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Artificial Intelligence Regulation: A Bibliometric Analysis

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Abstract

This research presents a bibliometric analysis of artificial intelligence regulation. The analysis is based on a comprehensive review of 3186 papers published between 2000 and 2024. We used bibliometric data analysis techniques such as keyword co-occurrence visualization, citation mapping, bibliographic coupling, and thematic analysis to map and visualize the current knowledge structure of AI regulation. The researchers used VOSviewer and Rstudio to conduct this study. This approach sheds light on emerging fields, research streams, and future research trends in AI regulation, contributing to a deeper understanding of AI regulation based on a thorough analysis of the AI literature.

Keywords: *Artificial intelligence (Al), generative artificial intelligence (GAI), Bibliometric analysis, regulation, Keywords Co-occurrence.*

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1 Introduction

Al is a computer algorithm that can perform cognitive functions such as perceiving, reasoning, learning, problem-solving, and decision-making [1]. Al has been applied in all activities, industries, and every aspect of our human life [2]; [3]; [4]. In recent years, deep learning and generative Al systems are the most developed Al-based Algorithms inspired by neural networks and large language models [5]; [6], [7]. As Al or GAl has become more ubiquitous, a crucial concern is regulating Al to be trustworthy and fair Al [8]; [9]. Across industries and businesses, Al has imposed a new challenge concerning Al regulations, policy, and governance. Beyond Al adoption and usage, the "Vienna Manifesto on Digital Humanism" and the recent volume titled "Perspectives on Digital Humanism" bear a vast impact imprint on these emerging challenges [10]. Consequently, ensuring trustworthy Al use involves stakeholders, governments, businesses, civil society organizations, and end users [9]. Al adoption and usage transform our way of life and work, societal structure, and specific values of humanism such as nights, freedom, rationality, spirituality, and human dignity [9]; [10]. de Almeida, et al. [11] developed a framework for Al regulation. The proposed Al framework answers how Al's uses and applications should be regulated.

However, the most advanced regulation in practice is the European Commission's Al Act proposal for regulating Al (digital-strategy. ec. Europa. eu). It is the first-ever regulatory framework on Al, classifying risks associated with Al use into four levels: unacceptable, limited, and minimal. This proposal framework encompasses fundamental rights, prohibited Al practices, transparency obligations, and codes of Al conduct.

Thus, the European Al Act is assumed to become the world regulatory framework for Al regulation. Consequently, Al regulation has been a focal point in the existing literature either from an analytical point of view or from ethical, legal, and theoretical perspectives. In this line, the call for Al or GAI regulation grows stronger [13] due to the crucial role of AI in the emerging digital economy. Through bibliometric analysis, this research fills the research gaps on Al regulation and answers the following questions:

1. How are Al regulation research practices clustered?
2. What are emerging Al and regulation research streams?
3. What future Al regulation research topics offer opportunities to enhance trustworthy AI?

A clear visualization or mapping of Al regulation, namely, computational regulation research, is needed to identify research gaps in the literature and specify ethical and regulatory challenges of Al use in various industries and businesses [12]. This research delves into the main research streams and regulatory concerns entangled with the development of Al and GAI.

2 Methodology

2.1 Data sources

Data was collected from Elsevier Scopus core collections. Scopus is a highly reputed database offering peer-reviewed, influential journals and other scientific sources. The data collection

process started on May 25, 2024; thus, the scope of the search is from 2000 to 2024. Bibliographic data was downloaded for all documents. The search was limited to English and articles; the authors downloaded 3186 articles. Synonyms such as AI, GAI, and regulations are considered in the search process.

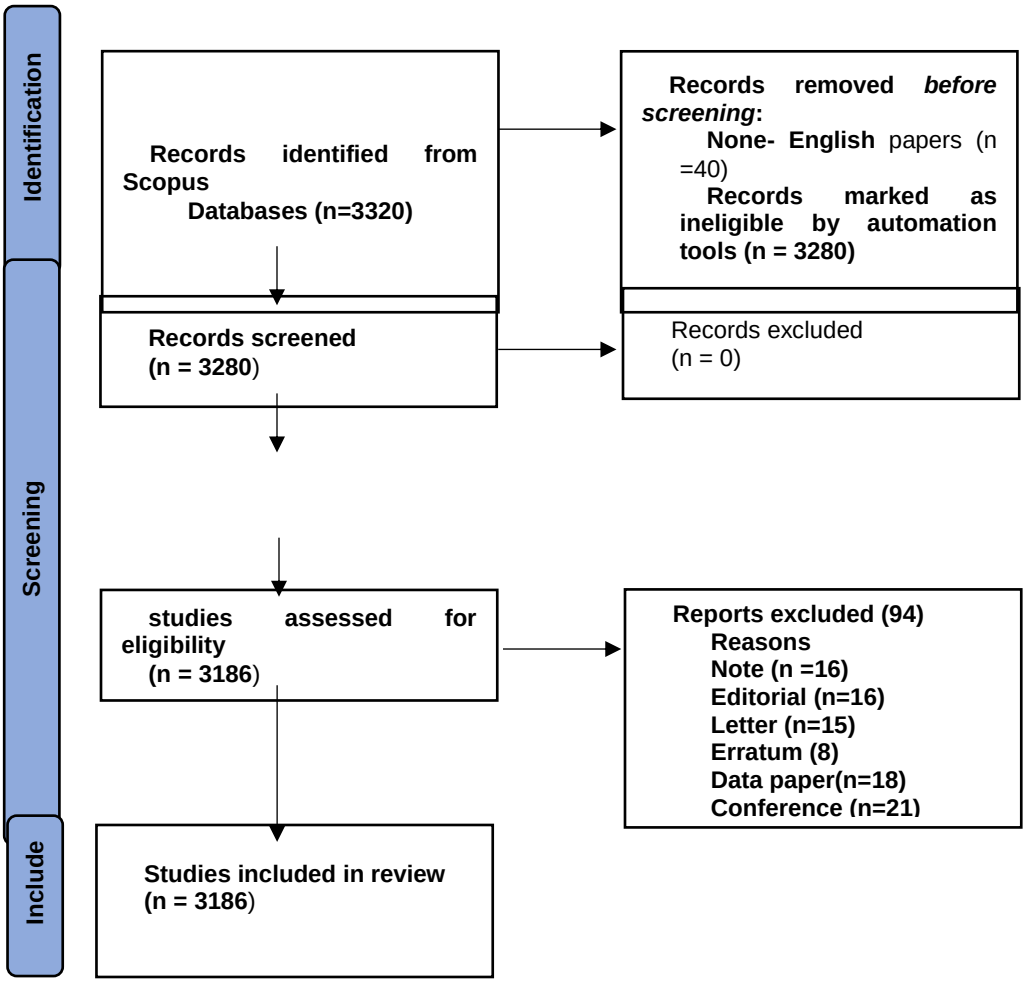

Figure 1: PRISMA framework

2.2 Data selection strategy

The relevant data were retrieved from Scopus. Scopus is chosen because of its ease of use and comprehensive coverage. It is the world's largest and most renowned database. Scopus has analytical tools with 97.3M+ records: 28,300+ active titles and 368,000+ books (Elsevier.com). Scopus database has been applied because it is a broad social science database. To ensure that the retrieved documents meet rigorous quality standards, Scopus enables researchers to access scientific data by providing options to search and analyze [14]. The search yielded a total of 3186 documents which were selected, exported, and saved for further investigation. The file was saved in the comma-separated values (CSV) format.

We used the preferred reporting items for systematic review and meta-analysis (PRISMA) framework as a filtering tool to select papers from the Scopus database. The PRISMA model,

developed by [15], serves as a methodological framework for conducting AI reviews. Figure (1) illustrates bibliometric analysis and review development through the identification, screening, and inclusion of documents.

Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009;339: b2535. doi:10.1136/bmj. b2535

3 Bibliometric analysis

Bibliometric analysis is a rigorous method for analyzing large amounts of scientific data [16]. It allows researchers to visualize knowledge development maps, networks, and high-quality visual representations [17]; [18].

In this research, the authors used VOSviewer software to visualize and map research in the Al field and regulation. VOSviewer encapsulates bibliometric analysis and quantitative techniques on bibliometric data. Notably, VOSviewer has been applied to visualize performance and science mapping. This technique summarizes large quantities of bibliometric data to offer the state of the Knowledge structure in the specific research field [19].

The number of documents about Al regulation during 2000-2024 is 3186. Figure (2) illustrates the number of articles published by year (726 papers published in 2023; 539 papers published in 2022; 333 articles published in 2021; 255 papers published in 2020, and 145 papers Published in 2019).

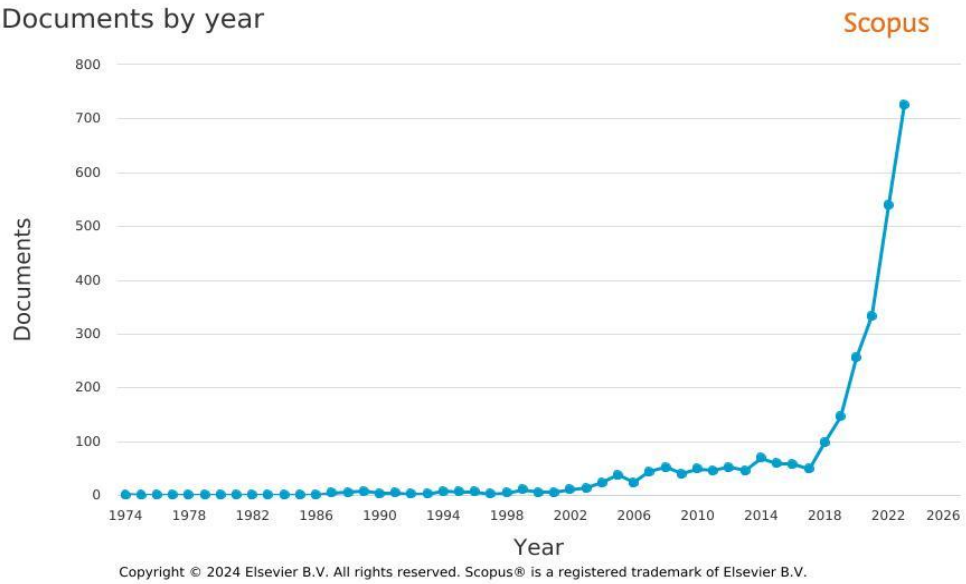

Figure 2: Articles by year

4 Analysis and findings

Bibliometric analysis findings indicated that Al regulation is a novel field. This research found the ten most influential institutions and counties. Table (1) represents the highest number of publications from various top affiliations. The table shows that the University of Oxford (n=41), Chinese Academy of Sciences (n=38), CNRS Centre National de la Recherché Scientifique (n=28), and University of Toronto (n=28) have received the maximum number of articles on Al regulation.

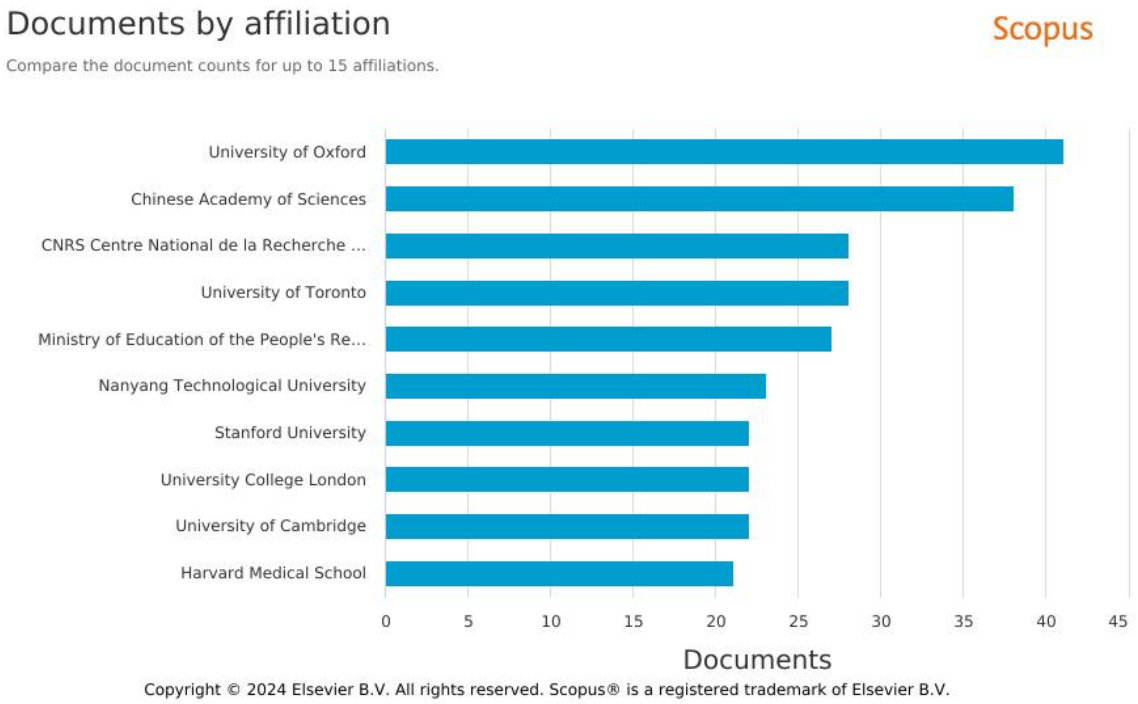

Figure 3: Articles by affiliation

Table 1: Articles by affiliation

No.	Affiliation	No. of Articles
1	University of Oxford	41
2	Chinese Academy of Sciences	38
3	CNRS Center National de la Recherche	28
4	University of Toronto	28
5	University of Education of the People's Republic of China	27
6	Nanyang Technological University	23
7	Stanford University	22
8	University College London	22
9	University of Cambridge	22
10	Harvard Medical School	21

The top 10 productive countries in AI regulation are the USA, with 617 articles, and China, with 389 articles. China is followed by the UK, with 307 articles; Germany is number four, with 182 articles. Italy is in the fifth and sixth positions, with 166 articles, and Spain has 144 articles. Figure (4) presents articles by country.

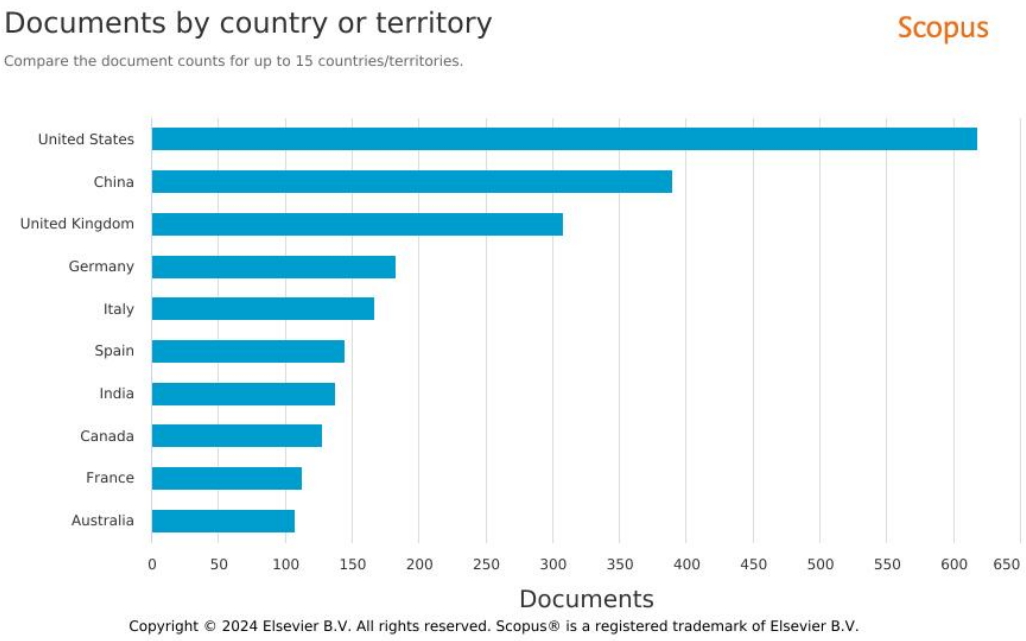

Figure 4: Article by country

Figure (5) presents the top most influential authors in AI regulation. The most prominent authors are Badnjeric, A (7 articles), followed by Chatterjee. S., having also (7 articles) Floridi, L. and Pokvic, L.G, having each (7 articles).

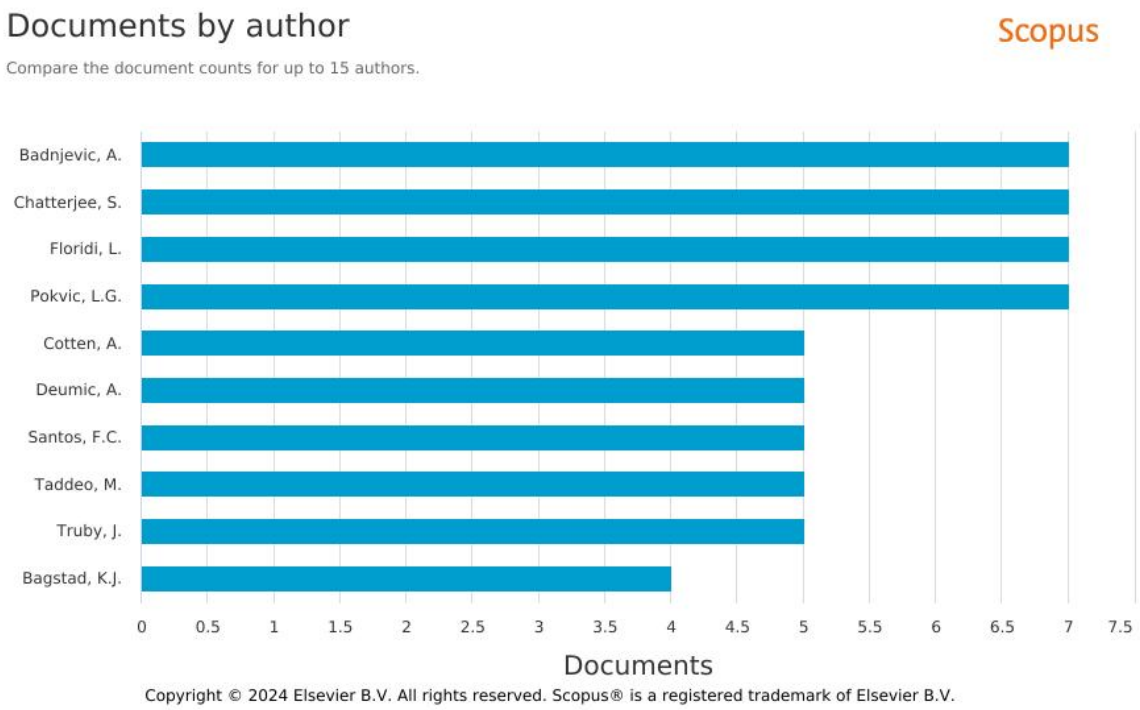

Figure 5: Article by author

Figure (6) illustrates the top prominent journals (IEEE Access, Computer Law and Security Review, Al and Society, and BMC Bioinformatics).

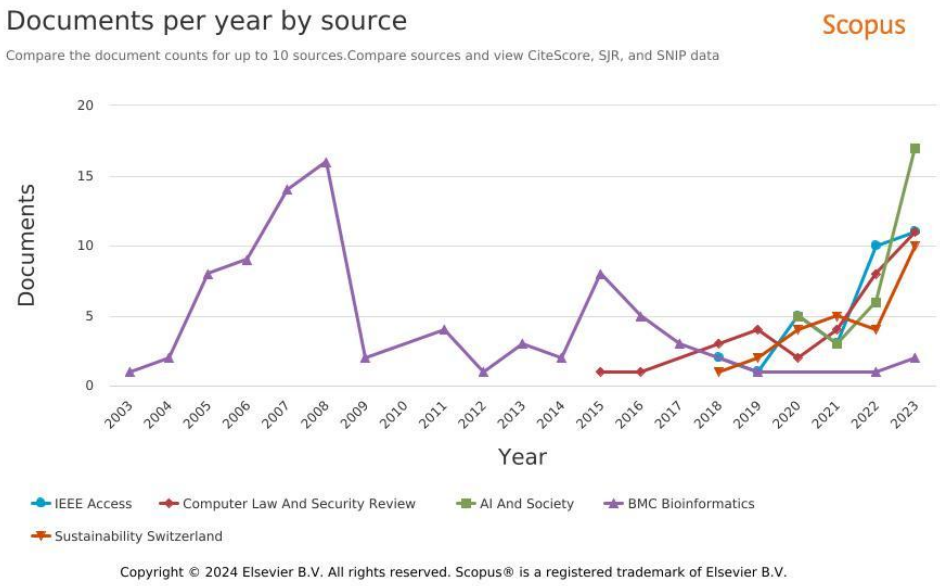

Figure 6: Article by journals

5 Keyword analysis

Science mapping encompasses citation analysis, co-citation analysis, bibliographic coupling, co-word analysis, and co-authorship analysis [20];[21]. Keyword co-occurrence network visualization was created using VOSviewer [22]. The node's size indicates the word's occurrence, and the links between the nodes indicate the co-occurrence between keywords. The higher the value, the stronger the link. The thicker the link between. Nodes are the greater of the occurrences between keywords [23]. Co-occurrences of keywords were 10; as the threshold level, 875 met the threshold, and selected keywords were 875. After performing a keyword analysis, the clusters of keywords are generated. In VOSviewer, clusters represent sets of related items (or topics) based on the similarity or co-occurrence within the data set. The keyword analysis results indicate four clusters of words that occur together and are associated with color—coding, as shown in Figure (7).

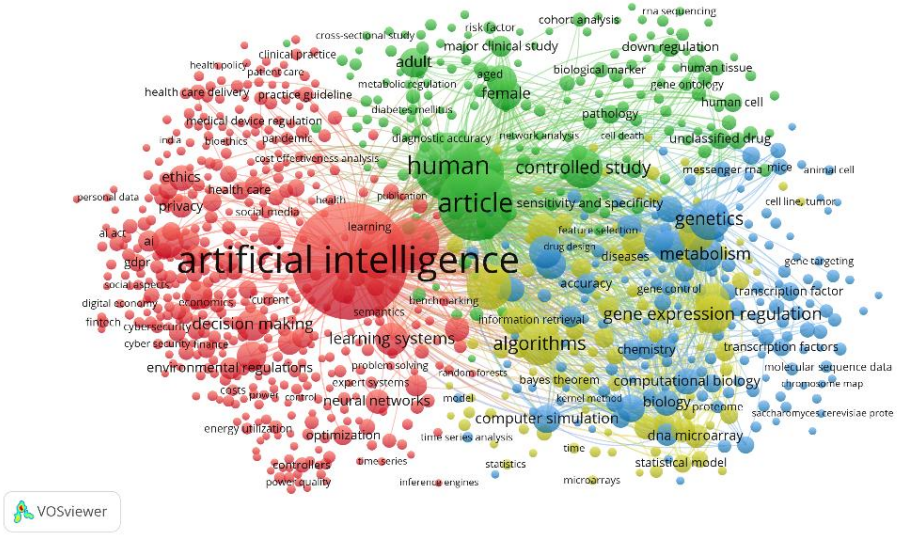

Figure 7: Keyword occurrence

Four clusters have been received out of this mapping. The red cluster has topics under the theme of AI. It includes keywords such as learning systems, decision-making, environmental regulations, neural networks, optimization, privacy, and ethics. The most frequent keywords in the red cluster are health policy, patient care, health care delivery, and medical regulation, followed by cyber security, bioethics, and the AI Act.

The green cluster mainly revolves around humans. The most frequent keywords in the green cluster are down-regulation, followed by gene ontology, unclassified drug, clinical study, diagnostic accuracy, controlled study aged female, and human issues.

The blue cluster contains keywords related to genetics, metabolism, transcription factors, messenger RNA, gene control, molecular sequence data, chromosome map, gene targeting, and all related keywords.

Yellow focuses on gene expression regulation, algorithms, and diseases. This cluster's most frequent keywords are algorithms, genetics, feature selection, and statistical models.

It can be noticed that the published articles in the blue cluster are related more to the yellow cluster. The green cluster pertains to the blue cluster and the yellow cluster. The bibliometric analysis revealed that Al regulation has received wide attention recently. Al or GAI imposes a set of crucial issues and challenges, especially in the field of responsible Al or trustworthy Al. The main research streams are AI, human- interaction, genetics, and medical regulation. The drivers of AI regulation are Al-based genetics, patient care, clinical study, diseases, and medical regulation. Future research is necessary to fill these gaps, especially in genetics, medical care, and clinical study regulation.

6 Citation analysis by author and country

Citation analysis was carried out using the top-cited authors and countries. It presented six clusters of authors that have been cited, as shown in Figure (7), as well as their first author country, as shown in Figure (8). The minimum threshold of (5) number of articles by the author and minimum (S) citations received by the author. The most cited author is Ponnefon (2016). Next in order is Catch (2018), Rahwan (2018), and Butcher (2019). Further, among all countries, the USA, UK, China, Germany, and Italy are the most productive countries. Findings revealed that the USA, UK, and China published more works in different clusters and have more relations with other countries.

Countries in small clusters, such as the Russian Federation, India, Canada, Switzerland, Belgium, Poland, Australia, and Singapore, are closely connected and cite more similar publications.

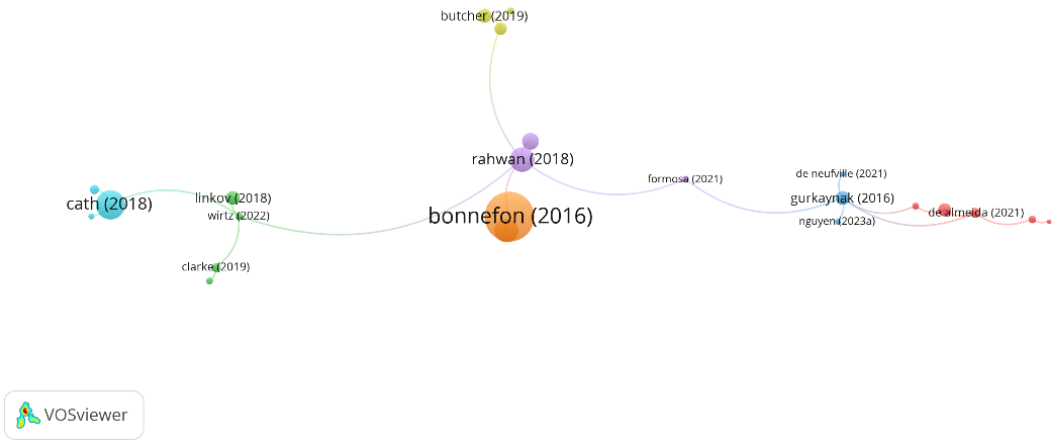

Figure 8: The top-cited authors

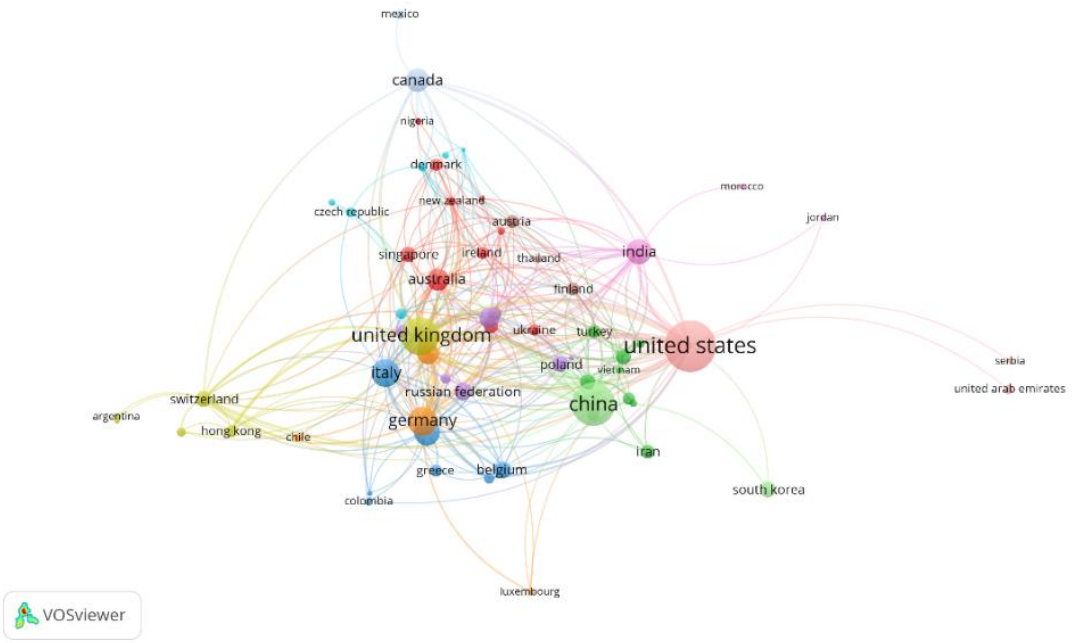

Figure 9: Cited articles by country

The analysis of highly cited authors offers an intellectual map of the most frequently cited articles in Al regulation. A node circle represents a country, and the size of the node circle determines the most.

Productive country. The line's thickness between countries represents the degree of collaboration between them. Findings indicated strong cooperation between USA, UK, and China researchers. This proves that Al regulation is still developing and worth researching.

7 Lotka's Law

Lotka's law explores the frequency of publications by authors in AI regulations in terms of the number of publications and authors. Figure (10) illustrates the author's productivity through Lotka's law.

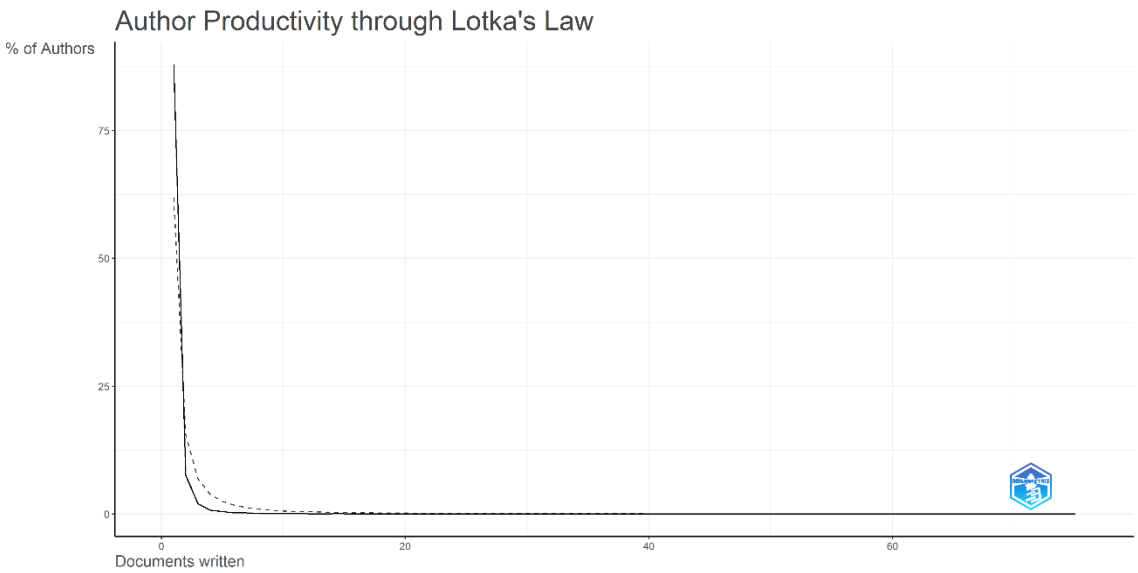

Figure 10: Lotka's Law

8 Bibliographic coupling

Bibliographic coupling is the reverse of co-citation [24]. It is about the intersection among published articles. The more references the two articles have in common, the stronger the bibliographic Coupling. In Figure (11), each circle signifies an author. A significant circle points to authors that have numerous publications. The closer the two authors are, the more related they are to each other regarding bibliographic coupling. It is observed from the analyses that authors [25] and [26] have an association with other authors with each other in the same clusters.

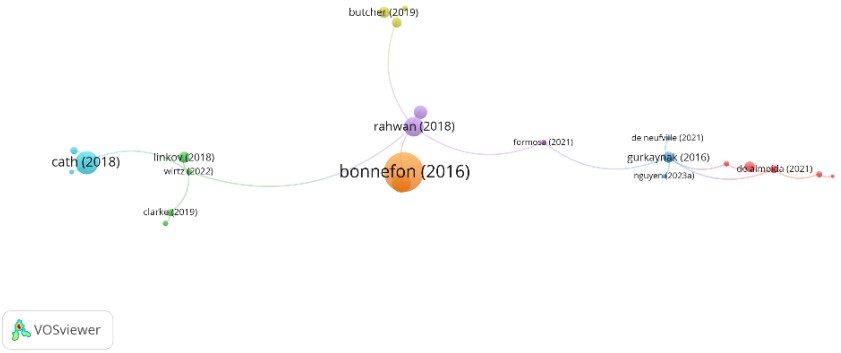

Figure 11: Bibliographic Coupling

9 Thematic analysis

Figure (12) presents four Themes characterized by density and centrality. The upper right quadrant signifies the maximum density and centrality of the themes in the field of AI regulation. The mainstream clusters represent the large portions of carried-out research. The upper left quadrant displays a high density of themes but insignificant external links with other fields. The third quadrant in the lower left is either emerging or declining themes. The fourth quadrant on the lower right represents centrality but has not yet matured and has the potential to grow.

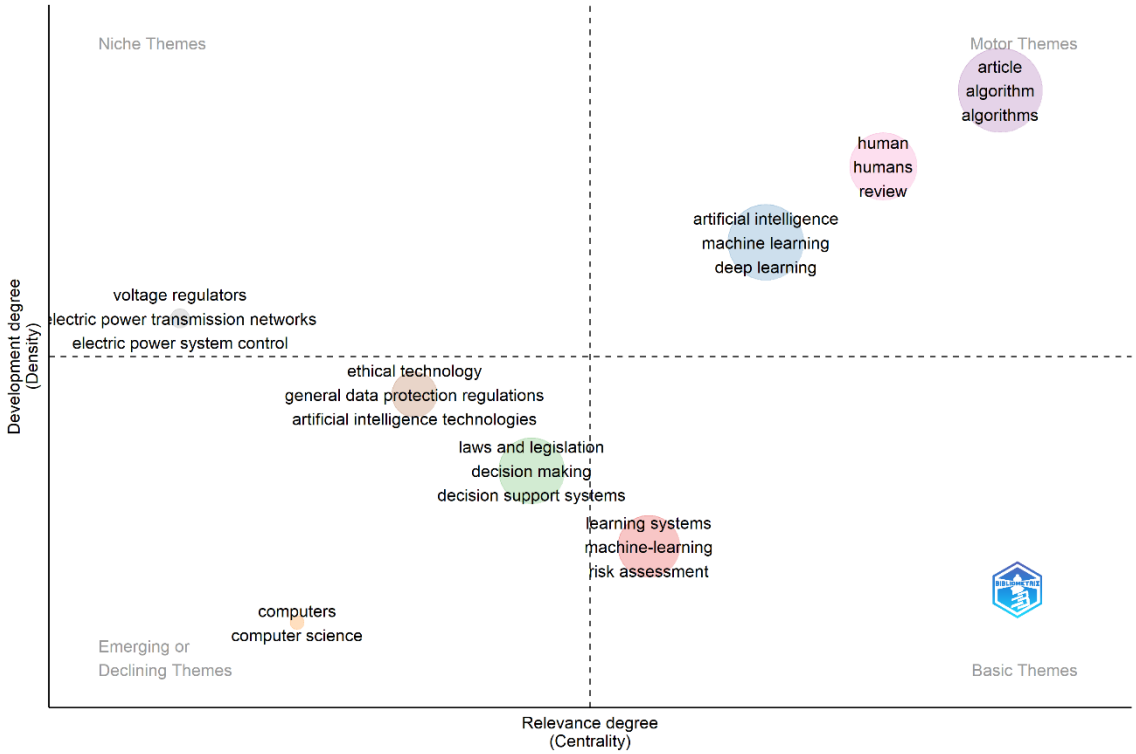

Figure 12: Thematic Density and Centrality

10 Discussion and conclusion

Al regulation has emerged as a new research field. Overall findings revealed that there is a steady growth in annual publications. Regarding country research trends, findings indicated that the USA and China are leading the research in Al regulation. The University of Oxford secured the top position with 41 publications. IEEE Access Computer Law and Security Review and Al and Society received highly produced titles, followed by BMC Bioinformatics and Sustainability. The first emerging research stream demonstrates A1-based health care services, cutting-edge medical applications using Al tools, clinical processes, and Al-based decision systems for high-accuracy solutions.

In this line, regulatory framework and ethical challenges should be addressed. Most Al and GAI applications in medicine and healthcare often lack regulation, posing legal and ethical concerns. Therefore, it is essential to understand the regulatory requirements associated with Al tools, techniques, and systems in clinical workflows, processes, and healthcare [12].

The second emerging research stream encompasses AI technologies directed at genetics studies. It implies regulatory challenges associated with genetics, gene expression regulation, genetics algorithms, feature selections, and clinical experiences.

The third emerging research stream is a risk-based approach to AI regulation and human interaction issues. The crucial perspective is regulating AI as righteous, human-centered, and fair. This research stream focuses on using AI technologies in different application settings and defining specific obligations for AI users, providers, and stakeholders.

Responsible Al has emerged to bring the perspective of law and regulations to Al applications. Thus, responsible Al regulation research includes topics such as Al transparency, Al fairness, and trustworthy Al, which positively impact the development of this interdisciplinary field. Future research should be directed to developing regulations, laws, and ethics regarding why and how users should apply Al-based systems in each domain. Often missing from these requirements is the regulatory framework of Al or GAI practices, which includes abuses and misuse of Al tools.

11 Implications, limitations, and future research

This research has several implications. First, scholars in Al law, Al regulation, Al ethics, and responsible AI can benefit from this research. They would know more about the most influential authors, journal affiliations, and countries in the Al regulation and may target them in the research design process. Second, researchers can also find relevant research questions to be answered while attempting to fill the existing gaps. Third, the different research streams (clusters) will help researchers explore their potential research journeys and clarify their implications. Finally, this research attempts to fill the existing Al regulation literature gap by conducting bibliometric data analysis, using keyword occurrence analysis, bibliographic coupling, and citation analysis. Based on the bibliometric analysis of the Al regulation literature, a vast body of intellectual structures and research around Al and GAI regulation was mapped, visualized, and analyzed for deeper understanding. However, this research focuses on a database from Scopus, and the articles represented are from (Q1, Q2, Q3, and Q4). There is a bias for ScienceDirect publications. Some (151) journal articles that might be impactful are not included. Future bibliometric analysis might be able to integrate articles from journals indexed in the Clarivate analytics (151) and the Scopus database. Furthermore, researchers can also use numerous visualization and knowledge-mapping techniques to analyze bibliometric data.

12 Declarations

10.1 Ethical approval and consent to participate

This study did not involve human participants, animals, or any biological materials. Ethical approval was therefore not required. All data used in this study were obtained from publicly

available resources. The study adheres to the standards for responsible research practices, including properly attributing sources and avoiding plagiarism. The study confirms transparency, data reporting accuracy, and research process integrity.

10.2 Consent for Publication

Not applicable. This manuscript does not contain any person's data in any format. The manuscript was conducted solely by the author.

10.3 Availability of supporting data

The datasets analyzed in the study are available from the corresponding author upon reasonable request. All other supporting data and information are included in the manuscript.

10.4 Competing interests/ authors' contributions

The authors declare that they have no competing interests. Author S.Y. conceived, designed the study, and analyzed the data. Author Q.A. contributed to the interpretation of the results. Author D.D contributed to writing and editing the manuscript.

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