Bibliometric review of research on decision models in uncertainty, 1990–2020

Luciano Barcellos-Paula[1,2], Iván de La Vega[1,2], Anna M. Gil-Lafuente[3]

[1]CENTRUM Católica Graduate Business School, Lima, Perú.
[2]Pontificia Universidad Católica del Perú, Lima, Perú. Email: lbarcellosdepaula@pucp.edu.pe
[3]Department of Business Administration, University of Barcelona, Barcelona, Spain.

Abstract

Societies experience intense and frequent changes in diverse environments, which increase uncertainty and complexity in decision-making. The decision-maker looks for alternatives to reduce risks and face these new challenges. In this context, science plays a vital role in proposing new solutions. The article aims to: i) to carry out a bibliometric review of decision models in uncertainty through scientific mapping and performance analysis between 1990 and 2020; ii) to know the scientific progress of 17 models that specialists validated. The Web of Science database and the VOSviewer, R, and Python software analyzed 26,835 articles in 9 bibliometric indicators. The results revealed a positive trend of the publications in the analyzed models, being the Analytic Hierarchical Process (AHP) the most used. Other findings showed China as the country with more scientific collaborations. There is enormous potential for future lines of research on the subject.

Keywords: decision models, uncertainty, science mapping, performance analysis, fuzzy logic

1 | INTRODUCTION

Societies experience intense and frequent changes in diverse environments, which increase uncertainty and complexity in decision-making. The decision-maker looks for alternatives to reduce risks and face these new challenges.

In this context, science plays a vital role in proposing new solutions. Appropriately, Fuzzy Logic[1] was born to guide decision models that reduce uncertainty and facilitate decision-making. Over time, Fuzzy Logic models have proven effective in addressing society's new needs, such as knowing the variables that affect the Sustainable Development Goals[2], and the pandemic effects of COVID 19 on the aging population[3]. In this sense, Fuzzy Logic had to evolve, and Zadeh presented in 1975 the Type-2 Fuzzy Set (T2FS)[4]. The T2FS would be more recommended than the Type-1 Fuzzy Sets to address a problem with a high level of data imprecision, such as, for example, perceptions[5]. Another study reinforces that T2FS offers more degrees of freedom in fuzzy logic systems[6]. According to other authors[7], the T2FS is a generalization of the standard fuzzy set in which the membership value for each member of the set is itself a fuzzy set. As a result, T2FS started to be used in several areas of knowledge, such as medicine[6,8], computational complexity, and hardware[5]. Another significant milestone was the introduction in 1986 of the Intuitionistic Fuzzy Set (IFS) "as a generalization of the notion of fuzzy set"[9]. Continuing to advance the frontier of knowledge, in 1991, Zadeh proposed "Soft Computing", a hybrid of methodologies including fuzzy logic, neural networks, evolutionary algorithms, and probabilistic reasoning[10]. Sukhveer Singh & Garg, in 2017, published the Type-2 Intuitionistic Fuzzy Set (T2IFS)[7], which consists of a family of distance measures based on Hamming, Euclid, and Hausdorff metrics and present a group decision-making method for ranking alternatives[7]. According to other researchers[11], T2IFS is a new extension of T2FS. The fuzzy preference of decision-makers towards their decisions under different parameters can be expressed[11].

Another study also confirms that the mathematics of uncertainty[12] is helpful in various areas of knowledge, such as engineering, biology, medicine, management, finance, human resources, geology, sociology, phonetics, and even music, among others[13]. For this reason, it is defined as an object of study in this article. As indicated in other studies[14,15], decisions in the real world take place in uncertain environments where the consequences of actions are not accurately known. An application of Fuzzy Logic precisely considers the intersection of objectives and constraints within a multi-stage process in which human subjectivity influences the decision. In recent years, bibliometric studies[15,16] have addressed the

issue of “Fuzzy decision-making”. However, there is a knowledge gap to evaluate some decision models in uncertainty. Researches have reinforced that “this discipline has strong potential and expectations for the future are that it will continue to grow”[16].

For these reasons, the article aims are i) to carry out a bibliometric review of decision models in uncertainty through scientific mapping and performance analysis between 1990 and 2020; ii) to know the scientific progress of 17 models that specialists validated.

A positive trend of publications in the models analyzed has been revealed in terms of results, being the AHP the most used. Other findings have shown China as the country with the most scientific collaborations, the growth of research lines linked to sustainable development, and the emergence of journals specialized in decision models. The main contribution of the manuscript is to deepen the studies on 17 decision models in uncertainty through bibliometric analysis. The most important limitation concerns the number of decision models in uncertainty included in the analysis. The article is structured as follows: Section 2 presents the methodology used. Section 3 shows the results of the bibliometric review. Section 4 describes the conclusions, contributions, and future lines of research, followed by acknowledgments and references.

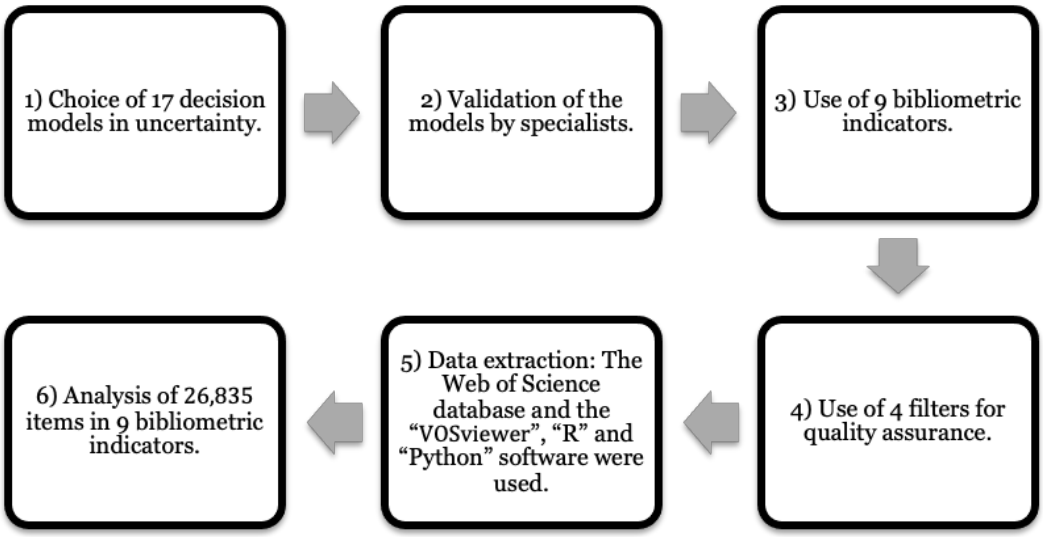
2 | METHODOLOGY

This section presents the methodology used to carry out the bibliometric review that follows an approach combined[17,18] with the scientific mapping (SM) and performance analysis (PA). According to Cobo et al.[19], the SM displays the structure and dynamic aspects of scientific research. On the other hand, the PA shows the evaluation of the groups of scientists and the impact of their activity on the bibliographic database[19]. According to this methodological line, 9 bibliometric indicators will be used: papers retrieved from each keyword; papers by year, cites, and countries; keywords analysis; countries collaboration; journal analysis; research areas; most cited articles; analysis by institutions; and author analysis.

The study begins with the validation of 17 decision models in uncertainty: Analytic Hierarchical Process[20]; Branch and Bound[21]; Hamming Distance[22]; Intuitionistic Fuzzy Set[9]; Owa Operator[23]; Type-2 Fuzzy Set[4]; Galois Theory[24]; Fuzzy Subset[1]; Adequacy Ratio[12]; Markov Chain[25]; Fuzzy Delphi Method[26]; Hungarian Algorithm[27]; Subjective Preferences[28]; Fuzzy Measure Theory[29]; Forgotten Effect[30]; Theory of Experton[31]; and Type-2 Intuitionistic Fuzzy Set[7]. To achieve this objective, five specialists on the subject participated. The consultation was carried out in September 2019 via e-mail. For confidentiality reasons, the names of the specialists cannot be disclosed.

Bibliometric indicators were used, and all languages were considered. For the keywords, all the keywords were analyzed one by one to refine the results. Finally, for the authors, the same analysis of the keywords was carried out. To guarantee the quality of the results, the following filters were used: i) Out of a total of 34,821 papers, 34,064 were identified as single articles; ii) 31,699 papers were only Science Citation Index, Social Sciences Citation Index, and Art & Humanities Citation Index; iii) 27,819 papers were for the period 1990-2020; iv) 26,835 were only single papers (duplicates were eliminated). With the validated models, indicators, and criteria established, the data extraction process began. Figure 1 shows the workflow for performing the bibliometric review.

FIGURE 1 Workflow for performing the bibliometric review



Source: Own elaboration.

The process of data extraction was carried out on December 27-29, 2021, using the Web of Science (WoS) database. The WoS was used because this database allows a more detailed citation analysis than others such as Scopus[32]. Also, it is the database collection with the widest coverage of structured information in terms of time range. The data extraction followed three steps. Firstly, a scraping process was performed using Python[33]. The results were stored in Excel format. Secondly, R software[34] was used for the generation of tables and graphs. Thirdly, the VOSviewer software[35] was used for the generation of the graph of connections and to obtain the complete list of authors. Finally, the analysis of 26,835 elements in 9 bibliometric indicators was carried out. In the next section, the results of the study are presented.

3 | RESULTS OF THE BIBLIOMETRIC REVIEW

This section shows the results of the bibliometric review. The outcomes will be presented through figures and tables with the respective analysis, and in the following order: papers retrieved from each keyword; papers by year, cites and countries; keyword analysis; countries collaboration; journal analysis; research areas; most cited articles; analysis by institutions; and author analysis.

3.1 | Papers retrieved from each keyword

This subsection is dedicated to presenting the result of the documents retrieved for each keyword in the period from 1990 to 2020. This indicator allows knowing the ranking of the keywords, in this case, the most used decision models will be revealed, and the percentage of total papers with the specific keywords-combination.

The consolidated result for the period is shown, and the results are separated by each decade (1990-1999; 2000-2009; 2010-2020). Table 1 presents a ranking of the 17 decision models in uncertainty that were validated by specialists. Specific words associated with the models were added as indicated in the table 1.

The results indicate that Analytic Hierarchical Process (AHP) leads the ranking with 12,441 papers, representing 44.2% of total papers with the specific keywords-combination of the papers, followed by "Branch and Bound" with 6,469 papers, which represents 23.0%, and Hamming Distance with 2,386 papers, which represents 8.5%. "Branch and Bound" was in the first position in the decades (1990-1999; 2000-2009) and that AHP assumed the first position in the decade 2010-2020.

TABLE 1 Papers retrieved from each keyword

Keyword	1990-1999		2000-2009		2010-2020		1990-2020	
	Papers	%	Papers	%	Papers	%	Papers	%
Analytic* Hierarch* Proces*	570	22.5	1,756	31.6	10,115	50.4	12,441	44.2
Branch* and Bound*	1,291	51.0	2,087	37.5	3,091	15.4	6,469	23.0
Ham* Distanc*	247	9.8	626	11.3	1,513	7.5	2,386	8.5
Intuitionistic* fuzzy set*	24	0.9	194	3.5	1,989	9.9	2,207	7.8
Owa* Operator*	50	2.0	219	3.9	790	3.9	1,059	3.8
Type-2 fuzzy set*	4	0.2	126	2.3	878	4.4	1,008	3.6
Galois theor*	110	4.3	247	4.4	469	2.3	826	2.9
Fuzzy subset*	183	7.2	177	3.2	219	1.1	579	2.1
Fuzzy Delphi method*	4	0.2	22	0.4	252	1.3	278	1.0
Adequacy Ratio*	17	0.7	37	0.7	218	1.1	272	1.0
Hungarian Algorithm*	4	0.2	26	0.5	228	1.1	258	0.9
("Markov Chain" AND "fuzzy")	11	0.4	31	0.6	197	1.0	239	0.8
("Subjective Preferences" AND "fuzzy")	2	0.1	6	0.1	41	0.2	49	0.2
Fuzzy measure* theor*	10	0.4	9	0.2	10	0.0	29	0.1
Forgotten Effect*	1	0.0	-		25	0.1	26	0.1
Type-2 intuitionistic* fuzzy set*	-		-		12	0.1	12	0.0
theory* of experton*	1	0.0	-		8	0.0	9	0.0

Source: Own elaboration based on WoS 2021. **%:** Percentage of total papers with the specific keywords-combination.

The consolidated result indicates that AHP's dominance is mainly due to the results of the last decade. There are several reasons for AHP's power, the main ones being: firstly, its simplicity and the results achieved in various complex applications. Secondly, AHP has been adopted as a decision support tool by companies in various countries, and thirdly, because it is the basis of many software packages designed for complex decision-making processes[36].

The results also indicate a significant increase in papers published on T2FS, IFS, and T2IFS in the last decade. In this case, there were several relevant contributions, such as, for example, the presentation of the method to use interval-valued survey responses from multiple experts multiple times to produce general T2FS[37]. Another study proposed an approach to minimize any loss of information when transferring interval-based data to fuzzy set models and to avoid assumptions about the data distribution[38]. In addition, researchers applied a type-2 fuzzy expert system for depression diagnosis, including system accuracy and diagnosis time as objectives[8]. Finally, a study used the extended TODIM method with fuzzy Gaussian numbers (FIT2) to analyze a healthcare device selection problem through an evaluation process in which the perspectives of different experts are considered[39]. In summary, despite the leadership of AHP, models generalized from T2FS, IFS, and T2IFS should increase their degree of importance and applications in the coming decades.

3.2 | Papers by year, cites and countries

This subsection presents the results of the papers by year, including the number of cites, cites per document (CPD), and the average number of authors per document. Finally, the consolidated result of the keywords by country in the period between 1990 and 2020 is analyzed. It also provides details on the most used keywords in various countries.

The main objectives of publishing articles are to disseminate the research results to the scientific community and contribute to society's development based on the knowledge generated. For these reasons, science needs to know the evolution of publications, which allows the identification of trends and main lines of research. Table 2 displays that the number of articles had constant growth during all the years, and that from 2010, this increase was more accentuated. This outcome shows almost 3,000 manuscripts published in 2020. Furthermore, these data indicate a positive trend in the number of publications and strengthening in this area of knowledge. However, there has been a reduction in the number of cites in the last two years. Another interesting fact concerns the gradual growth of the average number of authors per document, which goes from 1.8 in 1990 to 3.7 in 2020. This result indicates the increase of researchers publishing in this area and reveals the interest in using models that facilitate decision-making under uncertainty. Overall, the results are consistent and show the academic soundness of the 17 decision models under uncertainty.

TABLE 2 Papers by year, cites and CPD

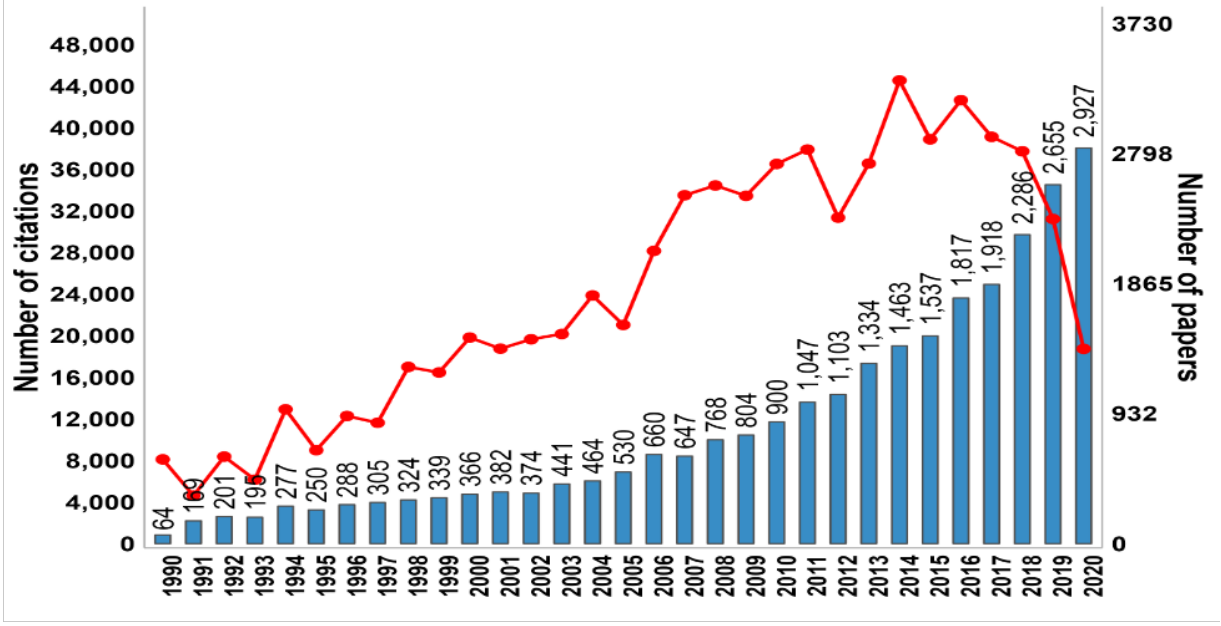
Year	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010
Papers	2,927	2,655	2,286	1,918	1,817	1,537	1,463	1,334	1,103	1,047	900
Cites	18,730	31,220	37,730	39,123	42,647	38,882	44,543	36,552	31,354	37,898	36,514
CPD	6.4	11.8	16.5	20.4	23.5	25.3	30.4	27.4	28.4	36.2	40.6
Authors	3.7	3.6	3.5	3.4	3.3	3.2	3	3	2.9	2.8	2.7
Year	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	
Papers	804	768	647	660	530	464	441	374	382	366	
Cites	33,447	34,444	33,503	28,153	21,034	23,866	20,161	19,655	18,751	19,819	
CPD	41.6	44.8	51.8	42.7	39.7	51.4	45.7	52.6	49.1	54.2	
Authors	2.7	2.6	2.6	2.6	2.5	2.4	2.4	2.4	2.4	2.3	
Year	**1999**	**1998**	**1997**	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**	**TOTAL**
Papers	339	324	305	288	250	277	195	201	169	64	26,835
Cites	16,463	16,993	11,626	12,276	8,985	12,917	6,155	8,371	4,619	8,104	754,535
CPD	48.6	52.4	38.1	42.6	35.9	46.6	31.6	41.6	27.3	126.6	28.1
Authors	2.2	2.3	2.4	2.2	2.1	2.2	2.1	2.1	2.0	1.8	2.6

Source: Own elaboration based on WoS 2021. CPD: Cites per document; Authors: Average authors per document.

Figure 2 shows the number of citations and documents from 1990 to 2020. As seen in Table 2, the positive trend over time in the number of articles published is more evident. As indicated above, the reduction in the number of citations is visually perceived from 2015 onwards. In summary, the results show that this topic is relevant to academia and that the frontier of knowledge is increasingly being extended. The main reason for the result would be the application and usefulness of the models to solve complex situations, as for example, on "Algorithms applied in decision-making for sustainable transport"[40], and to solve a biogas plant implementation problem[11].

On the other hand, it is also essential to know which countries are doing the most research and identifying the most widely applied models in each country. Table 3 shows the ranking of 20 countries with the number of papers associated with the keywords. Firstly, AHP leads in 15 countries, and "Branch and Bound" in 5 countries. Secondly, China leads the ranking among the countries, followed by the United States, Taiwan, Iran, and the United Kingdom. China's leadership is mainly explained by increased research and development spending over the last three decades. According to the World Bank[41], in 1996, this expenditure represented 0.53% of GDP, and in 2018, it was 2.141% of GDP. For comparison purposes, the United States was 2.83% of GDP, and the United Kingdom was 1.70% of GDP in 2018. Finally, it is noted that the system includes words associated with the 17 decision models, such as China, global optimization, and scheduling. In this case, the result indicates a relationship to the topic and possible applications of the models, such as China-supported research projects.

FIGURE 2 Papers by year



Source: Own elaboration based on WoS 2021.

TABLE 3 Keywords by country

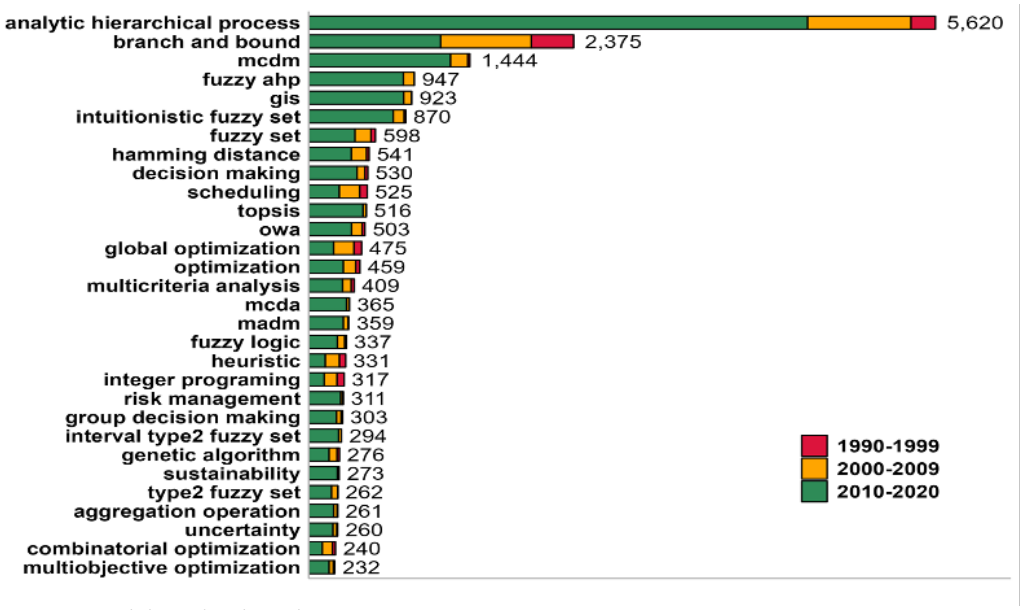
Country	Keyword	Papers	Country	Keyword	Papers
China	analytic hierarchical process	1184	South Korea	analytic hierarchical process	271
	intuitionistic fuzzy set	405		branch and bound	81
	branch and bound	358		gis	57
	mcdm	249		mcdm	36
	madm	208		fuzzy ahp	32
USA	analytic hierarchical process	633	Germany	branch and bound	196
	branch and bound	534		analytic hierarchical process	91
	mcdm	150		global optimization	75
	global optimization	141		scheduling	22
	hamming distance	137		combinatorial optimization	21
Taiwan	analytic hierarchical process	521	Italy	analytic hierarchical process	207
	fuzzy ahp	182		branch and bound	117
	branch and bound	116		mcdm	33
	scheduling	100		multicriteria analysis	30
	mcdm	97		fuzzy set	28
India	analytic hierarchical process	480	Japan	branch and bound	123
	mcdm	184		analytic hierarchical process	105
	intuitionistic fuzzy set	140		global optimization	34
	gis	106		hamming distance	24
	fuzzy ahp	94		optimization	19
Iran	analytic hierarchical process	353	Australia	analytic hierarchical process	165
	mcdm	158		gis	68
	gis	148		branch and bound	59
	fuzzy ahp	113		mcdm	35
	iran	92		fuzzy ahp	23
Turkey	analytic hierarchical process	457	Brazil	analytic hierarchical process	100
	mcdm	227		branch and bound	57
	fuzzy ahp	135		multicriteria analysis	28
	gis	112		mcdm	21
	topsis	103		gis	17
UK	analytic hierarchical process	276	Poland	analytic hierarchical process	73
	branch and bound	113		intuitionistic fuzzy set	31
	mcdm	81		branch and bound	28
	mcda	38		fuzzy set	18
	fuzzy ahp	34		differential galois theory	17
Spain	analytic hierarchical process	223	Malaysia	analytic hierarchical process	120
	owa	122		gis	53
	branch and bound	85		mcdm	38
	decision making	58		fuzzy ahp	27
	aggregation operation	57		fuzzy set	19
Canada	analytic hierarchical process	176	Netherlands	analytic hierarchical process	60
	branch and bound	106		branch and bound	58
	hamming distance	28		mcdm	15
	scheduling	28		fuzzy ahp	11
	mcdm	27		gis	11
France	branch and bound	248	Saudi Arabia	analytic hierarchical process	96
	analytic hierarchical process	60		mcdm	33
	scheduling	48		branch and bound	26
	combinatorial optimization	36		fuzzy ahp	25
	global optimization	36		gis	24

Source: Own elaboration based on WoS 2021.

3.3 | Keywords analysis

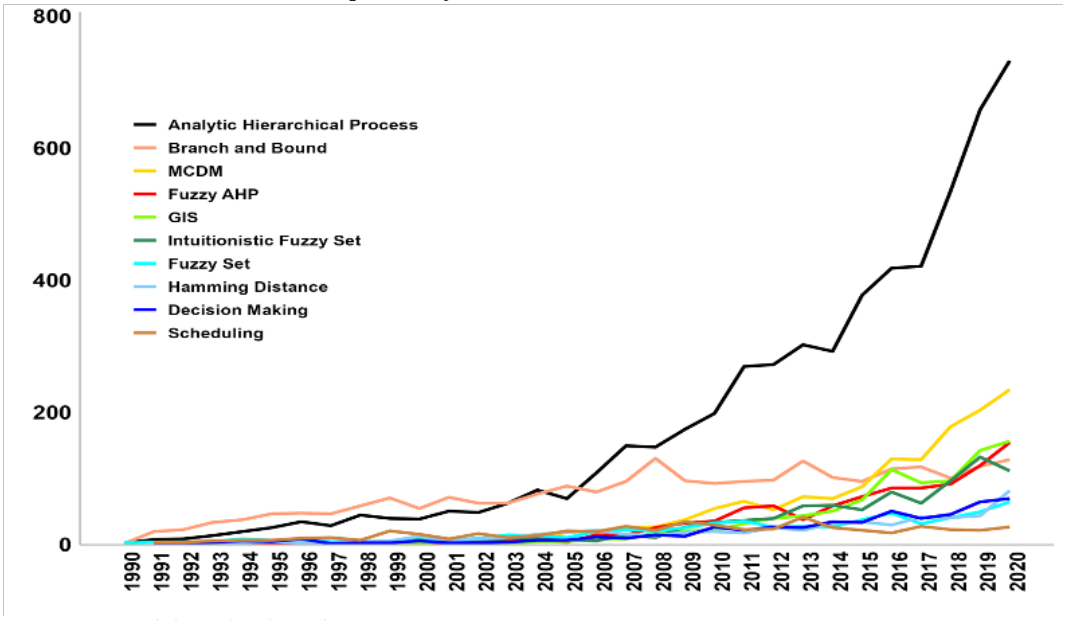
This sub-section presents a keyword analysis in which it shows the ranking and evolution of the top ten keywords from1990 to 2020. The keyword analysis indicator identifies the essence of the publications' content and the number of articles published on a specific topic. In addition, the indicator allows knowing an evolution of the terms and trends. Figure 3 shows an analysis of the keywords. This graph visually shows the growth of AHP compared to other keywords over the last decade. It can be seen as relevant that AHP leads the ranking with 5,620 papers, followed by "Branch and Bound" with 2,375 papers, and Multiple Criteria Decision Making (MCDM) with 1,444 papers. Figure 4 presents the results of the evolution of the top ten keywords from 1990 to 2020. The graph displays the evolution of all the keywords over the period, but also visually reinforces AHP's leadership and its growth from 2008 onwards.

FIGURE 3 Keywords Analysis



Source: Own elaboration based on WoS 2021.

FIGURE 4 Evolution of the top ten keywords from 1990 to 2020



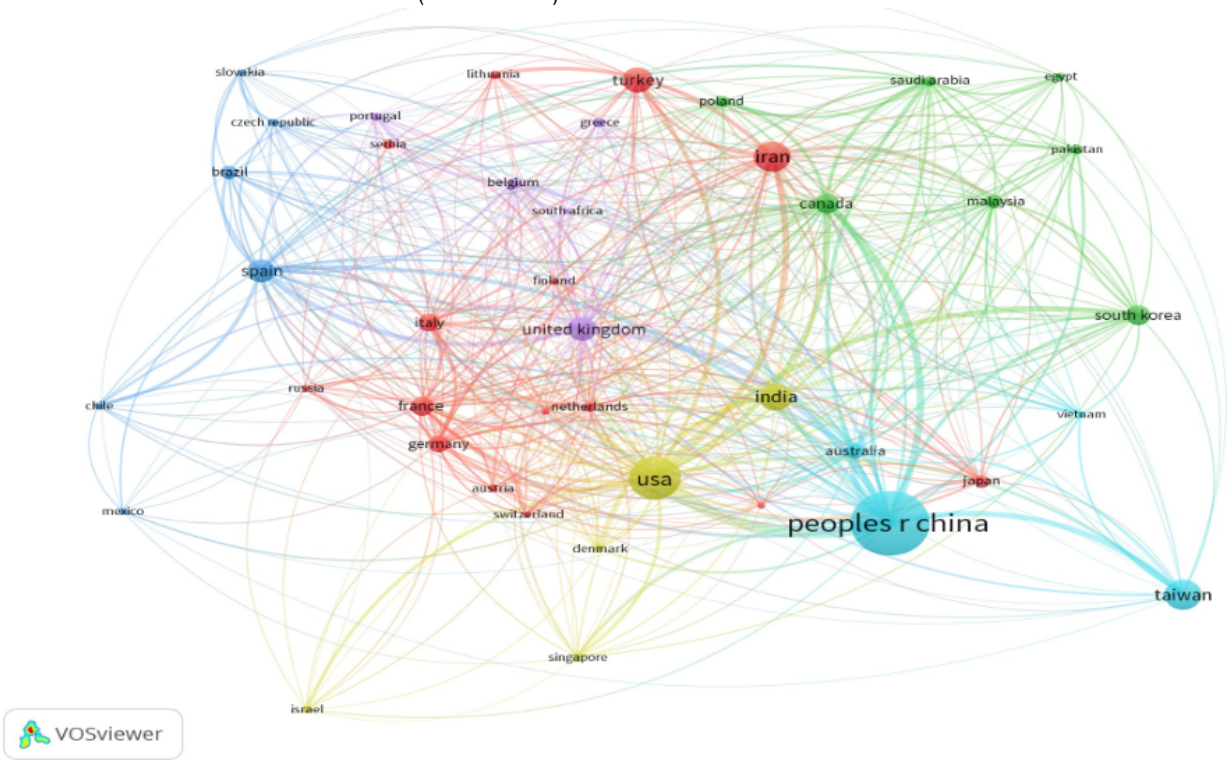
Source: Own elaboration based on WoS 2021.

3.4 | Countries collaboration

This sub-section shows the result of the collaboration between the countries in four stages. Firstly, the main groups of collaboration between the countries are presented through the VOSviewer software. Secondly, the countries with the most publications are presented. Thirdly, the most productive countries are displayed. Fourthly, the ranking of the contributions of 25 countries is shown.

The collaboration of researchers between countries is a crucial indicator for science. It allows the identification of international scientific cooperation links and shows the dissemination of knowledge at the global level. In this way, science can reach as many countries as possible and contribute to the progress of society. Figure 5 shows the collaborative networks between countries from 2010 to 2020. The size of each sphere represents the number of publications per country; for example, China leads the number of publications, followed by the United States, and Iran. The color of each sphere indicates the clusters of collaboration between countries; for example, China has stronger collaborative links with Taiwan, Australia, and Vietnam. On the other hand, the United States has more collaborative links with India, Singapore, Denmark, and Israel. And Iran has more collaborative links with Turkey, France, and Germany. However, a country can have links with several countries.

FIGURE 5 Countries collaboration (2010-2020)



Source: VOSviewer based on WoS 2021.

Table 4 describes the countries with the most publications. In 2020, China leads the ranking with 1,094 papers, followed by the United States with 297 papers, and India with 259 papers. The results also indicate China's leadership as the country with the most publications as of 2010 and the relatively rapid increase in recent years. Table 5 shows the evolution of country publications over the last three decades (1990-1999; 2000-2009; 2010-2020). As for indicators, the following were considered: Cites per document (CPD), Total of papers of each country (TPC), and Percentage of papers/TPC (%). The last column presents a consolidated result and China's leadership with 6,762 papers, followed by the United States with 4,779 papers, and Taiwan with 1,822 papers. Table 6 presents the productivity of countries taking into consideration the number of cites per document (CPD). In this case, the United States would have 178,142 cites and 37.3 CPD. Already China had 174,078 cites and 25.7 CPD. Table 7 displays the contribution of the top 25 countries considering: Total publications (TP); Single country publication rank (SPR); International collaborative publication rank (CPR); First author publication rank (FPR); and Corresponding author-publication rank (RPR). The result shows China's leadership with 6,972 published articles, representing 19.8%, followed by the United States with 4,942 published articles (14%), and Taiwan with 1,855 published articles (5.3%).

TABLE 4 Countries with most publications

Year	Country	Papers	CPY	Year	Country	Papers	CPY
2020	China	1,094	107	2004	USA	110	55
	USA	297			China	42	
	India	259			Japan	37	
2019	China	1,059	99	2003	USA	128	52
	USA	300			China	39	
	Iran	243			Italy	34	
2018	China	776	97	2002	USA	114	49
	USA	262			China	36	
	Iran	225			Germany	30	
2017	China	708	93	2001	USA	107	52
	USA	245			France	30	
	India	163			Japan	24	
2016	China	560	90	2000	USA	108	52
	USA	254			Japan	32	
	Iran	140			UK	31	
2015	China	437	77	1999	USA	104	49
	USA	197			Germany	27	
	Taiwan	108			UK	23	
2014	China	434	8.	1998	USA	121	47
	USA	224			UK	23	
	Taiwan	116			Japan	21	
2013	China	344	74	1997	USA	122	43
	USA	197			Japan	23	
	Taiwan	121			Canada	19	
2012	China	260	77	1996	USA	122	43
	USA	163			Italy	23	
	Taiwan	103			UK	20	
2011	USA	185	76	1995	USA	111	43
	China	165			Taiwan	19	
	Taiwan	151			South Korea	18	
2010	USA	160	70	1994	USA	132	39
	China	156			Canada	16	
	Taiwan	138			Taiwan	15	
2009	USA	147	65	1993	USA	88	37
	China	118			India	15	
	Taiwan	110			Canada	13	
2008	USA	160	69	1992	USA	101	36
	China	130			Canada	15	
	UK	86			UK	14	
2007	USA	145	65	1991	USA	86	40
	China	88			UK	10	
	Taiwan	60			USSR	10	
2006	USA	164	59	1990	USA	41	16
	China	105			UK	4	
	France	50			USSR	4	
2005	USA	146	61				
	China	72					
	France	39					

Source: Own elaboration based on WoS 2021.

TABLE 5 Countries with most publications (1990-2020)

	1990-1999					2000-2009					2010-2020					1990-2020				
	Papers	**Cites**	**CPD**	**TPC**	**%**	**Papers**	**Cites**	**CPD**	**TPC**	**%**	**Papers**	**Cites**	**CPD**	**TPC**	**%**	**Papers**	**Cites**	**CPD**	**TPC**	**%**
China	67	2,352	35	131,328	0.051	678	43,199	64	691,710	0.098	6,017	128,527	21	3,276,470	0.184	6,762	174,078	26	4,099,508	0.165
USA	1,028	57,640	56	2,322,726	0.044	1,329	68,033	51	2,803,731	0.047	2,422	52,469	22	4,253,868	0.057	4,779	178,142	37	9,380,325	0.051
Taiwan	95	3,332	35	59,675	0.159	470	21,644	46	158,738	0.296	1,257	26,450	21	293,066	0.429	1,822	51,426	28	511,479	0.356
India	88	2,187	25	138,376	0.064	163	9,620	59	255,191	0.064	1,393	33,706	24	680,536	0.205	1,644	45,513	28	1,074,103	0.153
Iran	6	942	157	4,739	0.127	111	3,579	32	57,091	0.194	1,416	34,903	25	344,107	0.411	1,533	39,424	26	405,937	0.378
Turkey	31	1,314	42	25,383	0.122	235	16,753	71	131,955	0.178	1,137	25,621	23	319,006	0.356	1,403	43,688	31	476,344	0.295
UK	137	7,325	54	589,572	0.023	294	18,078	62	789,303	0.037	907	27,414	30	1,330,286	0.068	1,338	52,817	40	2,709,161	0.049
Spain	47	3,883	83	148,885	0.032	282	15,492	55	302,334	0.093	829	23,287	28	629,106	0.132	1,158	42,662	37	1,080,325	0.107
Canada	131	6,006	46	309,902	0.042	256	9,529	37	408,945	0.063	668	15,494	23	717,331	0.093	1,055	31,029	29	1,436,178	0.073
France	105	3,264	31	393,014	0.027	310	9,088	29	526,378	0.059	592	9,046	15	785,230	0.075	1,007	21,398	21	1,704,622	0.059
South Korea	79	1,915	24	56,226	0.141	201	6,687	33	246,667	0.081	704	13,671	19	613,402	0.115	984	22,273	23	916,295	0.107
Germany	124	4,496	36	520,711	0.024	251	8,097	32	723,372	0.035	500	8,993	18	1,152,056	0.043	875	21,586	25	2,396,139	0.037
Italy	82	3,735	46	234,132	0.035	221	10,767	49	388,868	0.057	557	12,424	22	698,462	0.080	860	26,926	31	1,321,462	0.065
Japan	139	2,525	18	551,525	0.025	255	6,139	24	744,107	0.034	323	5,539	17	864,278	0.037	717	14,203	20	2,159,910	0.033
Australia	41	2,531	62	163,732	0.025	105	4,367	42	265,345	0.040	530	19,610	37	635,004	0.083	676	26,508	39	1,064,081	0.064
Brazil	36	571	16	57,885	0.062	89	2,539	29	183,092	0.049	361	5,137	14	481,036	0.075	486	8,247	17	722,013	0.067
Poland	22	554	25	68,949	0.032	96	5,071	53	138,492	0.069	297	5,274	18	289,790	0.102	415	10,899	26	497,231	0.083
Malaysia	1	156	156	5,268	0.019	12	299	25	18,411	0.065	379	12,183	32	114,154	0.332	392	12,638	32	137,833	0.284
Netherlands	55	1,689	31	154,624	0.036	107	3,667	34	223,032	0.048	204	5,640	28	416,014	0.049	366	10,996	30	793,670	0.046
Saudi Arabia	19	452	24	12,369	0.154	21	375	18	15,340	0.137	308	6,793	22	139,744	0.220	348	7,620	22	167,453	0.208
Belgium	43	2,067	48	75,407	0.057	100	7,116	71	123,413	0.081	201	11,675	58	232,359	0.087	344	20,858	61	431,179	0.080
Pakistan	-	-	-	-	-	5	155	31	15,500	0.032	279	5,699	20	107,390	0.260	284	5,854	21	122,890	0.231
Greece	16	332	21	31,627	0.051	64	2,729	43	73,780	0.087	191	5,411	28	116,210	0.164	271	8,472	31	221,617	0.122
Portugal	14	280	20	16,423	0.085	52	1,259	24	54,108	0.096	175	2,751	16	149,986	0.117	241	4,290	18	220,517	0.109
Vietnam	14	187	13	1,805	0.776	14	136	10	6,002	0.233	212	5,703	27	44,463	0.477	240	6,026	25	52,270	0.459

Source: Own elaboration based on WoS 2021. CPD: Cites per document; TPC: Total of papers of each country; %: Papers/TPC.

TABLE 6 Most productive countries from 1990 to 2020

	R(Papers)	Cites	CPD	R(Papers)		
				1990-1999	2000-2009	2010-2020
China	1(6,762)	174,078	25.7	7(67)	2(678)	1(6,017)
USA	2(4,779)	178,142	37.3	1(1,028)	1(1,329)	2(2,422)
Taiwan	3(1,822)	51,426	28.2	5(95)	3(470)	5(1,257)
India	4(1,644)	45,513	27.7	6(88)	9(163)	4(1,393)
Iran	5(1,533)	39,424	25.7	10(6)	10(111)	3(1,416)
Turkey	6(1,403)	43,688	31.1	9(31)	8(235)	6(1,137)
UK	7(1,338)	52,817	39.5	2(137)	5(294)	7(907)
Spain	8(1,158)	42,662	36.8	8(47)	6(282)	8(829)
Canada	9(1,055)	31,029	29.4	3(131)	7(256)	9(668)
France	10(1,007)	21,398	21.2	4(105)	4(310)	10(592)

Source: Own elaboration based on WoS 2021. R: Ranking position; CPD: Cites per document

TABLE 7 Contribution of the top 25 countries

Country	TP (%)	SPR (%)	CPR (%)	FPR (%)	RPR (%)
China	6,972(19.8)	4(0.68)	22(0.32)	2(0.73)	2(0.92)
USA	4,942(14)	13(0.5)	13(0.5)	16(0.51)	16(0.68)
Taiwan	1,855(5.3)	2(0.79)	24(0.21)	1(0.76)	1(0.93)
India	1,766(5)	3(0.7)	23(0.3)	4(0.65)	4(0.87)
Iran	1,590(4.5)	8(0.59)	18(0.41)	7(0.62)	6(0.83)
Turkey	1,451(4.1)	1(0.8)	25(0.2)	3(0.67)	3(0.91)
UK	1,448(4.1)	18(0.32)	8(0.68)	23(0.41)	23(0.58)
Spain	1,194(3.4)	12(0.5)	14(0.5)	12(0.55)	9(0.77)
Canada	1,090(3.1)	16(0.37)	10(0.63)	22(0.41)	20(0.61)
France	1,039(2.9)	15(0.45)	11(0.55)	10(0.57)	14(0.69)
South Korea	1,010(2.9)	10(0.56)	16(0.44)	9(0.57)	7(0.82)
Germany	920(2.6)	11(0.52)	15(0.48)	13(0.55)	12(0.74)
Italy	877(2.5)	14(0.46)	12(0.54)	15(0.53)	13(0.73)
Japan	732(2.1)	9(0.57)	17(0.43)	8(0.59)	11(0.74)
Australia	706(2)	23(0.25)	3(0.75)	25(0.34)	24(0.51)
Brazil	514(1.5)	5(0.68)	21(0.32)	5(0.65)	5(0.85)
Poland	426(1.2)	6(0.64)	20(0.36)	14(0.53)	10(0.76)
Malaysia	424(1.2)	21(0.3)	5(0.7)	6(0.63)	15(0.69)
Netherlands	388(1.1)	17(0.34)	9(0.66)	20(0.46)	22(0.59)
Saudi Arabia	363(1)	24(0.2)	2(0.8)	24(0.36)	25(0.45)
Belgium	356(1)	19(0.31)	7(0.69)	21(0.43)	21(0.6)
Pakistan	294(0.8)	22(0.28)	4(0.72)	17(0.51)	19(0.62)
Greece	281(0.8)	7(0.6)	19(0.4)	19(0.47)	8(0.82)
Vietnam	255(0.7)	25(0.15)	1(0.85)	18(0.48)	18(0.64)
Portugal	245(0.7)	20(0.31)	6(0.69)	11(0.56)	17(0.66)

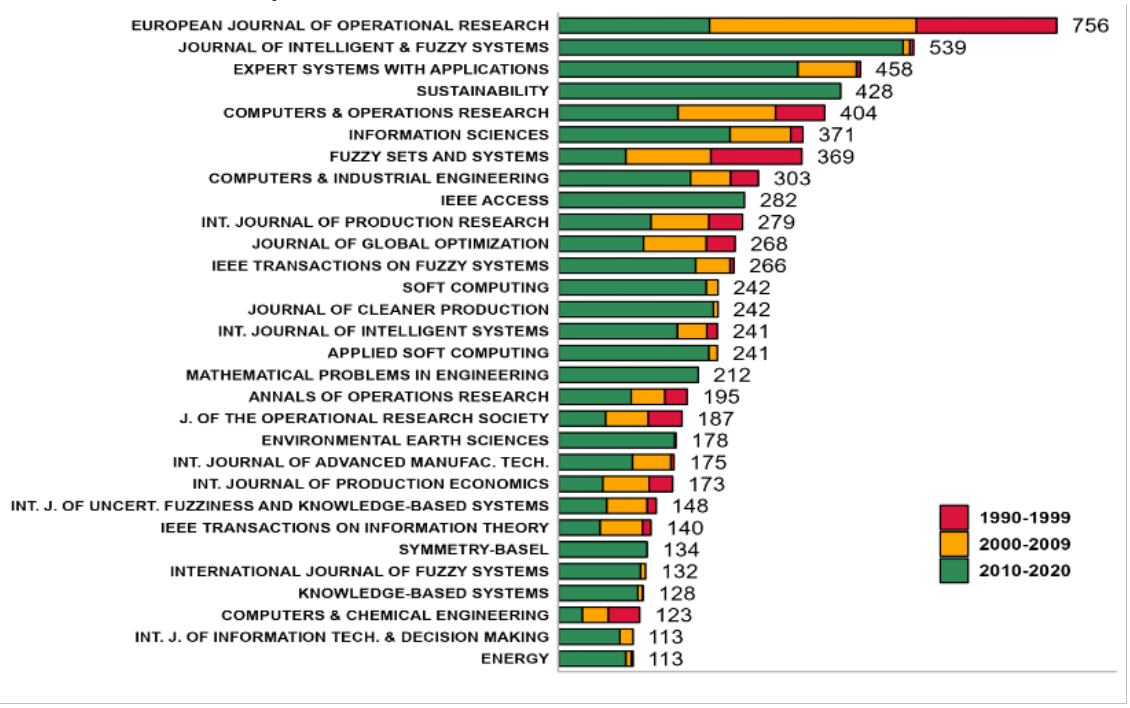
Source: Own elaboration based on WoS 2021. TP: Total publications; SPR: Single country publication rank; CPR: International collaborative publication rank; FPR: First author publication rank; RPR: Corresponding author publication rank.

3.5 | Journal analysis

This subsection presents an analysis of the journals between 1990 and 2020. Firstly, the consolidated result is displayed graphically with all publications by journals. Secondly, it shows in detail in total publications (TP), cites, cites per document (CPD), and total publication per journal (TPJ).

Scientific journals play an essential role in disseminating knowledge, and this indicator shows the most influential journals. The results indicate publications in specific and interdisciplinary journals due to the increasing academic interest in decision models in uncertainty. Figure 6 displays an analysis of the journals. The results indicate that the European Journal of Operational Research (EJOR) leads the ranking with 756 publications, followed by the Journal of Intelligent & Fuzzy Systems (JIFS) with 539 publications and Expert Systems with Applications (ESA) with 458 publications. The EJOR launched its first edition in 1977, while JIFS launched in 1993, and ESA in 1990. It can observe that the three journals are related to research in operations and application systems, which shows the importance of the research fields. Despite being older, EJOR maintains the lead on this indicator. However, in the last decade, the JIFS has had more publications than EJOR. The results also indicate the emergence of new journals in recent decades, such as Sustainability with the first edition in 2009; and Environmental Earth Sciences in 2009. These results of two journals indicate a growth trend for research on the 17 models applied to sustainable development themes. On the other hand, the IEEE Access, founded in 2013, stands out as an emerging journal for research areas such as Computer Science, Engineering, and Telecommunications.

FIGURE 6 Journals analysis



Source: Own elaboration based on WoS 2021.

In the other hand, Table 8 shows in detail the total publications (TP), number of cites, cites per document (CPD), and total publication per journal (TPJ). The results are presented by decade: 1990-1999, 2000-2009, and 2010-2020. And at finally the consolidated total 1990-2020 is shown. In the last column, the consolidated results (1990-2020) have presented, highlighting the journals with the most publications (TPJ) on the 17 decision models in uncertainty, in the following order: Int. Journal of Inf. Technology Decision Making (13.6%), International Journal of Intelligent Systems (12.3%), International Journal of Uncertainty Fuzziness and Knowledge-Based Systems (11.2%), and International Journal of Fuzzy Systems (10.6%). A comparison with other scientific journals has shown a greater interest in these 4 journals for the 17 decision models in uncertainty. An analysis of the results in the decades has shown that 9 journals have achieved higher growth than others in the number of papers in recent years. These journals are Expert Systems with Applications; Journal of Intelligence Fuzzy Systems; Information Sciences; Computers Industrial Engineering; IEEE Transactions on Fuzzy Systems; International Journal of Intelligent Systems; Int. Journal of Advanced Manufacturing Tech.; Knowledge-Based Systems; and Applied Mathematical Modelling.

TABLE 8 Journal analysis

	1990-1999					2000-2009					2010-2020					1990-2020				
Journal	**TP**	**Cites**	**CPD**	**TPJ**	**%**	**TP**	**Cites**	**CPD**	**TPJ**	**%**	**TP**	**Cites**	**CPD**	**TPJ**	**%**	**TP**	**Cites**	**CPD**	**TPJ**	**%**
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	213	16,555	77.7	3,161	6.7	314	20,791	66.2	5,176	6.1	229	7,876	34.4	6,680	3.4	756	45,222	59.8	15,017	5.0
JOURNAL OF INTELLIGENT & FUZZY SYSTEMS	6	83	13.8	141	4.3	10	197	19.7	314	3.2	523	6,902	13.2	6,186	8.5	539	7,182	13.3	6,641	8.1
EXPERT SYSTEMS WITH APPLICATIONS	6	26	4.3	650	0.9	89	8,855	99.5	2,783	3.2	363	20,864	57.5	9,443	3.8	458	29,745	64.9	12,876	3.6
SUSTAINABILITY	-	-	-	-		-	-	-	-		428	4,289	10.0	26,681	1.6	428	4,289	10.0	26,681	1.6
COMPUTERS & OPERATIONS RESEARCH	75	2,320	30.9	847	8.9	148	6,682	45.1	1,694	8.7	181	3,797	21.0	2,545	7.1	404	12,799	31.7	5,086	7.9
INFORMATION SCIENCES	19	563	29.6	1,048	1.8	92	11,474	124.7	2,009	4.6	260	13,548	52.1	7,067	3.7	371	25,585	69.0	10,124	3.7
FUZZY SETS AND SYSTEMS	138	10,377	75.2	2,504	5.5	129	13,884	107.6	2,433	5.3	102	2,058	20.2	2,147	4.8	369	26,319	71.3	7,084	5.2
COMPUTERS & INDUSTRIAL ENGINEERING	42	1,002	23.9	2,087	2.0	61	2,770	45.4	1,105	5.5	200	6,349	31.7	3,987	5.0	303	10,121	33.4	7,179	4.2
IEEE ACCESS	-	-	-	-		-	-	-	-		282	2,571	9.1	42,637	0.7	282	2,571	9.1	42,637	0.7
INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	51	2,020	39.6	1,833	2.8	88	4,333	49.2	2,680	3.3	140	3,946	28.2	4,864	2.9	279	10,299	36.9	9,377	3.0
JOURNAL OF GLOBAL OPTIMIZATION	44	2,210	50.2	306	14.4	95	2,783	29.3	905	10.5	129	1,076	8.3	1,494	8.6	268	6,069	22.6	2,705	9.9
IEEE TRANSACTIONS ON FUZZY SYSTEMS	6	1,291	215.2	237	2.5	52	11,345	218.2	844	6.2	208	10,995	52.9	1,747	11.9	266	23,631	88.8	2,828	9.4
JOURNAL OF CLEANER PRODUCTION	-	-	-	-		7	817	116.7	1,112	0.6	235	9,300	39.6	19,665	1.2	242	10,117	41.8	20,777	1.2
SOFT COMPUTING	-	-	-	-		18	409	22.7	693	2.6	224	4,199	18.7	4,857	4.6	242	4,608	19.0	5,550	4.4
APPLIED SOFT COMPUTING	-	-	-	-		13	1,382	106.3	495	2.6	228	10,420	45.7	5,876	3.9	241	11,802	49.0	6,371	3.8
INTERNATIONAL JOURNAL OF INTELLIGENT SYSTEMS	16	1,595	99.7	450	3.6	45	3,687	81.9	647	7.0	180	9,985	55.5	856	21.0	241	15,267	63.3	1,953	12.3
MATHEMATICAL PROBLEMS IN ENGINEERING	-	-	-	109	-	-	-	-	610	-	212	1,512	7.1	13,952	1.5	212	1,512	7.1	14,671	1.4
ANNALS OF OPERATIONS RESEARCH	34	1,184	34.8	698	4.9	51	1,459	28.6	1,161	4.4	110	1,811	16.5	3,016	3.6	195	4,454	22.8	4,875	4.0
JOURNAL OF THE OPERATIONAL RESEARCH SOCIETY	51	1,482	29.1	1,194	4.3	65	1,679	25.8	1,445	4.5	71	1,136	16.0	1,869	3.8	187	4,297	23.0	4,508	4.1
ENVIRONMENTAL EARTH SCIENCES	-	-	-	-		2	15	7.5	87	2.3	176	5,083	28.9	8,543	2.1	178	5,098	28.6	8,630	2.1
INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY	5	44	8.8	541	0.9	58	2,291	39.5	3,746	1.5	112	2,613	23.3	13,860	0.8	175	4,948	28.3	18,147	1.0
INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	36	1,855	51.5	1,186	3.0	70	5,610	80.1	2,002	3.5	67	3,384	50.5	3,343	2.0	173	10,849	62.7	6,531	2.6
INTERNATIONAL JOURNAL OF UNCERTAINTY FUZZINESS AND KNOWLEDGE BASED SYSTEMS	14	335	23.9	174	8.0	61	2,505	41.1	527	11.6	73	836	11.5	619	11.8	148	3,676	24.8	1,320	11.2
IEEE TRANSACTIONS ON INFORMATION THEORY	13	422	32.5	1,352	1.0	64	2,487	38.9	3,498	1.8	63	836	13.3	5,462	1.2	140	3,745	26.8	10,312	1.4
SYMMETRY-BASEL	-	-	-	-		-	-	-	11	-	134	1,847	13.8	4,927	2.7	134	1,847	13.8	4,938	2.7
INTERNATIONAL JOURNAL OF FUZZY SYSTEMS	-	-	-	-		8	175	21.9	101	7.9	124	2,525	20.4	1,150	10.8	132	2,700	20.5	1,251	10.6
KNOWLEDGE-BASED SYSTEMS	1	4	4.0	302	0.3	7	651	93.0	586	1.2	120	7,285	60.7	3,697	3.2	128	7,940	62.0	4,585	2.8
COMPUTERS & CHEMICAL ENGINEERING	48	3,052	63.6	2,255	2.1	39	1,901	48.7	1,845	2.1	36	673	18.7	3,006	1.2	123	5,626	45.7	7,106	1.7
ENERGY	3	44	14.7	1,141	0.3	8	872	109.0	1,531	0.5	102	3,615	35.4	15,806	0.6	113	4,531	40.1	18,478	0.6
INTERNATIONAL JOURNAL OF INFORMATION TECHNOLOGY & DECISION MAKING	-	-	-	-		20	571	28.6	241	8.3	93	1,718	18.5	588	15.8	113	2,289	20.3	829	13.6

Source: Own elaboration based on WoS 2021. TP: Total publications; CPD: Cites per document; TPJ: Total publication per journal.

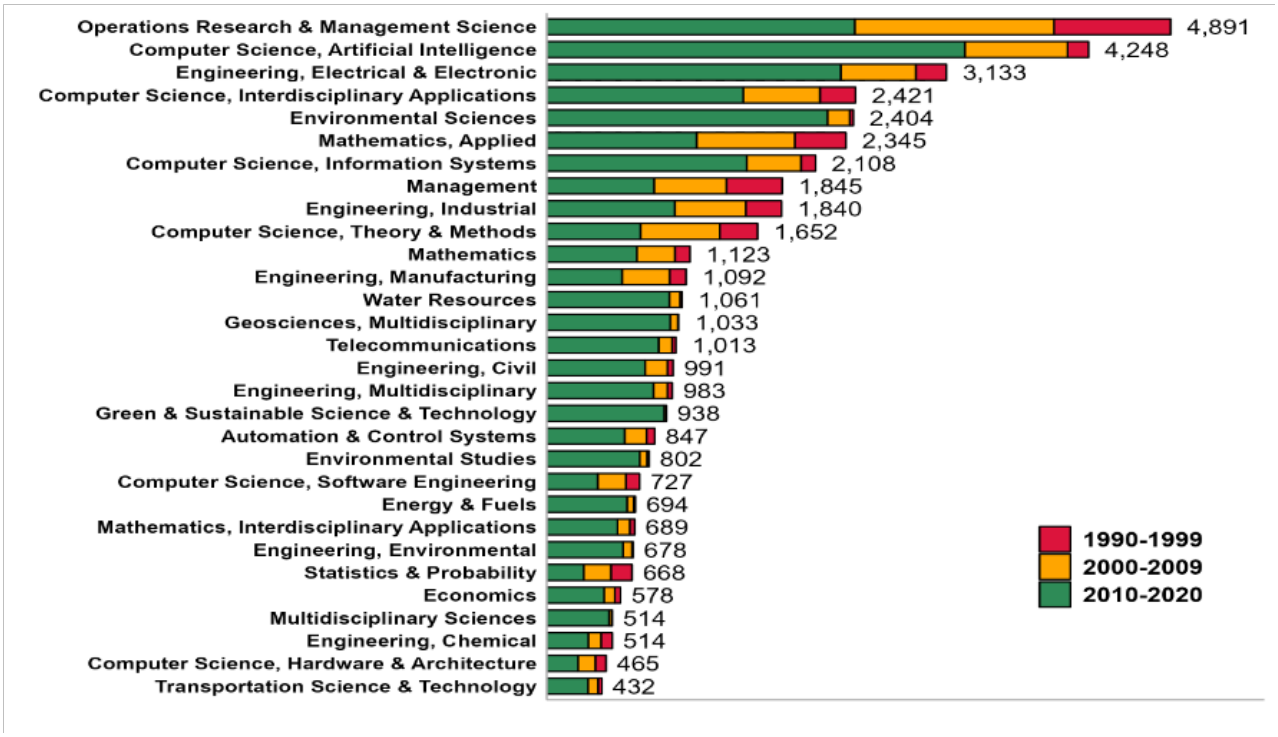
3.6 | Research areas

This subsection presents the results of the main research areas related to the 17 decision models in uncertainty, covering the period between 1990 and 2020. Firstly, the analysis of the research areas is displayed graphically. Secondly, the keywords in each research area are shown in detail.

The research area is an indicator that identifies the sectors where knowledge is most studied and applied. In addition, it allows knowing future lines of research and field of study for a given methodology or theory. Figure 7 shows the research areas with the most publications on the subject. The top three positions are Operations Research & Management Science with 4,891 papers, Computer Science, Artificial Intelligence with 4,248 papers, and Engineering, Electrical & Electronic with 3,133 papers.

Also, the results have shown the occurrence of new areas of research linked to the models of the decision in uncertainty in recent decades, for example, Green & Sustainable Science & Technology; Energy & Fuels; Environmental Studies; and Geosciences. This result reinforces the interest and usefulness of the models in issues related to sustainable development. For example, a study proposes applying "fuzzy logic theory to perform the tasks of determining the market value of agricultural lands"[42], and another research "deals with the sustainability analysis of desalination processes using a generic sustainability ranking framework based on Mamdani Fuzzy Logic Inference Systems"[43].

FIGURE 7 Research Area Analysis



Source: Own elaboration based on WoS 2021.

Table 9 shows in detail the keywords in each research area. AHP leads in 14 research areas, and "Branch and Bound" leads in 6 research areas. AHP leads in Environmental Sciences with 1,094 papers, followed by Computer Science, Artificial Intelligence (470), Engineering, Industrial (419), Water Resources (412), Geosciences, Multidisciplinary (388), Green & Sustainable Science & Technology (393), Engineering, Electrical & Electronic (378), Environmental Studies (366), Engineering, Manufacturing (334), Computer Science & Information Systems (325), Engineering, Civil (301), Engineering, Multidisciplinary (185), Telecommunications (144), and Automation & Control Systems (119).

On the other hand, "Branch and Bound" leads the areas of Management with 1,332 papers, followed by Operations Research & Management Science (1,329), Mathematics (629), Mathematics, Applied (547). Computer Science & Interdisciplinary Applications (365), and Computer Science, Theory & Methods (97).

TABLE 9 Keywords for each research area

Research area	Keyword	Papers	Research area	Keyword	Papers
Operations Research & Management Science	branch and bound	1,329	Mathematics	branch and bound	629
	analytic hierarchical process	814		global optimization	295
	scheduling	331		analytic hierarchical process	169
	global optimization	279		galois theory	148
	mcdm	237		hamming distance	135
Computer Science, Artificial Intelligence	analytic hierarchical process	470	Engineering, Manufacturing	analytic hierarchical process	334
	intuitionistic fuzzy set	454		branch and bound	169
	mcdm	341		scheduling	92
	owa	228		fuzzy ahp	73
	fuzzy set	212		mcdm	64
Engineering, Electrical & Electronic	analytic hierarchical process	378	Water Resources	analytic hierarchical process	412
	branch and bound	258		gis	251
	hamming distance	165		mcdm	56
	optimization	122		landslide	51
	intuitionistic fuzzy set	121		fuzzy ahp	50
Computer Science & Interdisciplinary Applications	branch and bound	365	Geosciences, Multidisciplinary	analytic hierarchical process	388
	analytic hierarchical process	361		gis	319
	mcdm	183		landslide	86
	scheduling	117		landslide susceptibility	78
	intuitionistic fuzzy set	101		remote sensing	62
Environmental Sciences	analytic hierarchical process	1,094	Telecommunications	analytic hierarchical process	144
	gis	351		branch and bound	83
	mcdm	181		hamming distance	57
	fuzzy ahp	137		optimization	52
	sustainability	106		resource allocation	47
Mathematics, Applied	branch and bound	547	Engineering, Civil	analytic hierarchical process	301
	global optimization	275		mcdm	72
	analytic hierarchical process	100		fuzzy ahp	59
	hamming distance	89		gis	53
	intuitionistic fuzzy set	86		risk management	42
Computer Science & Information Systems	analytic hierarchical process	325	Engineering, Multidisciplinary	analytic hierarchical process	185
	intuitionistic fuzzy set	137		branch and bound	88
	hamming distance	117		mcdm	60
	branch and bound	114		fuzzy ahp	46
	mcdm	113		scheduling	32
Management	branch and bound	1,332	Green & Sustainable Science & Technology	analytic hierarchical process	393
	analytic hierarchical process	1,080		mcdm	105
	scheduling	332		sustainability	91
	mcdm	291		fuzzy ahp	68
	global optimization	279		gis	57
Engineering, Industrial	analytic hierarchical process	419	Automation & Control Systems	analytic hierarchical process	119
	branch and bound	331		branch and bound	80
	scheduling	156		intuitionistic fuzzy set	57
	mcdm	100		mcdm	55
	heuristic	85		fuzzy ahp	33
Computer Science, Theory & Methods	branch and bound	97	Environmental Studies	analytic hierarchical process	366
	analytic hierarchical process	93		mcdm	69
	fuzzy set	76		gis	61
	owa	73		fuzzy ahp	55
	hamming distance	70		sustainability	45

Source: Own elaboration based on WoS 2021.

3.7 | Most cited articles

This sub-section is dedicated to presenting the most frequently cited articles. This indicator "shows how influential and popular this article is within the development of the research field"[16]. Table 10 displays the 12 most cited articles per year. It is interesting to note that the first three articles are from the journal "Diabetes Research and Clinical Practice", in Endocrinology & Metabolism field. This result reveals that decision models in uncertainty are applied in various areas and can be very useful in medicine.

In "Cites per year" (CPY), the article "How to make a decision: The analytical hierarchy process" by Saaty (1990) presents the best result with 0.62 CPY, followed by Guariguata, L. et al. (2014) Whiting, David R. et al. (2011)'s article with 0.38 CPY, and Whiting, D. et al. (2011) with 0.36 CPY. The result indicates Saaty's paper as a reference for AHP and corroborates its strength among the 17 models analyzed in this study.

3.8 | Analysis by institutions

This subsection presents an analysis of the institutions, in which it detailed a ranking of the institutions considering the total of papers (TP), the total percentage of papers in each period (PP), and the participation of the leading institution collaborator in the institution's publications (PPI).

The development of research depends largely on support for researchers, environment, and collaboration between institutions[16]. For this reason, this study identifies the institutions with the highest scientific output in this area and the external partnerships carried out. Table 11 presents an analysis of institutions and collaborations between institutions. The result indicates that the Chinese Academy of Sciences (CAS) ranks 440 papers, followed by the Indian Institute of Technology with 429 papers, and the Islamic Azad University with 397 papers.

The CAS has achieved an impressive growth in the last decade, with 7 papers in 1990-1999, 61 papers in 2000-2009, and 372 papers in 2010-2020. The results have revealed that the University of Chinese Academy of Sciences is its main collaborating institution with 31.8% PPI. The CAS started its activities in 1949 in Beijing and is engaged in most areas of basic science and technology, advanced strategic technologies, and areas related to public welfare and the development of emerging industries. Over the past decades, its research center was structured with 104 research institutes, 12 branch academies, three universities and 11 supporting organizations in 23 regions in China. Its strategy combines research, education, and interdisciplinary and cross-sectoral cooperation in innovation. The institution has a staff of 56,000 professional researchers, 22,800 of whom are research professors or associate professors. These researchers carry out about 30% of China's critical basic science projects under the nation's 973 Program. In addition, 40% of projects funded by the National Natural Science Foundation of China are with CAS researchers. In summary, factors such as structure, environment, external collaboration, and support for researchers justify CAS's leadership.

The results also show the emergence of new institutions in this ranking since 2000, such as the Islamic Azad University; the Southeast University China; the Central South University; and the Yildiz Technical University.

TABLE 10 The 12 most cited articles per year

N	Title	Authors	Journal	Area	Year	Cites	Cites %	CPY
1	IDF Diabetes Atlas: Global estimates for the prevalence of diabetes for 2015 and 2040[44]	Ogurtsova, K.; et al.	Diabetes Research and Clinical Practice	Endocrinology & Metabolism	2017	1,791	448	0.24
2	Global estimates of diabetes prevalence for 2013 and projections for 2035[45]	Guariguata, L.; et al.	Diabetes Research and Clinical Practice	Endocrinology & Metabolism	2014	2,846	407	0.38
3	cryoSPARC: algorithms for rapid unsupervised cryo-EM structure determination[46]	Punjani, Ali.; et al.	Nature Methods	Biochemical Research Methods	2017	1,356	339	0.18
4	IDF Diabetes Atlas: Global estimates of the prevalence of diabetes for 2011 and 2030[47]	Whiting, D.; et al.	Diabetes Research and Clinical Practice	Endocrinology & Metabolism	2011	2,718	272	0.36
5	Hesitant Fuzzy Sets[48]	Torra, Vicenc	International Journal of Intelligent Systems	Computer Science, Artificial Intelligence	2010	2,285	208	0.30
6	Best-worst multi-criteria decision-making method[49]	Rezaei, Jafar	Omega International Journal of Management Science	Management; Operations Research & Management Science	2015	1,007	168	0.13
7	HOW TO MAKE A DECISION - THE ANALYTIC HIERARCHY PROCESS[50]	SAATY, TL	European Journal of Operational Research	Management; Operations Research & Management Science	1990	4,650	150	0.62
8	Pythagorean Membership Grades in Multicriteria Decision Making[51]	Yager, Ronald R.	IEEE Transactions on Fuzzy Systems	Computer Science, Artificial Intelligence; Engineering, Electrical & Electronic	2014	1,033	148	0.14
9	Multiple-Attribute Group Decision-Making Based on q-Rung Orthopair Fuzzy Power Maclaurin Symmetric Mean Operators[52]	Liu, P.; et al.	IEEE Transactions on Systems Man Cybernetics Systems	Automation & Control Systems; Computer Science, Cybernetics	2020	133	133	0.02
10	Intuitionistic fuzzy aggregation operators[53]	Xu, Zeshui	IEEE Transactions on Fuzzy Systems	Computer Science, Artificial Intelligence; Engineering, Electrical & Electronic	2007	1,750	125	0.23
11	Generalized Orthopair Fuzzy Sets[54]	Yager, Ronald	IEEE Transactions on Fuzzy Systems	Computer Science, Artificial Intelligence; Engineering, Electrical & Electronic	2017	455	114	0.06
12	Hesitant fuzzy information aggregation in decision making[55]	Xia, Meimei; Xu, Zeshui	International Journal of Approximate Reasoning	Computer Science, Artificial Intelligence	2011	1,137	114	0.15

Source: Own elaboration based on WoS 2021. CPY: Cites per year.

TABLE 11 Analysis by Institutions

Institution	Country	1990-1999		2000-2009		2010-2020		1990-2020		Main institution collaborator			
		TP	PP	TP	PP	TP	PP	TP	PP	Institution	Country	TP	PPI
Chinese Academy of Sciences	China	7	0.28	61	1.10	372	1.89	440	1.58	University of Chinese Academy of Sciences	China	140	31.8
Indian Institute of Technology	India	37	1.46	67	1.21	325	1.65	429	1.54	Indian Institute of Technology Kharagpur	India	87	20.3
Islamic Azad University	Iran			15	0.27	382	1.94	397	1.43	University of Tehran	Iran	62	15.6
Centre National De La Recherche Scientifique	France	28	1.10	92	1.66	230	1.17	350	1.26	Universite De Toulouse	France	47	13.4
Tehran	Iran	2	0.08	27	0.49	267	1.35	296	1.06	University of California Berkeley	USA	62	20.9
University of California System	USA	58	2.28	83	1.50	143	0.73	284	1.02	Islamic Azad University	USA	69	24.3
Istanbul Technical University	Turkey	2	0.08	36	0.65	219	1.11	257	0.92	University of Florida	USA	30	11.7
State University System of Florida	USA	52	2.05	68	1.23	135	0.68	255	0.92	Yildiz Technical University	Turkey	106	41.6
Southeast University China	China			39	0.70	197	1.00	236	0.85	PLA University of Science Technology	China	15	6.4
National Institute of Technology	India	1	0.04	12	0.22	209	1.06	222	0.80	Nankai University Technology	China	35	15.8
Sichuan University	China	2	0.08	1	0.02	213	1.08	216	0.78	University of Pittsburgh	USA	35	16.2
Hong Kong Polytechnic University	Hong Kong	10	0.39	53	0.96	148	0.75	211	0.76	Chinese Academy of Sciences	China	12	5.7
Tsinghua University	China	3	0.12	55	0.99	153	0.78	211	0.76	Feng Chia University	Taiwan	15	7.1
National Yang Ming Chiao Tung University	Taiwan	21	0.83	64	1.15	108	0.55	193	0.69	PLA University of Science Technology	China	15	7.8
The Pennsylvania State System of Higher Education	USA	50	1.97	57	1.03	77	0.39	184	0.66	University of Texas Austin	USA	92	50.0
Central South University	China			6	0.11	172	0.87	178	0.64	Polytechnique Montreal	Canada	11	6.2
Yildiz Technical University	Turkey			15	0.27	153	0.78	167	0.60	AIX Marseille Universiteit	France	30	18.0
National Taiwan University of Science and Technology	Taiwan	16	0.63	27	0.49	123	0.62	166	0.60	Qingdao University of Technology	China	10	6.0
University of Texas System	USA	46	1.81	42	0.76	78	0.40	166	0.60	Fuzhou University	China	68	41.0
University of Montreal	Canada	45	1.77	52	0.94	66	0.33	163	0.59	National Chiao Tung University	Taiwan	76	46.6
City University of Hong Kong	Hong Kong	11	0.43	57	1.03	91	0.46	159	0.57	Georgia Institute of Technology	USA	10	6.3
Egyptian Knowledge Bank	Egypt	4	0.16	11	0.20	144	0.73	159	0.57	Yuanpei University	Taiwan	37	23.3
North China Electric Power University	China			6	0.11	147	0.75	153	0.55	Monash University	Australia	11	7.2
University System of Georgia	USA	38	1.50	45	0.81	67	0.34	150	0.54	Istanbul Technical University	Turkey	96	64.0
Zhejiang University	China	4	0.16	24	0.43	122	0.62	149	0.54	King Saud University	Saudi Arabia	7	4.7

Source: Own elaboration based on WoS 2021. TP: Total of papers; PP: % of the total papers in each period; PPI: Participation of the main institution collaborator in the institution's publications.

3.9 | Author analysis

This subsection set out the analysis of authors considering the total of papers (TP), a total of cites (TC), and cites per document (CPD). This type of analysis is essential to know the ranking of the most published authors in the study area. It also allows identifying through the number of cites the importance of the research and the emergence of new researchers. Table 12 presents the results of the authors with the most publications on the subject in the last three decades. Zeshui Xu leads the ranking with 180 TP, 22,137 TC, and 123 CPD, followed by Ronald R. Yager with 130 TP, 12,986 TC, and 100 CPD, and Jose M. Merigo with 110 TP, 4,968 TC, and 45 CPD.

Zeshui Xu is a leading IFS researcher, and his most cited paper is "Intuitionistic Fuzzy Aggregation Operators"[56] from 2007. A study states that "Ronald Yager is probably the most prominent author in aggregation operators and is one of the most cited authors"[57]. In 1988, Yager proposed the OWA Operator[23], and he has six studies within the 50 most cited papers in aggregation operators[57]. José M. Merigo, Highly Cited Researcher Web of Science in Intelligent Systems and Computer Science. His most cited article is "The induced generalized OWA operator"[58] from 2009.

TABLE 12 Authors Analysis

Authors	1990-1999			2000-2009			2010-2020			1990-2020		
	TP	TC	CPD	TP	TC	CPD	TP	TC	CPD	TP	TC	CPD
Xu, ZS	1	308	308	37	11,480	310	142	10,349	73	180	22,137	123
Yager, RR	39	4,802	123	33	4,365	132	58	3,819	66	130	12,986	100
Merigo, JM	-	-		1	362	362	109	4,606	42	110	4,968	45
Wang, J	-	-		9	187	21	101	2,498	25	110	2,685	24
Garg, H	-	-		-	-		104	4,850	47	104	4,850	47
Kahraman, C	-	-		18	3,368	187	83	2,875	35	101	6,243	62
Liu, Y	3	108	36	7	301	43	87	1,541	18	97	1,950	20
Wang, Y	-	-		4	85	21	76	1,430	19	80	1,515	19
Wu, CC	1	7	7	14	522	37	63	1,245	20	78	1,774	23
Zavadskas, EK	-	-		-	-		74	4,369	59	74	4,369	59
Liu, XW	-	-		16	716	45	54	2,487	46	70	3,203	46
Liu, PD	-	-		-	-		69	3,319	48	69	3,319	48
Chen, XH	-	-		1	8	8	66	3,365	51	67	3,373	50
Mendel, JM	2	1,279	640	29	9,544	329	36	1,747	49	67	12,570	188
Zhang, J	1	22	22	4	45	11	62	719	12	67	786	12
Bustince, H	4	1,631	408	11	949	86	49	1,924	39	64	4,504	70
Chen, W	-	-		-	-		63	3,083	49	63	3,083	49
Wang, L	1	10	10	4	387	97	58	964	17	63	1,361	22
Zhang, Y	-	-		5	227	45	57	771	14	62	998	16
Pradhan, B	-	-		1	113	113	59	4,451	75	60	4,564	76
Li, Y	2	19	10	2	135	68	55	984	18	59	1,138	19
Mesiar, R	3	13	4	8	243	30	47	1,085	23	58	1,341	23
Zhang, L	1	1	1	-	-		57	631	11	58	632	11
Li, J	-	-		3	72	24	54	934	17	57	1,006	18
Zhang, Q	-	-		4	46	12	53	691	13	57	737	13
Chen, Y	-	-		3	106	35	53	1,793	34	56	1,899	34
Zhang, H	-	-		3	23	8	53	1,257	24	56	1,280	23
Wang, JQ	-	-		1	8	8	53	3,237	61	54	3,245	60
Chen, HY	-	-		1	55	55	51	1,868	37	52	1,923	37
Wang, H	2	70	35	2	124	62	48	1,041	22	52	1,235	24

Source: Own elaboration based on WoS 2021. TP: Total of papers; TC: Total of cites; CPD: Cites per document.

The results also reveal the emergence of researchers in recent years, such as Merigo, Kahraman, Zavadskas, Chen, Garg, Liu, Zhou and Pourghasemi. It is evidence of a renewal of researchers and, at the same time, indicates a continuity of research lines on decision models under uncertainty.

Finally, the consolidated results (1990-2020) indicate that the authors with the most CPD are: Mendel JM in first place with 188, followed by Zeshui Xu with 123, and Ronald R. Yager with 100. The result shows the relevance of the research, and it indicates that these authors are a reference to other researchers. For example, Mendel reinforces that T2FS allows linguistic uncertainties and presents the type-2 TSK fuzzy logic systems[59]. Also, he makes essential contributions to implementing a T2FS by discussing set operations in T2FS, algebraic operations, properties of membership degrees of T2FS, and type-2 relations and their compositions[60]. Another relevant

contribution was the reader's introduction to T2FS through a series of questions and answers, which seeks to teach and motivate applications[61].

4 | CONCLUSION

Research on decision models under uncertainty has gained much relevance in recent years. Science through Fuzzy Logic has fulfilled its role of advancing the frontier of knowledge and presenting models that seek to reduce uncertainty and facilitate decision-making. The bibliometric review has shown its usefulness through a combined approach with scientific mapping and performance analysis, allowing a complete analysis on a specific topic. However, this research identified a knowledge gap to evaluate some decision models under uncertainty. In this context, the study sought to reduce this gap through a bibliometric review of research on 17 decision models in uncertainty from 1990 to 2020 using the Web of Science database. The study analyzed 26,835 articles in 9 indicators.

The result indicated that AHP is the most widely used with 12,441 papers, representing 44.2% of total papers, followed by “Branch and Bound” with 23.0%, and Hamming Distance with 8.5%. The study also revealed significant growth in the publications on T2FS, IFS, and T2IFS, increasing the importance and applications in the coming decades and highlighting researchers Sukhveer Singh & Garg, John, Zarandi, and Garibaldi.

Another finding was the number of researchers publishing in this area, from 1.8 in 1990 to 3.7 in 2020. This output reinforces the interest in using models that facilitate uncertainty decision-making and solve complex situations, such as climate change.

Other outcomes have shown China as the leader in publications, followed by the United States, Taiwan, Iran, and the United Kingdom. China has stronger collaborative links with Taiwan, Australia, and Vietnam. China's leadership is mainly explained by increased spending on research and development in recent decades and international cooperation. Keyword analysis showed AHP leads with 5,620 articles in 15 countries and "Branch and Bound" with 2,375 articles in 5 countries.

Journal analysis indicator has indicated that the European Journal of Operational Research leads the ranking with 756 publications, followed by the Journal of Intelligent & Fuzzy Systems with 539 publications and Expert Systems with Applications with 458 publications. The results also showed the emergence of new journals in recent decades, such as Sustainability, Environmental Earth Sciences, and IEEE Access.

Operations Research & Management Science leads as a research area with 4,891 papers, Computer Science, Artificial Intelligence in the second position with 4,248 papers, and Engineering, Electrical & Electronic in the third position with 3,133 papers. Also, the results indicated new research areas related to the 17 models with sustainable development, for example, Green & Sustainable Science & Technology; Energy & Fuels; Environmental Studies; and Geosciences. In addition, AHP leads in 14 research areas, and "Branch and Bound" leads in 6 research areas. AHP leads in Environmental Sciences, and "Branch and Bound" leads in management.

The most cited articles have highlighted three articles from the journal "Diabetes Research and Clinical Practice" in Endocrinology & Metabolism field. On the other hand, in cites per year, the article "How to make a decision: The analytical hierarchy process" by Saaty (1990) presents the best result with 0.62. This outcome confirms this paper as a reference for AHP methodology.

Institution analysis indicator has revealed that the Chinese Academy of Sciences (CAS) ranks with the best performance, followed by the Indian Institute of Technology and the Islamic Azad University. The study indicates that structure, environment, external collaboration, and support for researchers justify CAS's leadership.

Finally, author analysis has shown Zeshui Xu as the most author influential, leading the ranking with 180 TP, 22,137 TC, and 123 CPD, followed by Ronald R. Yager with 130 TP, 12,986 TC, and 100 CPD, and Jose M. Merigo with 110 TP, 4,968 TC, and 45 CPD. The study also revealed the emergence of researchers such as Merigo, Kahraman, Zavadskas, Chen, Garg, Liu, Zhou, and Pourghasemi. In CPD, Mendel leads with 188, Zeshui Xu with 123, and Yager with 100. The result shows the relevance of the research, and it indicates that these authors are a reference in this area.

As main contributions, the manuscript has advanced the frontier of knowledge by deepening studies on 17 decision models under uncertainty through a bibliometric analysis and has reduced the identified knowledge gap. Likewise, the article has contributed to understanding the evolution and trends in Fuzzy Logic research. Finally, the study guides new researchers interested in these topics. The most important limitation is the number of decision models under uncertainty included in the analysis. Future research lines remain open for applying the models in managing pandemics and socioeconomic crises, climate change, and sustainable development.

ACKNOWLEDGMENTS

The authors wish to thank the Royal Academy of Economic and Financial Sciences, Spain, CENTRUM Católica Graduate Business School, Peru, and the University of Barcelona, Spain.

REFERENCES

1. Zadeh LA. Fuzzy sets. *Inf Control*. 1965;8(3):338-353. doi:10.1016/S0019-9958(65)90241-X
2. Barcellos-Paula L, De la Vega I, Gil-Lafuente AM. The Quintuple Helix of Innovation Model and the SDGs: Latin-American Countries' Case and Its Forgotten Effects. *Mathematics*. 2021;9(4):416. doi:10.3390/math9040416
3. Barcellos-Paula, L., Gil-Lafuente, A., & Castro-Rezende A. Los efectos olvidados de la pandemia del COVID 19 sobre en el envejecimiento de la población. *Cuad Del CIMBAGE*. 2021;2(23):1-17.
4. Zadeh LA. The concept of a linguistic variable and its application to approximate reasoning—I. *Inf Sci (Ny)*. 1975;8(3):199-249. doi:10.1016/0020-0255(75)90036-5
5. John R, Coupland S. Type-2 Fuzzy Logic: A Historical View. *IEEE Comput Intell Mag*. 2007;2(1):57-62. doi:10.1109/MCI.2007.357194
6. Fazel Zarandi MH, Zarinbal M, Izadi M. Systematic image processing for diagnosing brain tumors: A Type-II fuzzy expert system approach. *Appl Soft Comput J*. 2011;11(1). doi:10.1016/j.asoc.2009.11.019
7. Singh S, Garg H. Distance measures between type-2 intuitionistic fuzzy sets and their application to multicriteria decision-making process. *Appl Intell*. 2017;46(4):788-799. doi:10.1007/s10489-016-0869-9
8. Fazel Zarandi MH, Soltanzadeh S, Mohammadi A, Castillo O. Designing a general type-2 fuzzy expert system for diagnosis of depression. *Appl Soft Comput*. 2019;80:329-341. doi:10.1016/j.asoc.2019.03.027
9. Atanassov KT. Intuitionistic fuzzy sets. *Fuzzy Sets Syst*. 1986;20(1):87-96. doi:10.1016/S0165-0114(86)80034-3
10. Barcellos de Paula L, Gil-Lafuente AM, Rezende A de C. Sustainable Management of the Supply Chain Based on Fuzzy Logic. *Cybern Syst*. 2021;52(7):579-600. doi:10.1080/01969722.2021.1910763
11. Karmakar S, Seikh MR, Castillo O. Type-2 intuitionistic fuzzy matrix games based on a new distance measure: Application to biogas-plant implementation problem. *Appl Soft Comput*. 2021;106:107357. doi:10.1016/j.asoc.2021.107357
12. Gil-Aluja J. *Elements for a Theory of Decision in Uncertainty*. Vol 32. Springer US; 1999. doi:10.1007/978-1-4757-3011-1
13. Barcellos de Paula, L., & Gil Lafuente A. Una Contribución al Desarrollo Sostenible de las Empresas a partir de Lógica Borrosa. *Cuad Del CIMBAGE*. 2018;1(20):51-83.
14. Bellman RE, Zadeh LA. Decision-Making in a Fuzzy Environment. *Manage Sci*. 1970;17(4):B-141-B-164. doi:10.1287/mnsc.17.4.B141
15. Blanco-Mesa F, Lindahl JMM, Gil-Lafuente AM. A bibliometric analysis of fuzzy decision making research. In: IEEE; 2016:1-4. doi:10.1109/NAFIPS.2016.7851585
16. Blanco-Mesa F, Merigó JM, Gil-Lafuente AM. Fuzzy decision making: A bibliometric-based review. *J Intell Fuzzy Syst*. 2017;32(3):2033-2050. doi:10.3233/JIFS-161640
17. Noyons ECM, Moed HF, Luwel M. Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. *J Am Soc Inf Sci*. 1999;50(2):115-131. doi:10.1002/(SICI)1097-4571(1999)50:2<115::AID-ASI3>3.0.CO;2-J
18. Noyons ECM, Moed HF, Van Raan AFJ. Integrating research performance analysis and science mapping. *Scientometrics*. 1999;46(3):591-604. doi:10.1007/BF02459614
19. Cobo MJ, Lopez-Herrera AG, Herrera-Viedma E, Herrera F. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *J Informetr*. 2011;5(1):146-166. doi:10.1016/j.joi.2010.10.002
20. Saaty TL. How to make a decision: The analytic hierarchy process. *Eur J Oper Res*. 1990;48(1):9-26. doi:10.1016/0377-2217(90)90057-I
21. Land AH, Doig AG. An Automatic Method of Solving Discrete Programming Problems. *Econometrica*. 1960;28(3):497. doi:10.2307/1910129
22. Hamming RW. Error Detecting and Error Correcting Codes. *Bell Syst Tech J*. 1950;29(2):147-160. doi:10.1002/j.1538-7305.1950.tb00463.x
23. Yager RR. On ordered weighted averaging aggregation operators in multicriteria decisionmaking. *IEEE Trans Syst Man Cybern*. 1988;18(1):183-190. doi:10.1109/21.87068
24. Kaufmann, A.; Gil-Aluja J. *Técnicas Especiales Para La Gestión de Expertos*. Milladoiro; 1993.
25. Markov A. Extension of the limit theorems of probability theory to a sum of variables connected

in a chain. *Dyn Probabilistic Syst*. Published online 1971. doi:citeulike-article-id:911035
26. Saffie NAM, Shukor NM, Rasmani KA. Fuzzy delphi method: Issues and challenges. In: *2016 International Conference on Logistics, Informatics and Service Sciences (LISS)*. IEEE; 2016:1-7. doi:10.1109/LISS.2016.7854490
27. Kuhn HW. The Hungarian method for the assignment problem. *Nav Res Logist Q*. 1955;2(1-2):83-97. doi:10.1002/nav.3800020109
28. Kaufmann, A.; Gil-Aluja J. *Técnicas Operativas de Gestión Para El Tratamiento de La Incertidumbre*. Editorial Hispano Europa; 1987.
29. Wang Z, Klir GJ. Fuzzy Measure Theory-. *IEEE Trans Fuzzy Syst*. Published online 1995. doi:10.1109/TFUZZ.1995.481959
30. Kaufmann, A.; Gil-Aluja J. *Modelos Para La Investigación de Efectos Olvidados*. Editorial Milladoiro; 1988.
31. Kaufmann, A. *Les Expertones*. Ed. Hermés; 1987.
32. Bunclark L, Barcellos-Paula L. "Sustainability reporting for sustainable supply chain management in Peru." *Sustain Prod Consum*. 2021;27:1458-1472. doi:10.1016/j.spc.2021.03.013
33. Sanner MF. Python: a programming language for software integration and development. *J Mol Graph Model*. 1999;17(1):57-61.
34. Aria M, Cuccurullo C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J Informetr*. 2017;11(4):959-975. doi:10.1016/j.joi.2017.08.007
35. van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. 2010;84(2):523-538. doi:10.1007/s11192-009-0146-3
36. Osorio Gómez J, Orejuela Cabrera J. El proceso de análisis jerárquico (AHP) y la toma de decisiones multicriterio. Ejemplo de aplicación. *Sci Tech*. 2008;2(39):247-252. doi:10.22517/23447214.3217
37. Miller S, Wagner C, Garibaldi JM, Appleby S. Constructing General Type-2 fuzzy sets from interval-valued data. In: *2012 IEEE International Conference on Fuzzy Systems*. IEEE; 2012:1-8. doi:10.1109/FUZZ-IEEE.2012.6251221
38. Wagner C, Miller S, Garibaldi JM, Anderson DT, Havens TC. From Interval-Valued Data to General Type-2 Fuzzy Sets. *IEEE Trans Fuzzy Syst*. 2015;23(2):248-269. doi:10.1109/TFUZZ.2014.2310734
39. Tolga AC, Parlak IB, Castillo O. Finite-interval-valued Type-2 Gaussian fuzzy numbers applied to fuzzy TODIM in a healthcare problem. *Eng Appl Artif Intell*. 2020;87:103352. doi:10.1016/j.engappai.2019.103352
40. Barcellos de Paula L, Marins FAS. Algorithms applied in decision-making for sustainable transport. *J Clean Prod*. 2018;176:1133-1143. doi:10.1016/j.jclepro.2017.11.216
41. Unesco Institute fo Statistic. Research and development expenditure (% of GDP) - China. The World Bank. Published 2021. https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=CN
42. Zrobek S, Kovalyshyn O, Renigier-Biłozor M, Kovalyshyn S, Kovalyshyn O. Fuzzy logic method of valuation supporting sustainable development of the agricultural land market. *Sustain Dev*. 2020;28(5):1094-1105. doi:10.1002/sd.2061
43. Rustum R, Kurichiyanil AMJ, Forrest S, et al. Sustainability Ranking of Desalination Plants Using Mamdani Fuzzy Logic Inference Systems. *Sustainability*. 2020;12(2):631. doi:10.3390/su12020631
44. Ogurtsova K, da Rocha Fernandes JD, Huang Y, et al. IDF Diabetes Atlas: Global estimates for the prevalence of diabetes for 2015 and 2040. *Diabetes Res Clin Pract*. Published online 2017. doi:10.1016/j.diabres.2017.03.024
45. Guariguata L, Whiting DR, Hambleton I, Beagley J, Linnenkamp U, Shaw JE. Global estimates of diabetes prevalence for 2013 and projections for 2035. *Diabetes Res Clin Pract*. Published online 2014. doi:10.1016/j.diabres.2013.11.002
46. Punjani A, Rubinstein JL, Fleet DJ, Brubaker MA. CryoSPARC: Algorithms for rapid unsupervised cryo-EM structure determination. *Nat Methods*. Published online 2017. doi:10.1038/nmeth.4169
47. Whiting DR, Guariguata L, Weil C, Shaw J. IDF Diabetes Atlas: Global estimates of the prevalence of diabetes for 2011 and 2030. *Diabetes Res Clin Pract*. Published online 2011. doi:10.1016/j.diabres.2011.10.029
48. Torra V. Hesitant fuzzy sets. *Int J Intell Syst*. Published online 2010. doi:10.1002/int.20418
49. Rezaei J. Best-worst multi-criteria decision-making method. *Omega*. 2015;53:49-57. doi:10.1016/j.omega.2014.11.009
50. Saaty TL. How to make a decision: The analytic hierarchy process. *Eur J Oper Res*. Published online 1990. doi:10.1016/0377-2217(90)90057-I

51. Yager RR. Pythagorean Membership Grades in Multicriteria Decision Making. *IEEE Trans Fuzzy Syst*. 2014;22(4):958-965. doi:10.1109/TFUZZ.2013.2278989
52. Liu P, Chen SM, Wang P. Multiple-Attribute Group Decision-Making Based on q-Rung Orthopair Fuzzy Power Maclaurin Symmetric Mean Operators. *IEEE Trans Syst Man, Cybern Syst*. 2020;50(10). doi:10.1109/TSMC.2018.2852948
53. Zeshui Xu. Intuitionistic Fuzzy Aggregation Operators. *IEEE Trans Fuzzy Syst*. 2007;15(6):1179-1187. doi:10.1109/TFUZZ.2006.890678
54. Yager RR. Generalized Orthopair Fuzzy Sets. *IEEE Trans Fuzzy Syst*. 2017;25(5). doi:10.1109/TFUZZ.2016.2604005
55. Xia M, Xu Z. Hesitant fuzzy information aggregation in decision making. *Int J Approx Reason*. Published online 2011. doi:10.1016/j.ijar.2010.09.002
56. Xu Z. Intuitionistic fuzzy aggregation operators. *IEEE Trans Fuzzy Syst*. Published online 2007. doi:10.1109/TFUZZ.2006.890678
57. Blanco-Mesa F, León-Castro E, Merigó JM. A bibliometric analysis of aggregation operators. *Appl Soft Comput*. 2019;81:105488. doi:10.1016/j.asoc.2019.105488
58. MERIGO J, GILLAFUENTE A. The induced generalized OWA operator. *Inf Sci (Ny)*. 2009;179(6):729-741. doi:10.1016/j.ins.2008.11.013
59. Qilian Liang, Mendel JM. An introduction to type-2 TSK fuzzy logic systems. In: *FUZZ-IEEE'99. 1999 IEEE International Fuzzy Systems. Conference Proceedings (Cat. No.99CH36315)*. IEEE; 1999:1534-1539 vol.3. doi:10.1109/FUZZY.1999.790132
60. N. Karnik N, M. Mendel J. Operations on type-2 fuzzy sets. *Fuzzy Sets Syst*. 2001;122(2):327-348. doi:10.1016/S0165-0114(00)00079-8
61. Mendel J. Type-2 fuzzy Sets: Some Questions and Answers. *IEEE Connect Newsl IEEE Neural ….* 2003;(August).