top contributors.

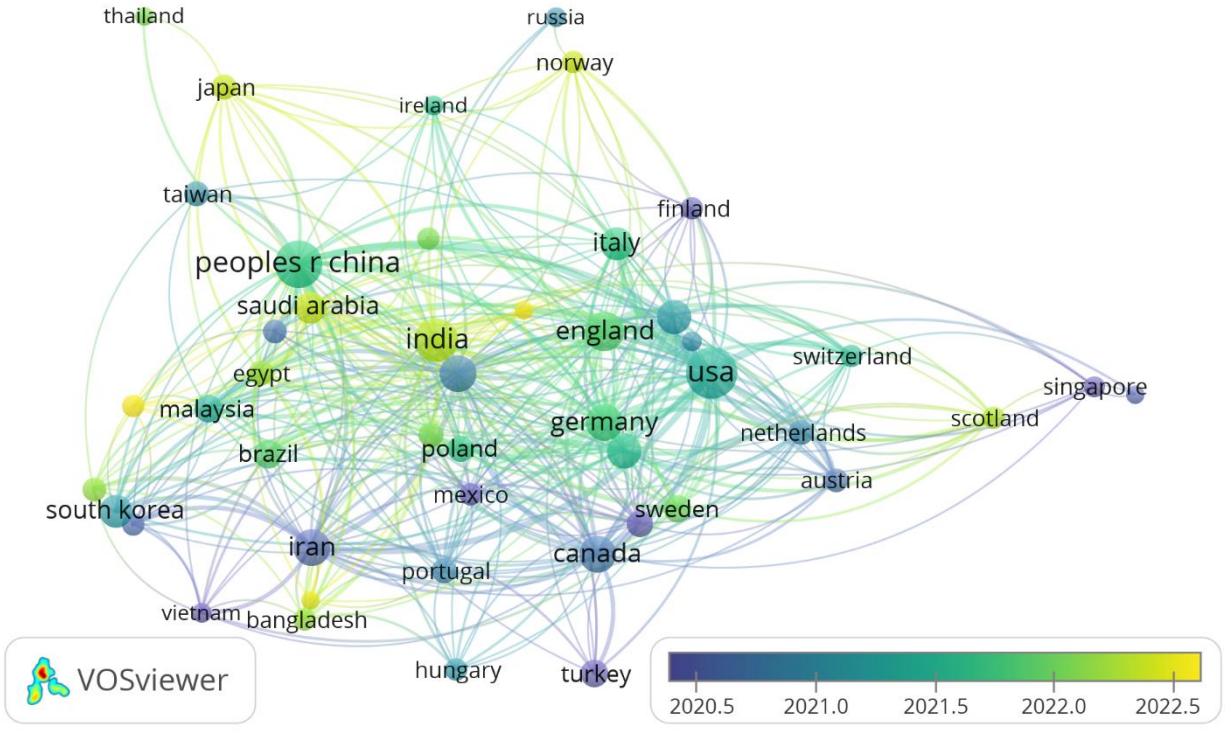

Figure 4. Countries of origin of the authors of the publications

Source: Web of Science database, Authors` computation using VOS Viewer.

Conclusion

According to the analysis, since about 2015, there has been a noticeable increase in research papers examining the relationship between artificial intelligence (AI) and climate change. The urgency and severity of climate change are causing widespread worry, which is fueling the quest for novel solutions. Artificial intelligence is one such promising approach. Upgrades in AI technology, machine learning and data analytics, have enabled the development of complex systems capable of dealing with environmental issues.

Moreover, the availability of data from numerous sources, combined with advances in computing power, has given researchers unprecedented chances to use AI to analyze large datasets and extract insights related to climate change. Interdisciplinary collaboration among specialists from several domains has resulted in research and publications on the interface of AI and climate change. Leading contributors to this research field include the United States, China, and India, owing to their advanced technological capabilities, access to extensive data resources, and supportive policy environments.

While AI offers solutions for addressing climate change, researchers warn of the hazards and limitations involved with large-scale application, noting the importance of carefully considering ethical, social and implications.

Potential research directions may develop towards a stronger economic link between AI-based tools and climate change mitigation models.

The study presents a limitation, namely that this review focuses only on the scientific papers taken from the Web of Science database, thus limiting the coverage of the specialized literature related to the topic explored from other databases.

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