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The Exploration of Hybrid Metaheuristics-Based Approaches: A Bibliometric Analysis

Nur Hidayah Azmidi[1], Noryanti Muhammad[1,*], Rozieana Khairuddin[1]

[1] Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300 Kuantan, Pahang Darul Makmur, Malaysia

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ABSTRACT

The rapid evolution of computational intelligence has driven significant interest in hybrid metaheuristics, which combine multiple optimization algorithms to solve complicated problems more efficiently. This study performs a comprehensive bibliometric analysis of hybrid metaheuristics-based approaches aimed at exploring the landscape in scientific literature. Employing an analysis of publications, this study maps the historical development, key terms and the most dominant works in this field. The analysis is conducted using data extracted from the bibliometric database, which is Web of Science (WoS), covering publications from 2020 to 2024 with a keyword associated with hybrid metaheuristics. Utilizing the R Studio with Bibliometrix package and Shiny UI, the bibliometric study uncovered the thematic structure of the research area using co-occurrence network, revealed the intercorrelation concepts, represented the central themes and the evolution of research focus over 5 years through word clouds, Sankey diagram and others. The study findings indicate a growing and broader trend towards the integration of metaheuristics and optimization algorithms, echoing the interdisciplinary nature of this domain. The findings also highlighted the diversity of applications in this field such as artificial intelligence and cloud computing, underscoring the relevancy of hybrid metaheuristics. The identification of leading authors and institutions contributed to a better insight of their contributions in this field. The overall knowledge of this bibliometric study is expected to guide the researchers in their future study to identify the emerging trends and understand the impact of their work.

1. Introduction

The field of optimization is known has been essential for operational research, mathematical programming and computer science for decades. It involves the development of methods and algorithms to find the best solution within a defined problem [1]. As computational abilities have advanced and the complexity of problem had increased day by day, traditional method of optimization have been extended and sometimes vanished by metaheuristics approaches. Osman *et*

* *Corresponding author.*
E-mail address: noryanti@umpsa.edu.my

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al., [2] defined a metaheuristic as an iterative algorithm designed to strengthen simpler heuristics by combining multiple theories for exploring and exploiting strategically and used the learning approaches to organize information to find near optimal solutions efficiently. Since the first metaheuristic was proposed, extensive improvements have been made, and a lot of new algorithms have been proposed over the years. A study by Mahdavi *et al.,* [3] has recognized that metaheuristics algorithms can effectively solve high-dimensional problems in various domains, with applications in business, engineering, economics and science. Lameesa *et al.,* [4] mentioned that the metaheuristic algorithm has been an effective computational tool over the years to address a complex optimization problem in many areas. Due to its flexibility and ability, metaheuristics have become particularly prominent and making them relevant for various fields of applications.

However, the essential understanding among exploration and exploitation in metaheuristics has led to the research of hybrid approaches. The concept of hybridization in metaheuristics is not new plus, the literature on hybrid metaheuristics has expanded rapidly. Due to the advancement and intricacy of optimization problems nowadays, researchers are trying to adopt more dynamic algorithms to solve them by combining two or more algorithms. Nassef *et al.,* [5] mentioned that the collaboration of two or more algorithms in hybrid structure has presented very good advancements in term of algorithms' performance. Additionally, according to Hassan *et al.,* [6], hybrid metaheuristics have demonstrated their effectiveness to solve complex problems.

Despite the growing interest in hybrid metaheuristics, there is a need for an understanding of the current reliability of this method. Hence, this study conducted a bibliometric analysis to understand a broader context of hybrid metaheuristics in recent years. The bibliometric analysis aims to equip a broad review of the research landscape by identifying the trends, recent studies and the emerging areas of interest. This type of analysis is crucial to understand how hybrid metaheuristics have evolved over the years and how they have been applied to various fields. It involves systematic reviews of a huge number of scientific publications, citation patterns and collaboration networks. On important aspects of the bibliometric analysis is the identification of major research themes and keywords within the field. For example, studies may focus on the expansion of new hybrid algorithms, comparative analysis of different metaheuristic techniques or the integration of hybrid metaheuristics with other machine learning methods. Besides, the analysis could discover the research focus over time and understanding this trend would help to highlight the areas that have received the most attention and might benefit future research.

Therefore, the research is directed towards answering the following research question: What are the key research trends, thematic areas, and emerging directions in the field of hybrid metaheuristics as revealed through bibliometric analysis?

2. Related Works

Researchers have been concentrating on combining multiple algorithms into a new hybrid algorithm. Previously, several research studies have shown the favorable implementation of hybrid metaheuristics algorithms. The aim of combining algorithms through hybridization is to boost the overall performance of each algorithm and reduce their disadvantages in hybrid processes [7]. In addition, Saadaoui *et al.,* [8] stated that hybrid metaheuristics have shown an improvement to the optimization and parameter estimation efficiency and achieved preferable accuracy. A study by Satir Akpunar *et al.,* [9] designed a new hybrid metaheuristic to deal with the location routing problem by combining the adaptive large neighbourhood search (ALNS) and variable neighbourhood search (VNS). The new proposed approach by them reached satisfaction in their performance to solve the problem when the ALNS enhanced the performance incorporated with VNS. Besides, Wang *et al.,*

[10] applied their hybrid algorithms utilizing the ant colony optimization and genetic algorithm to flexible flow shop scheduling which could minimize the total energy consumption.

Moreover, a recent study from Saadaoui *et al.,* [8] aimed to increase the parameter extraction precision for different photovoltaic models by integrating the backtracking search optimization algorithm with the differential evolution algorithm. Significantly, various algorithms have been hybridized in various domains. A new finding in supply chain network studied by Goodarzian *et al.,* [11] they developed new hybrid algorithms which combining firefly algorithms and simulated annealing, resulting in a promising outcome. In computer science field, Ahsan *et al.,* [12] implemented particle swarm optimization alongside genetic algorithms for code coverage testing and the finding presented a noteworthy efficiency in detecting security vulnerabilities during the testing. Following that, the study by Kalayci *et al.,* [13] revealed their proposed algorithm is competitive enough for solving cardinality constrained portfolio optimization problem. The authors combined the artificial bee colony, continuous ant colony optimization, and genetic algorithm. Overall, the landscape of hybrid metaheuristics is being significantly widely used by the researcher in various domains.

This study aims to thoroughly understand the existing literature on a hybrid metaheuristics-based approach. It highlights the absence of bibliometric analysis in this area and delves to close the gap. By focusing on bibliometric analysis, this study is intended to present a broad overview of the past, current and future research direction in this field. Consequently, the objectives of the study are aligned with specific bibliometric analysis, giving insights to achieve a broad overview. Hence, the study aims to assess notable past research and examine current trends for hybrid metaheuristics approaches and to identify emerging trends in hybrid metaheuristics approaches by utilizing bibliometric analysis.

3. Methodology

In this section, the study designs to discuss the bibliometric characteristics of the article published in various sources, gathered through a Web of Science (WoS) database using “hybrid metaheuristic/hybrid meta-heuristic” keywords. According to Kurtulus *et al.,* [14], the benefit from bibliometric study could obtain the accumulated data on the publications that are related to the research areas as well as this method helps to summarize and interpret existing information. It should be noted that the sampling of the study has some limitations. As this current study using Web of Science (WoS) database, the year of publication is only limited only from 2020 up until 2025. To ensure consistency in the analysis of publication trends by year, the year 2025 has been intentionally removed from the sampling process, as it is not yet complete.

3.1 Search String and Inclusion Criteria

This section explores the search string and inclusion criteria practiced in this bibliometric study. Table 1 shows the criteria considered in this study.

Table 1
Search string and inclusion criteria

Web of Science database	
Time period	2020 to 2024
Search field	Topic (Title, abstract, keyword plus, and author keywords)
Search keywords	"hybrid metaheuristic*" OR "hybrid meta-heuristic*" OR "hybrid metaheuristic* algorithm*" OR "hybrid meta-heuristic* algorithm*"
Document type	Article
Languages	English

The exploration was directed through the Web of Science (WoS) database, focusing the search field on article titles, abstracts and keyword plus and author keywords. The search string includes "hybrid metaheuristic*" OR "hybrid meta-heuristic*" OR "hybrid metaheuristic* algorithm*" OR "hybrid meta-heuristic* algorithm*". The search in the WoS database was conducted on February 2, 2025, and retrieved publications from the years 2020 to 2024. The preliminary search returned 839 records. For document type, only articles were selected, as they provide the most relevant and reliable sources of literature for bibliometric analysis. Before the analysis, all publications were manually reviewed in Biblioshiny to identify and eliminate inconsistencies and duplications to ensure the accuracy of the dataset. Along with that, a few keywords have been removed and standardized to avoid repeated keywords. Therefore, Table 2 presented the list of standardised keywords respectively and all the publications must be written in English to ensure the regularity.

Table 2
List of standardised keywords

Standardised keywords	
Hybrid metaheuristics	hybrid meta-heuristics, hybrid metaheuristic, hybrid meta-heuristic, hybrid meta-heuristic algorithm, hybrid meta-heuristic algorithms, hybrid metaheuristic algorithm
Metaheuristics	meta-heuristics, metaheuristic, meta-heuristic, meta-heuristic algorithm, metaheuristic algorithm, meta-heuristic algorithms, metaheuristic algorithms, metaheuristic optimization
Genetic algorithm	genetic, genetic algorithms
Particle swarm optimization	particle, swarm optimization, particle swarm optimization (pso), pso, particle swarm
Hybrid algorithm	hybrid, hybridization, algorithms, algorithm
Heuristic algorithm	heuristic algorithms, heuristic, heuristics
Internet of things	iot, internet of things (iot)
Multi-objective optimization	multi-objective
Artificial neural network	artificial neural networks
Energy consumption	energy efficiency, energy management
Optimization	optimization algorithm

3.2 Data Analysis and Procedure of Bibliometric Analysis

Bibliometric analysis is a study approach that relies on data to help researchers identify and understand patterns within scientific literature [15]. It involves using various techniques to analyze

the features and trends of publications, including co-citation patterns encompassed by authors and journals, and keyword co-occurrence in scientific articles. Bibliometric analysis can reveal research gaps that need to be addressed and highlight the most rising areas for future research [16].

The dataset of the articles was analysed using R-Studio, which is the official storage website of many bibliometric analysis packages. In this study, we effectively utilized the Biblioshiny function. According to Kurtulus *et al.,* [14], the R programming was chosen for conducting bibliometric analysis due to its ability to generate diverse and detailed results, hence they claimed the package in a R program to be effective. In this study, the data was first gathered from Web of Science (WoS) database based on the criteria determined. After selecting "All" records, the data was exported in file.bibtex format and saved. Then, the 'bibliometrix' package was activated in R to perform the analysis. Subsequently, R-Studio directed the process to Biblioshiny, a user-friendly web interface, accessed through a web address.

4. Results and Discussion

4.1 Annual Scientific Production

Within this section, results and discussion were presented. As a result of the bibliometric analysis directed on hybrid metaheuristics, 839 articles were chosen between the span of 5 years. According to the Web of Science (WoS) database, a total of 839 articles has been published between the years 2020 and 2024. Figure 1 visually depicted the relationship between the publication's count, mean total citation per article and the corresponding year. The publication rate experienced a significant increase from 2020 to 2021 and maintained growth until 2022, marking the highest scientific publications within the given timeframe.

However, a contrasting trend was observed when examining the mean total citation per article that started above 30 citations marked in 2020 and showed a steady decline through the years. The years 2023 and 2024 maintained a significant number of publications despite the mean total citation per article continued to decline, encompassing its lowest point in 2024. The overall representation visualized the imbalance between the number of articles and the mean total citation per article. Researchers have published a lot of papers, with the most publications in 2022. However, each one is not being referenced or cited as much as before. This could indicate a potential shift in publications practices and a change in the research focus.

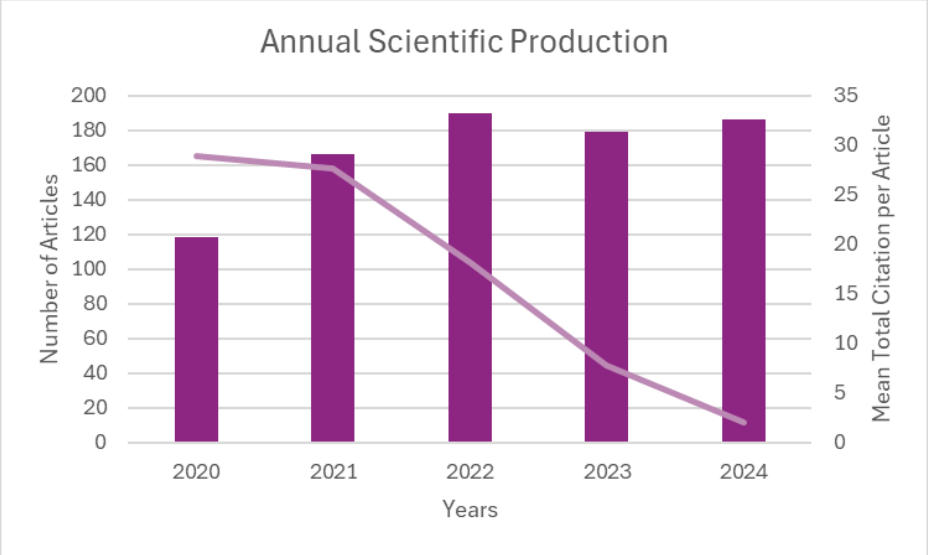

Fig. 1. Annual scientific production

4.2 Authors' Local Impact

A total of 2910 authors conducted a study on the hybrid metaheuristics algorithms. The h-index served as a benchmark for their research output. According to [17], h-index determines a simple measure to access the authors' contributions to their works by acknowledging the number of citations received and the number of their publications. Figure 2 shows authors' local impact where the size of each circle corresponded to the value of h-index for the authors in a given year while the darker shade of the circles indicated a higher measure of h-index. Two authors, Goodarzian Fariba and Hajiaghaei-Keshteli Mostafa, recorded the highest number of h-index with value of 8 for both. Table 3 displays the top 10 highest h-index in 5 years and their total number of citations. The level of productivity was assessed based on the number of citations received within a specific period. Authors with higher citation counts have established a lasting presence in their respective fields which positioning themselves as influential sources for other researchers.

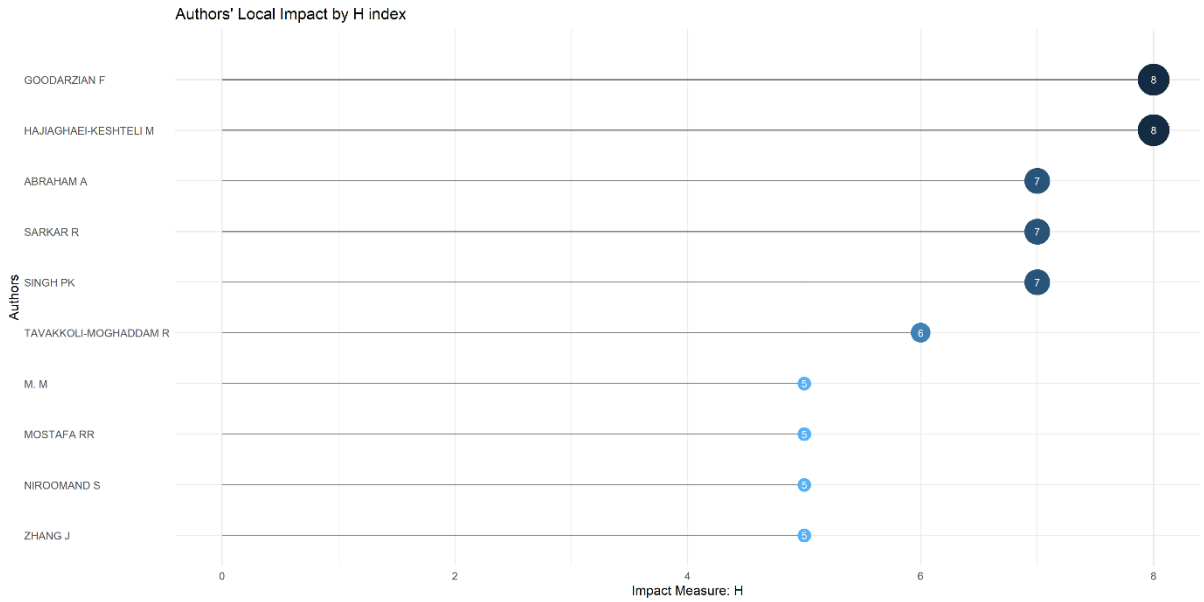

Fig. 2. Authors' local impact by h-index

Table 3
Top 10 highest h-index in 5 years and their total number of citations

Authors	h-index	Total number of citations
Goodarzian Fariba	8	423
Hajiaghaei-Keshteli Mostafa	8	457
Abraham Ajith	7	389
Sarkar Ram	7	286
Singh Pawan Kumar	7	264
Tavakkoli-Moghaddam Reza	6	345
M. M	5	305
Mostafa Reham R	5	337
Niroomand Sadegh	5	81
Zhang J	5	307

4.3 Most Relevant Sources and Affiliations

In this section the study discussed the most relevant authors and affiliations. Correspondingly, the publications were collected from 306 different journal sources. Figure 3 displays the top 10 journals with highest number of papers published in the field of hybrid metaheuristics. Among the journals involved, IEEE Access came out as the most productive, recorded a maximum of 51 articles within 5 years period, followed by the journal of Soft Computing with 25 publications. Besides, the Applied Soft Computing followed closely with 19 articles. The difference between the journals is quiet significance, meaning that IEEE Access is the most relevant source compared to the other journals.

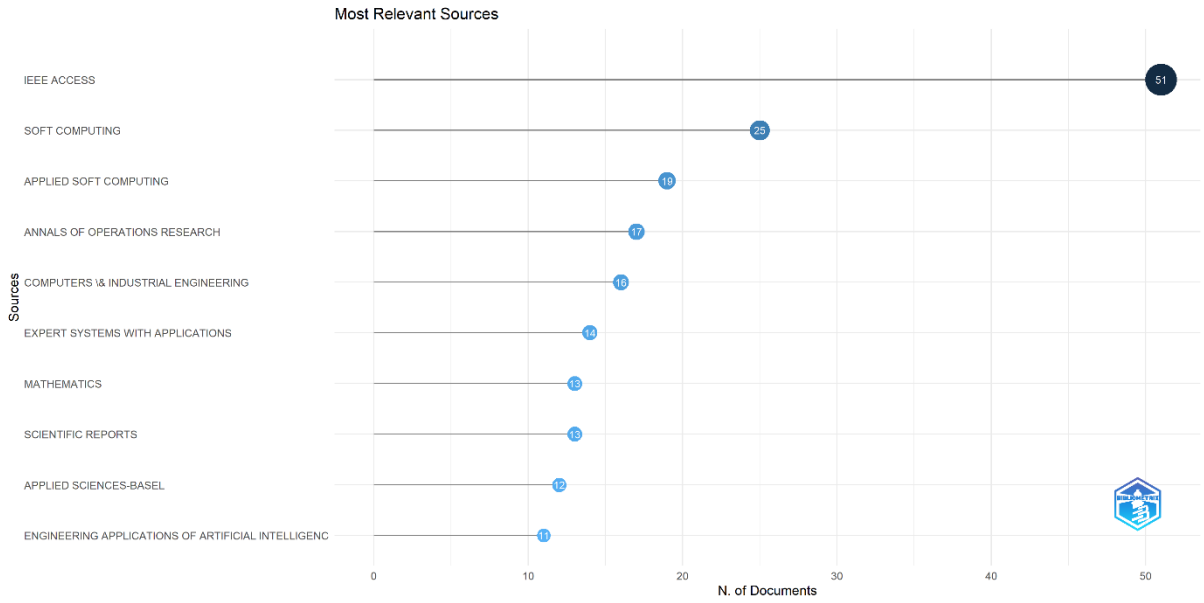

Fig. 3. Most relevant sources

Table 4 represented the measure of h-index and the total number of citations for each most relevant journal. IEEE Access recorded the highest measure of h-index with the value of 19 and the highest number of citations over the 5 years. This showing that the IEEE Access significantly the most influential sources as the total number of citations were aligned with the number of publications resulting on the highest measure of h-index. Additionally, the journal of Applied Soft Computing and Soft Computing shared the same measure of h-index with the value of 10. However, Applied Soft Computing received a slightly higher number of citations compared to Soft Computing.

Table 4
The measure of h-index and the total number of citations for each most relevant journal

Source	h-index	Total number of citations
IEEE Access	19	944
Applied Soft Computing	10	345
Soft Computing	10	335
Knowledge-Based Systems	9	509
Computers & Industrial Engineering	8	267
Engineering Applications of Artificial Intelligence	8	369
Engineering with Computers	8	347
Expert Systems with Applications	8	320

Journal of Cleaner Production	8	439
European Journal of Operational Research	7	295

Figure 4 illustrated the primary institutions involved in conducting a study on hybrid metaheuristic. Islamic Azad University emerges as the leading institution with 110 publications, followed by the University of Tehran with 34 publications. Important research in this field has also been focused at Prince Sattam Bin Abdulaziz University, Jadavpur University and Mansoura University, which are among the associated institution with the notable contributions.

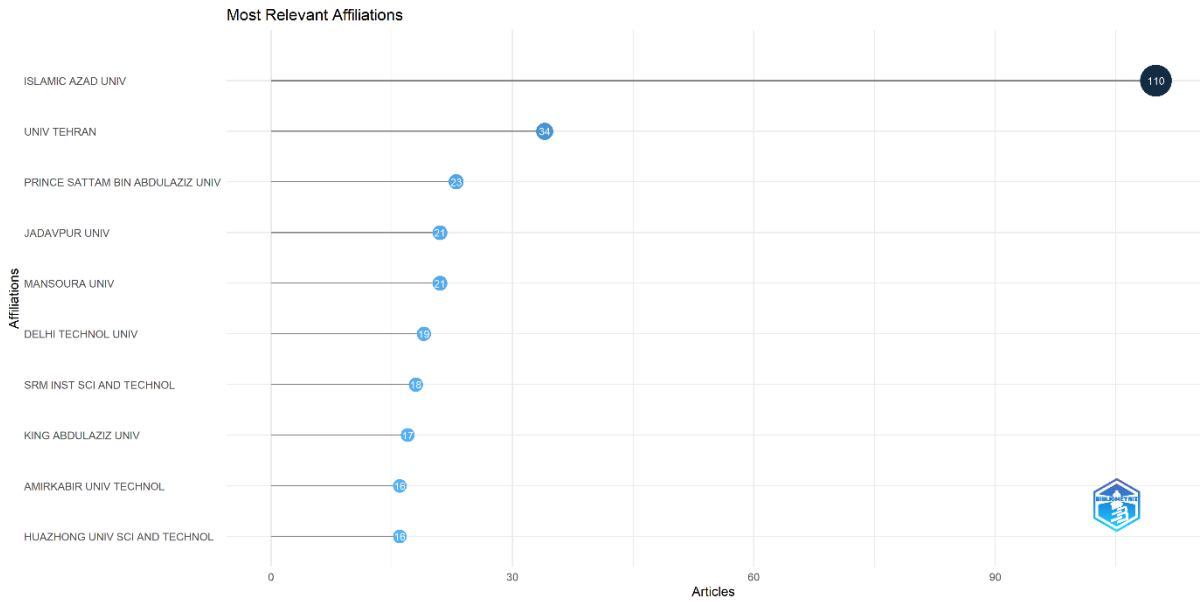

Fig. 4. Most relevant affiliations

4.4 Three Field Plot on Metaheuristics Approach/Thematic Evolution

This section employed a visualization to simplify complex relationship and understand the trends within a research domain. Therefore, Sankey diagrams serve as a valuable tool for visualizing the information flow and the connections between different entities in various field [18]. In the context of scientific research, these diagrams can effectively illustrate the connections between keywords, methodologies and research area. In Biblioshiny, the three-field plot is utilized to visually show how sources, countries, affiliations, keywords, prominent authors and citations are related to each other [19]. The Sankey diagram is used to explore the interconnections among various keywords in the field of hybrid metaheuristics from 2020 to 2024 as presented in Figure 5. The diagram highlights the evolution of research interest and the relationship between different concepts and keywords over time. Each of the keywords were represented in the colored rectangle-shaped, where the strength of the connection between the keywords was measured by the width of the rectangle. The rectangle with a broader range signifies more valuable interactions and influence within the research field.

The analysis of the three-field diagram as illustrated in Figure 5 acknowledged several extended trends and fluctuations on the research over 5 years. Taking a look at the time range from 2020 to 2021, keywords such as “metaheuristics”, “hybrid metaheuristics” and “artificial bee colony” were the most noticeable, reflecting the widely discussed of these topics during that time. As we move to the 2022, there is a prominent increase in the frequency of keywords such as “metaheuristics”, “vehicle routing problem” and “neural network”, indicating a growing interest in these research areas. By 2023 to 2024, the landscape of this research continues to develop, with the keyword

"metaheuristics" maintained its influential, while the keywords "variable neighborhood search", "feature selection", "deep learning" and "hybrid metaheuristics" continue to expand as well. The keywords shifted between years emphasis the integration of advanced computational techniques with optimization and metaheuristics algorithms to cater to the increasingly complex problem. The researchers also make use of the existing algorithms to hybridize them into a new algorithm which is called hybrid algorithm. The figure also highlighted the integrative nature of the research in this field, with the keywords "internet of things" and "particle swarm optimization" indicating the application of these techniques in various domains.

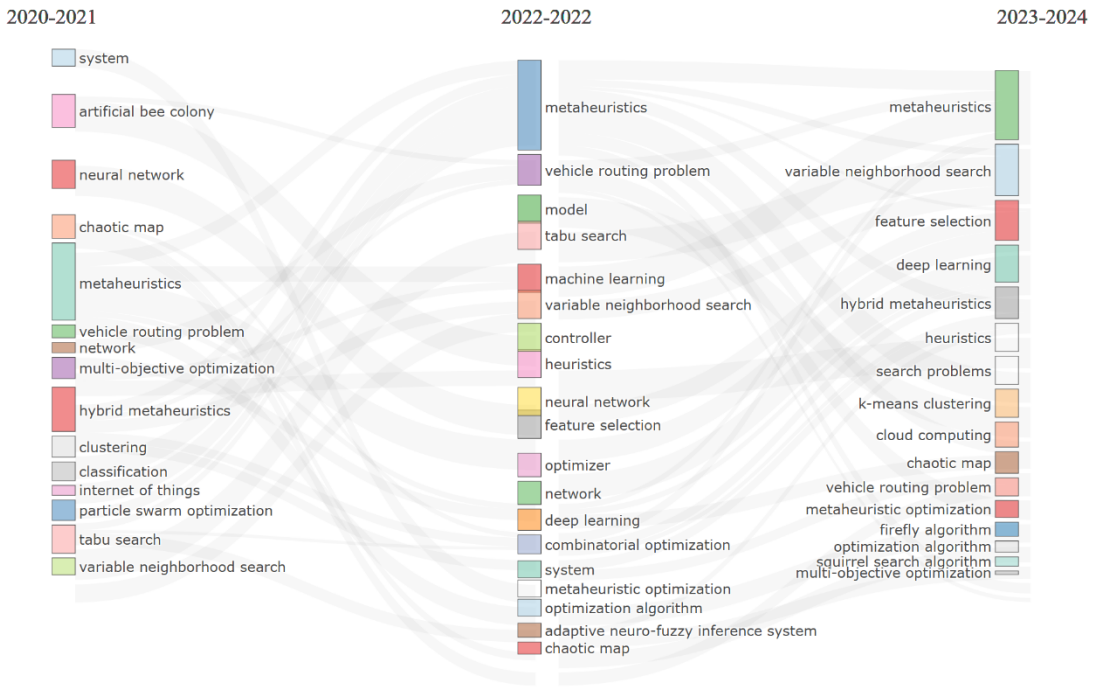

Fig. 5. The Sankey diagram

4.5 Co-occurrence of Keywords and Content Analysis

In this section, the study discussed the co-occurrence of keywords, an insightful method to visualize the interconnectedness of concepts within a specific domain. Figure 6 represented the co-occurrence of keywords in the field of hybrid metaheuristics, generated by Biblioshiny. In this figure, the keywords were represented using the node, and a connection between two nodes visualized the co-occurrence of the corresponding keywords in this field. Additionally, the size of nodes represented the individual frequency of each keyword, the larger the node, the more frequent the occurrence. The figure visualized the multiple clusters, with the most significance ones are green and blue. The blue cluster included term "optimization", "genetic algorithm" and "particle swarm optimization", reflecting a concentration on classic and contemporary optimization algorithms and their integration with machine learning methods. On the other hand, the green cluster encompassed the keywords related to "hybrid metaheuristics", "variable neighborhood search" and "sustainable" indicating a focus on advanced optimization techniques in sustainable applications.

"Metaheuristics" emerged as a central node in this co-occurrence network, marking its vital role in the literature of hybrid metaheuristics. The largest size of its node signifies the highest frequency of occurrence, underscoring it as a key within this field. Besides, the figure also showed some overlap

between the clusters, as seen with the keywords “artificial intelligence” and “machine learning” which appear in few clusters. This overlapping points to areas where different research theme intersects, highlighting the multidisciplinary nature of optimization and metaheuristics. On the contrary, it also aids in identifying current research trends and future exploration.

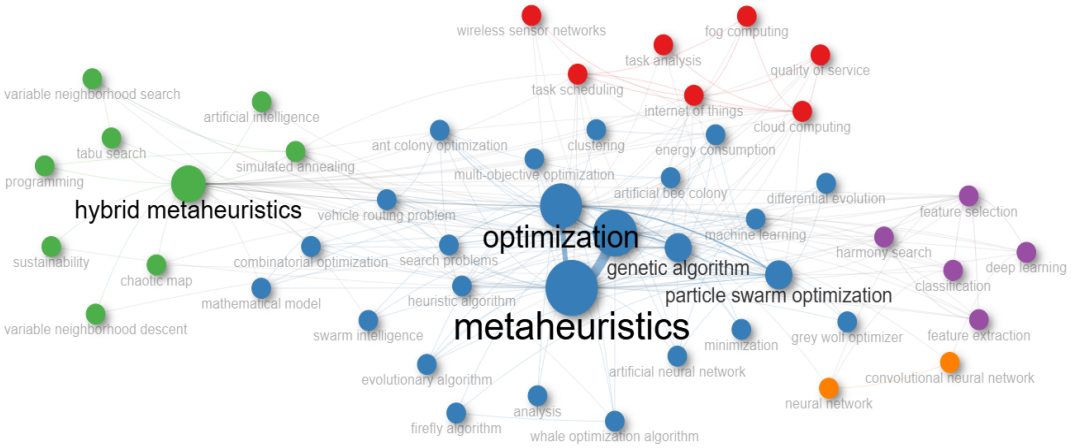

Fig. 6. The co-occurrence of keywords

4.6 Most Frequent Words and Word Cloud of the Keywords

The section posited the most frequent words that are regularly utilized and their respective frequency, as identified by the Biblioshiny software. Table 5 represented the highest 10 keywords respectively.

Table 5
The highest 10 keywords

Words	Occurrences
Metaheuristics	208
Hybrid Algorithm	158
Optimization	150
Hybrid Metaheuristics	124
Particle Swarm Optimization	90
Genetic Algorithm	74
Vehicle Routing Problem	43
Machine Learning	34
Cloud Computing	32
Task Scheduling	31

Figure 7 depicted the authors’ keywords, illustrated in a word cloud. These keywords were chosen by the researchers to reflect the core concepts of their work to ensure that their work can be found easily and recognized their contribution. In this particular word cloud, the terms “metaheuristics”, “optimization”, “genetic algorithm” and “particle swarm optimization” dominated the visualization, showing their influence in this research field. It is a direct reflection of their frequency of occurrence and on the other hand, their importance in this field. The size of the words giving signal of its

relevancy and influence where the larger the font, the more frequent the term mentioned in the literature study.

The appearance of terms “hybrid metaheuristics” and “hybrid algorithm” marks to a trend towards integrating two or more optimization techniques to enhance the capabilities of single technique in term of problem solving. This also reflected a broader concept within the field for the researchers to explore more innovative ways by combining the existing method to tackle more complex and various problems. Moreover, the presence of keywords “machine learning”, “cloud computing” and “deep learning” along with the traditional optimization terms reveals an associative approach to research. On the other words, the field of optimization is intersecting with other areas of computer science and artificial intelligence, noting to novel applications and advancements in these areas.

Fig. 7. Word cloud of the authors’ keyword

5. Conclusion and Future Directions

This study provides a brief landscape of the current state of research on hybrid metaheuristics approaches by providing a relevant trend. This bibliometric study made use of WoS database within 5 years period to analyse the emerging trends and visualize the impactful results. The analysis observed that the number of researches on hybrid metaheuristics continues to grow progressively in a wide range of metaheuristics algorithms as well as apply in the various domain. The field of hybrid metaheuristics approaches is closely related to the United Nations Sustainable Development Goals (SDGs), particularly those focused on environmental sustainability and efficient resource management. These approaches can contribute to several SDGs by optimizing processes and systems to reduce waste, improve resource efficiency and minimize environmental impacts. Consequently, it is in line with the SDG 9 (Industry, Innovation and Infrastructure) by enhancing the efficiency of logistics and transportation systems [20].

In conclusion, the bibliometric analysis is used to identify what has been done from previous publications discovering the key terms related to hybrid metaheuristics. A notable outcome revealed in this study is the increasing number of publications incorporating hybrid metaheuristics in various fields. The varied potential of hybrid metaheuristics to overcome complex optimization problems may influence the researchers to make use an existing algorithm by combining them to more new hybrid algorithms. Looking ahead, there is extensive scope for further research to broaden the analysis. Further study could benefit by incorporating the higher number of datasets, more diverse range of databases and utilizing different bibliometric tools such as VOSviewer, Pajek, BibExcel and

many more. These enhancements would provide a more comprehensive understanding of the evolution and impact of hybrid metaheuristics.

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