

## Bibliometric Analysis of the MCDM Methods in the Last Decade: WASPAS, MABAC, EDAS, CODAS, COCOSO, and MARCOS

*Son On Yuldaki ÇKKV Yöntemlerinin Bibliyometrik Analizi: WASPAS, MABAC, EDAS, CODAS, COCOSO ve MARCOS*

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### ABSTRACT

#### Keywords:

Bibliometric Analysis

WASPAS,

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MARCOS

#### Jel Codes:

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In recent years, multi-criteria decision-making (MCDM) techniques have expanded the corpus of existing techniques and demonstrated their effectiveness with applications in various fields. In this study, bibliometric analysis was conducted to evaluate the research trend on new ranking-based MCDM methods in the last decade, namely WASPAS, MABAC, EDAS, CODAS, COCOSO, and MARCOS. The various keyword combinations are searched on the Web of Science and the Scopus databases. Bibliometric analysis is carried out in R with the Biblioshiny app for the bibliometrix package. In total, 1,215 related publications are analyzed. The sources, authors, countries, and publications are examined in terms of production and total citation, and the most frequent keywords with trend topics are obtained. The summaries of the findings are as follows: The number of publications has increased over the years for all the methods. The most cited studies belong to the authors of the methods and fuzzy implementations related to the methods. For the author's impact and productivity, Zavadskas and Pamučar stand out. Turkey and India rank in the top five in terms of the number of publications produced on all methods. China is the most cited country for the three methods. According to keyword analysis, different research topics such as sustainability, renewable energy, optimization, supplier selection, hydrogen production and transport are investigated through these methods and other techniques are utilized such as SWARA, AHP, TOPSIS, Best-Worst, DEMATEL, MAIRCA, and CRITIC.

### ÖZET

#### Anahtar Kelimeler:

Bibliyometrik Analiz

WASPAS,

MABAC,

EDAS,

CODAS,

COCOSO,

MARCOS

#### Jel Kodları:

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Son yıllarda, çok kriterli karar verme (ÇKKV) teknikleri mevcut tekniklerin korpusunu genişletmiş ve çeşitli alanlardaki uygulamaları ile etkinliklerini göstermiştir. Bu çalışmada, son on yılda WASPAS, MABAC, EDAS, CODAS, COCOSO ve MARCOS olmak üzere yeni sıralama tabanlı ÇKKV yöntemlerine ilişkin araştırma eğilimini değerlendirmek için bibliyometrik analiz yapılmıştır. Çeşitli anahtar kelime kombinasyonları, Web of Science ve Scopus veritabanlarında aranmıştır. Bibliyometrik analiz, bibliometrix paketine ait Biblioshiny uygulamasıyla R programında gerçekleştirilmiştir. Toplamda 1.215 ilgili yayın analiz edilmiştir. Kaynaklar, yazarlar, ülkeler ve yayınlar üretim ve toplam atıf açısından incelenmiş ve trend konuları ile en sık kullanılan anahtar kelimeler elde edilmiştir. Bulguların özetleri şu şekildedir: Tüm yöntemler için yayın sayısı yıllar içinde artmıştır. En çok atıf alan çalışmalar, yöntemlerin ve yöntemlerle ilgili bulanık uygulamaların yazarlarına aittir. Yazar etkisi ve üretkenliği incelendiğinde Zavadskas ve Pamučar öne çıkmaktadır. Türkiye ve Hindistan, tüm yöntemlerde üretilen yayın sayısı bakımından ilk beşte yer almaktadır. Çin, üç yöntem için en çok alıntı yapılan ülkedir. Anahtar kelime analizine göre bu yöntemlerle sürdürülebilirlik, yenilenebilir enerji, optimizasyon, tedarikçi seçimi, hidrojen üretimi ve nakliye gibi farklı araştırma konuları araştırılmakta ve SWARA, AHP, TOPSIS, Best-Worst, DEMATEL, MAIRCA ve CRITIC gibi diğer yöntemler de bu çalışmalarda kullanılmaktadır.

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## 1. INTRODUCTION

Every moment of life entails making decisions that involve many participants, including people, groups, and institutions. With many decision criteria and various decision alternatives, multiple criteria decision-making (MCDM) is a crucial component of modern decision science (Toloie-Eshlaghy & Homayonfar, 2011). Researchers from several countries have studied MCDM approaches since the 1950s when the foundations of modern MCDM techniques were established, and new MCDM techniques have been developed (Zavadskas et al., 2014).

Applications for MCDM methods include social work, project management, business and financial management, transportation and logistics, environmental management, and many more fields (Toloie-Eshlaghy & Homayonfar, 2011). The criteria are weighted and/or the alternatives are ranked using MCDM methods. In the last decade, MOOSRA (Multi-objective Optimization on the Basis of Simple Ratio Analysis) (Das et al., 2012), WASPAS (Weighted Aggregated Sum Product Assessment) (Zavadskas et al., 2012), MAIRCA (MultiAtributive Ideal-Real Comparative Analysis) (Pamučar et al., 2014), MABAC (Multi-Attributive Border Approximation area Comparison) (Pamučar & Čirović, 2015), EDAS (Evaluation based on Distance from Average Solution) (Keshavarz Ghorabae et al., 2015), CODAS (COmbinative Distance-based ASsessment) (Keshavarz Ghorabae et al., 2016a), SECA (Simultaneous Evaluation of Criteria and Alternatives) (Keshavarz Ghorabae et al., 2018), COCOSO (COmbined COmpromise SOLution) (Yazdani et al., 2018), Stratified MCDM (Asadabadi, 2018), MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) (Stević et al., 2020a), and DNMA (Double Normalization-based Multiple Aggregation) (Liao & Wu, 2020) have been introduced as novel MCDM methods for evaluation of performance scores and ranking of alternatives.

Due to the increasing number of publications in the literature, it has become almost impossible to keep up with all the research on the topic, field, or method of interest. Bibliometric analysis has been used in the literature to provide “a quantitative analysis of written publications”, and covers a variety of categories of materials such as journal articles, books, theses, etc. (Ellegaard & Wallin, 2015, p.1810). The growth, usability, and accessibility of bibliometric software, scientific databases, as well as the interdisciplinary application of the bibliometric methodology, all contribute to the popularity of analysis (Donthu et al. 2021). Research carried out with bibliometric analysis can provide an overview of the subject area, so that knowledge gaps can be identified and new ideas for research can be shed light on (Donthu et al. 2021).

This study aims to provide a bibliometric analysis of the research on ranking-based MCDM methods introduced in the last decade. The lack of prior review research on these new approaches is the driving force for this study, which attempts to address the gap and demonstrate the current status of the research on these methods. Since the Web of Science (WoS) and Scopus databases are the main sources of bibliometric analysis (Zhu & Liu, 2020), the relevant keywords were decided based on the literature and were searched on these databases. For the research, MOOSRA, WASPAS, MAIRCA, MABAC, EDAS, CODAS, SECA, COCOSO, Stratified MCDM, MARCOS, and DNMA methods were searched with different possible combinations of keywords. According to the findings, MCDM methods with around a hundred or more publications were considered for the analysis, since it can be more appropriate to use a systematic literature review in examining studies under a hundred (Donthu et al. 2021). As a result, the total research output was 1,215; 407 publications for WASPAS, 204 publications for MABAC, 270 publications for EDAS, 134 publications for CODAS, 101 publications for COCOSO, and 99 publications for MARCOS.

The remainder of the article is structured as follows: The next section begins with an overview of bibliometric analysis and then presents a literature review of bibliometric research conducted on MCDM methods over the last decade. Then, the MCDM methods used in the analysis are briefly summarized. The methodology section provides detailed information about keyword searches, explains the research questions, and presents the flowchart of the methodology. Finally, the results of the analysis are given under each research question, and the findings are discussed in the conclusion section, with suggestions for future studies.

## 2. BIBLIOMETRIC ANALYSIS and MCDM METHODS

With the use of bibliometric techniques, researchers can “base their findings on aggregated bibliographic data produced by other scientists working in the field who express their opinions through citation, collaboration, and writing” (Zupic & Čater, 2015, p.430).

Bibliometric analysis has been applied in a variety of fields such as green supply chain management (Fahimnia et al., 2015), social entrepreneurship (Rey-Martí et al., 2016), knowledge management (Gaviria-Marin et al., 2019),

operations research and management science (Merigó & Yang, 2017), Covid-19 (Chahrour et al., 2020), transfer pricing (Kumar et al., 2021), blockchain applications in management (Tandon et al., 2021), sustainability and risk management (Nobanee et al., 2021), medical big data (Liao et al., 2018), Internet of Things in food safety (Bouzembrak et al., 2019), safety culture (Van Nunen et al., 2018), smart cities (Guo et al., 2019), artificial intelligence in health care (Guo et al., 2020), and review of some leading journals (Martínez-López et al., 2018; Gaviria-Marin et al., 2018; Donthu et al., 2020).

Among these fields, especially in decision-making research, MCDM related studies have been searched with bibliometric analysis. The bibliometric analysis of MCDM research is summarized in Table 1. The table shows that bibliometric research has usually focused on the applicability of MCDM approaches across a range of sectors, as opposed to particular methods. DEMATEL (Koca & Yildirim, 2021), MACBETH (Ferreira & Santos, 2021), and AHP and TOPSIS (Zyoud & Fuchs-Hanusch, 2017) studies are the only examples of method-specific research.

**Table 1.** Summary of the Studies on Bibliometric Analysis of MCDM-Related Research in the Last Decade

Author(s)	Scope	Timespan	Database	#Publications
Basílio et al. (2022)	MCDM	1945-2021	WoS and Scopus	20861
Koca & Yildirim (2021)	DEMATEL	1999-2020	WoS	1963
Ferreira & Santos (2021)	MACBETH	1994-2016	Scopus	192
de Souza et al. (2021)	MCDM in Research and Development (R&D) Project Portfolio Selection (PPS)	1970-2020	WoS and Scopus	66
Abdullah et al. (2021)	MCDM in managing water-related disaster events	2000-2020	WoS	149
Costa et al. (2021)	MCDM in personnel selection	1994-2020	Scopus	63
Minhas & Potdar (2020)	Decision support system in construction	2000-2016	WoS and Scopus	5418
Chowdhury & Paul (2020)	MCDM in corporate sustainability	2007-2019	Scopus, WoS, and Google Scholar	52
Morkūnaitė et al. (2019)	MCDM in heritage buildings	1994-2018	WoS	180
Chen et al. (2019)	ANP	1997-2018	WoS	1485
Yu et al. (2019)	Fuzzy optimization and decision making	2002-2017	Scopus	370
Yu et al. (2018)	MCDM	1977-2016	WoS	4464
Francik et al. (2017)	MCDM in agriculture	1979-2015	WoS	1355
Zyoud & Fuchs-Hanusch (2017)	AHP and TOPSIS	1976-2015	Scopus	AHP:10188; TOPSIS: 2412
Liu & Liao (2017)	Fuzzy decision	1970-2015	WoS	13901
Tramarico et al. (2015)	AHP in supply chain	1990-2014	WoS	116
Zopounidis et al. (2015)	MCDM in finance	2002-2014	Scopus	644
Guerrero-Baena et al. (2014)	MCDM in corporate finance	1980-2012	Scopus	347

Apart from the bibliometric analysis, the literature includes other review studies on MCDM methods' applications. Some focused on MCDM methods and applications in general (Zavadskas et al., 2014), while others examined MCDM applications in specific fields, such as sustainable engineering (Stojčić et al., 2019), sustainable renewable energy development (Kumar et al., 2017), corporate sustainability (Chowdhury & Paul, 2020), logistics performance evaluation (Chejarla et al., 2022), supplier selection (Yildiz & Yayla, 2015), construction (Zhu et al., 2021), energy policy and decision-making problems (Kaya et al., 2018), oncology (Adunlin et al., 2015), architecture and engineering (Ogrodnik, 2019), financial modeling (Almeida-Filho et al., 2021), health care (Khan et al., 2022), and Covid-19 pandemic (Sotoudeh-Anvari, 2022). There are also review studies based on a specific MCDM method, such as TOPSIS (Behzadian et al., 2012), ELECTRE (Govindan & Jepsen, 2016), SWARA and WASPAS (Mardani et al., 2017), VIKOR (Gul et al., 2016), and COPRAS (Stefano et al., 2015).

The information about the methods used in the study is summarized as follows:

- **WASPAS:** WASPAS (Weighted Aggregated Sum Product Assessment) is an MCDM method proposed by Zavadskas et al. in 2012. This method is an integrated method in which WSM (Weighted Sum Model) and WPM (Weighted Product Method) are considered together. In their study, it is emphasized that using two methods together instead of a single method would give more accurate and reliable results. Since WASPAS is a method in which WSM and WPM methods are used in an integrated way, the steps of these two methods are applied first. Then, the result is obtained according to the relative significance value given to both methods. Finally, alternatives are ranked according to these values (Zavadskas, 2012).
- **MABAC:** MABAC (Multi-Attributive Border Approximation Area Comparison) method is an MCDM method proposed by Pamučar and Čirović in 2015. The basis of the method, unlike other MCDM methods, is based on calculating the distances of each alternate criterion function to the border proximity area. It has been observed that this method gives more consistent results than methods such as SAW, COPRAS, TOPSIS, and MOORA (Pamučar & Čirović, 2015).
- **EDAS:** EDAS (Evaluation based on Distance from Average Solution), proposed by Keshavarz Ghorabae et al. (2015), is an MCDM method in which distances from the mean are considered. This method is particularly useful when there are conflicting criteria. In MCDM methods such as TOPSIS and VIKOR, the best decision alternative is the closest to the positive ideal solution and the furthest from the negative ideal solution, while the distances from the mean value are considered in the EDAS method. Therefore, in this method, there is no need to calculate positive and negative ideal values. Two types of distances from the mean are calculated, which are positive distances from the mean (Positive Distance from Average) and negative distances from the mean (Negative Distance from Average) for each alternative. The ranking of alternatives is made according to the high positive mean solution and low negative mean solution. In other words, the alternative closest to the positive mean solution and furthest from the negative mean solution is the best alternative (Keshavarz Ghorabae et al. 2015).
- **CODAS:** CODAS (Combinative Distance-based Assessment) is an MCDM method proposed by Keshavarz Ghorabae et al. (2016a). In this method, unlike other methods, Euclidean and Taxicab distances from the negative ideal solution are considered. First, the Euclidean distance is used in the method. However, if the Euclidean distances of the two alternatives are very close to each other, the Taxicab distances are compared. In this case, the question of how to measure the degree of closeness of Euclidean distances comes to mind. In this context, degrees are set by a threshold parameter (Keshavarz Ghorabae et al., 2016a).
- **COCOSO:** COCOSO (Combined Compromise Solution) is an MCDM method proposed by Yazdani et al. (2018). This method has emerged as a result of the integration of SAW (Simple Additive Weighting) and EWP (Exponentially Weighted Product) methods. In this method, utility values are calculated from different perspectives. Then, a compromise solution is obtained by combining the utility values of each alternative using an aggregation function (Yazdani et al., 2018).
- **MARCOS:** MARCOS (Measurement of Alternatives and Ranking According to COmpromise Solution) is one of the newest MCDM methods and was proposed by Stević et al. (2020). The basis of this method is based on defining the relationship between alternatives and reference values (ideal and anti-ideal solutions). Based on these relations, the utility functions of the alternatives are obtained, and a compromise ranking is obtained according to the ideal-anti-ideal solutions. Utility functions show the position of an alternative relative to the ideal and anti-ideal solution. Therefore, the best alternative is the closest to the ideal solution and at the same time, the furthest from the anti-ideal solution (Stević et al., 2020a).

### 3. METHODOLOGY

For the study, bibliometric analysis was conducted using Biblioshiny, an app providing a web interface for the bibliometrix package (Aria & Cuccurullo, 2017). This software tool is used due to its advantages with its user interface, Biblioshiny, and gaining more popularity in recent years compared to other tools (Moral-Muñoz et al., 2020).

The keywords in this study were determined by considering the MCDM-based bibliometric analysis studies conducted in the literature in recent years. First, the method's name and its abbreviation were selected as the search

strings. Then, in addition to these keywords, MCDM-related keywords were added to avoid unrelated studies from being included in the dataset in case the method's abbreviation is used in other fields.

Basílio et al. (2022) searched for MCDM-related keywords as “MULTI-ATTRIBUTE DECISION MAKING” OR “MADM” OR “MCDA” OR “MODM” OR “MCDM” OR “MULTICRITERIA” OR “MULTI-CRITERIA” OR “MULTIPLECRITERIA” in “articles, titles, abstracts, and keywords”. Abdullah et al. (2021) searched for “MCDM” OR “MCDA” OR “Multi-criteria decision making” OR “Multi-criteria decision analysis” keywords and de Souza et al. (2021) searched for different MCDM combinations as “MCDM” OR “multicriteria decision making” OR “multi-criteria decision making” OR “multi criteria decision making” OR “multiplecriteria decision making” OR “multiplecriteria decision making” OR “multiple criteria decision making” OR “MCDA” OR “multicriteria decision analysis” OR “multi-criteria decision analysis” OR “multi criteria decision analysis” OR “multiplecriteria decision analysis” OR “multiple-criteria decision analysis” OR “multiple criteria decision analysis” OR “multicriteria decision aiding” OR “multi-criteria decision aiding” OR “multi criteria decision aiding” OR “multiplecriteria decision aiding” OR “multiple-criteria decision aiding” OR “multiple criteria decision aiding” in “titles, abstracts, and keywords”.

By taking all these relevant searches into account, multiple combinations were searched on WoS and Scopus databases and the search strings were decided as follows:

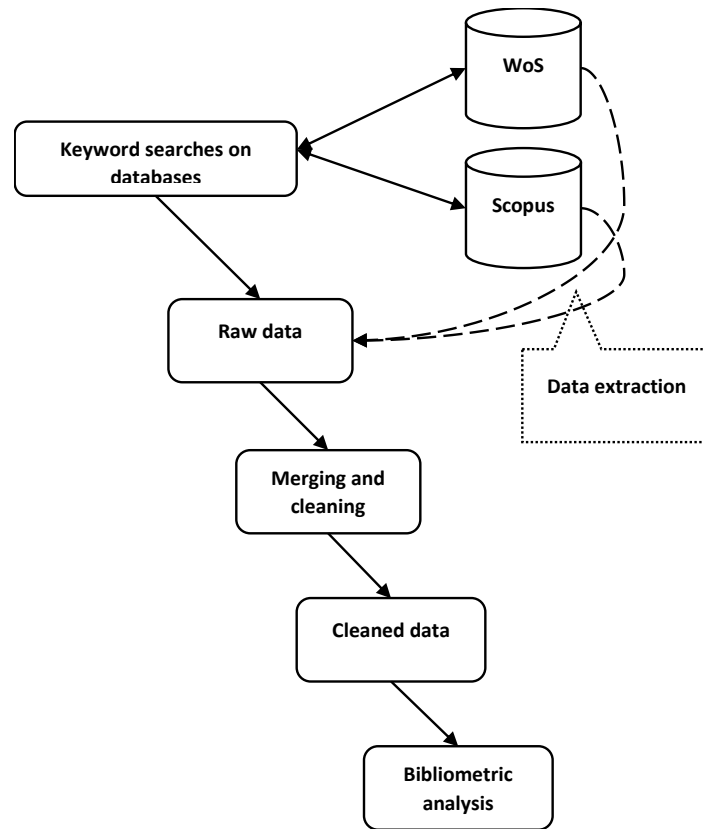
- On WoS: (“Method’s full name”) OR (“Method’s abbreviation”) AND (“MCDM” OR “MADM” OR “MCDA” OR “MODM” OR “multi\* decision making” OR “multi\* decision analysis” OR “multi\* decision aiding”) in Topic search (it searches the title, abstract, author keywords, and Keywords Plus), Language=English.
- On Scopus: (TITLE-ABS-KEY({Method’s full name}) OR TITLE-ABS-KEY({Method’s abbreviation})) AND (TITLE-ABS-KEY(MCDM) OR TITLE-ABS-KEY(MADM) OR TITLE-ABS-KEY(MCDA) OR TITLE-ABS-KEY (MODM) OR TITLE-ABS-KEY(multi\* AND decision AND making) OR TITLE-ABS-KEY(multi\* AND decision AND analysis) OR TITLE-ABS-KEY(multi\* AND decision AND aiding)) AND LANGUAGE(ENGLISH)

After all the relevant searches were conducted on August 4, 2022, all the publications found in two separate databases were extracted in BibTex format with the full record and cited references’ information for each method. These two separate datasets were merged in the R programming language by removing all duplicates. The bibliometrix package functions used for merging and cleaning were `convert2df` and `mergeDbSources` (Aria & Cuccurullo, 2022). At the last stage, the datasets of each method were checked manually and studies with missing information were removed from the data set.

Research questions are formed as follows (publications are defined as “publications on WASPAS, MABAC, EDAS, CODAS, COCOSO, and MARCOS methods” in the research questions):

- *RQ1: What is the trend of the publications over the years?*
- *RQ2: What are the most relevant and cited research components regarding countries, authors, and sources?*
- *RQ3: Which publications have received more interest in terms of total citations?*
- *RQ4: What are the most frequent keywords and trend topics in publications?*

Figure 1 depicts the methodology’s workflow. The first three research questions (RQ1, RQ2, and RQ3) concern descriptive statistics regarding publications about trends, countries, authors, and sources. With keywords’ statistics and trend topics’ plots, the fourth research question is addressed.



**Figure 1.** The Flowchart of the Methodology

#### 4. RESULTS

The main information about the dataset is given in Table 2. Among the document types, the majority are articles (WASPAS for 86.73%, MABAC for 93.63%, EDAS for 90.37%, CODAS for 88.81%, COCOSO for 93.07%, and MARCOS for 91.92%). The average age of documents and average citations per document are lower for methods published in recent years, as expected. The highest annual growth rate belongs to the COCOSO method. WASPAS is the method by which the most publications and most different sources are produced.

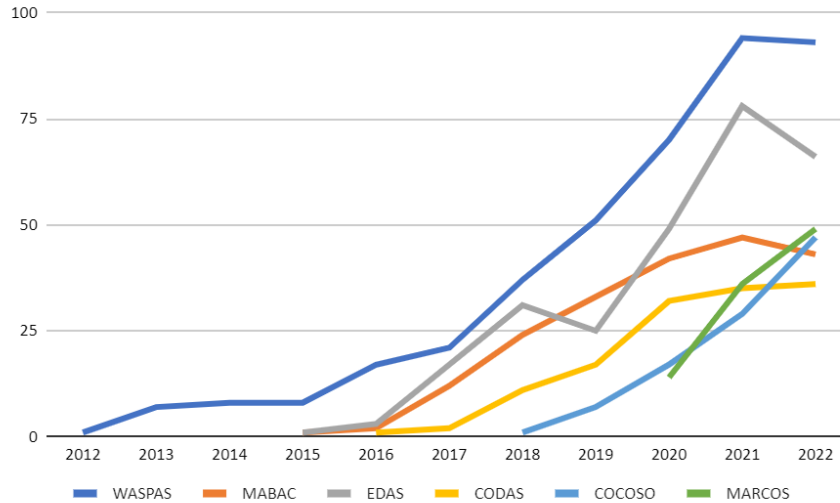
**Table 2.** Main Information about Publications

Description	WASPAS	MABAC	EDAS	CODAS	COCOSO	MARCOS
<b>Timespan</b>	2012: 2022	2015: 2022	2015: 2022	2016: 2022	2018: 2022	2020: 2022
<b>Documents</b>	407	204	270	134	101	99
<b>Sources</b>	213	119	161	96	72	69
<b>Annual Growth Rate %</b>	57.34	71.14	81.94	81.71	161.83	87.08
<b>Document Average Age</b>	2.3	1.99	1.8	1.57	0.871	0.646
<b>Average citations per doc</b>	19.24	25.51	17.98	15.28	12.66	10.78
<b>Document Type:</b>						
<b>Article</b>	353	191	244	119	94	91
<b>Conference paper</b>	24	8	14	7	5	4
<b>Others</b>	54	6	12	8	2	6

##### 4.1. RQ1: What is the trend of the publications over the years?

The year-wise frequency of publications on the methods is demonstrated in Figure 2. It should be noted that the data for 2022 does not include the publications for the whole year, as the data was drawn on August 4, 2022.

The first articles in the databases for all methods are published by the creators of the methods. Regarding the year of the first publications of all methods except MARCOS, there is only one publication. It is seen that there are 14 publications related to the method in 2020 when the MARCOS method was introduced. In addition, the number of publications conducted on all methods has increased over time, which shows an increasing interest in methods. There is a decrease in the publications related to the EDAS method only in 2019 compared to the previous year (2018:31; 2019:25), but the increase continued in the following years.



**Figure 2.** Annual scientific production

#### 4.2. RQ2: What are the most relevant and cited research components regarding sources, authors, and countries?

The most relevant sources (the sources with the most publications on methods) are examined (Table 3). Symmetry-Basel is the most relevant source for WASPAS with 13 publications, and the third most relevant source for MABAC and CODAS. Decision Making: Applications in Management and Engineering is the most relevant source considering MABAC publications, second for CODAS, and third for MARCOS. The Technological and Economic Development of Economy ranks first as the most relevant source for EDAS. The Journal of Intelligent & Fuzzy Systems is the most relevant source for CODAS and the third for MABAC and EDAS. The Journal of Cleaner Production is the first on the list for COCOSO, second for WASPAS, and third for CODAS. Mathematics ranks first as the most relevant source for MARCOS.

To observe the most cited sources, total citations for the journals are examined (Table 4). The journals with the highest total citations are found to be the Journal of Cleaner Production for WASPAS and COCOSO, Expert Systems with Applications for MABAC, Informatica for EDAS, Economic Computation and Economic Cybernetics Studies and Research for CODAS, Computers & Industrial Engineering for MARCOS.

**Table 3.** Top Three Most Relevant Sources

WASPAS		MABAC		EDAS	
Sources	f	Sources	f	Sources	f
Symmetry-Basel	13	Decision Making: Applications in Management and Engineering	11	Technological And Economic Development of Economy	10
Applied Soft Computing	10	Expert Systems with Applications	8	Soft Computing	9
Journal of Cleaner Production	10	International Journal of Intelligent Systems	8	Journal of Intelligent & Fuzzy Systems	7
Sustainability	9	Journal of Intelligent & Fuzzy Systems	7		
		Symmetry-Basel	7		

CODAS		COCOSO		MARCOS	
Sources	f	Sources	f	Sources	f
Journal of Intelligent & Fuzzy Systems	5	Journal of Cleaner Production	5	Mathematics	6
Decision Making: Applications in Management and Engineering Informatica (Netherlands)	4	Sustainability	4	Sustainability	5
International Journal of Intelligent Systems	4	Sustainable Cities and Society	4	Applied Intelligence	3
Journal of Multiple-Valued Logic and Soft Computing	4	Axioms	3	Applied Soft Computing	3
Advances in Intelligent Systems and Computing	3	Expert Systems with Applications	3	Decision Making: Applications in Management and Engineering	3
Ieee Transactions on Engineering Management	3	Ieee Access	3	Expert Systems with Applications	3
Journal of Cleaner Production	3	International Journal of Fuzzy Systems	3	Facta Universitatis-Series Mechanical Engineering	3
Sustainability	3			Socio-Economic Planning Sciences	3
Symmetry-Basel	3				

**Table 4.** Top Three Most Cited Sources

WASPAS		MABAC		EDAS	
Sources	TC	Sources	TC	Sources	TC
Journal of Cleaner Production	526	Expert Systems with Applications	769	Informatica	408
Applied Soft Computing	431	Decision Making: Applications in Management and Engineering	459	Technological And Economic Development of Economy	286
Elektronika Ir Elektrotehnika	418	International Journal of Intelligent Systems	353	Journal Of Cleaner Production	186
CODAS		COCOSO		MARCOS	
Sources	TC	Sources	TC	Sources	TC
Economic Computation and Economic Cybernetics Studies and Research	268	Journal of Cleaner Production	190	Computers & Industrial Engineering	238
Decision Making: Applications in Management and Engineering	226	Management Decision	163	Decision Making: Applications in Management and Engineering	137
International Journal of Intelligent Systems	129	Artificial Intelligence Review	79	Mathematics	117

The top three most relevant authors with the most publications on methods are presented in Table 5. It is seen that Zavadskas, the author of the first articles in which all methods except MABAC and MARCOS methods are introduced, has contributed the most publications on the WASPAS, EDAS, and COCOSO methods. Pamučar, the author of the first article in which the MABAC method was published, is the most productive on this method and the CODAS method. The author with the most publications on the MARCOS method is Stević, the first author of the MARCOS article.

The authors' impact on methods is given considering total citations in Table 6. The highest total citations belong to the creators of the methods, as expected, but there is one exception. Pamučar, one of the creators of the MABAC and MARCOS methods, has received the highest total citations on MABAC, MARCOS, and CODAS. Zavadskas has received the highest total citations on the WASPAS, EDAS, and COCOSO methods.



**Table 5.** Top Three Most Relevant Authors

<b>WASPAS</b>		<b>MABAC</b>		<b>EDAS</b>	
<b>Authors</b>	<b>f</b>	<b>Authors</b>	<b>f</b>	<b>Authors</b>	<b>f</b>
Zavadskas E.	54	Pamučar D.	32	Zavadskas E.	24
Antuceviciene J.	30	Chakraborty S.	12	Turskis Z.	18
Turskis Z.	19	Stević Z.	11	Wei G.	14
<b>CODAS</b>		<b>COCOSO</b>		<b>MARCOS</b>	
<b>Authors</b>	<b>f</b>	<b>Authors</b>	<b>f</b>	<b>Authors</b>	<b>f</b>
Pamučar D.	15	Zavadskas E.	18	Stević Z.	19
Kahraman C.	10	Pamučar D.	11	Pamučar D.	13
Bolturk E.	7	Liao H.	10	Torkayesh A.	7

**Table 6.** Top Three Most Cited Authors

<b>WASPAS</b>		<b>MABAC</b>		<b>EDAS</b>	
<b>Author</b>	<b>TC</b>	<b>Author</b>	<b>TC</b>	<b>Author</b>	<b>TC</b>
Zavadskas E.	2992	Pamučar D.	1738	Zavadskas E.	1487
Antuceviciene J.	1594	Ćirović G.	706	Keshavarz Ghorabae M.	1180
Turskis Z.	1298	Zavadskas E.	591	Turskis Z.	1112
<b>CODAS</b>		<b>COCOSO</b>		<b>MARCOS</b>	
<b>Author</b>	<b>TC</b>	<b>Author</b>	<b>TC</b>	<b>Author</b>	<b>TC</b>
Pamučar D.	426	Zavadskas E.	369	Pamučar D.	529
Zavadskas E.	361	Yazdani M.	302	Stević Z.	496
Antuceviciene J.	339	Turskis Z.	251	Puška A.	256

Table 7 shows the top five countries that produce the most publications on WASPAS, MABAC, EDAS, CODAS, COCOSO and MARCOS, with f representing the publication frequency. Turkey and India rank in the top five in terms of the number of publications produced on all methods. India ranks first in WASPAS and COCOSO methods. China is the country that produces the most publications in the MABAC and EDAS methods. For CODAS and MARCOS methods, Turkey ranks first.

**Table 7.** Top Five Most Relevant Countries

<b>WASPAS</b>		<b>MABAC</b>		<b>EDAS</b>	
<b>Country</b>	<b>f</b>	<b>Country</b>	<b>f</b>	<b>Country</b>	<b>f</b>
India	133	China	78	China	97
Iran	125	India	63	India	79
Lithuania	122	Serbia	53	Lithuania	72
Turkey	94	Turkey	28	Turkey	71
China	86	Lithuania	24	Iran	50
<b>CODAS</b>		<b>COCOSO</b>		<b>MARCOS</b>	
<b>Country</b>	<b>f</b>	<b>Country</b>	<b>f</b>	<b>Country</b>	<b>f</b>
Turkey	54	India	48	Turkey	40
India	45	China	31	Serbia	32
China	33	Serbia	27	India	22
Iran	27	Turkey	26	Vietnam	15
Serbia	24	Lithuania	25	Iran	12

The five most cited countries in the publications produced on WASPAS, MABAC, EDAS, CODAS, COCOSO and MARCOS are given in Table 8. The most cited country in WASPAS studies is Lithuania. China is the most

cited country for its studies on MABAC, EDAS, and COCOSO methods. Turkey is the most cited for the CODAS method, and Bosnia is the most cited country for MARCOS.

**Table 8.** Top Five Most Cited Countries

WASPAS		MABAC		EDAS	
Country	TC	Country	TC	Country	TC
Lithuania	2663	China	1957	China	1111
India	1022	Serbia	1384	Lithuania	984
Iran	958	India	522	Turkey	592
China	636	Bosnia	365	Iran	568
Turkey	547	Lithuania	317	Bosnia	402
CODAS		COCOSO		MARCOS	
Country	TC	Country	TC	Country	TC
Turkey	477	China	377	Bosnia	482
Serbia	282	Turkey	239	Turkey	179
China	258	Spain	175	India	89
Lithuania	239	India	147	Serbia	53
Iran	193	Serbia	127	Chile	42

#### 4.3. RQ3: Which publications have received more interest in terms of total citations?

Among the studies on all methods, the most cited articles belong to the creators of the methods, as expected (Table 9). The other top-cited articles are about different applications of the methods, such as the second and third cited articles on WASPAS as an application in solar projects (Vafaeipour et al., 2014), and green suppliers' evaluation (Keshavarz Ghorabae et al., 2016b). In addition, top cited articles for all the methods include fuzzy implementation of the methods (Peng & Yang, 2016; Keshavarz Ghorabae et al., 2016b; Keshavarz Ghorabae et al., 2016c; Kahraman et al., 2017; Keshavarz Ghorabae et al., 2017; Pamučar et al., 2018a; Ecer & Pamucar, 2020; Peng et al., 2020; Stanković et al., 2020).

#### 4.4. RQ4: What are the most frequent keywords and trend topics in publications?

The most frequently used keywords related to each method are given in the appendix (Appendix-A). Some preprocessing methods were used in this phase. As expected, it was observed that the name of the method and the MCDM keywords had high frequencies. Also, some similar words are treated as separate words due to different spellings (such as ahp and analytic hierarch process). For this reason, unnecessary words were cleaned with the dictionary named "remove.txt" and the frequencies of words with the same meaning were combined with another newly created "replace.txt" dictionary. There are two groups of unnecessary words or phrases in "remove.txt". The first group is the words related to the name of the method whose word cloud will be extracted. The second group includes MCDM-related words and other non-informative words (e.g., method, model, analysis, etc.). The first group is modified and extracted for each method, while the second group is the same for all methods.

- Example of remove.txt dictionary content for WASPAS method: waspas, weighted aggregated sum product assessment, sum product assessment, method, model, framework, group decision-making, decision making, decision-making, mcdm, multicriteria decision-making, multicriteria analysis, multi criteria decision-making, multi criteria decision making, multiple criteria, multicriterion decision makings, ..., etc.
- Example of replace.txt dictionary content for all methods: ahp, analytic hierarchy process, \n system, systems, \n anp, analytic network process, \n ..., etc. (a list of synonyms (each row) are merged into a single term (the first word contained in the row) and rows are separated by return separator (\n)).

**Table 9.** Top Three Most Cited Publications

	<b>Authors (Year)</b>	<b>Source</b>	<b>Title</b>	<b>TC</b>
<b>WASPAS</b>	Zavadskas et al. (2012)	Elektronika ir elektrotechnika	Optimization of weighted aggregated sum product assessment	418
	Vafaiepour et al. (2014)	Energy Conversion and Management	Assessment of regions' priority for implementation of solar projects in Iran: New application of a hybrid multi-criteria decision-making approach	177
	Keshavarz Ghorabae et al. (2016b)	Journal of Cleaner Production	Multi-criteria evaluation of green suppliers using an extended WASPAS method with interval type-2 fuzzy sets	168
<b>MABAC</b>	Pamučar & Ćirović (2015)	Expert systems with applications	The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC)	373
	Peng & Yang (2016)	International Journal of Intelligent Systems	Pythagorean fuzzy Choquet integral based MABAC method for multiple attribute group decision making	229
	Pamučar et al. (2018a)	Expert systems with applications	Modification of the Best–Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers	189
<b>EDAS</b>	Keshavarz Ghorabae et al. (2015)	Informatica	Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS)	404
	Keshavarz Ghorabae et al. (2016c)	International journal of computers communications & control	Extended EDAS method for fuzzy multi-criteria decision-making: an application to supplier selection	152
	Kahraman et al. (2017)	Journal of Environmental Engineering and Landscape Management	Intuitionistic fuzzy EDAS method: an application to solid waste disposal site selection	138
<b>CODAS</b>	Keshavarz Ghorabae et al. (2016a)	Economic Computation & Economic Cybernetics Studies & Research	A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making	224
	Mukhametzyanov & Pamucar (2018)	Decision making: applications in management and engineering	A sensitivity analysis in MCDM problems: A statistical approach	102
	Keshavarz Ghorabae et al. (2017)	Journal of Business Economics and Management	Fuzzy extension of the CODAS method for multi-criteria market segment evaluation	84
<b>COCOSO</b>	Yazdani et al. (2018)	Management Decision	A Combined Compromise Solution (COCOSO) method for multi-criteria decision-making problems	163
	Ecer & Pamucar (2020)	Journal of Cleaner Production	Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy COCOSO with Bonferroni (COCOSO'B) multi-criteria model	104
	Peng et al. (2020)	Artificial Intelligence Review	Pythagorean fuzzy MCDM method based on COCOSO and CRITIC with score function for 5G industry evaluation	78
<b>MARCOS</b>	Stević et al. (2020a)	Computers & Industrial Engineering	Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)	238
	Stanković et al. (2020)	Mathematics	A new fuzzy MARCOS method for road traffic risk analysis	77
	Stević & Brković (2020b)	Logistics	A novel integrated FUCOM-MARCOS model for evaluation of human resources in a transport company	65

- The most often occurring method-related terms in publications related to the WASPAS approach are SWARA, fuzzy, AHP, TOPSIS, and Best-Worst. Other than methods, the terms sustainability, renewable energy, optimization, supplier selection, and sustainable supply chain management are frequently used.

- Best-Worst, fuzzy, TOPSIS, DEMATEL, EDAS, and MAIRCA are the most frequently used methods as keywords in MABAC papers. The most used keywords, besides techniques, are supplier selection, green supplier selection, logistics, risk evaluation, and geographic information system (GIS).
- Examining the EDAS method reveals that TOPSIS, fuzzy, Best-Worst, AHP, and entropy are repeated the most. It is acknowledged that publications are produced utilizing this methodology in the fields of sustainability, supplier selection, green supplier selection, and hydrogen production.
- The top three method-related keywords used in CODAS publications are fuzzy, sensitivity analysis and AHP. Other keywords that come up regularly are sustainability, supplier selection, and renewable energy.
- Fuzzy, CRITIC, Best-Worst, SWARA, and MARCOS are the COCOSO method's most often used method-related keywords. The keywords sustainability, supplier selection and optimization are at the top of the list of the most frequent words in publications.
- FUCOM, Best-Worst and CRITIC keywords are the most frequently used methods in MARCOS publications. The keywords transport, sustainability and supply chain management are also used more than other words.

Trend topics' plots are generated on Biblioshiny and demonstrated in the Appendix. The trends for the years after 2021, according to the WASPAS trend topics, include sustainability and wind energy. In the current year, the trending topic of hydrogen production has emerged. It has been noted that the topic of supplier selection has gained popularity for MABAC since 2020 and beyond, for CODAS between 2020 and 2021, and EDAS since 2019. Sustainability is a trend for COCOSO. Transport has become a trend for MARCOS recently.

Additionally, the methods vary from year to year. For instance, the WASPAS graph shows Fuzzy AHP in recent years, while MABAC is displayed as a trend between 2018 and 2019. In terms of MABAC, the DEMATEL and EDAS methods appear to be on the rise between 2017 and 2020, followed by the AHP method from 2018 to 2021 and TOPSIS from 2018 to 2020. The distribution for EDAS is as follows: TOPSIS is trending between 2019 and 2021, AHP is between 2017 and 2022, COPRAS is between 2018 and 2021, WASPAS and MABAC are between 2017 and 2020. Trending CODAS techniques include EDAS and AHP. The CRITIC technique is in vogue for COCOSO and MARCOS. In recent years, ENTROPY and FUCOM methods have become more popular for MARCOS.

## 5. CONCLUSION

Numerous researchers continue to use MCDM techniques in a wide range of fields. In addition to the techniques that have been in use for a long time, new techniques advance the discipline. The researchers working in the field can benefit from observing the development of these methods. Therefore, to contribute to the field, this study aims to conduct a bibliometric analysis on research in ranking-based MCDM methods introduced in the last decade. Relevant keywords are searched both in the WoS and Scopus databases. In total, 1,215 related publications are analyzed: 407 publications for WASPAS, 204 publications for MABAC, 270 publications for EDAS, 134 publications for CODAS, 101 publications for COCOSO, and 99 publications for MARCOS.

Research results show that the number of publications for all methods has increased over the years, that is, the interest in methods is on the rise. The highest annual growth rate belongs to the COCOSO method with 161.83%, followed by MARCOS, EDAS, CODAS, MABAC, and WASPAS, respectively.

The findings also highlight that other than the publications belonging to the authors of the methods, fuzzy implementations of the methods have received interest, which is cited a lot. In addition, the results reveal the most productive and cited authors, journals, and countries for each method, which is valuable knowledge for researchers in the field. The journals in which the articles are published differ according to the methods, so do the most cited journals. However, there are prominent names among the authors; Zavadskas and Pamučar are among the names that produce the most publications and are cited by methods. When the findings for the countries are examined, it is seen that India, China and Turkey stand out.

According to the most used keywords and trend topics, it is observed that different research topics (sustainability, renewable energy, optimization, supplier selection, hydrogen production, transport, etc.) and methods (SWARA, AHP, TOPSIS, Best-Worst, DEMATEL, MAIRCA, CRITIC, etc.) are applied in the publications.

The contributions of the current study to the literature can be listed as the MCDM methods and the databases included in the research. In this study, bibliometric analysis is used to assess new MCDM methods introduced in

the last decade that have not been examined before to the authors' knowledge (there is a review study related to WASPAS, see Mardani et al. (2017)). While most of the previous MCDM-focused bibliometric studies in the literature are carried out in a single database, the Web of Science and Scopus databases are considered together in this study.

Future research may also focus on a bibliometric study for newly discovered weighting based MCDM methods, such as the Full consistency method (FUCOM) (Pamučar et al., 2018b) and Level Based Weight Assessment (LBWA) (Žižović & Pamučar, 2019). A systematic literature review can also be conducted for other methods that are not included in the study (MOOSRA, MAIRCA, SECA, Stratified MCDM, and DNMA). Mixed methods can also be applied with these review techniques, such as content analysis with bibliometric indicators.

#### AUTHORS' DECLARATION

This paper complies with Research and Publication Ethics, has no conflict of interest to declare, and has received no financial support.

#### AUTHORS' CONTRIBUTIONS

Conceptualization, writing-original draft, editing – BA and SA, data collection, methodology, formal analysis – BA, Final Approval and Accountability – BA and SA

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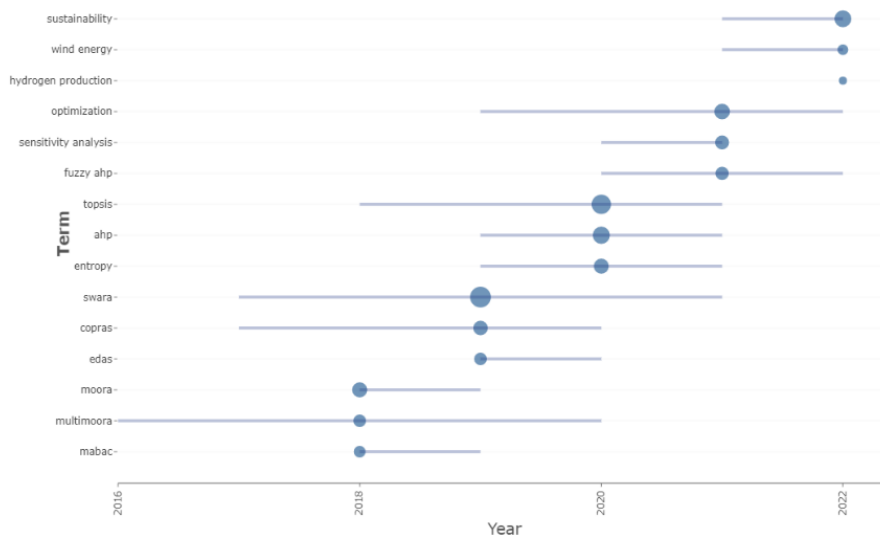
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## APPENDIX

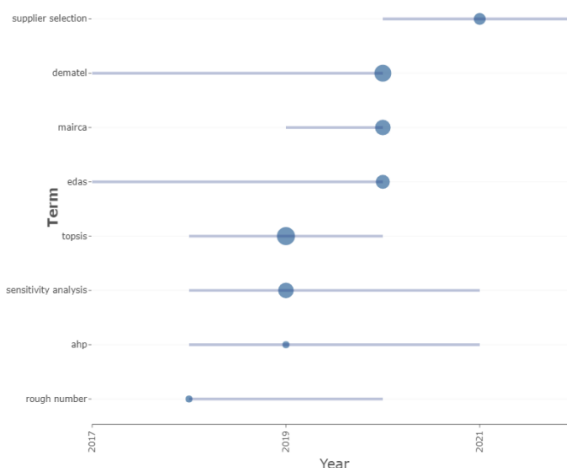
Appendix-A. Most Frequent Keywords

WASPAS		MABAC		EDAS		CODAS		COCOSO		MARCOS	
Terms	f	Terms	f	Terms	f	Terms	f	Terms	f	Terms	f
swara	38	best-worst	14	topsis	26	fuzzy	9	fuzzy	10	fucom	10
sustainability	31	fuzzy	14	fuzzy	18	sensitivity analysis	9	sustainability	9	best-worst	9
fuzzy	25	topsis	11	sustainability	15	ahp	8	critic	7	transport	9
ahp	24	dematel	10	supplier selection	12	sustainability	8	best-worst	6	sustainability	7
topsis	23	edas	9	best-worst	11	supplier selection	7	sustainable supply chain management	6	critic	6
renewable energy	19	mairca	9	ahp	10	edas	6	swara	6	entropy	5
best-worst	17	sensitivity analysis	9	entropy	9	aras	5	marcos	4	fuzzy	5
fuzzy ahp	17	fucom	8	copras	8	entropy	5	pythagorean fuzzy sets	4	supply chain management	5
entropy	16	supplier selection	8	critic	8	renewable energy	5	sensitivity analysis	4	topsis	5
copras	13	entropy	7	fuzzy ahp	8	site selection	5	supplier selection	4	uncertainty	5
optimization	13	waspas	7	uncertainty	8	software	5	ahp	3	circular economy	4
supplier selection	13	ahp	6	sensitivity analysis	7	best-worst	4	hesitant fuzzy linguistic term set	3	fuzzy ahp	4
fuzzy waspas	12	COCOSO	6	codas	6	critic	4	mabac	3	logistics	4
moora	12	green supplier selection	6	dematel	6	fuzzy codas	4	optimization	3	mabac	4
neutrosophic set	12	logistics	6	green supplier selection	6	material selection	4	q-rung orthopair fuzzy sets	3	sustainable supply chain management	4
critic	11	risk evaluation	6	hydrogen production	6	optimization	4	score function	3	swara	4
edas	11	critic	5	mabac	6	topsis	4	similarity measure	3	COCOSO	3
sensitivity analysis	10	gis	5	waspas	6	cloud computing	3	bonferroni	2	covid-19	3
mabac	9	rough numbers	5	aras	5	COCOSO	3	circular economy	2	fuzzy piprecia	3
sustainable supply chain management	9	vikor	5	renewable energy	5	covid-19	3	cloud service provider selection	2	health care waste management	3
covid-19	8	aras	4	swara	5	evaluation	3	covid-19	2	mairca	3
delphi	8	copras	4	wind energy	5	green supply chain management	3	edas	2	merec	3

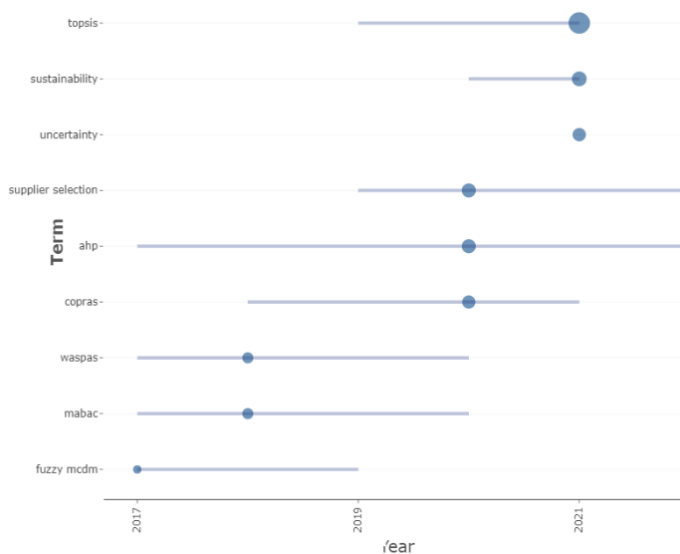
### Appendix-B. WASPAS Trend Topics



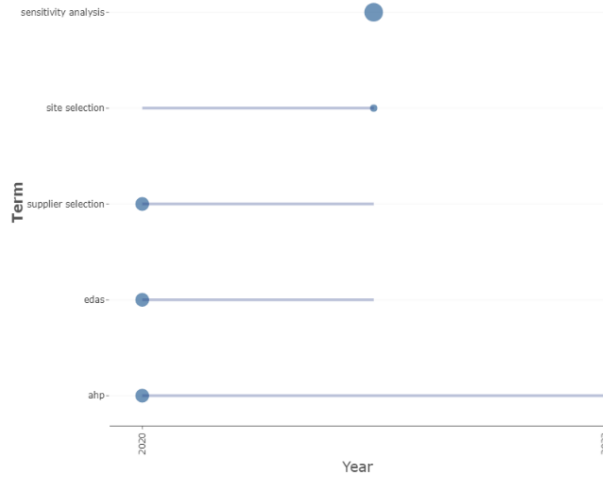
### Appendix-C. MABAC Trend Topics



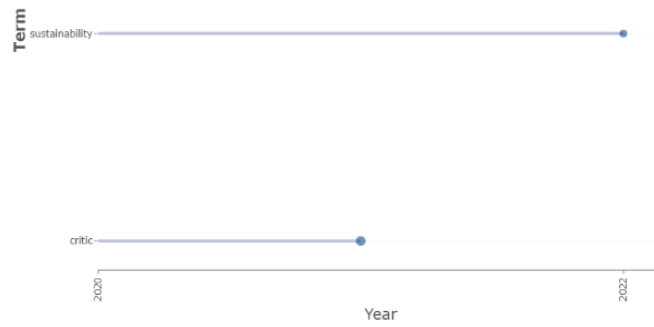
### Appendix-D. EDAS Trend Topics



### APPENDIX-E. CODAS Trend Topics



### Appendix-F. COCOSO Trend Topics



### Appendix-G. MARCOS Trend Topics

