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Review

A STATE-OF-THE-ART REVIEW OF THE BWM METHOD AND FUTURE RESEARCH AGENDA

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Abstract. The superiority of BWM over other weighting methods for obtaining the weight values of the attributes is that it achieves high-confidence results with a reasonable number of pairwise comparisons. Although the best-worst method (BWM) is a well-known multi-criteria decision-making (MCDM) method that has been successfully utilized in almost all scientific areas to solve challenging real-life problems, no research has comprehensively examined the state-of-the-art in this regard. The present study depicts a detailed overview of publications concerned with BWM during the period 2015–2022. Based on the information obtained from the Scopus database, this work presents a big picture of current research on BWM. In other words, this paper analyzes the existing literature about BWM and identifies thematic contexts, application areas, emerging trends, and remaining research gaps to shed light on future research agendas aligning with those gaps. Further, the most recent BWM research is analyzed in the top ten scientific areas, from engineering to materials science. "Engineering", "computer science", and "business, management, and accounting" are the hottest fields of BWM research. China is the most active country regarding "engineering" and "computer science", whereas India is the leader in "business, management, and accounting". The study also reveals that there are still many research gaps in BWM research. The big picture taken in this study will not only showcase the current situation of BWM research but will also positively impact the direction and quality of new research.

Keywords: best-worst method, bibliometric analysis, vosviewer, co-occurrence, co-citation, MCDM.

JEL Classification: C02, C44, E17.

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1. Introduction

Decision-making is one of the most crucial and complicated tasks in human life. Decision-making involves stating the objectives accurately, identifying possible solutions and evaluating their feasibility, analyzing each solution's implementation results, and selecting and performing the optimal solution. Since it is an interdisciplinary research domain, it attracts researchers' attention in all science fields more and more. As a branch of the decision-making field, multiple criteria decision-making (MCDM) continues to attract the attention of researchers due to its useful structure, efficiency, and easy adaptation to any field. Evidently, MCDM is vital in improving decision quality by making the decision-making process more transparent, rational, and efficient. An MCDM problem includes a specific aim, attributes (evaluation criteria), alternatives, and decision-maker(s). In an MCDM problem, it is aimed at making accurate decisions within the framework of various and conflicting criteria. MCDM

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is categorized under two classes: multi-attribute decision-making (MADM) is for discrete problems, and multi-objective decision-making (MODM) is for continuous problems. In other words, the alternatives' number is assumed to be infinite in MODM problems, and continuous functions are utilized to describe the trade-offs among attributes. Nevertheless, MADM problems differ from MODM problems by offering acceptable solutions to determine the most preferable alternative among a finite number of alternatives. Thereby, MADM focuses on making the right choices in the presence of more than one conflicting criterion. Though a distinction is made theoretically, numerous researchers nowadays use the terms MCDM and MADM interchangeably.

On the other hand, MADM terminology can be classified as weighting and ranking methods. Ranking methods allow determining the best/optimal alternative from the set of alternatives considered, whereas weighting methods deal with determining the priority values of the attributes. The weighting methods have been developed based on the logic that the attributes should have diverse importance levels since they have different features. On the other hand, weighting techniques can be divided into two categories: objective and subjective. Objective weighting methods, such as Entropy, Criteria Importance Through Intercriteria Correlation (CRITIC), Logarithmic Percentage Change-Driven Objective Weighting (LOPCOW), Method Based On The Removal Effects Of Criteria (MEREC), etc., consider the nature of the data included in the evaluation process and allow the weighting of the evaluation criteria to be determined. In the subjective weighting approaches, such as Analytic Hierarchy Process (AHP), Best-worst Method (BWM), Step-wise Weight Assessment Ratio Analysis (SWARA), Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), etc., the weights are determined by using the data obtained within the framework of the thoughts, judgments, and experiences of the decision-maker/s. BWM, a vector-based weighting method, was initiated by Rezaei (2015). BWM, which determines the criteria weights with pairwise comparisons, offers an alternative solution to solve the inconsistency problem by significantly reducing the number of pairwise comparisons and changing the comparison method (Yaran Ögel et al., 2023; Altay et al., 2023; Liu et al., 2023; Tanrıverdi et al., 2022; Koohathongsumrit & Chankham, 2023; Ecer, 2021). Thus, it intends to compensate for the shortcomings and disadvantages of AHP (Ogundoyin & Kamil, 2023; Mohammed et al., 2023; Liu & Tahera, 2023; Hashemkhani Zolfani et al., 2020; Dehshiri et al., 2023). As detailed below, BWM has plenty of advantages and ease of implementation compared to other multi-criteria methods.

- BWM allows calculating aspect values by performing an optimization problem solution. Thanks to this advantage, there is no need for challenging calculations; thus, the results can be easily achieved.
- BWM allows practitioners to focus on the best and worst aspects of a decision-making problem, making it easier to make decisions without going into fine details and leading to more dependable pairwise comparisons. In this way, BWM has found the opportunity to be applied in almost every research field and attracted attention.
- By considering the worst reference element of a problem in the pairwise comparisons as well as the best reference element, the possible bias could be reduced.
- In AHP, as a pairwise comparison-based technique, the whole decision matrix is utilized. Though consistency check is performed in AHP, utilizing all matrix elements in

pairwise comparisons causes a waste of time, and obtaining consistent results may not be possible for practitioners.

- AHP requires n(n-1)/2 pairwise comparisons, whereas BWM is only (2n-3), where n is the number of aspects in a problem. Thus, BWM produces simpler and more rapid solutions compared to AHP.
- Unlike employing both integers and decimal numbers employed in SWARA, AHP, and FUCOM, making calculations a little hard, BWM exploits merely integers, making computations easier.
- In the MACBETH, SWARA, and AHP methods, asking too many questions to respondents may result in inconsistent results due to confusion. However, by considering reference elements for pairwise comparisons in BWM, respondents can make more consistent and reliable evaluations.
- The ability to solve BWM problems with Excel and a software program (https://best-worstmethod.com/) that is accessible to everyone makes BWM different from its counterparts, such as SWARA, MEREC, Full Consistency Method (FUCOM), LOPCOW, and CRITIC.
- BWM is a novel multi-criteria technique compared to many MCDM methods, such as AHP, SWARA, CRITIC, and entropy.
- Depending on the data structure, BWM may find multiple optimal solutions. This provides more flexibility in group decision-making processes since a unique decision can be reached by consensus among more than an optimal solution.

Thanks to its easy application to many real-world problems and its ability to produce effective results, BWM has managed to attract the attention of many researchers in a short time. Further, BWM is an exceedingly active area of research among the MCDM techniques as well as it is a successful characteristic example of the various implementation of the MCDM techniques together with other research disciplines. Given that BWM-based research has lasted for nearly a decade and is gaining more and more scholars' attention, a comprehensive overview of this field is required to seek the BWM development path, identify knowledge gaps, and establish a future research agenda. Bibliometric analysis, which has gained remarkable popularity by the scientific society, especially with the technological advances in recent years, is a meticulous, effective, and favored technique utilized to obtain and analyze large volumes of scientific data (Alamoodi et al., 2023). Not surprisingly, the bibliometric analysis has been employed in some well-known methods in MCDM, including AHP (Yu et al., 2021), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Zyoud & Fuchs-Hanusch, 2017), MACBETH (Ferreira & Santos, 2021), Data Envelopment Analysis (DEA) (Lampe & Hilgers, 2015), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Koca & Yıldırım, 2021), and Multi-Objective Optimization on the basis of a Ratio Analysis plus the full Multıplicative form (MULTIMOORA) (Hafezalkotob et al., 2019), wherein the implementation of bibliometric is relatively detailed, i.e., analyzing publications regarding the structural relationships between journals, authors, countries, institutions, keywords, etc. In that sense, the bibliometric technique has been conducted to ensure retrospectives of decision-making methods in the MCDM field. Systematic literature reviews, driven by qualitative methods, may be biased by researchers' interpretations, whereas the bias problem can be eliminated entirely or reduced in quantitative methods-driven bibliometric analyzes (Guo et al., 2019).

Easy access to information, one of the advantages of the Internet age, has led to a rapid increase in the number of publications in all fields of science. However, large datasets have made traditional review methods bulky and impractical. Fortunately, databases such as Web of Science (WoS) and Scopus have made accessing large-scale bibliometric data much more straightforward. Further, the VOSviewer software developed to analyze such large volumes of data has made the work of researchers easier (Ferreira & Santos, 2021).

Although authoritative reviews on some MCDM methods are available, it is essential to note that a bibliometric analysis of the BWM method remains absent except for Mi's et al. (2019), up to the authors' knowledge, posing a critical challenge for researchers who wish to use this technique in their research in the future. Mi et al. (2019) did a bibliometric analysis on BWM at the beginning of 2019, but it covered only 124 documents spanning four years, of which 82 were indexed in WoS. However, at the time of the research, the BWM method was not yet mature; thus, the researchers were not familiar with BWM very well. The authors accepted that their paper is a bibliometric study of an MCDM technique still in its infancy. Thus, research gaps could not be identified precisely in their paper, and implications could not be made sufficiently. Moreover, a comprehensive bibliometric analysis of BWM has not yet appeared since Mi's et al. (2019) article. Keeping in mind that BWM-related studies have increased dramatically in the following years, their compilation and analysis are crucial. In this vein, a fresh and detailed bibliometric study is expected to guide researchers by revealing both the present state and future prediction. Further, this paper considers papers indexed in Scopus, a database with more comprehensive indexing than WoS (Elsevier, 2020), whereas they focus on papers indexed in WoS. Consequently, although it is undeniable that Mi's et al. (2019) bibliometric analysis contributes to the literature, this study will better reveal the gaps in the topic and provide a much more rational taxonomy for the literature.

Given the aforementioned research gaps, this work aims to (i) offer a comprehensive review of BWM, including 1103 BWM research from Scopus, and (ii) explain how future work could potentially perform BWM. More clearly, using information from the Scopus as the database, the goal of this work is to provide an overview of the research studied at BWM in the period 2015–2022. The aim is to identify the most efficient and effective studies and researchers related to BWM and guide the direction for future studies by considering the ongoing evolution of the method. The contributions of the study are (i) to obtain a quantitative breakdown of the literature on what has been done on BWM from 2015 to 2022, (ii) to aid in noticing the contributions of various stakeholders (region, institute, author, journal, etc.) towards the progress of BWM, (iii) to clarify the current situation and tendencies of BWM research, and (iv) to assist scholars in developing future work activities.

The remaining sections of this work are organized as below. Section 2 introduces BWM briefly. The following section presents the research method preferred in this paper, whereas Section 4 discusses the results obtained. Bibliometric analysis is shown in Section 5, whereas Section 6 discusses future work. Finally, the last section concludes the research.

2. The BWM method

BWM employs five steps to extract the weights of attributes. These steps are summarized below (Rezaei, 2015).

Step 1. The identification of attributes. The family of the attributes can be determined as *C1*, *C2*,..., C_n.

Step 2. Deciding the best and worst elements.

Step 3. Comparing the best element with all the attributes. Hence, the best to others vector (A_b) could be formed as:

$$A_b = \left(a_{1B}, a_{2B}, a_{3B}, ...a_{nB}\right). \tag{1}$$

Step 4. Comparing all the attributes with the worst element. Hence, the others to worst vector (A_w) could be formed as:

$$A_w = \left(a_{1w}, a_{2w}, \ldots, a_{nw}\right). \tag{2}$$

Step 5. Deriving the attributes' relative importance. A min-max model (Eq. (3)) could be formed:

$$\begin{aligned} &\min \max_j \left\{\left|\left(w_B / w_j\right) - a_{Bj}\right|, \left|\left(w_j / w_W\right) - a_{jW}\right|\right\} \\ &\text{subject to } \sum_j w_j = 1 \\ &w_j \geq 0, \text{for all the values of } j. \end{aligned} \tag{3}$$

Solving Eq. (3), the weight values of attributes could be generated. After solution, a consistency check is essential.

3. Research method

The literature on BWM is mapped using the VOSviewer software package. The various stages are depicted in Figure 1. This paper prefers the Scopus database to search and retrieve publications interested in BWM since Scopus is assumed to be the most extensive database, indexing more documents than other authority databases. With nearly 24,000 peer-reviewed journals and 78 million records, Scopus yields researchers the most exhaustive overview (Elsevier, 2020). So, the data was retrieved from Scopus on January 27, 2023. Throughout the data searching and retrieving in the title, abstract, and keywords, whole subject fields of Scopus (health, science, social, engineering, etc.) are considered. The data covers the period 2015 to 2022 and publications other than English language are excluded. Thus, a total of 1103 publications in English are retrieved. The research's final sample includes 1095 articles and articles in press as well as 8 reviews. Note that conference papers, conference reviews, book chapters, erratum, notes, books, reports, short surveys, and letters are excluded from the search. In sum, publications are identified addressing the following search string:

(TITLE-ABS-KEY("best-worst method") OR TITLE-ABS-KEY ("best worst method")) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR

LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English"))

Abbreviations in the search query refer to: cp: conference paper, cr: conference review, ch: book chapter, er: erratum, no: note, bk: book, rp: re- port, sh: short survey, le: letter. Note that the outputs of the search from Scopus are exported to CSV Excel spreadsheets.

4. Results

The VOSviewer software is examined to compare the bibliometric transactions of correlations among institutions, authors, journals, keywords, etc. With VOSviewer, networks between objects are revealed. VOSViewer looks for similarities in co-authorship in the context of authors, organizations, and countries. Additionally, it maps that show the co-occurrence of keywords and co-citations. The information highlighted helps clarify what has been done with the BWM method and identifies research flows and gaps in this subject.

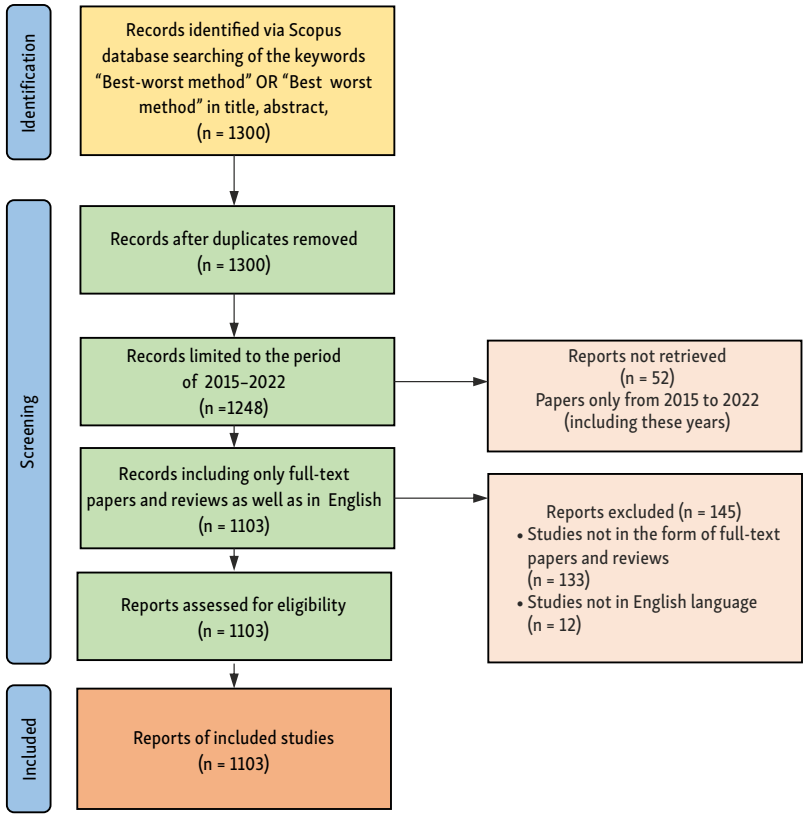

Figure 1. PRISMA flowchart for information search (own elaboration)

4.1. Most productive journals

As illustrated in Figure 2, the total number of articles, articles in press, and review papers related to BWM amount to 1103 in the core database of Scopus during the period 2015–2022. Figure 3 demonstrates the top 10 journals with the most publications on BWM by year. In a detailed way, Table 1 shows the most productive journals in the BWM field, including total publications (TP), total citations (TC), TC/TP (average citations), and their rank regarding each indicator. Journal of Cleaner Production ranks first in all three categories, while Sustainability, in second place in publication order, is fourth according to TC and third according to TC/TP. Journal of Cleaner Production also published 5.71% of all BWM publications. Although ESWA is in sixth place in terms of TP, it is in second place concerning TC/TP, which emphasizes the effectiveness of the journal. Further, ESPR is the only journal among these to increase its publication performance each year, meaning that BWM is receiving increased attention in environmental and pollution studies. Last, the top ten most productive journals contributed approximately 31% to the BWM literature.

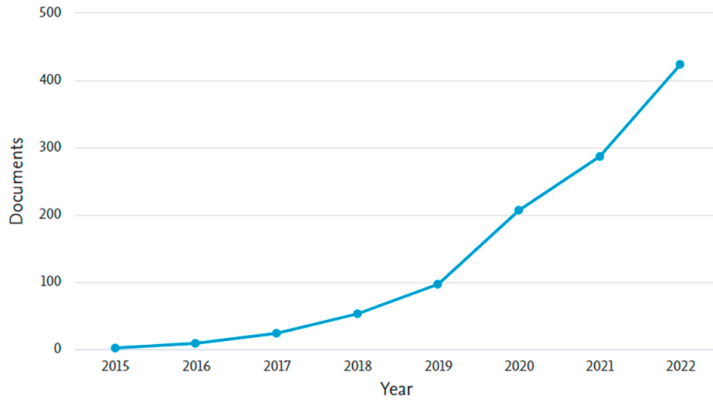

Figure 2. No. of publications (articles, articles in press, and review papers) related to BWM (source: Scopus)

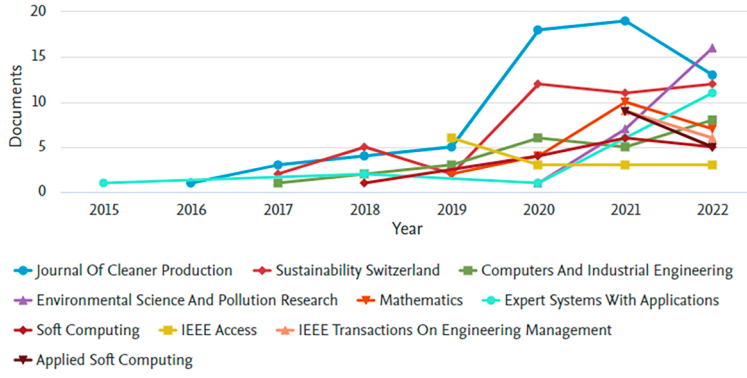

Figure 3. Changing in the annual number of publications of the most productive journals (source: Scopus)

Table 1. Top ten most productive journals

Rank		2015	2016	2017	2018	2019	2020	2021	2022	TP	%	TC	Rank	TC/TP	Rank
1	J. Clean. Prod.	–	1	3	4	5	18	19	13	63	5.71	3495	1	55.48	1
2	Sustainability	–	–	2	5	2	12	11	12	44	3.99	747	4	16.98	3
3	CAIE	–	–	3	7	5	18	16	20	69	6.26	789	3	11.43	7
4	ESPR	–	–	1	2	3	7	12	24	49	4.44	218	7	4.45	10
5	Mathematics	–	–	–	–	2	4	10	17	33	2.99	292	5	8.85	8
6	ESWA	1	–	–	2	–	1	6	11	21	1.90	912	2	43.43	2
7	SOCO	–	–	–	1	–	4	6	5	16	1.45	215	8	13.44	6
8	IEEE Access	–	–	–	–	6	3	3	3	15	1.36	214	9	14.27	5
9	IEEE TEM	–	–	–	–	–	–	9	6	15	1.36	74	10	4.93	9
10	ASOC	–	–	–	–	–	–	9	5	14	1.27	234	6	16.71	4

Note: J. Clean. Prod.: Journal of Cleaner Production, CAIE: Computers and Industrial Engineering, ESPR: Environmental Science and Pollution Research, ESWA: Expert Systems with Applications, SOCO: Soft Computing, IEEE TEM: IEEE Transactions on Engineering Management, ASOC: Applied Soft Computing.

4.2. Most crucial contributions

4.2.1. Most productive scholars

Regarding Table 2, the most productive author is Rezaei, J., the discoverer of BWM, who published 48 (0.044) publications in the areas related to BWM, followed by Gupta, H. (25; 0.023) from Indian Institute of Technology, India, Pamučar, D. (25; 0.023) from University of Defence in Belgrade, Serbia, and Zavadskas, E. K. (21; 0.019) from Vilnius Gediminas Technical University, Lithuania, respectively. Rezaei, J. ranks first in the TC and TC/TP categories, whereas Gupta, H., which ranks second in the TP category, falls back to third place in the TC/TP category. It is further noteworthy that three of the 15 academics are from China, and two are from Taiwan. The Netherlands leads with the most contributions (48; 0.044), followed by China (47; 0.043) and Taiwan (31; 0.028). Moreover, a very strong relationship is detected between the number of publications (TC) and the average citation (TC/TP) regarding the Spearman's rank correlation test ($r = 0.92$).

4.2.2. Most cited publications

One of the pillars of bibliometric analysis is to analyze the most cited studies to emphasize the quality of research. Thereby, Table 3 presents the fifteen most cited articles. The most cited article is "Best-worst multi-criteria decision-making method" by Rezaei (2015), and it harvested 1750 citations at the time of analysis. In that paper, Jafar Rezaei presented the reasons behind developing the BWM multi-criteria weighting method and his arguments in this context. Below are brief introductions to the most cited papers in descending order.

A paper entitled "Best-worst multi-criteria decision-making method: Some properties and a linear model" by Rezaei (2016) placed the second rank with 793 citations. In that work, the author analyzed the multi-optimality of BWM through an interval analysis. He introduced

Table 2. Ranking of the top fifteen most productive authors

Author	TP	%	Rank	TC	Rank	TC/TP	Rank	Affiliation	Country
Rezaei, J.	48	0.044	1	5660	1	117.9	1	Transport and Logistics Group, Delft University of Technology	Netherlands
Gupta, H.	25	0.023	2	1735	2	69.4	3	Department of Management Studies, Indian Institute of Technology	India
Pamučar, D.	25	0.023	2	1320	3	52.8	6	Department of Logistics, University of Defense in Belgrade	Serbia
Zavadskas, E. K.	21	0.019	3	719	7	34.2	10	Department of Construction Technology and Management, Vilnius Gediminas Technical University	Lithuania
Liu, P.	17	0.015	4	174	14	10.2	15	School of Management Science and Engineering, Shandong University of Finance and Economics	China
Ren, J.	17	0.015	4	439	11	25.8	11	School of Geography and Remote Sensing, Nanjing University of Information Science & Technology	Hong Kong
Liao, H.	16	0.015	5	882	5	55.1	5	Business School, Sichuan University	China
Lo, H. W.	16	0.015	5	629	10	39.3	9	Graduate Institute of Industrial and Business Management, National Taipei University of Technology	Taiwan
Moktadir, M. A.	16	0.015	5	665	9	41.6	8	Institute of Leather Engineering and Technology, University of Dhaka	Bangladesh
Gul, M.	15	0.014	6	253	13	16.9	13	Department of Emergency Aid and Disaster Management, Munzur University	Turkey
Kusi-Sarpong, S.	15	0.014	6	1201	4	80.1	2	Southampton Business School, University of Southampton	UK
Liou, J. J. H.	15	0.014	6	667	8	44.5	7	Department of Industrial Engineering and Management, National Taipei University of Technology	Taiwan
Amiri, M.	14	0.013	7	172	15	12.3	14	Department of Industrial Management, Faculty of Management and Accounting, Allameh Tabatabai University	Iran
Guo, S.	14	0.013	7	778	6	55.6	4	School of Economics and Management, North China Electric Power University	China
Tavana, M.	14	0.013	7	293	12	20.9	12	Department Distinguished Chair of Business Analytics, La Salle University	US

a linear BWM framework. Ultimately, his novel approach reached a unique solution. It was followed by research entitled "Fuzzy best-worst multi-criteria decision-making method and its applications", in which the authors successfully extended the BWM method to a fuzzy environment to deal with uncertainty and ambiguity.

Table 3. Top fifteen most cited publications

Rank	Author/s	Title	Journal	No. of citation
1	Rezaei (2015)	Best-worst multi-criteria decision-making method	Omega	1750
2	Rezaei (2016)	Best-worst multi-criteria decision-making method: Some properties and a linear model	Omega	793
3	Guo and Zhao (2017)	Fuzzy best-worst multi-criteria decision-making method and its applications	Knowledge-Based Systems	451
4	Rezaei et al. (2016)	A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method	Journal of Cleaner Production	375
5	Gupta and Barua (2017)	Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS	Journal of Cleaner Production	337
6	Badri Ahmadi et al. (2017)	Assessing the social sustainability of supply chains using Best Worst Method	Resources, Conservation and Recycling	329
7	Rezaei et al. (2015)	Linking supplier development to supplier segmentation using Best Worst Method	Expert Systems with Applications	255
8	Mi et al. (2019)	The state-of-the-art survey on integrations and applications of the best worst method in decision making: Why, what, what for and what's next?	Omega	217
9	Pamučar et al. (2018)	Modification of the Best Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers	Expert Systems with Applications	203
10	Moktadir et al. (2018)	Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection	Process Safety and Environmental Protection	195
11	Gupta and Barua (2016)	Identifying enablers of technological innovation for Indian MSMEs using best-worst multi criteria decision making method	Technological Forecasting and Social Change	191
12	Kusi-Sarpong et al. (2019)	A supply chain sustainability innovation framework and evaluation methodology	International Journal of Production Research	190
13	Gupta (2018)	Evaluating service quality of airline industry using hybrid best worst method and VIKOR	Journal of Air Transport Management	189
14	Ahmad et al. (2017)	Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method	Journal of Cleaner Production	160
15	Lo et al. (2018)	An integrated model for solving problems in green supplier selection and order allocation	Journal of Cleaner Production	157

It was followed by research entitled "Fuzzy best-worst multi-criteria decision-making method and its applications", in which the authors successfully extended the BWM method to a fuzzy environment to deal with uncertainty and ambiguity (Guo & Zhao, 2017). This article is also the first study to adapt BWM to uncertain environments.

The fourth position is occupied by a paper on applying BWM to the supplier selection process (Rezaei et al., 2016). The study focused on environmental sustainability, and a BWM-based application was carried out in the food supply chain.

In fifth place, there was a research paper entitled "Supplier selection among SMEs based on their green innovation ability using BWM and fuzzy TOPSIS" by Gupta and Barua (2017). Integrating crisp BWM and fuzzy TOPSIS methods, the authors solved a supplier selection

problem for SMEs. In the study, BMW was performed to prioritize the factors influencing SMEs' success in green innovation. This is followed by a paper entitled "Assessing the social sustainability of supply chains using Best Worst Method" by Badri Ahmadi et al. (2017). The authors revealed their originality by emphasizing that social sustainability was a neglected dimension until the date of their work. As predicted, BWM was effectively handled to weigh the social sustainability criteria.

A work entitled "Linking supplier development to supplier segmentation using Best Worst Method" by Rezaei et al. (2015) assumed the seventh most cited paper place with 255 citations. In their study, suppliers were analyzed for their capabilities and willingness to collaborate. In the capability dimension, there were eight main criteria and eleven sub-criteria. The willingness to collaborate dimension consisted of four main criteria and their seven sub-criteria. The BWM method was utilized to obtain the global weights of all criteria and sub-criteria.

The eighth position is occupied by a review paper on the application of BWM over three years (Mi et al., 2019). The authors aimed to summarize the achievements of BMW in its early years and to guide future studies. A paper on extending the BWM method with interval-valued fuzzy-rough information occupied the ninth position in the most cited papers list (Pamučar et al., 2018). The authors also conducted a sensitivity and comparison analysis to check their approach's robustness. Using BWM, Moktadir et al. (2018) prioritized challenges for implementing Industry 4.0 for the leather industry in Bangladesh. Among the ten challenges, the technological infrastructure problem of the sector took first place. Eleventh position on the list of most cited articles was the article entitled "Identifying enablers of technological innovation for Indian MSMEs using best-worst multi criteria decision making method" by Gupta and Barua (2016). 4 criteria and 13 enablers were weighted via the BWM method. A supply chain sustainability innovation model by Kusi-Sarpong et al. (2019) was in the twelfth position with 190 citations. The thirteenth article in the list, entitled "Evaluating service quality of airline industry using hybrid best worst method and VIKOR" by Gupta (2018), focused on determining the service quality of the airline industry and was cited 189 times at the time of analysis. The fourteenth most cited paper is Ahmad's et al. (2017), with 160 citations. They assessed the external factors affecting the sustainability of the oil and gas supply chain and found that economic and political stabilities are the first two critical forces. In the last place on the list, a paper that aimed to evaluate and select a proper green supplier was offered by Lo et al. (2018). The authors further optimized order allocation for suppliers considered.

It is revealed that the Journal of Cleaner Production was the most productive journal regarding the number of papers in the list of top-cited papers concerned with BWM research. Four studies have been published in this journal. Omega follows it with three papers. Regarding citation rates, Scopus is one of the most reliable databases from which data can be obtained for bibliometric analyses, although the number of citations for each published document is likely to differ in various databases (Zyoud & Fuchs-Hanusch, 2017).

4.2.3. Most prolific countries

From a country perspective, Table 4 presents the bibliometric performance indicators assessment outcomes for the most prolific countries that have published papers implementing BWM. This analysis realized each country's performance regarding the number of publications

and citations for each year, the proportion of publications and citations, the h-index of the published papers, most preferred journals, and most cited papers. Regarding Table 4, the highest h-index is 38, recorded by Iran, followed by 37 for China, 35 for India, 28 for the US, and 27 for the UK. Concerning the analysis of the most preferred journals among countries, as depicted in Table 4, the Journal of Cleaner Production is the dominant journal. It is the most preferred journal in six of ten countries. Sixty-eight papers are published in this prestigious journal, 13 by Chinese, 11 by Iranians, 11 by the British, 21 by Indians, six by Americans, and six by Dutch researchers. Moreover, Table 4 displays the most cited articles for each country.

Table 4. Most productive countries regarding corresponding authors

Rank			2015	2016	2017	2018	2019	2020	2021	2022	Total	%	h-index	Most preferred journal	Most cited paper
1	China	Paper	–	2	6	12	32	60	85	101	298	27.02	37	J. Clean. Prod. (13)	Fuzzy best-worst multi-criteria decision-making method and its application (Guo & Zhao, 2017).
		Citation	–	–	17	93	418	912	1778	2751	5969	26.78			
2	Iran	Paper	–	1	5	16	24	57	67	112	282	25.57	38	J. Clean. Prod. (11)	ZBWM: The Z-number extension of Best Worst Method and its application for supplier development (Aboutorab et al., 2018).
		Citation	–	1	19	64	235	639	1246	2182	4386	19.68			
3	India	Paper	–	1	2	7	14	33	56	83	196	17.77	35	J. Clean. Prod. (21)	Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS (Gupta & Barua, 2017).
		Citation	–	3	19	76	229	518	1173	2072	4090	18.35			

Continue of Table 4

Rank			2015	2016	2017	2018	2019	2020	2021	2022	Total	%	h-index	Most preferred journal	Most cited paper
4	Turkey	Paper	–	–	–	2	2	19	34	48	105	9.52	23	ESPR (8)	Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model (Ecer & Pamucar, 2020).
		Citation	–	–		1	7	64	391	929	1392	6.25			
5	The UK	Paper	–	–		2	7	16	22	40	87	7.89	27	J. Clean. Prod. (11)	A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case (Yadav et al., 2020).
		Citation	–	–	–	1	54	250	644	1203	2152	9.66			
6	The US	Paper	–	3	2	–	7	8	19	31	70	6.35	28	J. Clean. Prod. (6)	A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method (Rezaei et al., 2016).
		Citation	–	2	3	57	129	269	459	796	1715	7.70			
7	Netherlands	Paper	2	3	6	5	9	16	7	11	59	5.35	15	J. Clean. Prod. (6)	Best-worst multi-criteria decision-making method (Rezaei, 2015).
		Citation	5	22	63	170	668	1053	1450	1770	5201	23.34			

End of Table 4

Rank			2015	2016	2017	2018	2019	2020	2021	2022	Total	%	h-index	Most preferred journal	Most cited paper
8	Taiwan	Paper	–	–	–	2	4	7	16	15	44	3.99	17	Sustainability (7)	An integrated model for solving problems in green supplier selection and order allocation (Lo et al., 2018).
		Citation	–	–	–	5	45	154	264	385	853	3.83			
9	Australia	Paper				2	2	9	13	17	43	3.90	14	ANOR (3)	ZBWM: The Z-number extension of Best Worst Method and its application for supplier development (Aboutorab et al., 2018).
		Citation	–	–	–	7	34	115	291	501	948	4.25			
10	Spain	Paper	–	–	1	1	3	10	6	18	39	3.54	18	ASOC (3)	Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: Fuzzy group BWM-MULTIMOORA-GIS (Rahimi et al., 2020).
		Citation	–	–	–	4	22	91	222	308	647	2.90			

Note: ANOR: Annals of Operational Research, ASOC: Applied Soft Computing, ESPR: Environmental Science and Pollution Research, J. Clean. Prod.: Journal of Cleaner Production.

4.2.4. Most prolific institutions

Table 5 shows the origins of the papers using the BWM method. Concerning Table 5, the leading institution in BWM literature is the University of Tehran, Iran, which published 74 documents (6.71%), followed by the Delft University of Technology, the Netherlands (56; 5.08%), and Islamic Azad University, Iran (38; 3.45%). Although the University of Tehran is in first place in the publication ranking, Delft University of Technology takes first place regarding the citation ranking with 5153 citations. Further, these ten leading universities have 32.91% of publications and 51.14% of citations in the field of BWM. The four Iranian-based institutions are among the most productive institutions. Moreover, one institution each from

Table 5. Top ten most productive institutions

Rank		Country		2015	2016	2017	2018	2019	2020	2021	2022	Total	%	h-index	Rank
1	University of Tehran	Iran	Paper	–	1	4	5	7	12	14	31	74	6.71	22	2
			Citation	–	1	18	49	119	244	368	698	1497	6.72		
2	Delft University of Technology	Nether-lands	Paper	2	3	5	5	9	16	7	9	56	5.08	27	1
			Citation	5	22	63	169	657	1043	1441	1753	5153	23.12		
3	Islamic Azad University	Iran	Paper	–	–	–	2	3	7	5	21	38	3.45	11	7
			Citation	–	–	–	6	23	67	141	227	464	2.08		
4	Vilniaus Gedimino Technikos Universitetas	Lithuania	Paper	–	–	1	4	9	11	6	5	36	3.26	19	3
			Citation	–	–	–	33	98	175	294	378	978	4.39		
5	Daneshgahe Elm va Sanat e Iran	Iran	Paper	–	–	–	2	1	6	8	12	29	2.63	9	8
			Citation	–	–	–	–	–	–	71	159	263	1.18		
6	Allameh Tabataba'i University	Iran	Paper	–	–	–	–	–	–	11	6	29	2.63	12	6
			Citation	–	–	–	–	–	–	102	208	335	1.50		
7	North China Electric Power University	China	Paper	–	–	2	4	3	3	5	10	27	2.45	12	6
			Citation	5	–	8	31	83	162	257	354	900	4.04		
8	Indian Institute of Technology	India	Paper	–	–	–	–	1	4	10	11	26	2.36	11	7
			Citation	–	–	–	–		16	128	353	497	2.23		
9	Hong Kong Polytechnic University	Hong Kong	Paper	–	–	1	3	2	5	8	5	24	2.18	13	5
			Citation	–	–	7	27	66	82	104	181	467	2.10		
10	Sichuan University	China	Paper	–	–	1	1	6	7	4	5	24	2.18	15	4
			Citation	–	–	5	21	48	152	283	335	844	3.79		

the Netherlands, Lithuania, India, and Hong Kong. Regarding the h-index, Delft University of Technology (27) ranks first, followed by the University of Tehran (22), Vilniaus Gedimino Techniko Universitetas (19), and Sichuan University (15), respectively.

4.2.5. The distribution of publications regarding research domains

A significant piece of published documents related to BWM is in the engineering domain (463; 41.98%), as given in Table 6. The most preferred journal in engineering is the Journal of Cleaner Production (63; 5.71%), the country with the highest contributions to this area is China (139; 12.6%), and the most active institution is Delft University of Technology (21; 1.9%). Computer Science (359; 32.55%) and Business, Management, and Accounting (329; 29.83%) followed the Engineering field regarding the number of publications, respectively. Overall,

China is succeeded in being the most active country in eight of these research areas, with 517 documents and a share of 46.88%. Iran is followed by China, which is dominant in six research areas. Iran has 141 publications and a 12.79% share of these publications. Also, India, which has 101 publications and a percentage of 9.16%, is the leader in the field of Business, Management, and Accounting. The Journal of Cleaner Production (252; 22.84%) has the most

Table 6. Main research areas where BMW studies were published

Subject field	no. of publications	%	Most preferred journal	no. of publications	%	Most active country	no. of publications	%	Most active institution	no. of publications	%
Engineering	463	41.98	J. Clean. Prod.	63	5.71	China	139	12.60	Delft University of Technology	21	1.90
Computer science	359	32.55	Comput Ind Eng	25	2.27	China	131	11.88	University of Tehran	22	1.99
Business, management and accounting	329	29.83	J. Clean. Prod.	63	5.71	India	101	9.16	Delft University of Technology	29	2.63
Environmental science	256	23.21	J. Clean. Prod.	63	5.71	China	62	5.62	Delft University of Technology	14	1.27
Energy	203	18.40	J. Clean. Prod.	63	5.71	China	61	5.53	North China Electric Power University	17	1.54
Mathematics	194	17.59	Mathematics	23	2.09	China	86	7.80	North China Electric Power University	10	0.91
Social sciences	193	17.50	Sustainability	44	3.99	Iran	47	4.26	University of Tehran	17	1.54
Decision sciences	175	15.87	Information Sciences	13	1.18	Iran	48	4.35	Delft University of Technology	16	1.45
Economics, econometrics and finance	64	5.80	Socio-Econ. Plan. Sci.	11	1.00	Iran	19	1.72	University of Tehran	7	0.63
Materials science	40	3.63	IEEE Access	15	1.36	China	16	1.45	Ministry of Education China	4	0.36
Medicine	31	2.81	Int. J. Environ. Res. Public Health.	8	0.73	Iran	9	0.82	University of Tehran	4	0.36
Chemical engineering	28	2.54	Applied Sciences	8	0.73	China	10	0.91	Ministry of Education China	3	0.27
Physics and astronomy	28	2.54	Applied Sciences	8	0.73	China	12	1.09	Ministry of Education China	6	0.54
Agricultural and biological sciences	26	2.36	Int J Environ Sci Technol	4	0.36	Iran	9	0.82	University of Tehran	4	0.36
Earth and planetary sciences	23	2.09	ISPRS Int. J. Geo-Inf.	3	0.27	Iran	9	0.82	Islamic Azad University	4	0.36

Note: Comput Ind Eng: Computers and Industrial Engineering, Socio-Econ. Plan. Sci.: Socio-Economic Planning Sciences, Int. J. Environ. Res. Public Health.: International Journal of Environmental Research and Public Health, Int J Environ Sci Technol: International Journal of Environmental Science and Technology, ISPRS Int. J. Geo-Inf.: ISPRS International Journal of Geo-Information.

publications related to BWM in Engineering, Business, management and accounting, Environmental science, and Energy. The University of Tehran (54; 4.88%) is the most active institution in the five research areas, followed by the Delft University of Technology (80; 7.25%) with four research areas and the Ministry of Education China (13; 1.17%) with three research areas, respectively. Although the Delft University of Technology ranks second with four research areas, it ranks first concerning research share, which is remarkable.

5. Bibliometric analysis of articles on BWM

Systematic reviews continue to be frequently criticized for their reliability and objectivity. Various qualitative and quantitative tools have been developed to solve these crucial problems. Among the valuable tools suggested, one of the most reliable and transparent is the bibliometric analysis based on VOSviewer. Thanks to the bibliometric method, current research trends are determined, the most prolific authors, countries, and organizations are pictured, and the most preferred journals are revealed. For performing in-depth analyses, the superiorities of VOSviewer-based bibliometrics are that it is easy to understand, does not require professionalism, and is open source (Alamoodi et al., 2023). Thereby, the present research adopts VOSviewer-based bibliometrics.

Table 7 presents the top 20 frequent author keywords of BWM research. "Best-worst method", as predicted, is the most widely utilized keyword. In the analysis, it is noticed that

Table 7. The top 20 frequent author keywords

Rank	Keyword	Occurrence (Frequency)
1	Best-worst method	666
2	MCDM	189
3	Fuzzy best-worst method	80
4	Sustainability	75
5	Supplier selection	41
6	TOPSIS	40
7	COVID-19	31
8	Fuzzy sets	27
9	Circular economy	26
10	VIKOR	26
11	Sustainable development	26
12	Sensitivity analysis	22
13	Industry 4.0	21
14	Supply chain management	20
15	Barriers	20
16	DEMATEL	18
17	Fuzzy TOPSIS	17
18	Group decision-making	14
19	Blockchain	12
20	Resilience	12

some different keywords have the same meaning. For instance, "best-worst method", "best worst method", "best-worst method (BWM)", "best worst method (BWM)", and "BWM" indicate the same meaning. Consequently, we use the phrase "best-worst method" to handle them to get more accurate results. The following frequent author keyword is MCDM. The "fuzzy best-worst method" takes third place in the list. "Sustainability" and "supplier selection" are the author keywords that follow. "COVID-19", "fuzzy sets", and "circular economy" are other keywords in the top ten of the list. Some effective MCDM methods, such as TOPSIS, VIKOR, and DEMATEL, appear in the keywords list. "Barriers", "sustainable development", "industry 4.0", "blockchain", and "resilience" are also noted.

A wide range of real-life practices for the BWM technique imposes a powerful motivation for classifying documents across various areas in line with Scopus' categorization. In this section, therefore, it is decided the hottest topics of BWM research for each of the top 10 key scientific areas, such as Engineering, Computer Science, Business, Management, and Accounting, Environmental Science, Energy, Mathematics, Social Sciences, Decision Sciences, Economics, Econometrics and Finance, and Materials Science.

5.1. BWM research in the field of Engineering

Bibliometric data from Scopus presents 1502 keywords associated with BWM in the "Engineering", indicating the most popular field among others. The co-occurrence of keywords is analyzed with VOSviewer to display research trends. The co-occurrence threshold of the keywords is adjusted as 6; thus, 38 items are visualized (Figure 4). In network visualization, the size of the circles is proportional to the occurrences of a keyword. In other words, a keyword with a larger circle has been used more in BWM research. The distance between any two keywords indicates relative strength and subject similarity. Circles in the identical color cluster recommend a similar subject across these documents (Guo et al., 2019). So, as noted above, we discover six primary clusters, each depicting a subfield of BWM. To date, sustainability, sustainable development, industry 4.0, supply chain management, risk assessment, sustainable supply chain management, and blockchain have been the primary research areas that focus on BWM-related research in the field of engineering. It is also understood that some well-known MCDM methods, such as TODIM, VIKOR, MULTIMOORA, COPRAS, DEA, FUCOM, EDAS, MABAC, DEMATEL, WASPAS, QFD, and TOPSIS, are performed with BWM or fuzzy extensions of BWM. To deal with uncertainty better, BWM was also expanded with fuzzy theory (fuzzy BWM, interval type-2 fuzzy BWM, hesitant fuzzy linguistic BWM, and probabilistic linguistic BWM), rough theory, D numbers, and Z numbers. However, it can be noted that some essential themes, such as transportation, manufacturing, product development, facility location, technology, innovation, construction, risk management, and smart cities, are not adequately addressed in BWM research.

5.2. BWM research in the field of Computer Science

In "Computer Science", bibliometric data offers 1116 keywords concerning BWM. As illustrated in Figure 5, 38 items are visualized when the co-occurrence threshold of the keywords is adjusted as 4. In this field, researchers concentrate more on the keywords, including blockchain, cloud computing, cloud service provider, failure mode and effect analysis, and risk assessment.

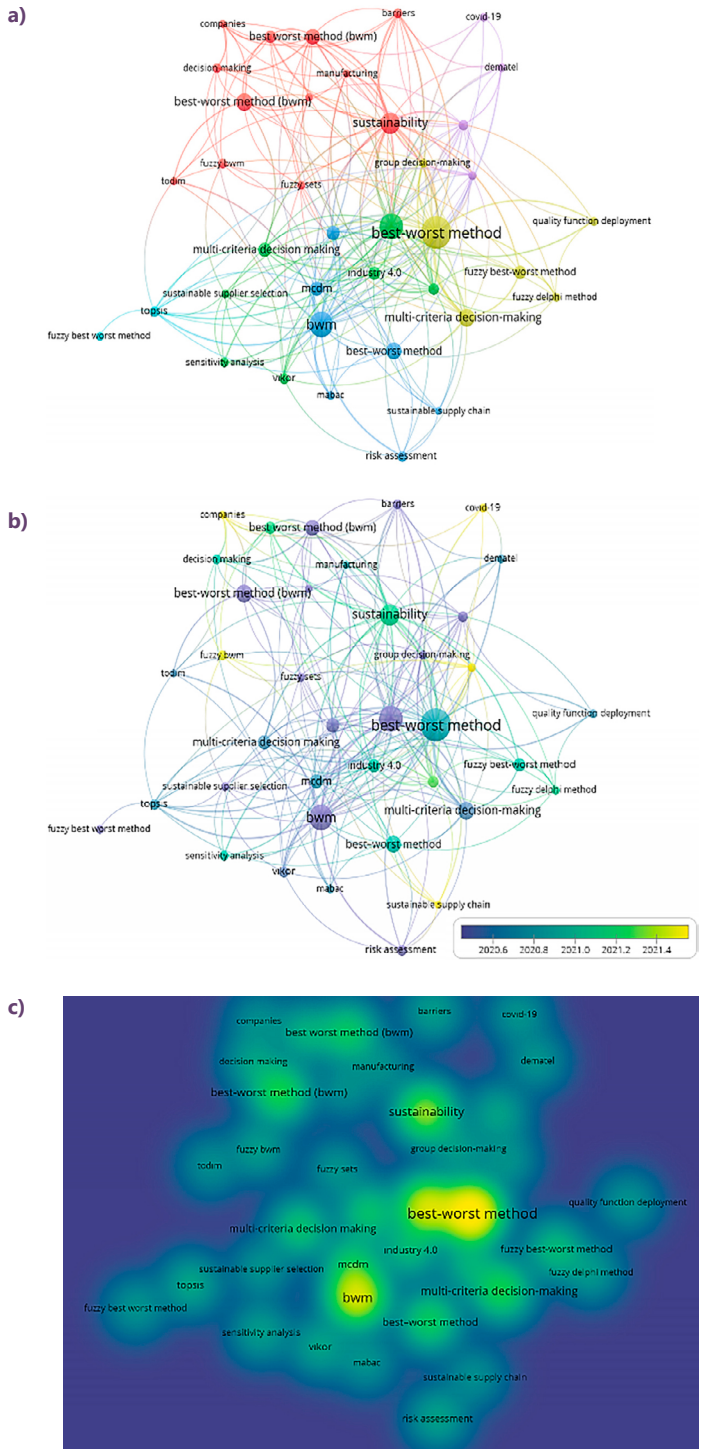

Figure 4. Co-keyword network visualization on BWM research in Engineering: a – Network visualization; b – Overlay visualization; c – Density visualization

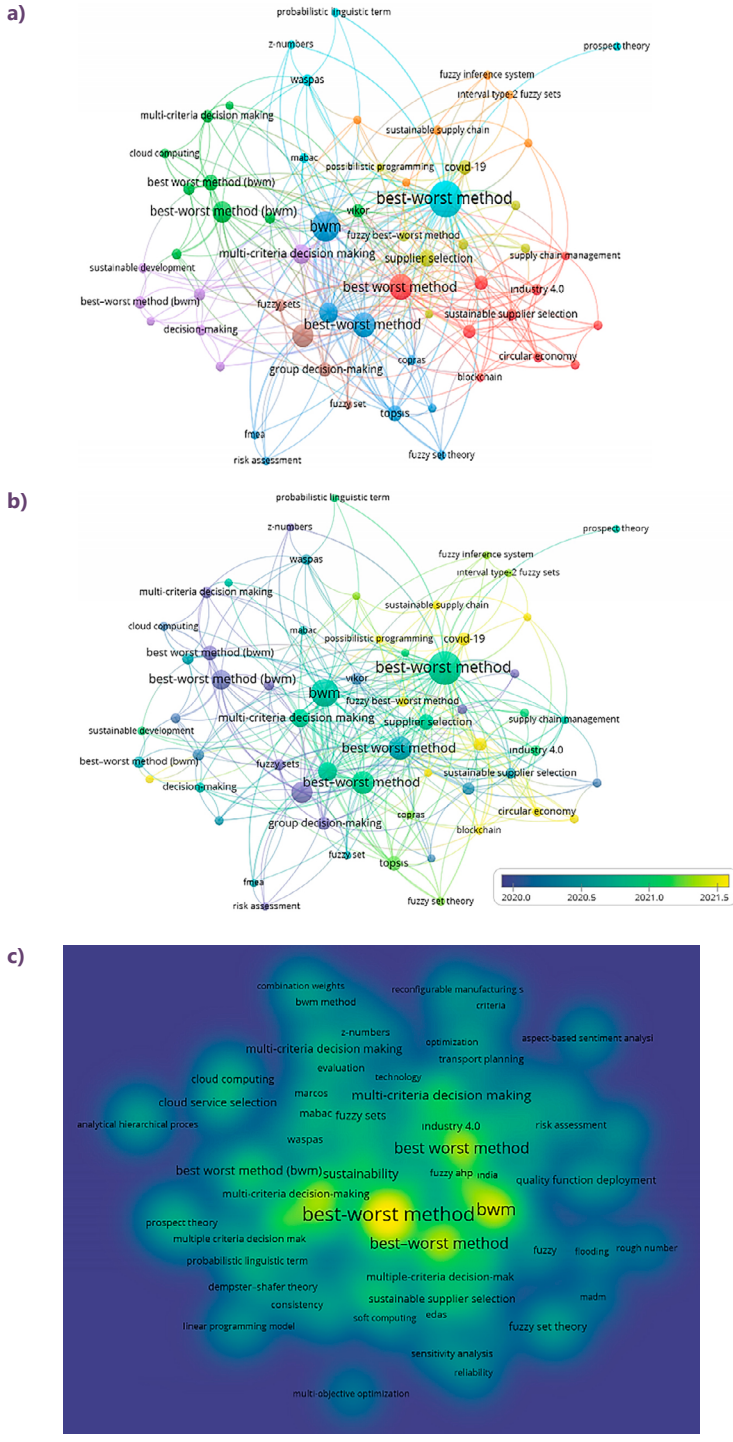

Figure 5. Co-keyword network visualization on BWM research in Computer Science: a – Network visualization; b – Overlay visualization; c – Density visualization

As per Figure 5b, blockchain, circular economy, sustainability, COVID-19, sustainable supply chain management, goal programming, and possibilistic programming highlight the freshest research areas. BWM has been used with ordinary fuzzy sets, type-2 fuzzy sets, probabilistic linguistic term sets, Z numbers, and fuzzy inference systems in computer science. Moreover, the most preferred multi-criteria techniques are VIKOR, COPRAS, TOPSIS, WASPAS, and QFD. On the other hand, BWM studies focused on zero-sum game theory, multi-objective optimization, and q-rung orthopair fuzzy sets have significant potential.

5.3. BWM research in the field of Business, Management, and Accounting

The co-occurrence of author keywords is analyzed with a minimum number of occurrences of a keyword as at least 3. Only 88 of the 1,120 keywords in this field meet the threshold. Supply chain management (i.e., food supply chain, humanitarian supply chain, halal supply chain, cold supply chain, sustainable supply chain, green/sustainable/resilience supplier selection), finance (i.e., investment, risk mitigation, risk identification), sustainable development and circular economy (i.e., green products, reverse logistics, green manufacturing, green innovation, social sustainability), knowledge management, R&D, technological innovation, site selection, performance evaluation, geographic information systems, performance measures, SMEs, service quality, cloud service, digitalization, flexibility, freight transportation, and lean six sigma are among the highlights of research that used BMW and promises for the future. Integrating BWM with the following MCDM methods is noteworthy: TODIM, MARCOS, TOPSIS, DEA, ELECTRE, ANP, DEMATEL, AHP, ARAS, PROMETHEE, and SAW. Moreover, in this area, various obscure extensions of BWM (i.e., Fuzzy BWM, hesitant fuzzy linguistic BWM, probabilistic fuzzy linguistic BWM, and Bayesian BWM) are used to facilitate decision-making. Finally, game theory, grey theory, and the Delphi technique are considered by researchers (Figure 6).

5.4. BWM research in the field of Environmental Science

The co-occurrence of author keywords is checked with a minimum number of occurrences of a keyword adjusted to 3. Solely 68 of the 834 keywords in this domain meet the threshold. The hotspot subjects of research that handled BWM as a decision tool and will continue to be critical in the future contain life cycle assessment, recycling, waste management, waste minimization, municipal solid waste management, environmental performance, land suitability, geographic information systems, site selection, reverse logistics, construction, green roof, renewable energy, solar energy, sustainable energy, circular/food/green/sustainable supply chain, circular economy, risk management, risk prioritization, risk assessment, blockchain, transparency, social sustainability, and performance evaluation. The MCDM methods combined with BWM in Environmental Science research are as follows: COCOSO, TOPSIS, TODIM, VIKOR, AHP, ANP, COPRAS, FUCOM, SWARA, MULTIMOORA, GRA, DEMATEL, and MABAC. Additionally, fuzzy BWM, IT2F-BWM, Bayesian BWM, rough BWM, and hesitant fuzzy linguistic BWM approaches have been proposed to deal with uncertainty more easily in this area (Figure 7).

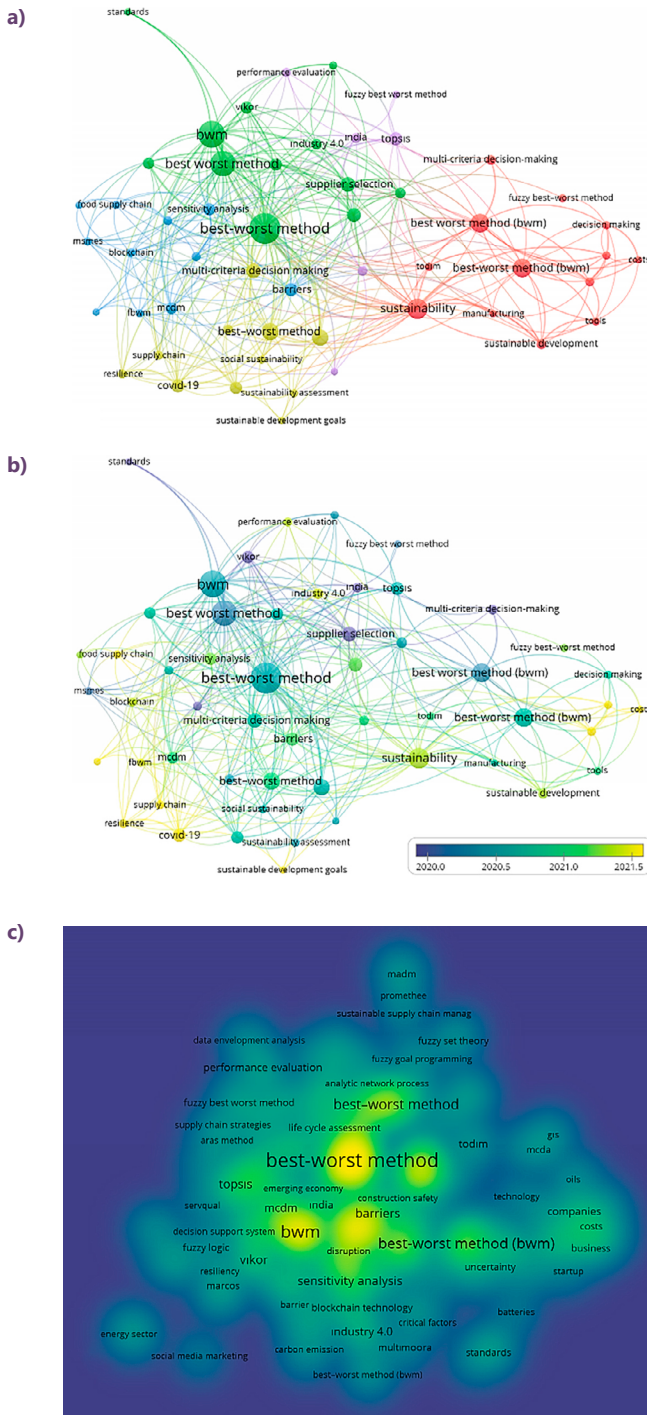

Figure 6. Co-keyword network visualization on BWM research in Business, Management, and Accounting: a – Network visualization; b – Overlay visualization; c – Density visualization

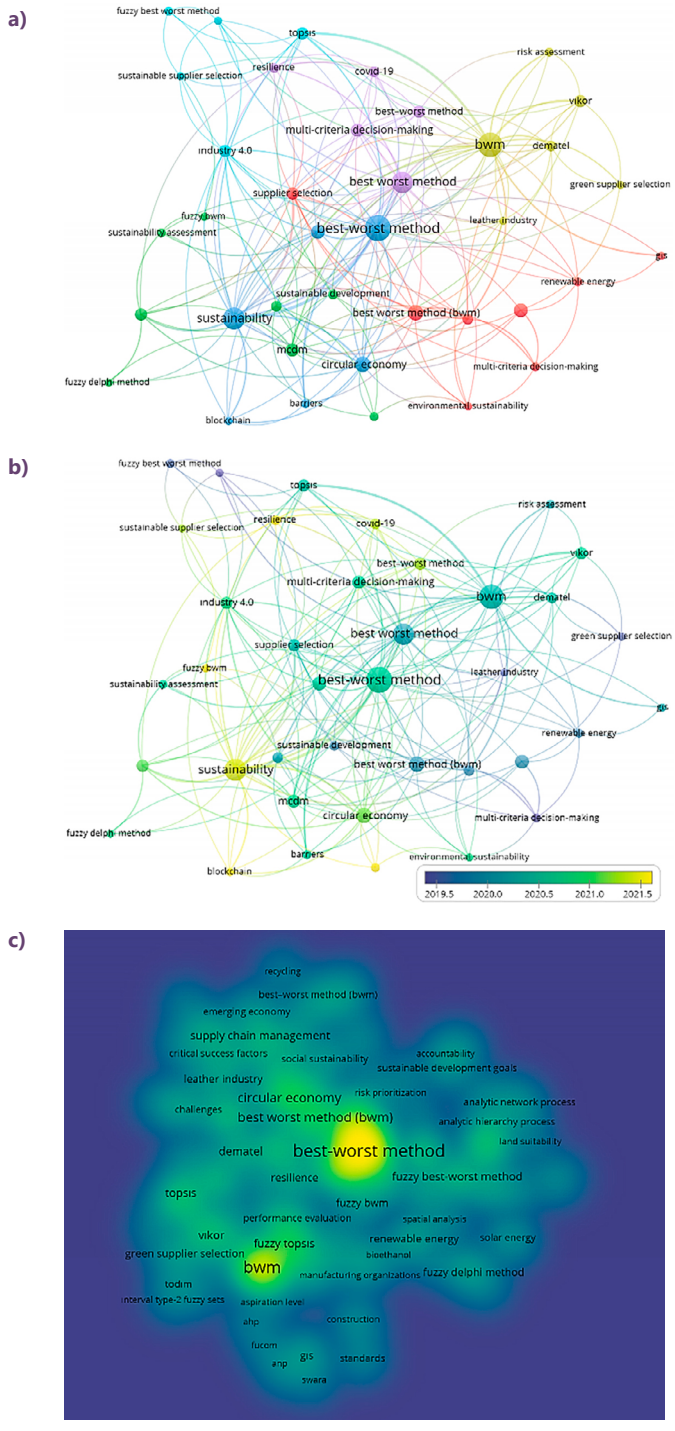

Figure 7. Co-keyword network visualization on BWM research in Environmental Science: a – Network visualization; b – Overlay visualization; c – Density visualization

5.5. BWM research in the field of Energy

The co-occurrence of author keywords is determined with a minimum number of occurrences of a keyword adjusted to 3. Merely 54 of the 680 keywords in this domain meet the threshold. The active subjects of research that utilized BWM as a decision support vehicle and will continue to be crucial in the future enclose geographic information systems, solar energy, wind energy, airborne wind energy systems, bioenergy, bioethanol, hybrid renewable energy systems, hydrogen production technology, sludge-to-energy technology, waste minimization, site selection, construction, landfill site selection, environmental sustainability, environmental performance, critical success factors, renewable energy supply chain, demand side management, sustainable development, circular economy, and technology. AHP, ANP, MARCOS, TOPSIS, TODIM, and WASPAS are multi-criteria methods integrated with BWM, whereas fuzzy BWM, Bayesian BWM, rough BWM, and fuzzy goal programming are the methodologies suggested for decision-making effectively in the field of energy (Figure 8).

5.6. BWM research in the field of Mathematics

The co-occurrence of author keywords is decided with a minimum number of occurrences of a keyword adjusted to 2. Only 78 of the 653 keywords in this domain meet the threshold. In the domain of Mathematics, the authors concentrate more on the keywords, including fuzzy sets, interval type-2 fuzzy sets, probabilistic linguistic fuzzy sets, fuzzy BWM, fuzzy inference systems, group decision-making, linear programming, goal programming, prospect theory, soft computing, Z numbers, Bayesian BWM, MABAC, QFD, TOPSIS, MOORA, MULTIMOORA, EDAS, COPRAS, and VIKOR. Furthermore, the hot themes of BWM research in this area cover COVID-19, GIS, supply chain management, risk management, supplier selection, sustainability, failure mode and effect analysis, reliability, performance evaluation, construction projects, new energy vehicles, consensus, site selection, standards battles, and road safety (Figure 9).

5.7. BWM research in the field of Social Sciences

The co-occurrence of author keywords is decided with a minimum number of occurrences of a keyword adjusted to 2. Only 89 of the 666 keywords in this domain meet the threshold. Furthermore, the hot subjects of BWM research in this area contain Industry 4.0, technology, quality, SERVQUAL, sustainable credit scoring, aviation, standardization, risk management, risk mitigation, risk identification, business strategy, efficiency, land valuation, site selection, critical success factors, sustainable development, resilience, accountability, COVID-19, GIS, supply chain management, food/humanitarian/sustainable supply chain, supplier selection, sustainability, air pollution, carbon emissions, and renewable energy. Moreover, DEMATEL, QFD, WASPAS, ANP, PROMETHEE, TOPSIS, MULTIMOORA, MARCOS, AHP, SAW, and VIKOR are the MCDM methods that are heavily preferred in this field. However, of the uncertain extensions of BWM, only rough BWM, Bayesian BWM, and fuzzy BWM are detected (Figure 10).

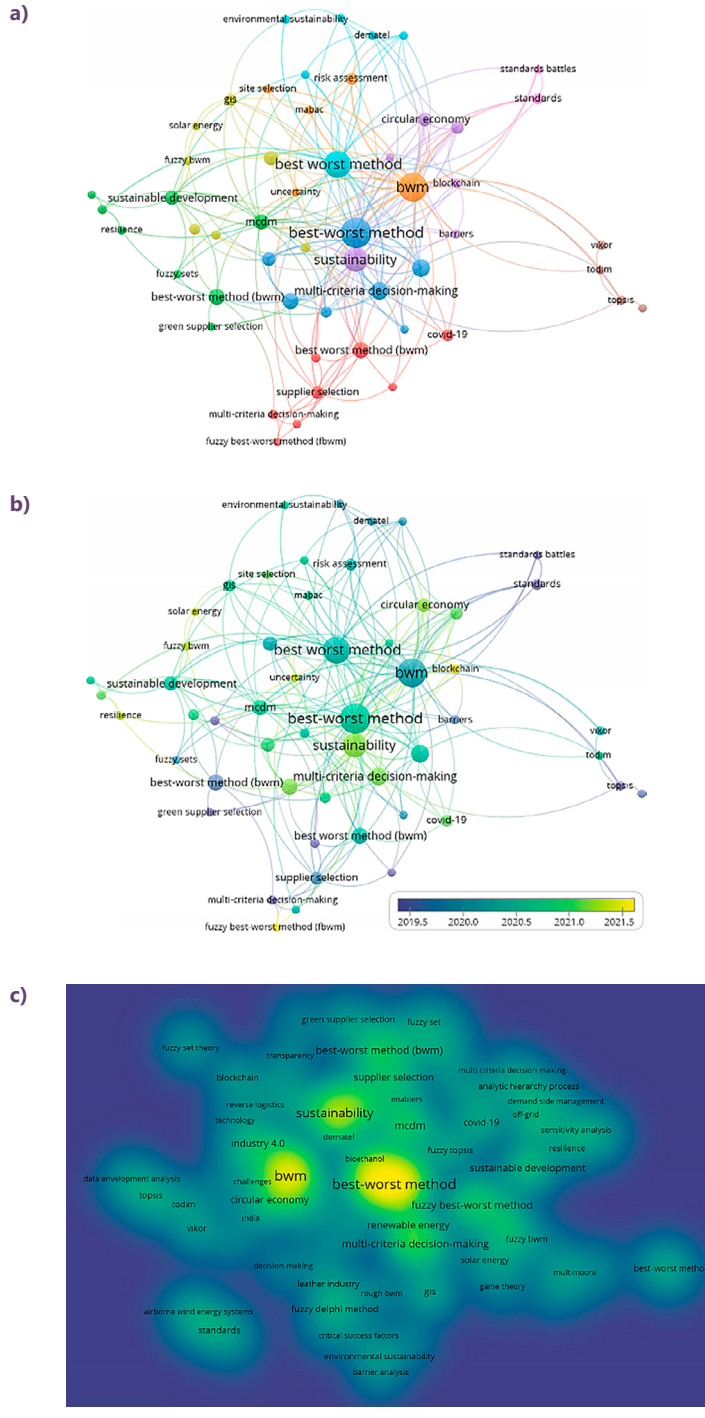

Figure 8. Co-keyword network visualization on BWM research in Energy: a – Network visualization; b – Overlay visualization; c – Density visualization

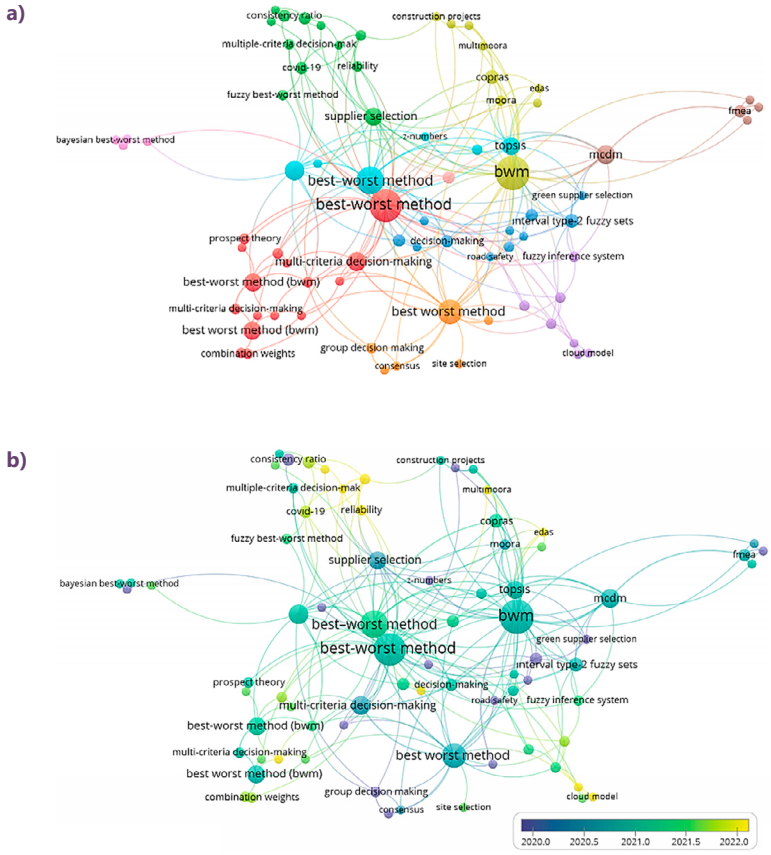

Figure 9. Co-keyword network visualization on BWM research in Mathematics: a – Network visualization; b – Overlay visualization; c – Density visualization

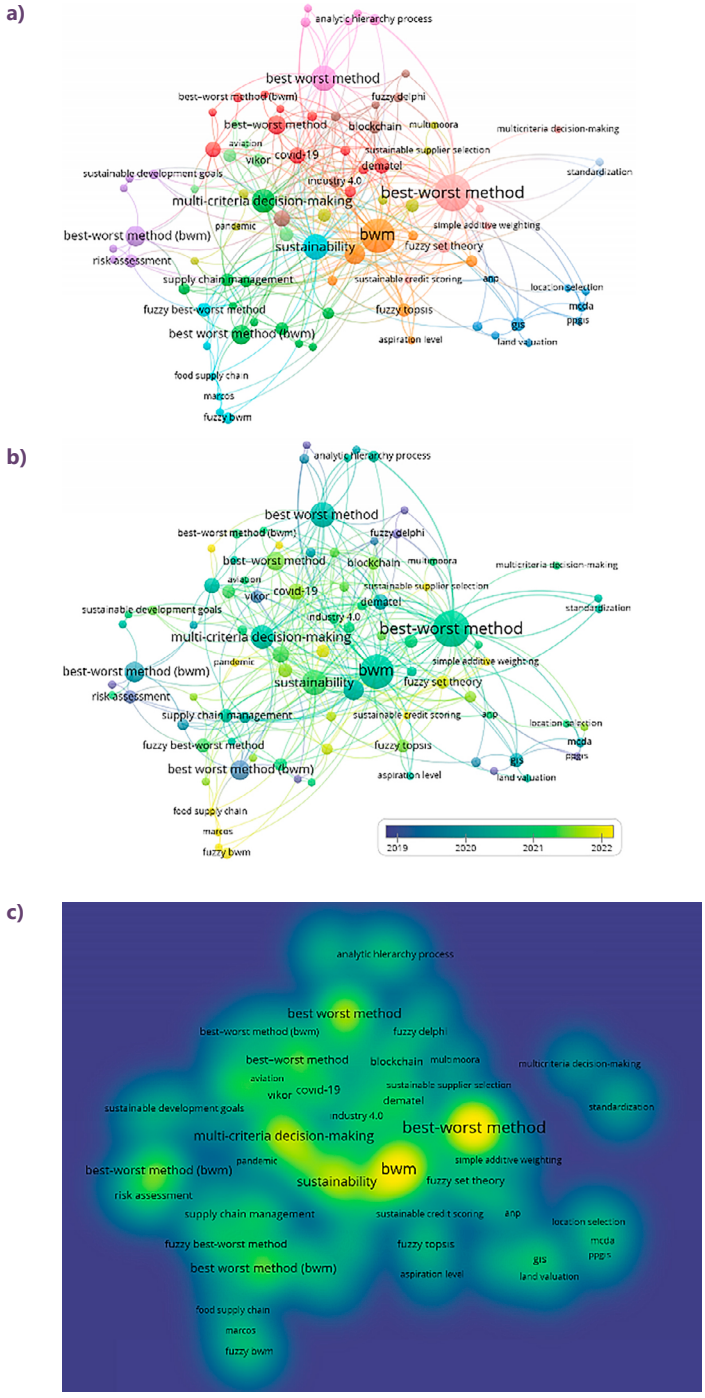

Figure 10. Co-keyword network visualization on BWM research in Social Sciences: a – Network visualization; b – Overlay visualization; c – Density visualization

5.8. BWM research in the field of Decision Sciences

The co-occurrence of author keywords is decided with a minimum number of occurrences of a keyword adjusted to 2. Merely 82 of the 591 keywords in this domain meet the threshold. In this field, consistency, fuzzy Delphi, pairwise comparison, sensitivity analysis, ranking, big data analytics, cognitive bias, dominant designs, and robust optimization are the hot topics of research that used BWM. Further, MABAC, MAIRCA, TOPSIS, VIKOR, MARCOS, AHP, TODIM, QFD, MULTIMOORA, DEA, and DEMATEL are the fresh MCDM methods that performed with BWM. We clarify that BWM is used with only traditional fuzzy information, rough information, and interval type-2 fuzzy information. Yet, we notice that BWM uses only traditional fuzzy, rough, and interval type-2 fuzzy information in this domain (Figure 11).

5.9. BWM research in the field of Economics, Econometrics, and Finance

The co-occurrence of author keywords is decided with a minimum number of occurrences of a keyword adjusted to 2. Only 32 of the 259 keywords in this domain meet the threshold. The hot subjects of research that used BWM are resiliency, efficiency, barrier, and COVID-19. In this area, the following MCDM methods are used: COSOSO, MARCOS, TOPSIS, VIKOR, and DEMATEL. Last, it is identified that BWM uses only traditional fuzzy information (Figure 12).

5.10. BWM research in the field of Materials Science

The co-occurrence of author keywords is decided with a minimum number of occurrences of a keyword adjusted to 2. Solely 19 of the 180 keywords in this field meet the threshold. The most current research areas using BWM are supplier selection, cloud computing, cloud service provider, optimization, sensitivity analysis, and sustainable development, whereas TOPSIS and AHP are the multi-criteria methods combined with BWM. To deal with vagueness and ambiguity effectively, only traditional fuzzy extension of BWM is considered in this field. To deal with vagueness and ambiguity effectively, only the traditional fuzzy extension of BWM is regarded in this field (Figure 13).

6. Current situation and future research directions

This section is divided into two sub-sections. First, the current state of BWM research is addressed. Next, future study directions are detailed based on research gaps.

6.1. The current status of BWM research

According to a comprehensive overview, the current status can be summarized as follows.

- Journal of Cleaner Production ranks 1st in BWM research regarding the total number of publications, total citations, and average citations. Regarding the total number of publications, Sustainability is in 2nd place, whereas Computers and Industrial Engineering is in 3rd place. Concerning the total number of citations, Expert Systems with Applications is the 2nd and Computers and Industrial Engineering is the 3rd most successful journal. Additionally, Expert Systems with Applications ranks 2nd regarding average citation count, followed by Sustainability.

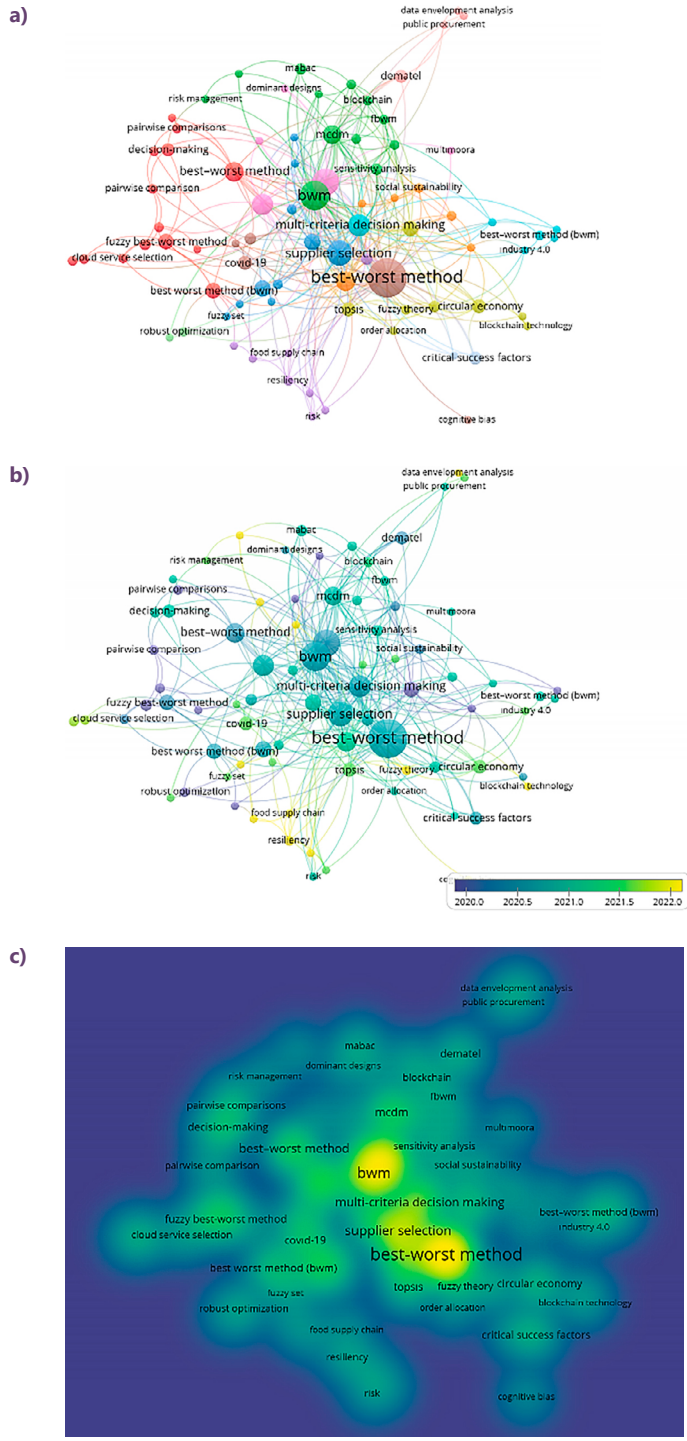

Figure 11. Co-keyword network visualization on BWM research in Decision Sciences: a – Network visualization; b – Overlay visualization; c – Density visualization

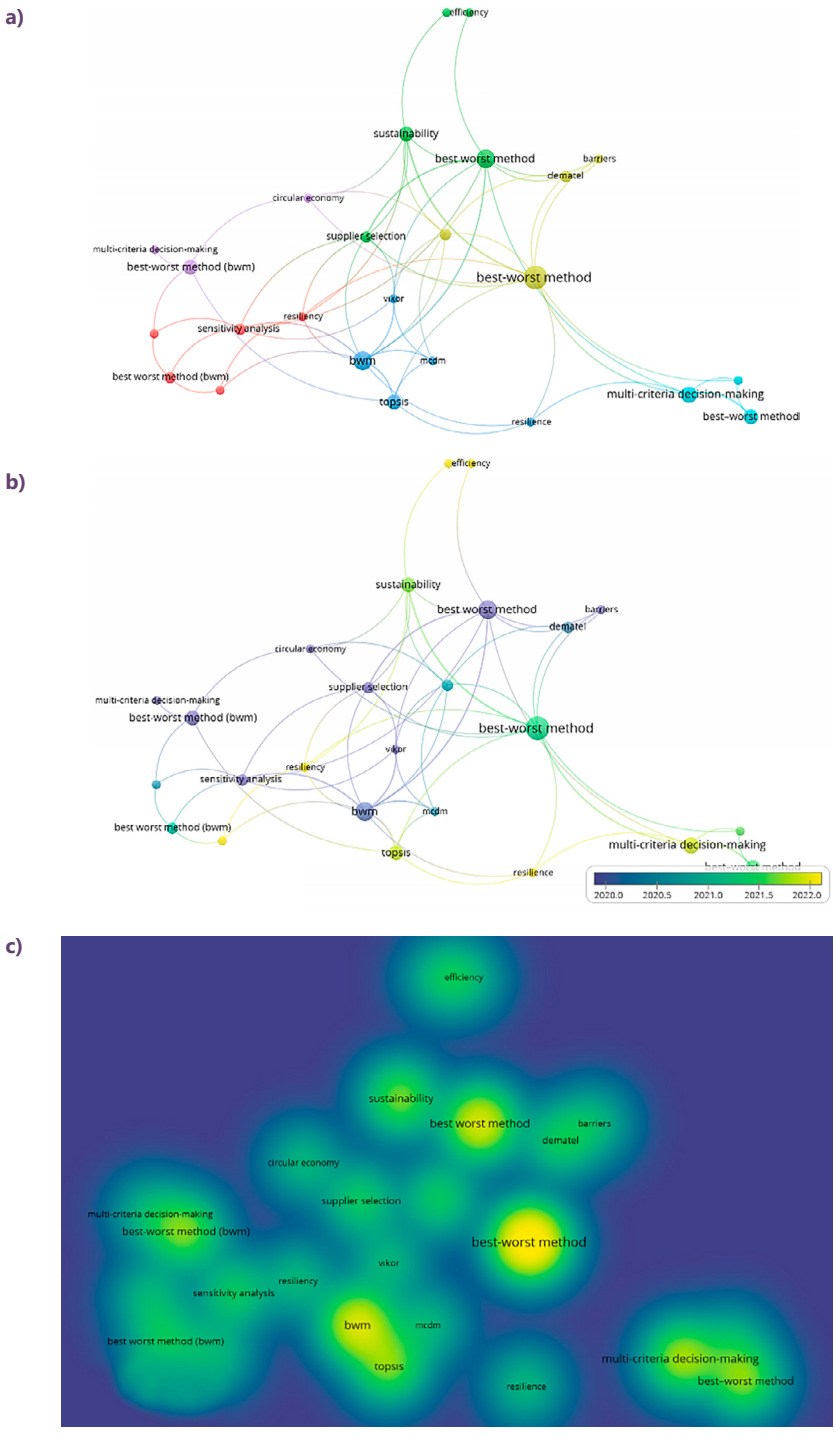

Figure 12. Co-keyword network visualization on BWM research in Economics, Econometrics, and Finance: a – Network visualization; b – Overlay visualization; c – Density visualization

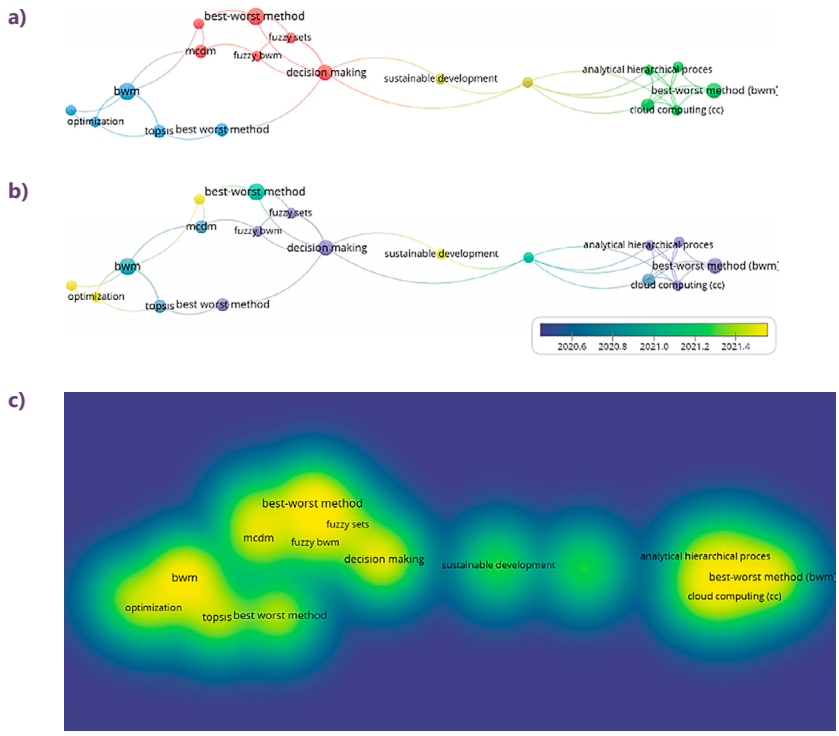

Figure 13. Co-keyword network visualization on BWM research in Materials Science: a – Network visualization; b – Overlay visualization; c – Density visualization

- Rezaei, J., the inventor of the BWM method, is the first researcher in terms of the total number of publications, total citations, and average citations.
- Among the most cited publications, Rezaei, J. has three documents.
- China is the most prolific country in BWM research, followed by Iran, India, and Turkey.
- University of Tehran, Delft University of Technology, and Islamic Azad University are the most prolific institutes, respectively. Given the h-index, Delft University of Technology is the leading institution.
- BWM attracts the most attention in the fields of Engineering, Computer Science, Business, Management, and Accounting, Environmental Science, and Energy.
- Journal of Cleaner Production is the most preferred journal in the fields of Engineering, Business Management and Accounting, Environmental Science, and Energy, whereas Computers and Industrial Engineering rank first in Computer Science.
- Of the 15 scientific areas with the most BWM research, China is the most active country in 8, Iran in 6, and India in only one.
- Notably, the keywords, including sustainability, supplier selection, COVID-19, fuzzy sets, circular economy, sustainable development, sensitivity analysis, industry 4.0, supply chain management, barriers, DEMATEL, fuzzy TOPSIS, group decision-making, blockchain, and resilience, are related to hot topics for the BWM research in the whole scientific fields.

- Specifically, sustainability, sustainable development, industry 4.0, supply chain management, risk assessment, and blockchain are hotspots in Engineering, whereas blockchain, cloud computing, cloud service provider, failure mode and effect analysis, and risk assessment are in Computer Science, supply chain management, investment, risk mitigation, green products, reverse logistics, green manufacturing, green innovation, social sustainability, knowledge management, R&D, technological innovation, site selection, performance evaluation, geographic information systems, performance measures, SMEs, service quality, cloud service, digitalization, flexibility, freight transportation, and lean six sigma are in Business, Management, and Accounting, life cycle assessment, recycling, waste management, environmental performance, land suitability, geographic information systems, site selection, reverse logistics, construction, green roof, renewable energy, solar energy, sustainable energy, supply chain management, circular economy, risk management, risk prioritization, risk assessment, transparency, social sustainability, and performance evaluation are in Environmental Science, geographic information systems, solar energy, wind energy, airborne wind energy systems, bioenergy, bioethanol, hybrid renewable energy systems, hydrogen production technology, sludge-to-energy technology, waste minimization, site selection, construction, landfill site selection, environmental sustainability, environmental performance, critical success factors, renewable energy supply chain, demand side management, sustainable development, circular economy, and technology are in Energy, fuzzy sets, interval type-2 fuzzy sets, probabilistic linguistic fuzzy sets, fuzzy BWM, fuzzy inference systems, group decision-making, linear programming, goal programming, prospect theory, soft computing, and Z numbers are in Mathematics, industry 4.0, technology, quality, SERVQUAL, sustainable credit scoring, aviation, standardization, risk management, risk mitigation, risk identification, business strategy, efficiency, critical success factors, sustainable development, resilience, accountability, COVID-19, geographic information systems, supply chain management, supplier selection, sustainability, air pollution, carbon emissions, and renewable energy are in Social Sciences, fuzzy Delphi, pairwise comparison, sensitivity analysis, ranking, big data analytics, cognitive bias, dominant designs, and robust optimization are in Decision Sciences, resiliency, efficiency, barrier, and COVID-19 are in Economics, Econometrics, and Finance, and finally, supplier selection, cloud computing, cloud service provider, optimization, sensitivity analysis, and sustainable development are in Materials Science.
- To make BWM more valuable and feasible when addressing challenging problems, it was integrated or compared with outranking-based MCDM methods, including PROMETHEE (Wu et al., 2023) and ELECTRE (Nghiem & Chu, 2022), ranking-based MCDM methods, including TOPSIS (Wu et al., 2022; Polat et al., 2023), COCOSO (Torkayesh et al., 2021; Ali et al., 2023), MARCOS (Yadav & Kumar, 2023; Ecer et al., 2024), VIKOR (Jain et al., 2023), QFD (Chang et al., 2023), WASPAS (Tavakoli Haji Abadi & Avakh Darestani, 2023), MOORA (Riahi et al., 2023), MULTIMOORA (Koppiahraj et al., 2023), SAW (Darvazeh et al., 2022), TODIM (Kumar et al., 2023), COPRAS (Sahraei et al., 2023), GRA (Hsu et al., 2023), MABAC (Chauhan et al., 2022), DEA (Eskandari et al., 2022), ARAS (Almutairi et al., 2023), and EDAS (Liang et al., 2023), weighting-based MCDM methods, including AHP (Koppiahraj et al., 2023), ANP (Nasiri Khiavi et al., 2023), DEMATEL

(Bongo & Seva, 2023), FUCOM (Fazeli & Peng, 2023), and SWARA (Karakuş, 2023), some theories, including game theory (Fard et al., 2022), grey theory (Ulutaş et al., 2022), prospect theory (Zheng et al., 2023), and zero-sum game theory (Li et al., 2021), and mathematical programming, including goal programming (Do et al., 2023), and possibilistic programming (Shaw et al., 2023).

- To handle problems with uncertain, incomplete, and ambiguous information, researchers improved BWM with ordinary fuzzy sets (Ahmad et al., 2023), interval type-2 fuzzy sets (Chen et al., 2022; Aycin et al., 2022), hesitant fuzzy sets (Karbassi Yazdi et al., 2023), hesitant fuzzy linguistic term sets (Liang et al., 2022; Liao et al., 2019), probabilistic linguistic term sets (Xian et al., 2023; Xu et al., 2022; Liu et al., 2022), q-rung orthopair fuzzy sets (Xiao et al., 2022), Z numbers (Abbasi Kamardi et al., 2022), D numbers (Navaei et al., 2023), Bayesian theory (Hashemkhani Zolfani et al., 2022), and rough sets (Huang et al., 2022).

6.2. Future research directions

Future work on BWM may be extended in diverse directions. In terms of implementation, scientific areas, research topics, decision support software for BWM, and BWM's uncertain extensions are among notable future directions. Below are several significant future directions in BWM research.

- Although BWM is frequently used as a decision-making tool in some areas, such as Engineering, Computer Science, Business, Management, and Accounting, Environmental Science, and Energy, other scientific fields have a big potential for BWM research in the future, such as Medicine, Physics and astronomy, Agriculture, and Earth sciences.
- Some BWM studies were not cited at all. It is recommended that researchers from different countries collaborate in the future. Collaboration with researchers who stand out with their BWM studies may also be considered.
- In the future, sustainability, technology, supply chain management, blockchain, circular economy, waste management, and renewable energy studies could continue to be active BWM areas. However, BWM also has the potential to be extended to various current issues, such as Metaverse, Industry 5.0, carbon footprint, clean vehicles, cryptocurrencies, etc.
- Artificial intelligence and machine learning approaches can improve the abilities of multi-criteria techniques. Yet, they are usually missed in an integrated manner in the BWM research, such as neural networks, random forests, k-nearest neighbors, reinforcement learning, support vector machines, genetic algorithms, particle swarm optimization, etc.
- The MCDM field is a subfield of decision-making theory that is dramatically growing with new methods developed. Thence, the BWM method could be integrated manner new multi-criteria methods in the future, such as Logarithmic Additive Weights (LMAW), Dombi Bonferroni (DOBI), Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval (RAFSI), Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS), Alternative Ranking Order Method Accounting for two-step Normalization (AROMAN), etc.

- Aggregation operators, used to aggregate the judgments of decision-makers when making decisions in a group, are rarely used in BWM research. Future research may benefit from aggregation operators, such as Schweizer-Sklar, Einstein, Dombi, Hamy, Aczel-Alsina, Maclaurin, Bonferroni, Hamacher, Frank, Heronian, etc.
- BWM was either too scarcely extended or not at all extended to intuitionistic fuzzy sets (Chen et al., 2023), Fermatean fuzzy sets (Zeng et al., 2023), Pythagorean fuzzy sets (He et al., 2022), picture fuzzy sets (Liu et al., 2021), neutrosophic fuzzy sets (Li & Yazdi, 2022), spherical fuzzy sets (Bonab et al., 2023), soft sets (Zhang et al., 2020), hypersoft sets, and plithogenic sets (Sudha & Martin, 2022). Uncertain extensions of the BWM method will be more active research areas in the future. So, future work can focus on generating BWM frameworks that cover uncertainty modeling.
- Future research could as well discover the implementation of multi-objective evolutionary optimization models in decision-making procedures, combining those algorithms with the BWM method.
- A decision support software for BWM and its uncertain extensions is needed to enhance calculation speed and reliability. This software can allow practitioners and scholars to use BWM effectively and widely. Though Rezaei (2015) developed an Excel solver for BWM solutions, a new software may allow BWM to be preferred more and thus become more popular.

7. Conclusions

This study presents the big picture of current research on BWM, identifies critical research gaps, and intends to create a future research agenda. This research aims to analyze the developmental levels, leader countries, the most influential individuals, institutions, and journals as well as collaboration networks and citation numbers in areas of research concerning BWM's applications. This study stems from the truth that BWM research covers literature from various scientific disciplines. Giving detailed information on this subject, which is of great interest to researchers, and putting forward the future research agenda will contribute to advancing BWM research.

Data from Scopus were used in the study for bibliometric analysis, but Web of Science data could not be included. Thus, one of the study's limitations is that the data in Web of Science could not be used in the analysis. Further, since it was not possible, the time interval considered for the bibliometric analysis had to be kept somewhat narrow. Assuming that the dramatic increase in BWM studies will continue, it can be noted that studies to be carried out after a few years are better able to fill the gaps in the literature.

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