



ORIGINAL

## Bibliometric Analysis of the Worldwide Scholarly Output on Artificial Intelligence in Scopus

### Análisis bibliométrico de la producción académica mundial sobre inteligencia artificial en Scopus

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#### ABSTRACT

**Introduction:** the use of bibliometric analyses is useful to gain insight into the development, trends, and impact of scholarly output on artificial intelligence (AI) in several fields.

**Objective:** to characterize the worldwide scholarly output on AI in Scopus in the period 2013-2022.

**Method:** a descriptive observational bibliometric study was carried out. The study population consisted of the 776,961 documents identified using SciVal. The following variables were studied: number of documents (Ndoc), year of publication, annual variation rate (AVR) of the scholarly output, type of document, source, number of citations (Ncit), field-weighted citation impact (FWCI), author(s), author-level h-index, institution, country, type of collaboration, and keyphrases.

**Results:** the scholarly output showed a steady quantitative increase during the period studied, with a positive AVR. Conference papers (68,5 %) and articles (26,5 %) were the main types of documents. Neurocomputing led the list of sources in both Ndoc (12 989) and Ncit (351 837). The highest FWCI (3,02) corresponded to Proceedings - IEEE International Conference on Robotics and Automation. China, the United States and India were the countries with the highest Ndoc by year of publication. Institutional collaboration was the most common (46,7 %) type of collaboration. The most prominent keyphrases were: Robot, Artificial Intelligence, Deep Learning, Convolutional Neural Network and Robotics.

**Conclusions:** the scholarly production analyzed is characterized by its constant quantitative growth and is mostly represented by conference papers. Productivity and impact indicators based on citations show remarkable results. The science produced was led by China, and scientific collaboration played a relevant role.

**Keywords:** Artificial Intelligence; Bibliometrics; Scientific Publication Indicators.

#### RESUMEN

**Introducción:** el uso de análisis bibliométricos es útil para conocer el desarrollo, las tendencias y el impacto de la producción académica sobre inteligencia artificial (IA) en diversos campos.

**Objetivo:** caracterizar la producción académica mundial sobre IA en Scopus en el periodo 2013-2022.

**Método:** se llevó a cabo un estudio bibliométrico observacional descriptivo. La población de estudio consistió en los 776 961 documentos identificados utilizando SciVal. Se estudiaron las siguientes variables: número de documentos (Ndoc), año de publicación, tasa de variación anual (AVR) de la producción científica, tipo de documento, fuente, número de citas (Ncit), Impacto de las citas ponderadas por campo (FWCI), autor(es), índice h a nivel de autor, institución, país, tipo de colaboración y frases clave.

**Resultados:** la producción académica mostró un aumento cuantitativo constante durante el periodo estudiado, con una AVR positiva. Las ponencias en congresos (68,5 %) y los artículos (26,5 %) fueron los principales tipos de documentos. Neurocomputing encabezó la lista de fuentes tanto en Ndoc (12 989) como en Ncit (351 837). El FWCI más alto (3,02) correspondió a Proceedings - IEEE International Conference on Robotics and Automation. China, Estados Unidos e India fueron los países con mayor Ndoc por año de publicación. La colaboración institucional fue el tipo de colaboración más común (46,7 %). Las frases clave más destacadas fueron: Robot, Artificial Intelligence, Deep Learning, Convolutional Neural Network y Robotics.

**Conclusiones:** la producción académica analizada se caracteriza por su constante crecimiento cuantitativo y está representada mayoritariamente por ponencias en congresos. Los indicadores de productividad e impacto basados en citas muestran resultados notables. La ciencia producida fue liderada por China y la colaboración científica jugó un relevante rol.

**Palabras clave:** Inteligencia Artificial; Bibliometría; Indicadores de Producción Científica.

## INTRODUCTION

Artificial intelligence (AI) is a multidisciplinary field that automates tasks requiring human intelligence and is revolutionizing various aspects of life. It involves machines perceiving, synthesizing and inferring information, and is used in tasks such as speech recognition, machine vision and language translation.<sup>(1)</sup>

AI has become a tool created by humans to process information quickly, but its understanding of organisms and its purpose is limited.<sup>(2)</sup> Its development, along with fifth-generation (5G) data networks and the Internet of Things, presents both benefits and challenges in terms of privacy security and cybercrime. Its use in different fields, such as information systems, health, education, and industry, has different functions and contributions, but it must be used responsibly.<sup>(3)</sup>

Various research demonstrates the use of bibliometric analyses to gain insight into the development, trends, and impact of scholarly output on AI in several fields. For example, one study focused on the intersection between AI and intelligent vehicles, identifying major research trends and contributors.<sup>(4)</sup> Another study analyzed highly cited articles on the use of AI in relation to COVID-19, with the aim of understanding the characteristics of the research and the influence of the authors.<sup>(5)</sup> The application of AI in software testing has also been explored, examining collaborative trends and providing feedback to software engineers and researchers.<sup>(6)</sup> In addition, the emerging concept of decentralized AI, which combines AI and blockchain, has been investigated through thematic and bibliometric analyses, highlighting research areas such as digital transformation and cybersecurity.<sup>(7)</sup>

The objective of this research was to characterize the worldwide scholarly output on AI in Scopus in the period 2013-2022.

## METHOD

A descriptive observational bibliometric study of the worldwide scholarly output on AI in Scopus in the period 2013-2022 was carried out.

Using SciVal (<https://www.scival.com>), which allows advanced metric analyses of Scopus data, 776 961 documents in the “Artificial Intelligence” research area were identified in the aforementioned period. These constituted the study population.

The following variables were studied: number of documents (Ndoc), year of publication, annual variation rate (AVR) of the scholarly output, type of document, source, number of citations (Ncit), field-weighted citation impact (FWCI), author(s), author-level h-index, institution, country, type of collaboration, and keyphrases.

All data were extracted from SciVal. The AVR was defined as the increase or decrease (%) in the Ndoc with respect to the initial year of the period analyzed, and it was calculated using the equation  $AVR = [(Ndoc_f - Ndoc_i) / Ndoc_i * 100]$ , where  $Ndoc_f$  and  $Ndoc_i$  are, respectively, the Ndoc corresponding to the final and initial years of the analysis period.<sup>(8)</sup>

## RESULTS

The scholarly output showed a steady quantitative increase during the period studied. The AVR was always positive (Figure 1).

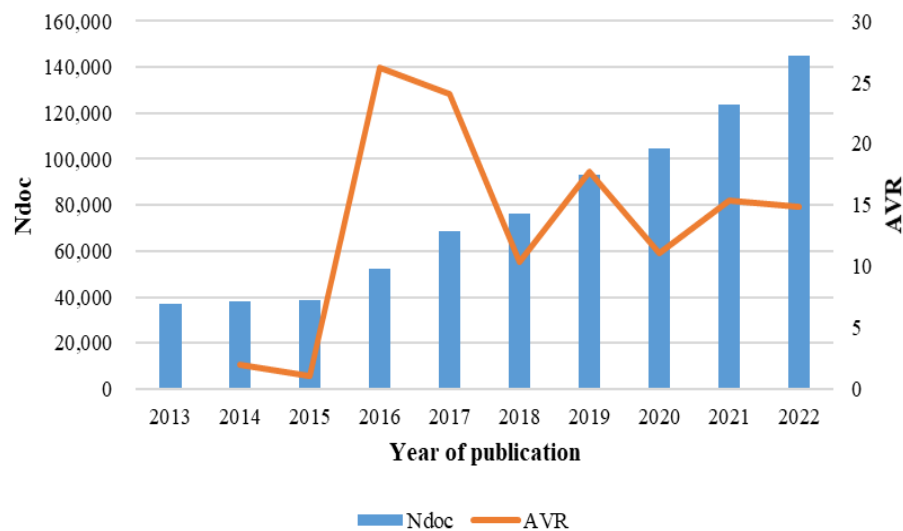


Figure 1. Ndoc and AVR by year of publication

Conference papers and articles were the main types of documents (Table 1).

Type of document	Ndoc	%
Conference paper	531 902	68,5
Article	205 793	26,5
Chapter	13 357	1,7
Editorial	11 296	1,5
Conference review	5 790	0,7
Review	4 598	0,6
Note	1 989	0,3
Erratum	1 198	0,2

*Neurocomputing* led the list of sources in both Ndoc and Ncit. The highest FWCI corresponded to *Proceedings - IEEE International Conference on Robotics and Automation* (Table 2).

Source	Ndoc	Ncit	FWCI
Neurocomputing	12 989	351 837	1,43
Studies in Computational Intelligence	11 619	48 822	0,69
Proceedings - IEEE International Conference on Robotics and Automation	9 580	202 907	3,02
Expert Systems with Applications	9 058	333 633	2,58
Information Sciences	8 671	298 464	2,18
Journal of Intelligent and Fuzzy Systems	8 597	74 699	0,88
Proceedings of Machine Learning Research	8 300	72 016	1,98
Proceedings of the International Joint Conference on Neural Networks	7 203	53 623	0,72
International Joint Conference on Artificial Intelligence	6 782	142 534	2,40
Neural Computing and Applications	6 595	142 649	1,22

The period 2017-2020 was the most active. Older documents had a higher Ncit per document. The FWCI was stable throughout the decade analyzed (Figure 2).

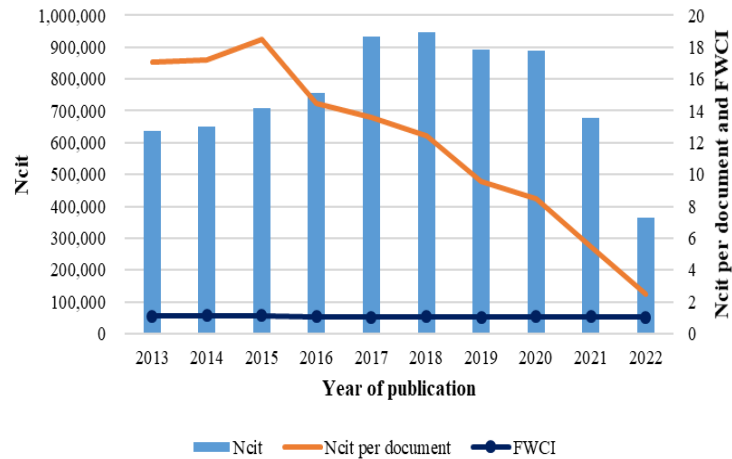


Figure 2. Ncit, Ncit per document and FWCI by year of publication

Tables 3 and 4 show some relevant characteristics of the top 5 most active authors and institutions.

Last name, first (and middle) name(s)	Ndoc	Ncit	Ncit per document	h-index
Pedrycz, Witold	478	11 477	24	96
Xu, Zeshui	355	20 724	58,4	129
Cao, Jinde	340	15 228	44,8	132
Dadios, Elmer P.	329	2 166	6,6	24
Kreinovich, Vladik Ya	321	765	2,4	33

Institution	Country	Ndoc	Ncit	Ncit per document
French National Centre for Scientific Research (CNRS)	France	11 885	131 158	11
Chinese Academy of Sciences	China	11 601	193 601	16,7
Anna University	India	8 411	43 272	5,1
Tsinghua University	China	5 947	104 610	17,6
University of Chinese Academy of Sciences	China	5 450	67 066	12,3

China, the United States, India, the United Kingdom, and Japan were the top 5 most productive countries, all of which showed a steadily increasing scholarly output (Figure 3).

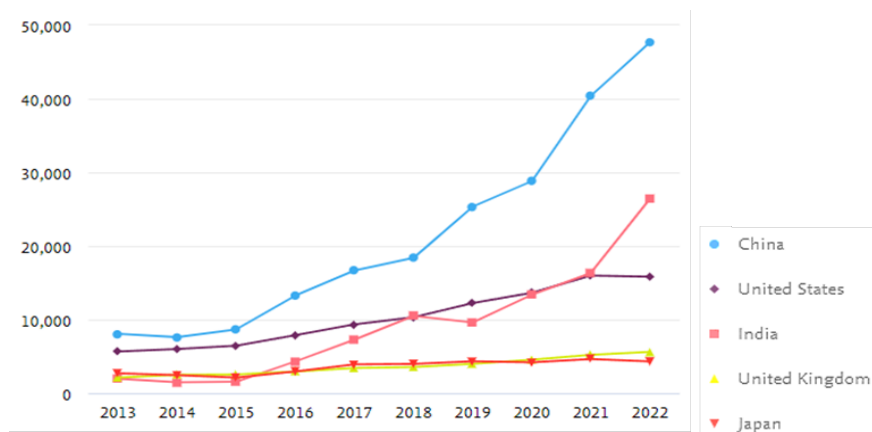


Figure 3. Top 5 countries' Ndoc by year of publication

Institutional collaboration was the most common type of collaboration. In only 8,4 % of the documents there was no collaboration due to single authorship (Table 5).

Type of collaboration	%	Ndoc	Ncit	Ncit per document	FWCI
International collaboration	17,4	134 789	2 308 393	17,1	1,65
Only national collaboration	27,5	213 773	2 023 995	9,5	1,05
Only institutional collaboration	46,7	362 714	2 773 043	7,6	0,93
No collaboration	8,4	65 865	355 145	5,4	0,58

As can be seen in Figure 4, the most prominent keyphrases were, in decreasing order: *Robot*, *Artificial Intelligence*, *Deep Learning*, *Convolutional Neural Network* and *Robotics*.

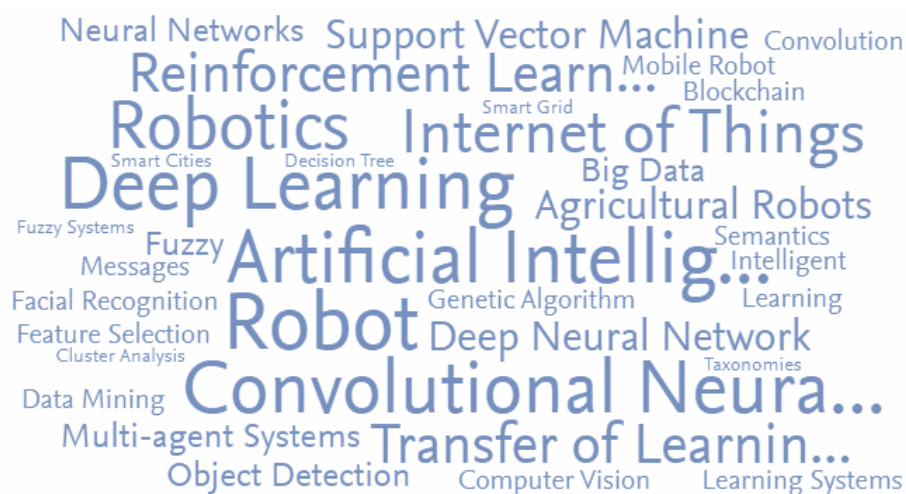


Figure 4. Keyphrase cloud according to relevance

## DISCUSSION

The growing interest in AI research is evident in the scholarly output. Academics are increasingly exploring various aspects of AI, including its impact on individuals, businesses, society, and the environment.<sup>(9)</sup> The balance in AI research is shifting towards industry, as industry dominates the key ingredients of modern AI research, such as computing power, large datasets, and highly skilled researchers.<sup>(10)</sup> This behavior, evidenced in the present study, may be due to the rapid growth of AI technologies and their potential to solve complex social problems.

Conference papers are journal articles that were initially presented at a conference and later adapted for publication in a journal. Articles, on the other hand, generally present original research results and go through a more rigorous reviewing process.<sup>(11)</sup> Although it is widely stated that articles are the most important contributions to a scientific journal, in this case the predominance of conference papers could be due to the prominence of journals such as *Proceedings - IEEE International Conference on Robotics and Automation* and *International Joint Conference on Artificial Intelligence*, which ranked first and third, respectively, in terms of their FWCI.

According to some authors,<sup>(12,13)</sup> the countries with the highest scientific output on AI are the United States, the United Kingdom, Germany, France, Spain, and Italy. These countries have been the most prolific producers of AI publications, with the United States accounting for the highest number of published papers.<sup>(14)</sup> Additionally, Switzerland, the Netherlands, and the United Kingdom have shown high research production relative to their population size.<sup>(15)</sup> Although the present study provides evidence that partially reaffirms those ideas, both in terms of the quantitative trend of scientific output by country and in terms of the most productive institutions, China could have stood out due to its considerable economic and technological development.

Collaboration is crucial in scientific research as it brings many benefits, such as building professional relationships and addressing complex scientific problems that are too big for one discipline.<sup>(16)</sup> However, collaboration also raises ethical, legal, and practical issues that researchers should address, including authorship, conflict of interest, and data management.<sup>(17)</sup> Successful collaborations require mutual involvement

and active participation of academic and industry scientists, leveraging the strengths of each organization through collaborative governance mechanisms.<sup>(18)</sup> Barriers to effective collaboration include domain disparity and motivation, and engagement, which can be mitigated through active and constant learning.<sup>(19)</sup> Although it is positive that most of the documents analyzed showed some type of scientific collaboration, the fact that the lowest percentage corresponds to international collaboration is a weakness.

The bibliometric analysis of AI research articles has revealed a growing academic interest in topics such as deep learning, machine learning, and the Internet of Things,<sup>(20,21)</sup> which is congruent with what is reported in the present article. It is also consistent with the subject areas covered by the most prominent sources analyzed in this bibliometric study.

## CONCLUSIONS

The scholarly production analyzed is characterized by its constant quantitative growth during the period and is mostly represented by conference papers. Productivity and impact indicators based on citations show remarkable results that point to future improvement. The science produced was led by China, and scientific collaboration, especially institutional, played an important role.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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