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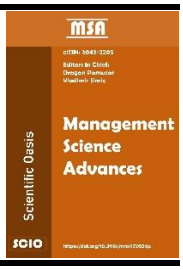

Half a Century of Fuzzy Decision Making in Italy: A Bibliometric Analysis

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ABSTRACT

Italy is a developed country, and researchers in fuzzy decision-making are publishing actively. However, the extent and impact of contributions remain unexplored in scholarly evaluations. Thus, this study aims to provide a bibliometric analysis of fuzzy research in Italy from 1973–2024, utilizing the Scopus database and VOSviewer software. The main findings show a significant growth, with total publications increasing from 45 (1973-1999) to 543 (2000-2024). Early research focused on foundational concepts like fuzzy sets and fuzzy logic, while recent studies emphasize applied domains such as decision-making, artificial intelligence, and machine learning. Leading contributors include Fausto Cavallaro from the University of Molise, with the University of Naples Federico II (41 total papers) as the most productive institution. Collaboration analysis identifies India as the primary partner. The topical and keyword analysis reveals that the focus of the area of research is less aligned with global trends in fuzzy theories. Institutions can encourage strategic publishing to improve global rankings and citation impact.

1. Introduction

Decision-making under uncertainty is a key area of research in many fields, spanning from engineering, economics, artificial intelligence (AI), to operations research. Fuzzy set theory tends to be a very useful mathematical tool to bridge the gap between vagueness and inaccuracy in real-world problems. Since the introduction of fuzzy sets by Zadeh [1], numerous applications have been established based on fuzzy sets, such as fuzzy decision-making, fuzzy clustering, fuzzy aggregation operators, etc. Researchers across the globe have built Zadeh's original framework [1] over the decades, both in theoretical works as well as practical applications. This kind of research has become more prominent in its impact on the worldwide science community and spans many areas of applied computer intelligence and uncertainty modeling.

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Nevertheless, although several individual contributions to fuzzy research in Italy are retrievable, to the best of our knowledge but no bibliometric analysis [2-3] of their impact has so far been carried out. This bibliometric analysis uses the Scopus database [4] and focuses on the impact and growth of fuzzy in the field of decision-making and optimization in Italy. It entails important insights such as publication trends, citation trends [5], h-index [6], top authors, top institutions, collaborations, etc. While the visualization of bibliometric indicators was studied through VOS viewer software [7]. Such metrics give an assessment of the growth of the discipline, where research works are focused, and new emerging research areas of fuzzy decision-making.

The rest of this paper is structured as follows: Section 2 presents the methodology. Section 3 presents a detailed metric analysis with the number of publications, citation impact, main contributors, and productive countries. In Section 4, the VOS viewer is used to visualize bibliometric indicators to showcase the landscape of research activities and collaborations in the field. To conclude, Section 5 presents the results, discussions, and implications for future research.

2. Methodology

The concept and definition of bibliometrics were introduced by Pritchard [8]. Bibliometric analysis is a strong statistical tool applied for evaluating the trends, visibility, and citation impact of the research within the research area [9]. This analysis aids in understanding the influential works, patterns of research, and areas in which new developments can be made, providing insight into a field's trajectory. Bibliometric analysis also assesses the global impact and collaborative nature of a research field using data on key contributors, institutions, co-authorship networks, leading journals, and distribution of research keywords [10]. The framework of the present study is given in Figure 1.

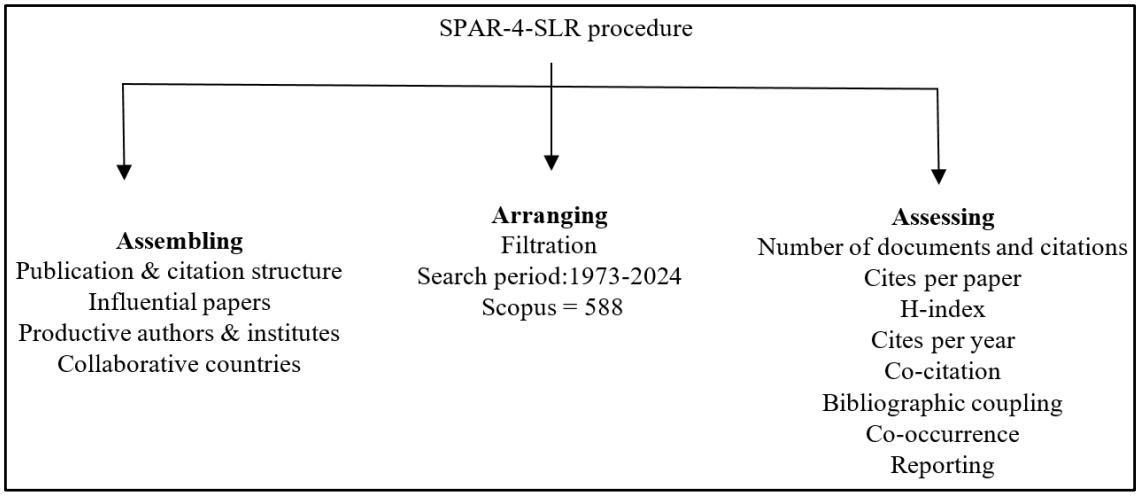

Fig. 1. SPAR-4-SLR procedure of the proposed study

Commonly used network-based methods for visualizing bibliographic relationships are co-citation analysis [11], bibliographic coupling [12], and keyword co-occurrence mapping [13]. These methods highlight how research is linked across different studies and how they disseminated through the research community [14].

Modern bibliometric studies have played an important role in analyzing fuzzy-related research in fields over the last few years [15]. Lopez-Herrera *et al.* [16] focused on the evolution of fuzzy research structure and the scientific development of fuzzy in Spain. Yu *et al.* [17] examined its 30-year development in China. A similar overview of fuzzy systems research in the United States and

Canada was done by Merino-Arteaga *et al.* [18]. A study on the applications of fuzzy logic and AI in financial analysis was conducted by Nica *et al.* [19]. Other bibliometric analyses have examined fuzzy decision-making [20-21] and performed a citation analysis of fuzzy set theory journals.

This analysis was performed on a bibliometric analysis of fuzzy research in Italy using the Scopus database on the topic "fuzzy" AND "Decision-Making" OR "Decision Making" for the interval 1973–2024 and identified 54,865 documents. Refining the data set with some filters (i.e. excluding 2025 publications) and selecting (i.e. articles & reviews), and selecting publication stage as final it gives us 36,106 documents. Then, further selection was made by selecting source type journal and from the country filter "Italy" restricted us to 588 documents.

3. Metric Analysis

This section presents the metric analysis of fuzzy decision-making research in Italy, focusing on key bibliometric indicators. The analysis examines the publication and citation structure of fuzzy research in the country, highlighting influential papers and the most cited documents in the field. Additionally, it identifies productive authors and institutions, explores co-authorship networks, and evaluates institutional and international collaborations. Through these metrics, we aim to provide a comprehensive overview of Italian contributions to fuzzy research and its global impact.

Table 1 highlights the evolution of fuzzy research in Italy over several decades, with a significant rise in publication output in the 21st century.

Table 1
Annual publication and citation record of fuzzy research in Italy

Year	Total papers	Total citations	Citations						
			≥300	≥200	≥100	≥50	≥25	≥5	0
1973-1982	3	62	0	0	0	1	1	2	0
1983-1992	12	1,422	2	3	3	6	6	11	0
1993-2002	40	2,191	1	2	7	13	21	33	3
2003-2012	103	7,429	4	9	18	37	64	92	3
2013	12	646	0	1	2	4	6	11	0
2014	22	883	0	1	2	6	11	20	0
2015	22	1,171	0	1	4	7	12	21	0
2016	22	895	0	0	2	6	12	21	0
2017	25	919	0	0	1	6	13	22	0
2018	37	1,370	0	1	1	7	20	36	0
2019	37	1,163	0	1	1	8	17	34	1
2020	40	1,565	0	0	3	13	16	36	0
2021	27	976	0	0	2	7	14	24	0
2022	51	1,377	1	1	1	5	18	40	1
2023	66	1,116	0	0	0	5	13	50	4
2024	69	253	0	0	0	0	0	19	13
Total	588	23,438	8	20	47	131	244	472	25
%	100%	100%	1.4%	3.4%	8.0%	22.3%	41.5%	80.3%	4.3%

The period from 2003 to 2012 saw the highest total citations (7429) and a substantial number of papers with over 100 citations, indicating the strong influence of research during that time. However, in recent years (2020–2024), there has been a surge in the number of publications, suggesting growing interest and ongoing contributions to the field. Despite the increase in research output, the distribution of citation impact reveals that only a small percentage of papers (1.4%) have garnered

300 or more citations, while 80.3% of publications have received at least five citations. This suggests that while fuzzy research in Italy has maintained steady engagement, achieving breakthrough contributions with widespread recognition remains a challenge. Encouraging interdisciplinary collaborations and targeting high-impact journals could further enhance the visibility and influence of Italian contributions to fuzzy decision-making and optimization.

Figure 2 illustrates the relationship between annual publications and citations in fuzzy decision-making research in Italy over the years. It highlights periods of high citation impact, particularly in 1988 and 1997, where certain publications received exceptionally high citations, suggesting the presence of influential works. While the number of publications remained relatively stable from the 2000s onward, citation distributions indicate that specific papers from years like 2006, 2010, and 2012 gained significant academic attention. In recent years, citations appear to be more evenly distributed across publications, reflecting a shift towards broader contributions rather than a few highly influential studies dominating the field.

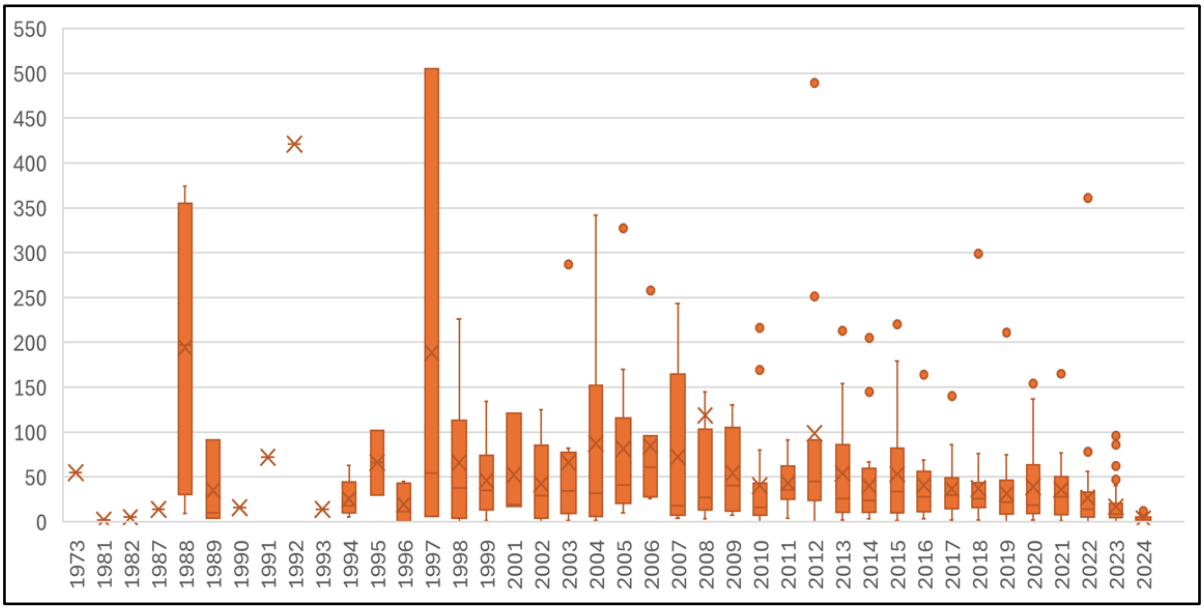

Fig. 2. Annual publication vs citation chart

Table 2 showcases the most cited documents in fuzzy research published by Italian authors, highlighting the top five influential papers.

Table 2
Most cited documents of fuzzy research published by Italian authors

Title of document	Year	Cites per year	Total citations
Advances in diagnostic techniques for induction machines	**2008**	**58.76**	**999**
A linguistic modelling of consensus in group decision making based on OWA operators	**1997**	**18.03**	**505**
Definition methodology for the smart cities model	**2012**	**37.61**	**489**
Group decision making and consensus under fuzzy preferences and fuzzy majority	**1992**	**12.02**	**421**
A 'soft' measure of consensus in the setting of partial (fuzzy) preferences	**1988**	**10.10**	**374**

The highest-cited paper, "Advances in diagnostic techniques for induction machines," has accumulated 999 citations with a strong citation rate of 58.76 per year. This suggests its significant

impact on the field, particularly in industrial applications. The remaining papers focus on fuzzy decision-making and consensus models in fuzzy preferences and group decision-making. The 2012 study on smart cities also stands out with a high citation rate (37.61 per year), indicating the growing relevance of fuzzy methods in urban planning. Overall, these highly cited works emphasize Italy's contributions to both theoretical advancements and practical applications of fuzzy research.

Table 3 highlights the foundational works in fuzzy research that have been highly cited by Italian authors. The most referenced work is "Fuzzy sets" by Zadeh [1], which laid the theoretical groundwork for fuzzy logic and has accumulated 107 citations. Other significant contributions include "The analytic hierarchy process" by Saaty [22] and "Intuitionistic fuzzy sets" by Atanassov [23], both of which are widely applied in decision-making and uncertainty modelling. Additionally, more recent works, such as "Best-worst multi-criteria decision-making method" by Rezaei [24] and "Multiple attribute decision making methods and applications" [25], reflect ongoing advancements in fuzzy-based decision-making approaches. The inclusion of both journal articles and books in Table 3 highlights the diverse sources influencing Italian researchers in fuzzy systems.

Table 3
Most cited documents by Italian authors in fuzzy research

Title of document	Reference	Type	Year	Total citations
Fuzzy sets	**[1]**	**Journal**	**1965**	**107**
The analytic hierarchy process	**[22]**	**Journal**	**1987**	**42**
Intuitionistic fuzzy sets	**[23]**	**Journal**	**1986**	**33**
Best-worst multi-criteria decision-making method	**[24]**	**Journal**	**2015**	**29**
Multiple attribute decision making methods and applications	**[25]**	**Book**	**1981**	**28**

Table 4 provides insights into the most productive authors and co-authors in fuzzy decision-making research in Italy. Among the most productive authors, Cavallaro F. (University of Molise) leads with 28 research papers and 1324 total citations, followed by Ahmadian A. and Loia V. from Italian universities. The list of productive co-authors indicates strong international collaborations, with researchers from India (Narayanamoorthy S., Mishra A.R., and Rani P.), South Korea (Kang D.), and the USA (Tavana M.).

Table 4
Most productive authors and co-authors

Productive authors								
Author name	**Country**	**University**	**Cites per paper**	**≥100 citations**	**≥10 citations**	**1985-2004**	**2005-2014**	**2015-2024**
Cavallaro, F.	**Italy**	**U Molise**	**47.29**	**3**	**22**	**0**	**1**	**27**
Ahmadian, A.	**Italy**	**U Reggio Calabria**	**17.67**	**0**	**16**	**0**	**0**	**24**
Loia, V.	**Italy**	**U Salerno**	**46.9**	**1**	**18**	**0**	**6**	**15**
Ferrara, M.	**Italy**	**U Reggio Calabria**	**16.29**	**0**	**10**	**0**	**0**	**14**
Orciuoli, F.	**Italy**	**U Salerno**	**34.36**	**0**	**9**	**0**	**1**	**10**
Productive co-authors								
Narayanamoorthy, S.	**IND**	**Bharathiar U**	**15.95**	**0**	**14**	**0**	**0**	**20**
Mishra, A.R.	**IND**	**Govt College Raigaon**	**36.17**	**1**	**13**	**0**	**0**	**18**
Rani, P.	**IND**	**K L Deemed U**	**38.65**	**1**	**14**	**0**	**0**	**17**
Kang, D.	**KOR**	**Inje U**	**16.35**	**0**	**11**	**0**	**0**	**17**
Tavana, M.	**USA**	**La Salle Philadelphia**	**40.27**	**1**	**11**	**0**	**1**	**14**

Table 5 gives insights into the most productive institutions and international collaborations in fuzzy decision-making research in Italy. Italian institutions contributing significantly include the University of Naples Federico II, the University of Trento, and the National Research Council, with high citation counts and research impact. Internationally, Bharathiar University (India), King Saud University (Saudi Arabia), and the University of Cyprus have been key collaborative institutes. At the country level, Italy's strongest research collaborations are with India, the United States, and Iran, showing a global network in fuzzy decision-making research.

Table 5
Most productive institutes, collaborative institutes, and countries

Productive institutes							
Institution	**Country**	**Cites per paper**	**≥100 citations**	**≥10 citations**	**1985-2004**	**2005-2014**	**2015-2024**
Bharathiar U	**IND**	**15.19**	**0**	**13**	**0**	**0**	**21**
King Saud U	**KSA**	**14.68**	**0**	**8**	**0**	**0**	**19**
U Cyprus	**CYP**	**16.25**	**0**	**9**	**0**	**0**	**16**
Lebanese American U	**LEB**	**11.19**	**0**	**9**	**0**	**0**	**16**
Paderborn U	**GER**	**40.27**	**1**	**11**	**0**	**1**	**14**
Productive collaborative institutes							
Institution							
Bharathiar U	**IND**	**15.19**	**0**	**13**	**0**	**0**	**21**
King Saud U	**KSA**	**14.68**	**0**	**8**	**0**	**0**	**19**
U Cyprus	**CYP**	**16.25**	**0**	**9**	**0**	**0**	**16**
Lebanese American U	**LEB**	**11.19**	**0**	**9**	**0**	**0**	**16**
Paderborn U	**GER**	**40.27**	**1**	**11**	**0**	**1**	**14**
Collaborative countries							
Country							
India		**25.11**	**1**	**36**	**0**	**0**	**54**
United States		**43.68**	**5**	**32**	**5**	**9**	**33**
Iran		**30.81**	**2**	**24**	**0**	**2**	**40**
Turkey		**17.26**	**0**	**23**	**0**	**0**	**39**
United Kingdom		**40.47**	**1**	**30**	**1**	**7**	**30**

Table 6 lists the most frequently used author keywords in fuzzy decision-making research in Italy, providing insights into the primary research themes.

Table 6
Most common author keywords used in fuzzy decision-making research in Italy

Keyword	**Total research papers**	**Total citations**
Decision Making	**376**	**14,517**
Fuzzy Sets	**136**	**7233**
Fuzzy Logic	**128**	**6374**
Fuzzy Mathematics	**80**	**3564**
Decision Support Systems	**48**	**1996**
Sustainable Development	**43**	**149**
Artificial Intelligence	**43**	**2824**
Uncertainty	**38**	**1036**
Decision Theory	**36**	**2487**
Multicriteria Analysis	**34**	**1339**

"Decision making" is the most prominent keyword, appearing in 376 papers with 14,517 total citations, reflecting the strong focus on applying fuzzy methods to decision-support processes (Table 6). Other foundational concepts like "fuzzy sets" (136 papers, 7233 citations) and "fuzzy logic" (128 papers, 6374 citations) indicate the theoretical backbone of the field. Emerging interdisciplinary topics include "artificial intelligence" (43 papers, 2824 citations) and "sustainable development" (43 papers, 149 citations), highlighting the application of fuzzy techniques in modern technological and societal challenges. "Uncertainty" and "multicriteria analysis" further reinforce the role of fuzzy research in complex decision-making scenarios. These keyword trends suggest that fuzzy research in Italy is both theoretically grounded and increasingly applied to diverse real-world problems.

4. Graphical Analysis Using VOS Viewer Software

Co-occurrence analysis, bibliographic coupling, and co-citation are essential bibliometric methods, each offering unique insights into the structure and evolution of scientific knowledge. When combined with network mapping and cluster analysis, these techniques provide intuitive, data-driven visualizations of research fields. Such visualizations help identify key contributions, track knowledge development, and uncover collaboration opportunities, making them valuable tools in bibliometric analysis. In these visual analyses, color gradients often represent different development periods or stages within a research field, offering a chronological perspective on scientific advancements. These visual tools enhance our understanding of the intellectual structure of the field and its evolving research dynamics.

The network visualization in Figure 3 illustrates the co-occurrence of author keywords in fuzzy research in Italy, considering terms that appear at least five times and have a minimum of 100 links.

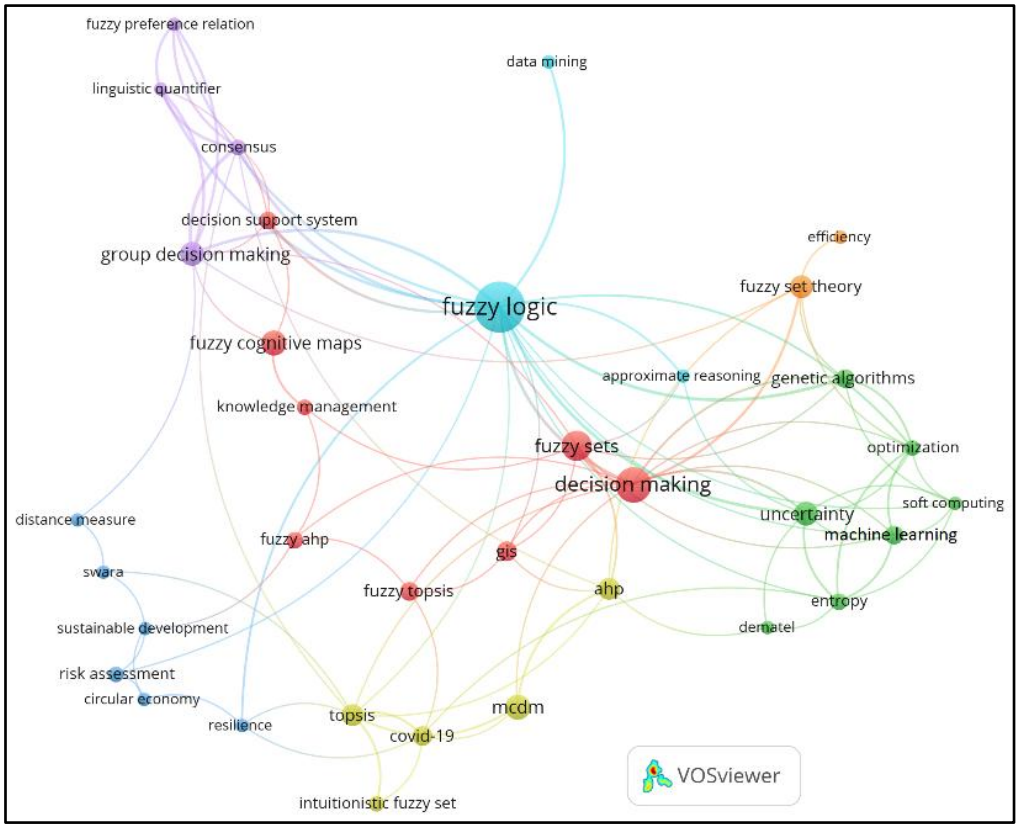

Fig. 3. Co-occurrence of author keywords of fuzzy research in Italy (minimum 5 occurrences & 100 links)

The central clusters focus on fuzzy logic and decision-making, emphasizing their dominant role in the field (Figure 3). Various subfields, such as fuzzy sets, uncertainty, machine learning, fuzzy theory, and approximate reasoning, exhibit strong interconnections, underscoring their significance in decision-making processes. Additionally, topics like group decision-making, fuzzy cognitive maps, and linguistic quantifiers highlight applications in social and computational sciences. The presence of terms such as data mining, sustainable development, and risk assessment suggests the interdisciplinary nature of fuzzy methodologies across diverse fields.

Figure 4 presents a co-citation analysis of journals in fuzzy research in Italy, focusing on journals with at least 100 citations and 100 links. The blue cluster centered around "sustainability" and "J. Clean. Prod.", indicates a strong connection between fuzzy research and environmental or sustainability studies. The green cluster, including "Renew. Sustain. Energy Rev." and "Energy Policy", highlights the integration of fuzzy methodologies in renewable energy and policy-related research. The red cluster, featuring "Eur. J. Oper. Res.", "Fuzzy Syst.", and "Expert Syst. Appl.", represents the core computational and decision-making aspects of fuzzy research. These connections suggest that fuzzy logic is widely applied across diverse domains, spanning energy sustainability, decision-making, and computational intelligence.

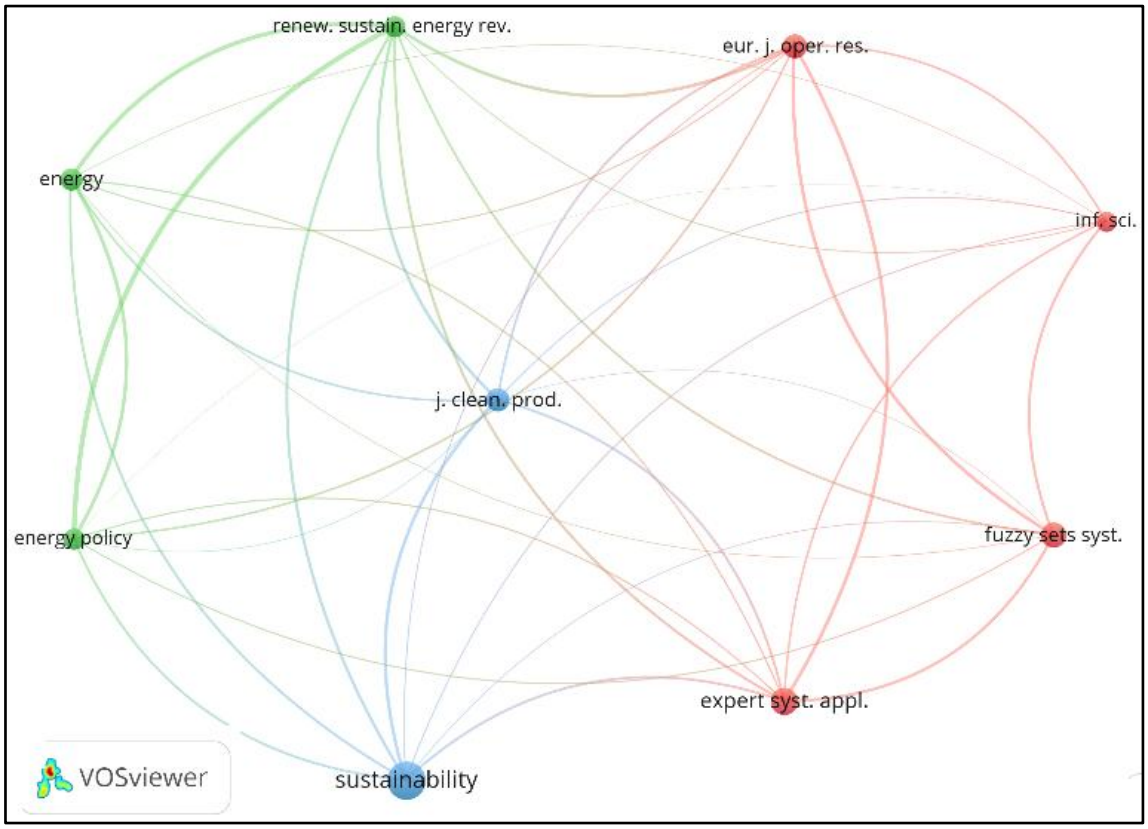

Fig. 4. Co-citation of journals of fuzzy research in Italy (minimum 100 citations & 100 links)

Figure 5 illustrates the bibliographic coupling of countries collaborating with Italy in fuzzy research, considering countries with a minimum of 10 publications. The network visualization positions Italy as the central node, reflecting its strong international research collaborations. The green cluster links Italy with Spain, Germany, and other European nations, signifying strong research partnerships within Europe. The red cluster connects Italy with India, Turkey, Saudi Arabia, and Lebanon, indicating collaborations with Middle Eastern and Asian researchers. The blue cluster

includes the United States, the United Kingdom, and Canada, showcasing transatlantic research partnerships. This network highlights Italy's extensive global involvement in fuzzy research, with significant collaborations across Europe, North America, and Asia.

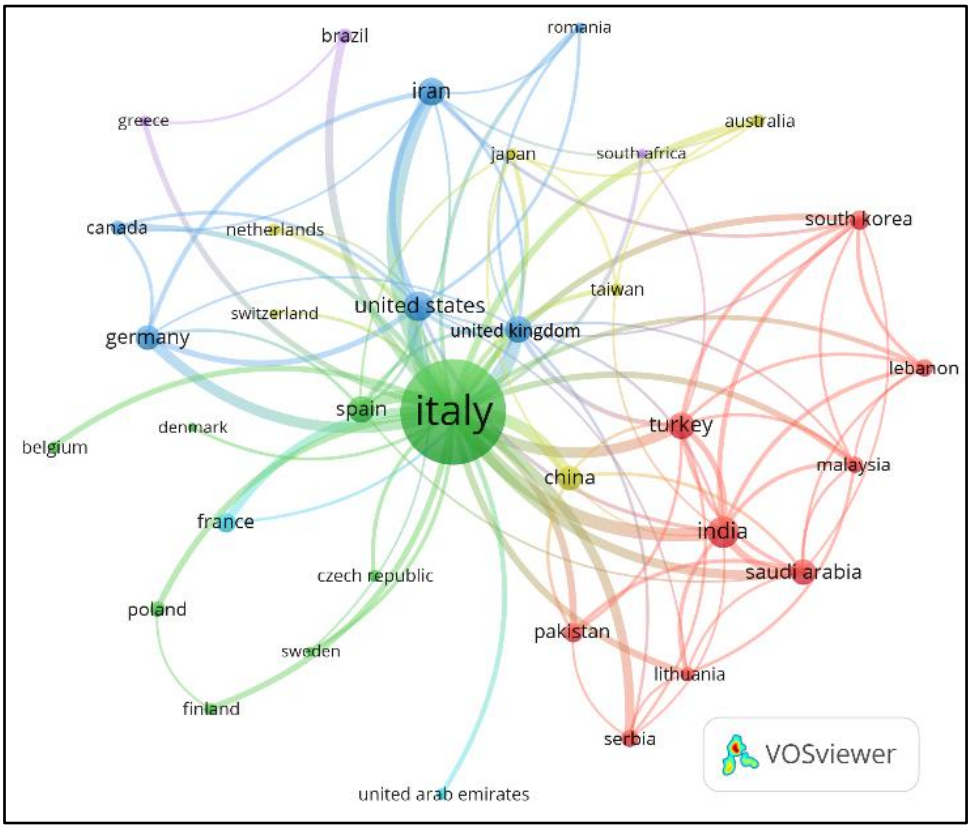

Fig. 5. Bibliographic coupling of countries publishing on fuzzy research in Italy (minimum 10 publications & 100 links)

5. Conclusion

The article provides a bibliometric analysis of fuzzy research in Italy, ranging from 1973 to 2024, and considering the data from Scopus databases. The study features the productive authors, institutes, countries, and trending author keywords.

The analysis reveals a steady growth in publication output over the past two decades, reflecting a sustained and expanding interest in fuzzy systems among Italian researchers. Prominent academic institutions such as the University of Pisa, the University of Naples Federico II, and Politecnico di Milano have played a key role in expanding fuzzy research. The core areas of application "decision-making" and "optimization" remain central to Italian fuzzy research, with topics such as "fuzzy multi-criteria decision-making", "fuzzy clustering", and "optimization algorithms" frequently explored. In recent years, an increase in interdisciplinary research, with fuzzy logic being combined with advanced AI techniques like neural networks, evolutionary algorithms, and machine learning, have been seen.

Our recommendations are:

i. Researchers should continue to strengthen their international visibility through collaborative projects, contributions to high-impact journals, and active engagement in global conferences.

ii. Deeper integration of fuzzy logic with emerging AI methodologies can lead to innovative solutions for complex societal and industrial challenges, particularly in areas such as healthcare, smart cities, and sustainability.
iii. Stronger engagement with industry and policymakers is essential to facilitate the practical implementation of fuzzy decision-making models and bridge the gap between academic theory and real-world application.

This study provides an overview of the country Italy from 1973-2024 using the Scopus database, but may exclude significant contributions from platforms like Web of Science and Google Scholar. Besides, the emerging topics, authors, and institutes can vary in the future due to publication trends.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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