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Analysis of trends in applications of artificial intelligence in environmental science : A bibliometric study

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Artificial intelligence (AI) has emerged as a powerful tool for addressing environmental challenges through advanced data analysis and predictive modelling. This study examines the global research landscape of AI applications in environmental science using a bibliometric approach. A total of 11,199 records were retrieved from the Scopus database, of which 9,504 English-language research articles published between 2014 and 2023 met the inclusion criteria and were analysed using Bibliometrix (RStudio), VOSviewer, and Microsoft Excel. The study analysed publication trends, leading authors, journals, countries, institutions, collaboration networks, keywords, and citation patterns. The findings reveal a rapid growth in research output, particularly after 2018, with China leading global publications. Sustainability, Science of the Total Environment, and Journal of Cleaner Production were the most productive journals, while Machine Learning was the most frequently occurring author keyword. The study provides a comprehensive overview of AI applications in environmental science by identifying major research trends, collaboration patterns, and emerging directions for future research.

Keywords: *Artificial intelligence, Environmental science, Bibliometric analysis, Machine learning, Research trends, Sustainability.*

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1. Introduction

In the field of environmental science, the use of artificial intelligence (AI) has grown significantly and has offered state-of-the-art for addressing major environmental problems [1]. Machine learning and data analytics-based AI techniques are helping researchers to study, monitor,

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and manage the environment more efficiently [2]. Remote sensing and monitoring are among the main applications of AI in environmental science. Advanced environmental data, such as imagery of the Earth's surface and atmospheric conditions are obtained, using satellites with advanced sensors that capture huge amounts of data [3]. The data is analyzed by AI algorithms to find patterns, monitor how the patterns change over time and evaluate environmental health [4]. In addition, AI is used to model and simulate environmental systems like climate dynamics and ecosystem processes [5]. These models allow researchers to understand the complex relationships between different environmental variables, and to predict possible futures under different conditions. AI techniques, such as machine learning and data analytics, are transforming the way researchers study, monitor, and manage the environment [2]. One of the primary applications of AI in environmental science is in remote sensing and monitoring [6]. Satellites equipped with advanced sensors capture vast amounts of environmental data, including imagery of the Earth's surface and atmospheric conditions [3]. AI algorithms analyze this data to detect patterns, monitor changes over time, and assess environmental health [4]. AI is also being used to model and simulate environmental systems, such as climate dynamics and ecosystem processes [5]. These models help researchers to understand the complex interactions between different environmental factors and predict future scenarios under various conditions. On top of that, AI is applied in the field of environmental conservation and management [7]. For instance, AI-based algorithms are capable of processing large datasets to determine areas of high biodiversity, and act as a tool for establishing areas of top priority for conservation, as well as determining the best allocation of resources for sustainable land use and natural resource management [8, 9].

The promise of integrating AI with environmental science, however, is tempered by the recognition that we need first to understand the broader trends and evolving research patterns within a rapidly growing research field [10]. A bibliometric analysis is a quantitative analysis that uses mathematical and statistical tools to investigate the trends in publishing, knowledge sharing and research clusters that emerge through the use of artificial intelligence (AI) in environmental science [11]. Using this method not only tracks the path of AI application growth but also identifies research gaps, collaboration networks, and fields of high impact citations; it provides a full overview of the state of the field [12].

Recently, researchers from different corners of the world have used bibliometric analysis more frequently [13]. Bibliometrics, formally introduced by Paul Otlet in 1934 (and later refined by Alan Pritchard in 1969), has become an essential tool for assessing scientific progress across disciplines since its development [14]. Bibliometric analysis can be used in the context of AI and environmental science to identify the most influential studies, prominent researchers and key research trends in order to guide future research and policy directions [15]. Using a bibliometric approach, our research systematically investigates current trends in AI applications in environmental science, and provides an extensive review of the development of this interdisciplinary field.

2. Literature Review

This section discusses the notable research on artificial intelligence related to environmental science written by well-known scholars. Information on important subjects, publication activities, citation trends, and the state of contributor collaboration based on the above studies, compilation of data on intelligence, and contributions to analytics research are provided [16, 17]. Recently, the application of artificial intelligence (AI) has been skyrocketing in science, and environmental science is no exception [18]. With enduring challenges like climate change, biodiversity loss, and resource depletion currently going on in the world, AI presents a potential tool for solving these challenges by dealing with data analysis, modeling, and monitoring systems [19]. Existing literature has been reviewed holistically to identify recent trends and provide illuminating insights into the application of AI in environmental science.

Introducing AI into environmental science has provided a window for large-scale environmental data analysis and interpretation [20]. Remote sensing driven by AI algorithms is significantly important in environmental health monitoring and assessment, with the capability of providing real-time information on changes in land cover, deforestation, urbanization and atmospheric conditions [6]. Machine learning and deep learning algorithms are found to be important for processing satellite and drone imagery to detect environmental anomalies, predict natural disasters and optimize resource management strategies [21]. Employing these AI-powered advances researchers can predict future climate scenarios more precisely by creating simulated environments under different conditions [22]. In ecosystem management and biodiversity conservation, AI has shown itself to be very helpful in identifying these areas of high ecological value. For example, AI-assisted tools enable conservation planning that focuses on regions that desperately need urgent attention upfront due to their biodiversity richness [23]. In addition, AI has also been used for sustainable land use planning in order to allocate such resources in an efficient way so as to improve the environment in the long term [24].

With the increasing use of AI in environmental science, the number of research studies dedicated to this interdisciplinary field is increasing [25]. Bibliometric analysis—a quantitative evaluation of research trends has been shown to be suitable for mapping knowledge development and dissemination of AI applications in environmental science [26]. Publication trends, co-citation networks and keyword co-occurrences related to AI and its environmental applications were analyzed using bibliometric tools including VOSviewer and RStudio [27, 28]. In recent years, a number of studies have shown a sharp increase in publications on AI in environmental science [29]. Another study used bibliometric analysis to find core journals, including Sustainability, Remote Sensing, and Journal of Cleaner Production, to be important platforms for publishing AI-related environmental research [30]. These journals are important in the field, as indicated by their high citation counts that adhere to Bradford's law. The geographical distribution of such research is visible, as the co-authorship networks analyzed in some studies show considerable collaboration between researchers in China, the U.S. and the U.K. [31-33].

According to Prahani, international collaborations can play a vital role in AI research for areas such cases as climate modelling and environmental monitoring [34]. In addition, research on AI has been steadily funded by major institutions like the National Science Foundation in the U.S. and the National Natural Science Foundation of China, which bears testimony to the recognition of the role of AI in tackling environmental issues at a global level [35].

The bibliometric analysis identifies numerous trends of significant importance. Research on the application of AI in climate science stands out due to its rigorous use of AI models to predict the impacts of climate change and to design adaptation strategies. The study conducted by researchers demonstrates how AI is applied to process climate data to forecast outcomes in the environment under different greenhouse gas emission scenarios. Such analysis also shows a rising interest for AI applications for environmental monitoring and management [16, 36]. In the report of El-Alfy and Mohammed, they show how AI algorithms are being used to tackle a variety of environmental systems, from water resource management to air quality monitoring, and so on [37]. Co-citation analysis also indicates that interdisciplinary approaches combining environmental science and AI and data analytics are becoming more important in the creation of robust environmental solutions [38]. Lastly, the co-occurrence analysis of keywords reveals that terms such as machine learning, deep learning, remote sensing and sustainability have become central to conducting AI research in environmental science over the years [39]. This tracks the trend of AI technologies being used toward achieving the goals of environmental sustainability.

2.1 *Research Gaps of the Study*

A significant gap exists in the literature on AI in environmental science regarding its real-world application to environmental policymaking and decision-making. Despite the research on AI in terms of its technical capabilities, limited research exists on how AI is being used to tackle concrete environmental issues. In order to identify knowledge-based research gaps, key recurrent metrics such as the number of publications, the number of citations, prominent authors and leading institutions were analyzed. Citation patterns, keywords and related organizations were analyzed using bibliometric analysis to reveal the areas where further research is needed. Roles for AI in climate risk assessment that have been undertaken include the use of AI in climate modeling and environmental monitoring, but AI has seen little use in the real-time, end-to-end climate risk assessment in developing regions. Moreover, while the application of AI to biodiversity conservation and sustainable resource management has rarely been investigated, particularly in fragile ecological regions, it is promising. Although the increasing number of AI studies, collaborations among AI experts, environmental scientists, and other disciplines are still rare. To address these gaps, integrative research is needed that marries AI's strength with domain expertise to create applications and tools.

Although traditional methods of literature reviews serve to disclose insights into the 'state of the art' of the research, they are time consuming and prone to bias, having a less than objective nature [40]. On the contrary, bibliometric analysis provides an objective and

exhaustive vision of the research trends, delivering a clear structure of the field and determining possible areas of knowledge deficit in contributions [41]. While also having its strengths, bibliometric analysis is more quantitative and can fail to reach the depth necessary for understanding the qualitative aspects of a research area. Because of this, a hybrid approach between the two methods presents a more comprehensive scope of the as of as-yet unsung areas of AI and environmental science research for current environmental issues.

3. Research Questions

Within this scope, this study aims to document the use and involvement of Artificial Intelligence (AI) in Environmental Science in depth with a broad bibliometric analysis. The following research questions have been formulated to guide this study:

RQ1: What are the top authors, institutions, and countries doing research on Artificial Intelligence applications in Environmental Science, and how do geographic features affect research output and patterns of collaboration?

RQ2: What are the primary concepts, themes and methodologies currently being investigated in the area of AI applications to Environmental science?

RQ3: What are the most prominent sources generating publications on AI driven research for Environmental Science over time?

4. Objectives of the Study

Based on the research questions outlined above, the primary objectives of this study are as follows:

a) To identify and analyze the most prominent authors, institutions, and countries contributing to AI applications in Environmental Science and to examine the geographical patterns and collaboration networks shaping the research landscape.

b) To investigate the major themes, emerging concepts, and methods used in AI applications in Environmental Science.

c) To examine the temporal trends in AI-driven research within Environmental Science.

5. Materials and Methods

To achieve the study objectives, bibliographic data on AI applications in environmental science were retrieved from the Scopus database for the year 2014 to 2023. The retrieved publications were subsequently screened and analysed using the methodology described below. This study used Scopus as the main source of data because it encompasses almost all of the peer-reviewed scientific literature, especially in the areas of science, technology and environmental studies. Scopus covers over 24,000 active titles from more than 5,000 international publishers and includes over 23 million abstracts from over 5,500 peer-

reviewed journals. It also provides advanced citation tracking tools that are essential for bibliometric analysis to track research effectively. The period of 2014–2023 was the focus of the search query, given the dramatic rise in AI applications in the Environmental Science area over this timeframe. Since 2014, widely available AI technologies such as machine learning and deep learning, which were driven by computational power, big data, and algorithms, have enabled researchers to look at environmental issues in the environment in a new way and start solving them. The methodology to identify, screen, and analyze the scientific publications on the application of AI in environmental science research over the past 10-year period studied in this work is shown in Figure 1.

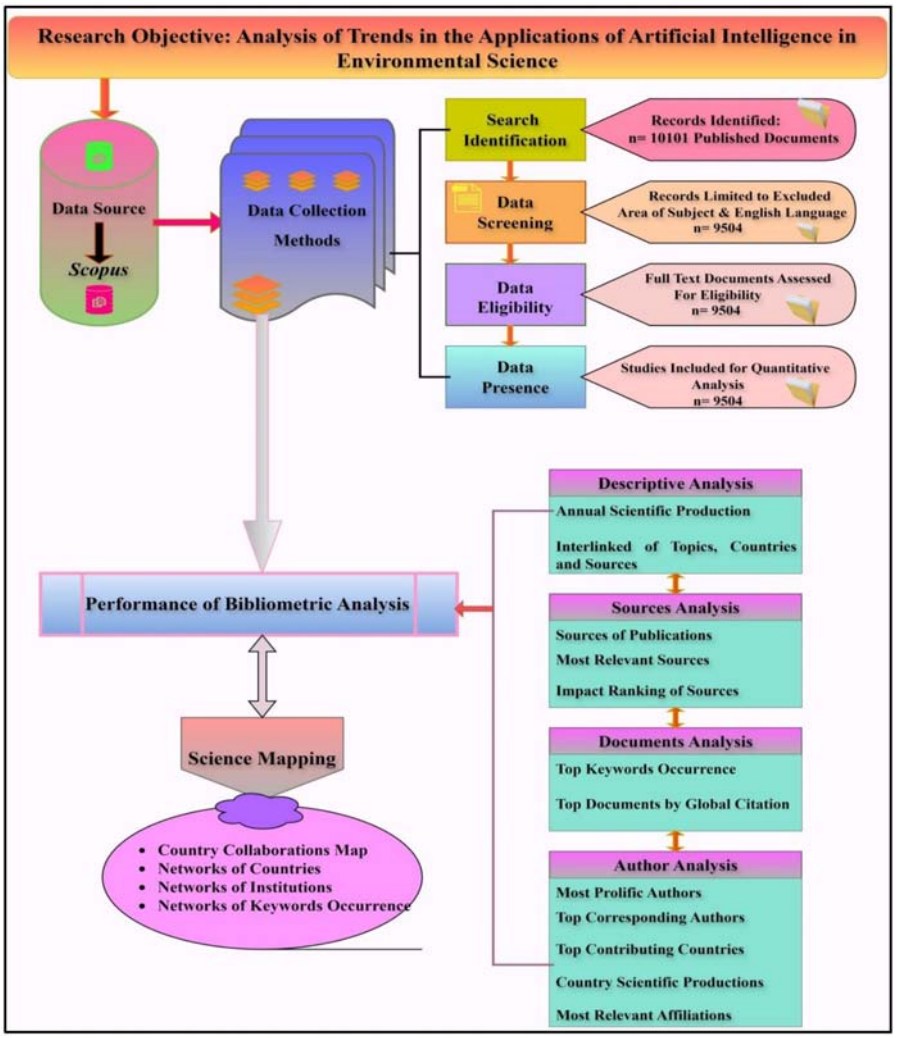


Figure 1

Flowchart showing the research design and methodology for the study

On the 2nd September 2024, an advanced search was carried out in the Scopus database to recover related scientific literature on the topic based on the query: TITLE-ABS-KEY ("Artificial intelligence" OR "AI" OR "Machine Learning" OR "Deep Learning" OR "Data Mining" OR "Data Science" OR "Machine Vision" OR "Natural Language Processing" OR "Neural Network") AND TITLE-ABS-KEY ("Environmental Science" OR "Environment" OR "Ecology" OR "Sustainable")) AND PUBYEAR > 2013 AND PUBYEAR < 2024. To capture the increasingly diversifying and evolving character of AI applications in environmental science, search terms for this study were selected. These terms cover the vast array of techniques and technologies being used in different subsectors of environmental science to deal with intricate issues like global warming, pollution control, and ecological planning. In order to select the keywords, terms that were both well established in prior research and represented emerging trends and methodologies in AI were chosen. Such a selection of these search terms enables the study to cover sufficiently the major AI techniques applied in environmental science but is nevertheless limited enough and specific enough to the objectives of the study.

The initial Scopus search retrieved 11,199 records. The retrieved records were subsequently screened using the Scopus LIMIT-TO and EXCLUDE functions to include only English-language research articles (DOCTYPE = "ar") published within the Environmental Science subject area (SUBJAREA = "ENVI") during 2014–2023. Conference papers, book chapters, reviews, editorials, notes, letters, errata, non-English publications, and records outside the Environmental Science subject area were excluded. After applying these inclusion and exclusion criteria, 1,695 records were removed, resulting in a final dataset of 9,504 research articles for bibliometric analysis.

The final dataset comprised 9,504 research articles identified through the search and screening process. The retrieved publication data were subsequently analysed using Microsoft Excel spreadsheets to examine demographic characteristics, publication trends, prolific authors, three-factor plots (countries, affiliations, and keywords), relevant sources, Bradford's Law, author keywords, affiliations, countries, and the most cited publications related to AI applications in environmental science. The publication data were subjected to bibliometric analysis to examine co-authorship networks, citation patterns, and keyword co-occurrences within the research field. Bibliometric analysis is a widely used statistical technique for analysing the research landscape of a particular field or topic [42]. Using specialised bibliometric software, researchers can identify and visualise the relationships among authors, documents, citations, and research hotspots. For this study, two bibliometric tools- VOSviewer and the Bibliometrix package in RStudio were employed. These complementary tools provide comprehensive capabilities for analysing AI applications in environmental science [43]. VOSviewer was used to visualise and analyse co-authorship networks, keyword co-occurrences, and co-citation patterns. Its strength lies in generating network maps of authors, institutions, countries, and keywords, thereby facilitating the exploration of collaboration patterns and research hotspots. The Bibliometrix package in RStudio was used to perform advanced bibliometric analyses, including three-factor plots,

citation networks, annual publication trends, leading authors, core journals based on Bradford's Law, and the thematic evolution of AI applications in environmental science.

6. Results

6.1. *Main Information*

The bibliometric analysis was conducted on 9,504 research articles published between 2014 and 2023. These publications involved 37,283 authors, of whom 367 contributed to single-authored articles, while the majority participated in collaborative research. The average number of co-authors per document was 4.81, reflecting the highly collaborative nature of AI applications in environmental science. The average citations per document were 21.17, indicating the growing scientific impact of this research field. The main bibliometric characteristics of the dataset are presented in Table 1.

Table 1

Bibliometric Dataset Used for Analysis

Section	Metric	Result
Study Coverage	Time span	2014–2023
	Sources analysed	788
	Documents analysed	9,504
Citation Metrics	Annual growth rate (%)	33.4
	Mean document age (years)	3.05
	Mean citations per document	21.17
Keyword Statistics	Keywords Plus (ID)	36,511
	Author keywords (DE)	25,942
Author Statistics	Total authors	37,283
	Authors of single-authored articles	367
Collaboration Statistics	Single-authored articles	389
	Average co-authors per article	4.81
	International co-authorship (%)	32.25
Publication Type	Research articles	9,504

The international co-authorship level found in the dataset (32.25%) is essential to fuel innovation and diversity within environmental science. The fact that AI applications are driven by research networks as global as this shows that true collaboration is taking place. This however, suggests that interdisciplinary research and, in the case of a field such as environmental science, collaborative research is highly beneficial.

6.2. *The Annual Growth of AI application in the Environmental Science*

One of the factors is the increase in the number of publications regarding any research theme over time [41]. AI applications are becoming more and more popular in environmental science, as the number of publications on the topic increased steadily between 2014 and 2023 (Figure 2). In 2015, the number was slightly down, but there were a strong upward trend and a spike beginning in 2016 (Figure 2). The increase was exponential with over 187 publications in 2015 and continuously rising in subsequent years, indicating the burgeoning potential of AI both technologically and environmentally. This trend is due to several factors: increasing availability of computational power, improving sophistication of algorithms, and the availability of large-scale environmental datasets. At the same time, this is the period when environmental concerns were most acute on the global scale, thus motivating AI experts to develop new AI-based 'green' AI solutions.

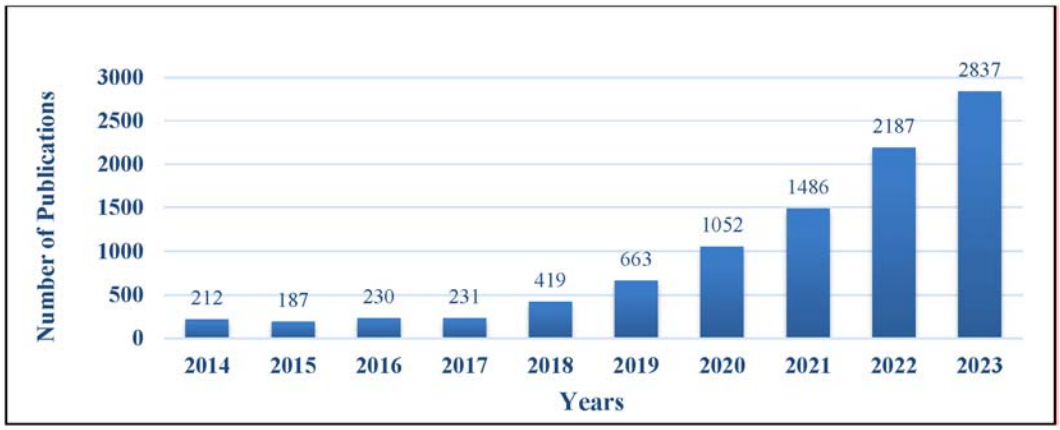


Figure 2

Change in the number of AI publications in the field of environmental science by year

However, the importance of the subject has grown in relevance as is indicated by the sharp rise in AI research within environmental science. Yet, the small decrease in 2015 is possibly attributable to exogenous influences including shifts in publishing patterns or funding oscillations. Nevertheless, the growth rate during that year of 33.4% shows an impressively high overall annual rate of growth, which indicates that the field will continue to progress rapidly; new environmental challenges always need AI-based innovations.

6.3 *Most Prominent Authors*

As shown in Table 2, for the top 10 most prolific authors in the field of AI applications in environmental science during the period 2014–2023 are ranked in terms of the number of articles and their citations. The authors of the published articles reviewed among these representative researchers have had many publications in this field of research. These 9504

Table 2

Most Prolific Authors

Rank	Authors	Articles	Citations	Average citations per item	H-Index
1	Wang Y	190	3131	36.30	32
2	Zhang Y	184	3700	34.38	30
3	Li Y	167	2977	32.86	31
4	Liu Y	144	3621	27.49	31
5	Wang Z	127	3008	26.17	30
6	Li J	126	2447	24.95	27
7	Zhang X	125	2126	26.36	27
8	Zhang J	122	2624	23.06	27
9	Wang J	121	2378	23.07	27
10	Li X	120	2704	21.61	29

records jointly have 37283 authors, particularly. In particular, they are ranked according to the citations received by their published records in the field of environmental science research itself. The top ten authors are systematically listed in Table 2. It displays the number of articles by each author, their citations, and the h-index for the most prolific authors. The h-index can be calculated through the Bibliometrix R package and is a measurement of the combination of an author's productivity and citations for their articles.

However, ten authors were distinguished as particularly productive within their own domain. Wang Y is the most prolific author in this field with 190 articles and 3131 citations, an average citation per item of 36.30, and the highest h index of 32. In second place is Zhang Y, with 184 published papers, 3700 citations (average citation per item = 34.38) and an h-index of 30. What's more, four authors have the same h-index of 27, but their citation metrics are different. Li X's contribution includes 120 publications, 2,704 citations, and an h-index of 29 in the application of AI to environmental science research. While some authors' h-indices are comparable, such as those of Zhang X and Wang J, their total citations and publication counts differ, thereby showing the differing influence of their work. Our analysis shows the significance that Chinese researchers have had, and continues to have, in the area of AI and environmental science; many Chinese authors appear in the top rankings.

6.4 *Three Field Plot of AI application in the environmental science research*

Figure 3 depicts the global landscape of AI applications in environmental science, relevant nations, organizations and key research areas. Often, research work is distributed depending on the availability of subject matter experts in particular areas. For instance, remote sensing, and machine and deep learning are areas in which China has a strong

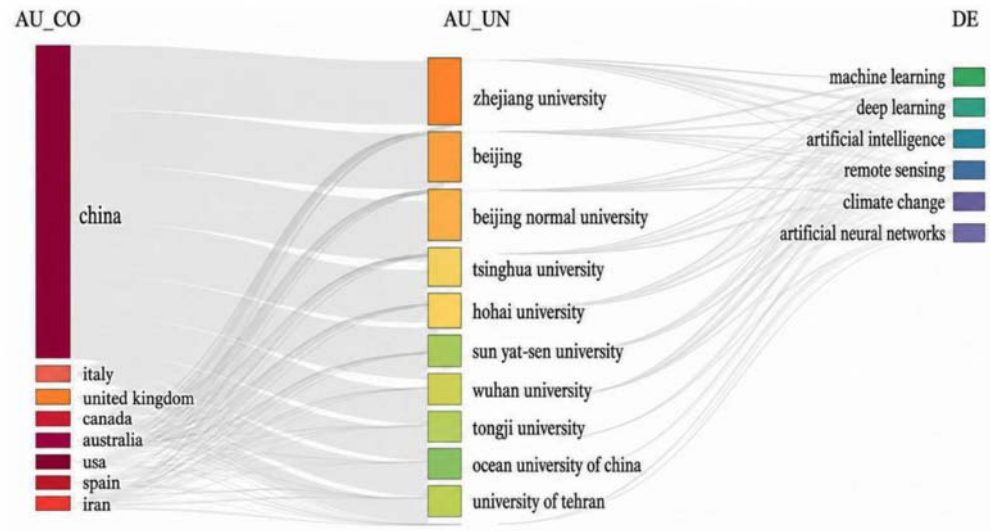


Figure 3

Three-factor plots (countries, affiliations, and keywords)

focus. Consequently, the USA focuses on artificial neural networks, machine learning and the broader AI.

It also shows the spread of affiliations in machine learning across different fields, perhaps depending on their areas of expertise. For instance, Zhejiang University is dedicated to machine learning, deep learning and artificial intelligence. Machine learning receives considerable attention from affiliations such as Beijing, Beijing Normal University, Hohai University and Tsinghua University. With regard to artificial intelligence, Chinese universities are basically conducting research on artificial intelligence along with artificial intelligence itself. Artificial neural networks, random forests, sustainability, distributed ledger technology, and climate change are the focus of the University of Tehran. Similarly, the Ocean University of China focuses on rural development with respect to neural networks, sustainable development, and machine learning.

6.5 *Most Prominent Journals of Environmental Science research*

All related scientific papers indexed in the Scopus database were analyzed comprehensively based on their contributions to applying AI within environmental science and their associated citation metrics. Here, the H–index, G–index and Impact Factor were calculated as applicable to the relevant publications in this research domain. The top ten most influential journals in the particular field of AI applications in environmental science (between 2014 and 2023) are shown in Table 3. The most productive journal is Sustainability (Switzerland) with 1,349 publications and 21,905 citations, with an H-index of 58. To put this in perspective, Energy (UK) has an output of only 155 articles but has racked up 6,034 citations and an H-index of 44, all while maintaining a high citation-to-publication ratio.

Table 3

Top ten sources with the highest publications on AI in the field of environmental science

Rank	Sources	Articles	Citations	H-Index	G-Index	IF (2023)	Country
1	Sustainability	1349	21905	58	95	3.6	Switzerland
2	Science of the Total Environment	398	13565	61	92	8.2	Netherland
3	Journal of Cleaner Production	372	14597	63	96	9.7	United Kingdom
4	Water	245	3753	32	47	3.3	Switzerland
5	International Journal of Environmental Research and Public Health	231	3410	28	46	4.614	Switzerland
6	Environmental Science and Pollution Research	205	3499	31	47	5.8	Germany
7	Building and Environment	189	6576	45	71	7.1	United Kingdom
8	Ecological Informatics	168	3617	29	52	5.6	Netherlands
9	Ocean Engineering	168	3711	31	53	4.6	United Kingdom
10	Energy	155	6034	44	70	9	United Kingdom
Total		3,480	80,667	-	-	-	-

Additionally, Journal of Cleaner Production tops the list with an IF of 9.7 and is complemented by Energy (IF of 9.0) and Science of the Total Environment (IF of 8.2), making them powerful journals at the intersection of AI and environmental science. These metrics validate the role of these journals as the central outlet for AI-based environmental research and confirm that the works have been immensely productive and impactful in an academic sense.

The top ten journals published 3,480 articles (36.62% of the total publications), while the remaining 6,024 articles (63.38%) were published across 778 other sources. This shows that research on AI applications in environmental science is published in a wide range of journals.

6.6 *Bradford's Law: core sources of the published documents of environmental science research*

As a bibliometric principle introduced by Samuel C. Bradford in 1934, Bradford's Law states that in a subset of books (or other bibliographic units), a small proportion of sources will account for a large percentage of papers on a certain subject [44]. The first known law states that in any given field, the majority of relevant publications can be found in a small number of journals, and additional publications become increasingly spread out among a

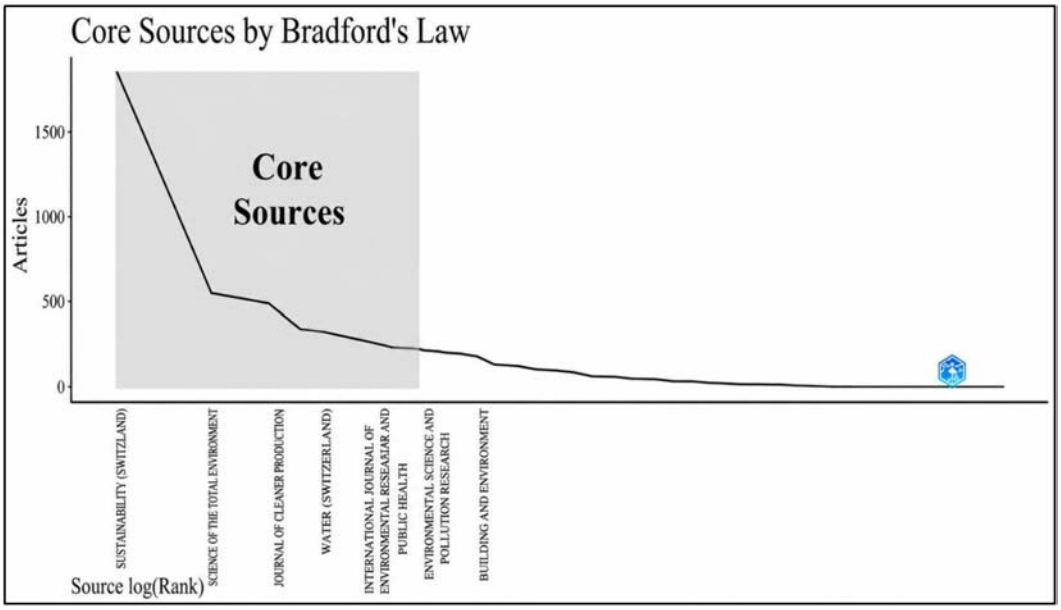


Figure 4

Bradford's Law: core sources

progressively larger number of journals. The application of Bradford's Law to AI applications in environmental science research allows one to focus on the most influential and most frequently cited sources in this area [45].

This law used in this study has identified four journals as the core sources for the publications centred on AI applications in the area of environmental science research (Figure 4): Switzerland, provides coverage for Sustainability, Science of the Total Environment, Journal of Cleaner Production, and Water, published in Switzerland. Other prominent journals are International Journal of Environmental Research and Public Health, Environmental Science and Pollution Research, Building and Environment and Ecological Informatics. The eight journals together yield 3,157 publications, constituting about 33.21% of the 9,504 documents examined. The concentration of these publications in a small number of journals reinforces their importance to the advancement of research at the intersection of artificial intelligence and environmental science. As core sources, these journals disseminate the frontier of research and help define the development and application of AI technologies to resolve environmental challenges.

6.7 *Top corresponding authors*

Table 4 presents the number of single-country publications (SCP), multiple-country publications (MCP), and the MCP ratio for the top ten corresponding author countries contributing to AI applications in environmental science research. China ranked first with 2,989 articles (31.4% of the total publications), comprising 2,230 single-country publications

Table 4

Top 10 Corresponding Author Countries and Publications

Rank	Country	Articles	% of Articles	SCP	MCP	% of MCP
1	China	2989	31.4	2230	759	25.4
2	USA	815	8.6	618	197	24.2
3	India	616	6.5	479	137	22.2
4	Korea	364	3.8	282	82	22.5
5	Iran	333	3.5	178	155	46.5
6	Australia	217	2.3	122	95	43.8
7	United Kingdom	217	2.3	104	113	52.1
8	Italy	207	2.2	119	88	42.5
9	Spain	199	2.1	127	72	36.2
10	Canada	191	2	119	72	37.7
Subtotal		6,148	64.7	4,378	1,770	28.8*

Note: *Overall MCP percentage calculated as MCP ÷ Articles × 100 for the top ten countries.

(SCP) and 759 multiple-country publications (MCP), resulting in an MCP ratio of 25.4%. This indicates that China not only produced the highest number of publications but also maintained substantial international collaboration. The United States ranked second with 815 articles, including 618 SCPs and 197 MCPs, corresponding to an MCP ratio of 24.2%. India ranked third with 616 articles, of which 479 were SCPs and 137 were MCPs, giving an MCP ratio of 22.2%. Although China and the United States produced the largest number of publications, their MCP ratios suggest a moderate level of international collaboration.

Collectively, the top ten corresponding author countries contributed 6,148 publications (64.7% of the total publications), while the remaining 3,356 publications (35.3%) were contributed by other countries. This indicates that AI research in environmental science has broad international participation beyond the leading countries. Countries with relatively high levels of international collaboration include the United Kingdom (52.1%), Iran (46.5%), Australia (43.8%), and Italy (42.5%), as reflected by their MCP ratios. These findings suggest that international collaboration plays an important role in advancing AI applications in environmental science by promoting knowledge exchange and collaborative research across countries.

6.8 *Country Collaboration Map*

The international collaboration of AI research applications in environmental science is represented visually in Figure 5. Blue colour signifies the collaboration taking place in each country. The darker the blue shade, the higher the occurrence of collaboration with other countries. The countries which dynamically collaborate with other countries in the world

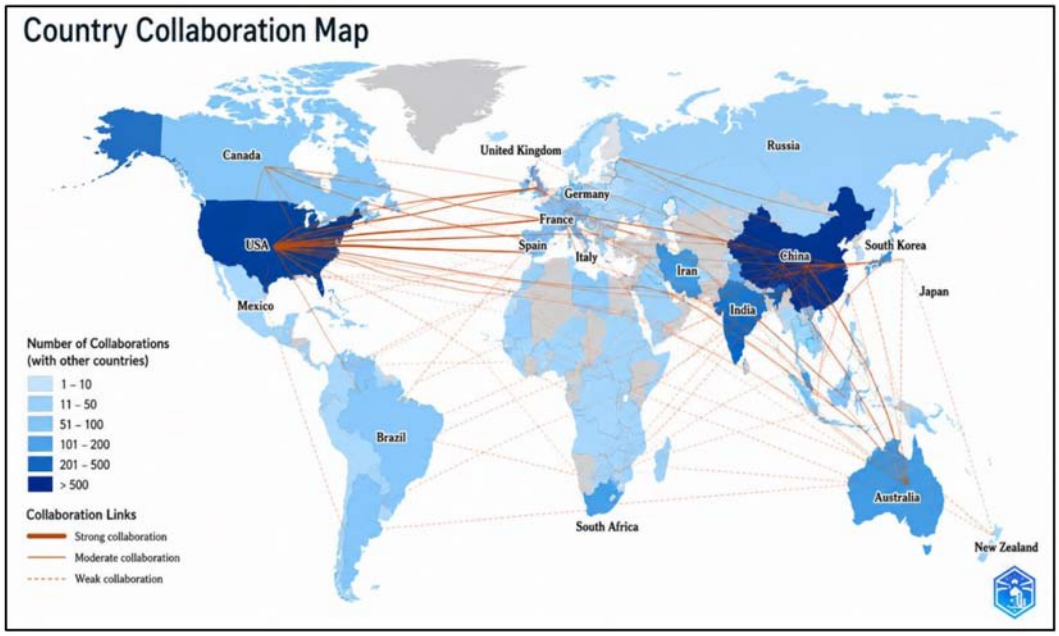


Figure 5

Country Collaboration Map of AI applications in environmental Science

are China, the USA, India, Korea, Iran, Australia, and the United Kingdom. The United States is the country that collaborates most with almost all the active countries in publishing research on the application of AI in environmental science research, followed by China and then the countries from Europe. Indeed, the aim is to boost the number of published articles because when there are partnerships among countries, the exchange of knowledge and resources increases.

6.9 *Keywords Analysis and Co-Occurrence Network*

The content was analysed through the viewpoint of keyword sharing in the context of AI applications for environmental scientific research. Figure 6 shows the co-occurrence network of the top 10 keywords that were obtained from the Scopus database. The network of keyword co-occurrence was created using the VOSviewer software. A total of 25942 author keywords were extracted from the dataset were extracted. A new keyword entering the network needed to have at least a certain minimum occurrence threshold, and 10 keywords were nominated as important for this study (Table 5).

The co-occurring keyword network, seen in Figure 6, has seven distinct clusters, 596 links and a cumulative link strength of 2,626. Several colours red, green, yellow and blue are employed in the network visualization to separate the components. Most notably, the keyword 'Machine Learning' has the highest frequency of 1763. Other important keywords by occurrence are "Deep Learning" (769), "Artificial Intelligence" (573), "Artificial Neural

Table 5

Keywords Occurrences of AI Application in the environmental Science

Rank	Keywords	Occurrences	Total Link Strength
1	Machine Learning	1763	1061
2	Deep Learning	769	524
3	Artificial Intelligence	573	493
4	Artificial Neural Network	458	230
5	Random Forest	314	246
6	Sustainability	259	232
7	Remote Sensing	244	231
8	Climate Change	216	168
9	Neural Network	192	106
10	Sustainable Development	178	138

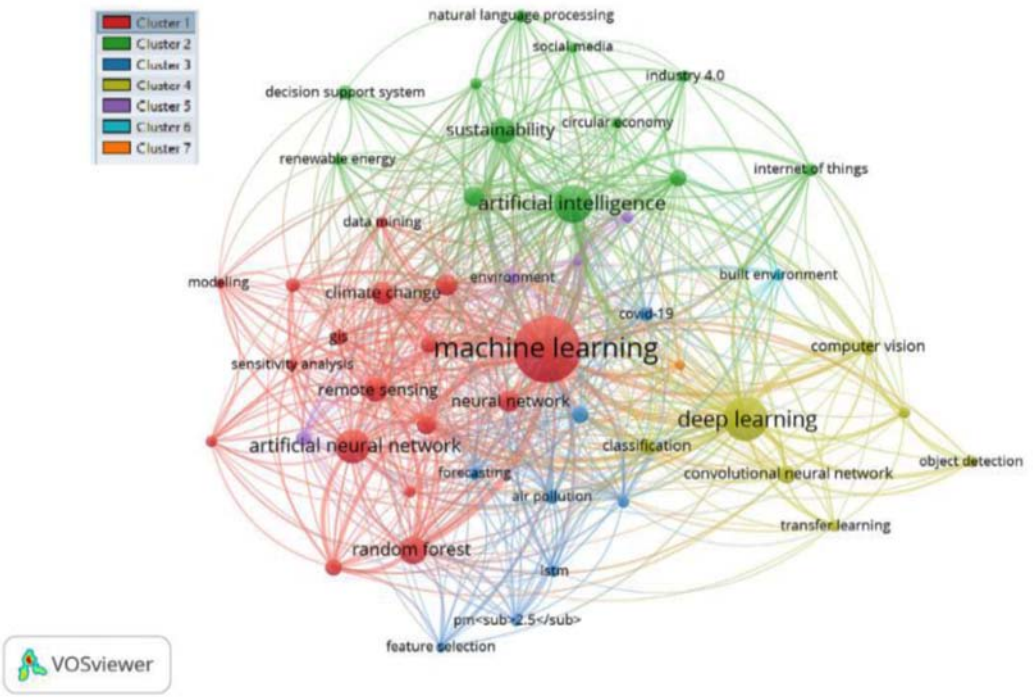


Figure 6

Co-occurrences of Keywords of Environmental Science

Network" (458), "Random Forest" (314), "Sustainability" (259), "Remote Sensing" (244), "Climate Change" (216), "Neural Network" (192) and "Sustainable Development" (178). It is proposed that these keywords evolved to provide a good way of finding important areas and aspects of research across disciplines. With their aid, we can discover important themes and characteristics of certain area. Moreover, the figure demonstrates how the authors recur to the term 'Machine Learning' in their study pursuits.

6.10 *Most Global Cited Documents of Environmental Science*

Through the use of the Bibliometrix software, scholars are able to determine the most cited publications by DOI, and the citation frequency per year [46]. Figure 7 shows a graphical representation of the top ten cited journals. In this section, we examine the worldwide cited documents ranked by total citations and citations per year. The analysis shows that the first publication on artificial intelligence and the environment was published in the Sustainability journal in 2019 and has been cited 753 times, indicating the systematic impact of artificial intelligence on environmental science. The second publication (Journal of Cleaner Production, 2017, 163 citations) is an analysis of the possibilities that show the most promise when employing machine learning in environmental science, what difficulties might appear and how to overcome them. According to the author, creating the models from the complex environmental data using the artificial intelligence technology is considered important. Front Sustain Food received 256 citations as the most recently cited journal.

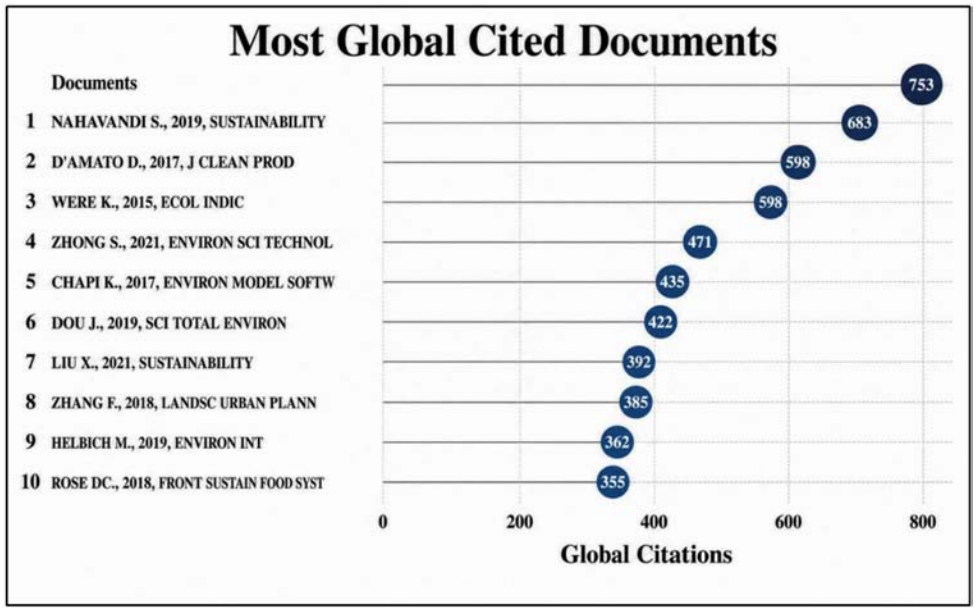


Figure 7

Top Global Cited Documents

6.11 *Productive Affiliation of AIES Research*

Table 6 lists the top ten most productive affiliations that contribute to research on the application of AI in environmental science. By looking into the table, it is seen that Zhejiang University comes out to be first with a total of 303 publications and also with the highest the number of citations of 2,005 among these institutions. In second place comes Beijing, with 279 articles and racking up 1,845 citations. Third is Beijing Normal University, which shows a profound impact in this research area with 260 publications and 1,284 citations. This data shows that these top-ranked institutions produce the top 10 most cited scholars in the applications of AI in environmental science and reflect their commitment to solving the contemporary global environmental challenges through innovative research. What is also interesting to see is that Ocean University of China has the lowest number of publications, i.e., 176 and the lowest citation count of 593.

Table 6 presents the ten most productive research affiliations in AI applications in environmental science. Zhejiang University ranked first with 303 publications (3.18%) and 2,005 citations, followed by Beijing University (279 publications; 1,845 citations) and Beijing Normal University (260 publications; 1,284 citations). The remaining leading institutions, including Hohai University, Tsinghua University, Wuhan University, University of Tehran, Tongji University, Sun Yat-Sen University, and Ocean University of China, also made substantial contributions to the field (Table 6).

Table 6

Most Relevant Affiliations of Environmental Science Research

Rank	Affiliations	Articles	Percent	Total Citations
1	Zhejiang University	303	3.18	2005
2	Beijing	279	2.93	1845
3	Beijing Normal University	260	2.73	1284
4	Hohai University	250	2.63	1259
5	Tsinghua University	249	2.61	1165
6	Wuhan University	223	2.34	1023
7	University of Tehran	190	1.99	692
8	Tongji University	187	1.96	686
9	Sun Yat-Sen University	179	1.88	618
10	Ocean University of China	176	1.85	593

The predominance of Chinese universities reflects the country's strong investment in artificial intelligence, environmental technologies, and interdisciplinary research. High publication outputs coupled with substantial citation counts indicate that these institutions have played a pivotal role in advancing AI-driven approaches to environmental monitoring, climate studies, pollution assessment, and sustainable resource management. Among the

top-ranked affiliations, the University of Tehran represents the growing contribution of institutions outside China, highlighting the increasing internationalisation of research in this domain. Collectively, the top ten affiliations produced 2,296 publications, accounting for 24.16% of the total 9,504 publications analysed, while the remaining output originated from a wide range of institutions worldwide. This distribution demonstrates that, although a few institutions serve as major research hubs, AI applications in environmental science have evolved into a globally distributed and collaborative research field.

7. Discussion

The findings show a substantial growth in environmental science research between 2017 and 2023, with the largest increase in production in 2023, which recorded the highest number of publications (2,837 articles). On the other hand, 2015 recorded the lowest research output, with only 187 articles published. Thereafter, the number of publications increased steadily, indicating a significant upward trend in scholarly activity in this domain. The top ten prolific authors identified by the analysis of author productivity consisted of Wang Y with 190 publications and 13,131 citations, yielding an h-index of 32. Li X demonstrated a lower productivity with 120 publications, 2,704 total citations, and an h-index of 29. The gap between researchers in this growing field highlights the differences in the contributions and impact that different researchers have made to the field. The Journal of Cleaner Production and Energy were found to be the main journals in terms of impact factor, with impact factors of 9.7 and 9.0, respectively. These findings indicate that these journals are among the leading publication sources for research on AI applications in environmental science. To complement these findings, the study also examined publication output, author affiliations, citation patterns, keyword usage, and collaborative networks using the Bibliometrix package in RStudio and VOSviewer.

As for the geographical context, China emerged as the leader in AIES research, accounting for 2,989 publications and 31.4% of the total output. The top 10 keywords illustrated that "Machine Learning" was the most frequently occurring keyword, with 1,763 occurrences, highlighting the increasing application of this methodology in environmental studies. In addition, Zhejiang University contributed the most to this research field by publishing 303 articles with the highest number of citations (2,005). The findings indicate that collaboration among authors, institutions, and countries has become an important characteristic of AI research in environmental science. The findings further highlight the importance of continued collaboration between AI researchers and environmental scientists to advance the application of AI in environmental science. The keyword co-occurrence analysis identified the major research themes and emerging areas of AI applications in environmental science, providing insights into the current direction and evolution of research in this field. Taken together, the findings demonstrate sustained growth in research on AI applications in environmental science and indicate continued opportunities for future investigation. Future studies may further explore emerging applications and methodological developments in AI for environmental science. Future

research may also investigate how AI can be applied to address emerging environmental challenges.

8. Conclusion

With regard to scientific research on artificial intelligence applications in environmental science (AIES), this study presents a comprehensive bibliometric analysis of publications published between 2014 and 2023, revealing an increasing trend in publication output and evolving research themes. The findings indicate significant growth in AI applications in environmental science during the study period, and China emerged as the leading contributor in terms of publication output and international research collaboration. Furthermore, Journal of Cleaner Production and Energy were identified as among the leading publication sources in terms of research impact in this field. The findings demonstrate that author keywords provide valuable insights into the thematic structure and evolution of research on AI applications in environmental science. The landscape of AI applications in environmental science continues to evolve, providing opportunities for future research to explore emerging environmental challenges. The study provides insights into the current research landscape and may support future interdisciplinary research on AI applications in environmental science. The findings will assist researchers, policymakers, and practitioners in understanding current research trends and identifying emerging directions in AI applications in environmental science.

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