Entropy-based dispatching: academic insights and perspectives through bibliometric analysis

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Abstract: Entropy-based dispatching has attracted more and more attention from professional scholars and engineers. The quantity and quality of publications related to this topic are increasing rapidly. To accurately measure this growth, we use bibliometric tools to evaluate publications in the field from 1985 to 2019, based on the Science Citation Index Expanded database. They compare and analyse the relationship between dispatching problems and entropy theory in different research fields, and provide detailed overviews and discussions on hot topics and potential research value based on keywords, citations, H-index, journals, institutions, countries and authors. The analysis shows that the application of information entropy to the quantification of dynamic information in flexible manufacturing systems, noise processing in power systems and channel rate prediction has potential research value. The result reveals that universities in mainland China have made the greatest contribution, which renders the number of publications from China in the lead, followed by the US and the UK. 'International Journal of Production Research' and 'European Journal of Operational Research' are two of the most noteworthy archives for researchers in this field. For interested readers, integrating entropy theory with economic scheduling, power scheduling, and job-shop scheduling will be the future trend of this field.

1 Introduction

The German physicist Clausius proposes the concept of entropy in 1865 to quantitatively explain the second law of thermodynamics. In 1877, Boltzmann combines the Boltzmann-H theorem with the theory of thermodynamic entropy, indicating the significance of statistics, thus linking the micro and macro worlds of thermodynamics and dynamics. In 1948, the father of information theory, Shannon, borrows the concept of thermodynamic entropy and proposes the concept of information entropy to express the uncertainty of information sources. In the paper [1], he points out that there is redundancy in any information, and the uncertainty of the occurrence of each symbol in the information of redundant size is related. The average amount of information after eliminating redundancy is called information entropy, and the relationship between probability and information redundancy is clarified in explicit formula for the first time. In 1951, Kullback and Leibler [2] propose a statistic that measures the difference between two random distributions. In order to accurately measure the similarity between two random distributions, the relative entropy (KL-divergence) and cross entropy are defined. In 1957, Jaynes [3] studies the relationship between information entropy and statistical mechanics, and establishes the principle of maximum entropy under the condition of incomplete information [4]; from 1959 to 1978, Kullback establishes the principle of minimum relative entropy. These two principles become two important and widely used principles in information theory. In 1972, Deluca and Termini define non-probabilistic entropy based on fuzzy set theory [5], which is then named fuzzy entropy. In 2005, Nadarajah and Zografos [6] propose high-dimensional joint information entropy in their paper. In 2006, Cover and Thomas [7] deduce and summarise the information entropy expressions of commonly used distributions. In 2010, Wu proposes a more accurate measure of crowding degree in its multi-objective differential evolution algorithm for environmental and economic power dispatching problems, namely crowding entropy [8]. In addition, the entropy theory has been extended to many areas, such as ‘Entropy of privacy’ [9, 10] and ‘Entropy of routing control’ [11–13]. The concept of entropy has evolved for >150 years since it was first introduced.

In recent years, entropy theory has been successfully applied to dispatching problems and achieved commendable results. Despite this prodigious achievement, there is still a lot of potential in this area. To facilitate further discussion, the entropy-based dispatching is defined as the dispatching problems solved by entropy theory, such as information entropy, fuzzy entropy, cross entropy, relative entropy, maximum entropy principle, crowding entropy. In 1992, Shmilovici [13] proposes a heuristic algorithm for flexible manufacturing system's acceptance strategy of new parts, which considers the impact of minimum entropy reduction on production, manufacturing and operation. In the same year, Karp and Ronen [14] proposed a new entropy based method to improve workshop management. Built on information theory and entropy measurement, this study proves that small batch production means less information demand. In order to measure the flexibility of dispatching paths in flexible manufacturing system, Pipiani and Talavage [15] proposes an entropy measurement based on flexibility in 1995. In 2005, Shuiabi et al.'s [16] paper, ‘Entropy as a measure of operational flexibility’, is cited frequently and attracts wide attention. In the article, the discrete workshop simulation clearly demonstrates that the entropy theory could accurately measure the flexibility when manufacturing requirements change. In the following decade, the entropy theory is widely used in dispatching models. For instance, in 2010, Wu combines the crowding entropy diversity measurement strategy with a multi-objective differential evolution algorithm for dispatching problems [8], which could more precisely depict the crowding degree caused by non-linear constraints. Although many of the existing literature also cover the challenges and prospects of the entropy theory in the future, the reviews and comments are organised sparsely by technical topics, not to mention the specific domain of entropy-based dispatching. Therefore, we hope to provide an intact overview of the historical map, and to comb through the related research papers via a bibliometric analysis. As an effective tool for academic evaluation, bibliometric measurement system provides various quantitative and
different areas with various entropy theories; (iii) contributions made by countries, institutions, research groups and authors; (iv) the target topic. It helps the researchers find research hotspots, know, this is the first paper to use bibliometric methods to analyse publications in top journals. Besides, it discovers the frequently cited literatures, and future research prospects. At present, it has been widely used in various research fields. However, as far as we know, this is the first paper to use bibliometric methods to analyse the entropy-based dispatching research field. The present paper mainly takes the following perspectives into the entropy-based dispatching domain: (i) the trajectory and development of historical research; (ii) comparative analysis of dispatching problems in different areas with various entropy theories; (iii) contributions made by countries, institutions, research groups and authors; (iv) cooperative relations among countries, institutes and authors; (v) top journals; (vi) influential work; (vii) research frontiers.

2 Methodology and data source

The analysis is based on the publications related to ‘Entropy-based Dispatching’ published from 1985 to 2019. The literature materials are obtained from the databases of Science Citation Index-Expanded (SCI) and Social Sciences Citation Index (SSCI) using two retrieval formulas on 15 April 2020. The first search formula is (low-entrop* or low entrop* or entrop* or entrop* theor*) and (arithmetic* or algorithm* or model* or pattern* or artific* intelligen* or AI) and (schedule* or dispatch * or *shop). The second search formula is (high-entrop* or high entrop* or entrop* or entrop* theor*) and (arithmetic* or algorithm* or model* or pattern* or artific* intelligen* or AI) and (schedule* or dispatch * or *shop). The results are manually re-filtered according to the search formula, and the document type is defined as articles in the subject field. Thus, as of April 15, 2020, there were 162 articles in the InCites data set, including the Web of Science (WoS) indexed content. Literature from England, Scotland, Northern Ireland and Wales are classified as United Kingdom literature. The impact factors of each journal mentioned in the literature were determined by the 2018 Journal Citation Report. The documents retrieved in this paper are obtained from the ‘topic’ search of WoS, which only searches the titles, abstracts and keywords of the literature. Thus some relevant literature may not be included.

3 Results and discussions

3.1 Global contribution and leading countries

The time span of literature retrieval was from 1985 to 2019. The results show that the earliest literature on entropy scheduling was published in 1992. Since then 39 countries have made contributions to the field of entropy-based scheduling research, and a total of 131 papers have been published, including one indexed by ESI with high citation. In 2017, ‘Optimal economic dispatch of FC-CHP based heat and power micro-grids’ [18] written by Nazari-heris and co-authors is identified as a highly cited paper. So far, China is the most productive country, with 51 articles since 1992, followed by the US (132) and Japan (97). Table 1 shows the top 20 most productive countries in entropy-based dispatching field during 1985–2019.

Table 1 Top 20 most productive countries in entropy-based dispatching field during 1985–2019

| Rank | Country       | TA  | TC  | ACPP | SP, % | nCC |
|------|---------------|-----|-----|------|-------|-----|
| 1    | China         | 51  | 720 | 1.36 | 76.47 | 8   |
| 2    | USA           | 22  | 199 | 0.79 | 86.36 | 6   |
| 3    | United Kingdom| 9   | 55  | 0.78 | 77.78 | 5   |
| 4    | India         | 7   | 97  | 1.20 | 85.71 | 2   |
| 5    | Iran          | 7   | 132 | 1.85 | 71.43 | 1   |
| 6    | France        | 4   | 110 | 1.22 | 75.00 | 2   |
| 7    | Israel        | 4   | 33  | 0.60 | 75.00 | 1   |
| 8    | Switzerland   | 3   | 26  | 0.67 | 66.67 | 1   |
| 9    | Australia     | 3   | 40  | 1.04 | 100.00| 2   |
| 10   | Singapore     | 3   | 26  | 0.51 | 100.00| 1   |
| 11   | Canada        | 3   | 86  | 1.42 | 100.00| 2   |
| 12   | Italy         | 3   | 67  | 2.14 | 100.00| 3   |
| 13   | Mexico        | 2   | 6   | 0.44 | 100.00| 1   |
| 14   | Netherlands   | 2   | 22  | 0.39 | 50.00 | 1   |
| 15   | Brazil        | 2   | 8   | 0.76 | 50.00 | 0   |
| 16   | Germany       | 2   | 0   | 0.00 | 0.00  | 1   |
| 17   | Czech Republic| 2   | 7   | 0.50 | 100.00| 0   |
| 18   | Spain         | 2   | 9   | 0.50 | 100.00| 0   |
| 19   | Japan         | 2   | 1   | 0.04 | 50.00 | 1   |
| 20   | Finland       | 1   | 0   | 0.00 | 0.00  | 1   |

Note: TA, total articles; TC, total citations; ACPP, average citations per publication; SP, share of publications; nCC, number of cooperative countries.

Fig. 1 Trends in the number of published articles related to entropy-based dispatching by year
articles published in each year. The red line indicates the cumulative number of the relevant articles until this year. From the curves in Fig. 1, it could be clearly observed that the number of related articles published each year shows a steady upward trend.

Fig. 2 is the bubble chart of 20 most productive countries/regions by year. The abscissa in the figure represents the year, and the ordinate is the countries and regions. The size of the bubble in the figure and the number in the bubble show the number of documents published by the country and region in a given year. By comparing the size of the bubbles and the density of the bubbles, it is shown that the number of publications in 2019 is much higher than in other years. Recently, the bubbles in China are quite large, indicating the greatest amount of published articles.

Fig. 3 shows the collaboration network among the top 20 productive countries/regions. The size of the circle is roughly proportional to the total number of articles in each country. The links between different circles represent the cooperation between countries, and the number of lines represents the intensity of cooperation. As can be interpreted from the figure, the cooperation among countries is not very strong in general. Globally, China is the country that maintains the most cooperation with other countries/regions in this field, especially with Norway [9, 19], the United Kingdom [20, 21] and the United States [22–25]. It is worth noticing that the links between Iran, Spain or Brazil and other countries/regions are quite limited, indicating a not so strong international cooperation in this field. Since there are growing numbers of scholars studying entropy-based dispatching, it could be conjectured that most of them focus on collaborative research locally.

3.2 Contribution of leading research areas

According to the statistics by WoS, entropy-based dispatching involves 29 research areas, of which Table 2 shows the top 20 research areas ranked according to the number of articles. The number of related literature in ‘Engineering, Electrical and Electronic’ [8, 26, 27] and ‘Operations Research and Management Science’ [11, 16, 28] are both ranked first, accounting for 19.85% of the total literature. Which are followed by ‘Computer Science’, ‘Artificial Intelligence’ [29–35] and ‘Engineering, Manufacturing’ [14, 36, 37], accounting for 12.21% of the total literature. In addition, ‘Computer Science, Information Systems’ [22, 28, 38–41] and ‘Computer Science, Interdisciplinary applications’ [29, 42, 43] are also the main research branches relevant to entropy-based dispatching. As for average citations per publication, Mechanics [44, 45], Thermodynamics [18, 46] and Engineering, Mechanical [47, 48] are ranked high on the ACPP list with 4.63, 4.27 and 2.15, respectively.

3.3 Comparative analysis

Fig. 4 demonstrates the contribution of the top 15 research fields in different entropy theories with histogram. The abscissa in the figure represents the number of articles of each entropy theory, and the ordinate represents 15 research fields with high relevance to dispatching topics. Table 2 lists in detail the number of related literature on dispatching problems in different research fields and different entropy theories. Combining Fig. 4 and Table 2 for comparative analysis, some correlations could be observed. For instance, Fig. 4 shows that the research conducted in the field of engineering electrical electronics is closely related to Entropy-based Dispatching, where Information entropy and Entropy weight, Fuzzy entropy, Cross-entropy (Mutual information), Relative Entropy (KL-divergence), the maximum entropy principle, Entropy of privacy, and Crowding entropy, seven different entropy theories are involved in this field. Among them, Information entropy and Entropy weight is the most popular, with the most articles published so far.

In solving the power/economic dispatching problem, Li [49] obtains the Pareto boundary based on the entropy weight and TOPSIS method, and sort the Pareto solutions. In order to reduce the power loss in the active distribution network, Zhao and Si also use a similar method after solving their dispatching model, using the entropy weight decision method to evaluate the Pareto solution to obtain the optimal dispatching strategy [50]. In the hierarchical dispatching model between electric vehicles (EVs) and the power
grid, Zhang et al. [51] determine the dispatching priority of each EV based on the entropy method. In its improved opportunistic dispatching algorithms, Mehmet et al. [41] applies information entropy to quantify the uncertainty in prediction and integrate the uncertainty into the decision-making process. After analysing the existing literature, we know that Information entropy has good research prospects in power system noise processing, and soft information processing, both are involved in dispatching systems, channel rate prediction and quantification in opportunistic dispatching, and improving the certainty of vehicle tracking position.

Table 2  Article count for entropy-based dispatching problems in different research areas

| Rank | The research fields of theories | Information entropy and entropy weight | Fuzzy entropy | Cross-entropy (mutual information) | Relative entropy (KL-divergence) | Maximum principle | Entropy of routing control | Entropy of privacy | Crowding entropy |
|------|--------------------------------|--------------------------------------|---------------|----------------------------------|---------------------------------|-------------------|---------------------------|-----------------|-----------------|
| 1    | engineering electrical electronic | 15                                   | 1             | 5                                | 1                               | 5                 | 0                         | 2               | 2               |
| 2    | operations research management science | 14                                   | 3             | 2                                | 5                               | 1                 | 2                         | 0               | 0               |
| 3    | engineering manufacturing | 13                                   | 1             | 3                                | 3                               | 1                 | 2                         | 0               | 0               |
| 4    | computer science information systems | 10                                   | 2             | 4                                | 2                               | 3                 | 0                         | 1               | 0               |
| 5    | engineering industrial | 9                                     | 3             | 1                                | 3                               | 0                 | 5                         | 0               | 1               |
| 6    | computer science artificial intelligence | 4                                     | 7             | 1                                | 2                               | 1                 | 1                         | 0               | 0               |
| 7    | energy fuels | 4                                     | 5             | 4                                | 0                               | 1                 | 0                         | 0               | 0               |
| 8    | physics multidisciplinary | 9                                     | 1             | 1                                | 0                               | 2                 | 0                         | 0               | 0               |
| 9    | computer science interdisciplinary applications | 6                                     | 1             | 0                                | 1                               | 3                 | 1                         | 0               | 1               |
| 10   | computer science theory methods | 3                                     | 1             | 3                                | 1                               | 3                 | 0                         | 1               | 0               |
| 11   | thermodynamics | 3                                     | 4             | 3                                | 0                               | 1                 | 0                         | 0               | 0               |
| 12   | telecommunications | 5                                     | 0             | 4                                | 0                               | 1                 | 0                         | 1               | 0               |
| 13   | automation control systems | 4                                     | 0             | 2                                | 0                               | 1                 | 2                         | 0               | 1               |
| 14   | computer science software engineering | 4                                     | 0             | 0                                | 1                               | 2                 | 0                         | 1               | 0               |
| 15   | mechanics | 1                                     | 3             | 0                                | 0                               | 0                 | 0                         | 0               | 0               |

Fig. 4  Contribution of the top 15 research fields in different entropy theories

Entropy weight is of great research value in the Pareto solution of the dispatching model. Cross-entropy [28, 52] is demonstrated as with good research potential in the area of economic load distribution. Immanuel Selvakumar [52] propose an improved cross-entropy method to solve the problem of dynamic economic dispatching with valve point effect. Subathra et al. [28] proposes a new method of combining cross-entropy algorithm with sequential quadratic programming (SQP) technology in economic load dispatching problems related to generating units, and verifies the feasibility. The introduction of maximum entropy principle in the related probability estimation problem in power dispatching system.
may be a subject worth exploring. Buan et al. [53] propose a power generation dispatching model based on the principle of maximum entropy, and find the most likely power flow probability distribution, thus providing an accurate probability environment for solving the power generation dispatching model.

In comparison, fuzzy entropy, entropy of privacy and crowding entropy are rarely mentioned in the literature. Zhifeng and Janet [20] provide a new perspective based on fuzzy entropy theory. They establish the production entropy model of production logistics system to measure the operation efficiency of production logistics. In Wu et al.’s [8] paper, in order to maintain the diversity of Pareto optimality, a crowding entropy diversity measurement strategy is proposed to more accurately measure the degree of crowding. His paper has therefore received a high number of citations (140). Zhou et al. [54] use the crowding entropy constraint processing in the calculation of power systems to effectively enhance the diversity and distribution of non-dominant fronts. They verify the superiority of the algorithm, and then work on the improvement of the Pareto solution. The evidence suggests that the crowding entropy presents high research value in the field of power system research.

According to Fig. 4 and Table 2, it is observed that Operations Research Management Science has a great correlation with entropy-based dispatching. Information entropy and entropy weight, fuzzy entropy, cross-entropy (mutual information), relative entropy (KL-divergence), the maximum entropy principle, entropy of routing control are all connected with this field. Information entropy and entropy weight is obviously superior to other entropy theories. Shuiabi et al. [16] demonstrates when the relative demand of product manufacturing changes, entropy could better measure flexibility, hence entropy is capable of monitoring the flexibility of the process. When Tavana [23] explores the use of multi-criteria decision-making models to determine risks and benefits, he uses analytic hierarchy process, subjective probability estimation method and entropy weight, and finally got reasonable results. In the work of Karp and Ronen [14], based on information theory and entropy weight, it is proved that the shift of manufacturing to small batches means the reduced demand for information, and the implementation of small batches will help increase production throughput. Smart revises and expands the structure and dynamic complexity metrics of manufacturing systems based on information entropy theory [55]. Pirlanti and Wetjens [11] discuss the entropy-based part dispatching problem in the flexible manufacturing system, and propose the minimum entropy reduction rule and the minimum relative entropy reduction rule, indicating that the entropy-based dispatching rules are superior to the traditional dispatching rules. After consulting the literature, the analysis shows that information entropy and entropy weight and relative entropy are inherent with a great potential in measuring flexibility and quantifying dynamic information in manufacturing systems.

In the correlation analysis of Engineering, Manufacturing, Computer Science and Information Systems, Engineering Industrial and Entropy-based dispatching, the number of related articles on information Entropy and Entropy weight is obviously more than others. In solving the flexible job shop dispatching problem, Wang et al. [56] use the principles of immunity and entropy to maintain the diversity of individuals, and overcome the problem of premature convergence of genetic algorithms. Noticeably, the paper has been cited many times ever since. Zhang [36] establishes the static entropy and dynamic entropy models of the manufacturing system based on the information entropy theory. After bibliometric analysis, it is shown that Information entropy and Entropy weight is of great research value when applied to measure the complexity of manufacturing systems [57–61]. Fuzzy entropy is dominant in the correlation between Computer Science Artificial Intelligence and entropy-based dispatching. Zhang et al. propose a hybrid method combining biogeographic optimisation algorithm and intuitionistic fuzzy entropy weight method [30], which could effectively solve the problem of manufacturing service supply chain optimisation. Based on the above key literature analysis, it is discovered that the mixed use of fuzzy entropy and some algorithms could be a fruitful future research direction.

Fig. 5 is the bubble chart of top 20 keywords in the field of entropy-based dispatching each year, showing relevant keywords frequency based on entropy dispatching research. The circle size in Fig. 5 indicates the number of times the keyword appears. In addition the number in the circle also represents the number of occurrences of the keyword. With the available published data, it can be concluded from Fig. 5 that the keywords ‘entropy’ and ‘multi-objective optimisation’ appear significantly more often than other keywords. It is also found that Information entropy and Entropy weight and multi-objective optimisation algorithms are usually used in a bundle, meaning the entropy value could effectively retain the diversity of Pareto solutions, which is a research hotspot [62, 63]. Keywords such as ‘system’, ‘particle swarm optimisation’ and ‘algorithm’ have significantly higher word frequency than other keywords, indicating that improving particle swarm optimisation based on entropy theory or mixed entropy theory and intelligent algorithms have also received more attention.

3.4 Contribution of leading institutions

Table 3 shows the top 20 most productive organisations in the field of entropy-based dispatching research, as well as their total number of publications, citations and h-index. Obviously, the high-yield institutions in Table 4 correspond to the high-yield countries in Table 1. China accounts for 70% among the top 10 high-yield institutions. North China Electric Power University [44, 51, 64-68] ranks first with the largest number of publications, followed by
South China University of Technology [54, 69–72] and University of Oxford [20, 55, 73, 74]. As for TC, the total number of papers published by Northeastern University - China is only 2, but its total number of citations is the most (160) [26, 27], followed by Huazhong University of Science and Technology (120) [47, 56, 75]. In terms of ACPP, Northeastern University – China (4.1) ranks the highest among the top 20 institutions, followed by Karunya Institute of Technology and Sciences (3.12) [28, 52]. In terms of h-index, the h-index of all institutions is usually small. North China Electric Power University, University of Oxford, Huazhong University of Science and Technology, and University of Leeds [55, 73, 74] possess the highest h-index, all being 3.0. According to the data in Table 4, the entropy-based dispatching field is less concerned at present.

### 3.5 Leading journals on the number of publications in entropy-based dispatching

From 1985 to 2019, 131 papers on entropy scheduling are published in 92 journals. As shown in Table 5, ‘International Journal of Production Research’ topped the list with seven articles. Followed by ‘European Journal of Operational Research’ (5), ‘Entropy’ (4), ‘Energies’ (4) and ‘International Journal of Advanced Manufacturing Technology’ (4). The total number of articles published in the above-mentioned journals accounted for 18.32% of the total number of articles published. In Table 3, 59 articles were published by the top 20 journals, accounting for 45% of the total number of papers, while the remaining journals accounted for <1%. According to the top 20 journals in the entropy-based scheduling field in Table 3, and the IF index in Table 5, among the top five journals in the entropy scheduling field in 2018. ‘European Journal of Operational Research’ ranked first, and its IF index was

### Table 3  Top 20 most productive institutions in 1985–2019

| Rank | Institutions | TA | TPR(%) | TC | ACPP  | h-index | Country               |
|------|--------------|----|--------|----|-------|---------|-----------------------|
| 1    | North China Electric Power University | 7  | 5.34   | 49 | 1.8   | 3       | China Mainland        |
| 2    | South China University of Technology | 4  | 3.05   | 32 | 1.13  | 2       | China Mainland        |
| 3    | University of Oxford | 4  | 3.05   | 34 | 1.05  | 3       | England               |
| 4    | Huazhong University of Science and Technology | 3  | 1.78   | 120| 2.5   | 3       | China Mainland        |
| 5    | University of Leeds | 3  | 1.78   | 33 | 0.73  | 3       | England               |
| 6    | University of Illinois Urbana-Champaign | 2  | 1.53   | 10 | 0.54  | 1       | USA                   |
| 7    | Zhejiang University | 2  | 1.53   | 27 | 1.23  | 1       | China Mainland        |
| 8    | Sichuan University | 2  | 1.53   | 19 | 1.37  | 2       | China Mainland        |
| 9    | Tianjin University | 2  | 1.53   | 5  | 0.34  | 2       | China Mainland        |
| 10   | Hohai University | 2  | 1.53   | 0  | 0     | 0       | China Mainland        |
| 11   | Nanjing University of Posts and Telecommunications | 2  | 1.53   | 26 | 1.25  | 1       | China Mainland        |
| 12   | Northeastern University – China | 2  | 1.53   | 160| 4.1   | 2       | China Mainland        |
| 13   | South China Agricultural University | 2  | 1.53   | 17 | 0.58  | 1       | China Mainland        |
| 14   | Ecole des Ponts ParisTech | 2  | 1.53   | 2  | 0.05  | 1       | France                |
| 15   | Iran University Science and Technology | 2  | 1.53   | 87 | 2.6   | 2       | Iran                  |
| 16   | National Yunlin University Science and Technology | 2  | 1.53   | 3  | 0.07  | 1       | Taiwan                |
| 17   | National University of Singapore | 2  | 1.53   | 4  | 0.37  | 1       | Singapore             |
| 18   | Nanjiang Hangkong University | 2  | 1.53   | 19 | 1.55  | 1       | China Mainland        |
| 19   | Karunya Institute of Technology and Sciences | 2  | 1.53   | 84 | 3.12  | 2       | India                 |
| 20   | Universite Paris-Est (ComUE) | 2  | 1.53   | 2  | 0.05  | 1       | France                |

Note: TPR%, the percentage of journal articles in total publications.

### Table 4  Top 20 research areas in entropy-based dispatching

| Rank | Research area                                                                 | TA | TPR, % | TC | ACPP |
|------|--------------------------------------------------------------------------------|----|--------|----|------|
| 1    | engineering, electrical and electronic                                         | 26 | 19.85  | 495| 1.41 |
| 2    | operations research and management science                                     | 26 | 19.85  | 259| 0.76 |
| 3    | computer science, artificial intelligence                                      | 16 | 12.21  | 84 | 0.70 |
| 4    | engineering, manufacturing                                                     | 16 | 12.21  | 210| 1.00 |
| 5    | engineering, industrial                                                        | 15 | 11.45  | 144| 0.75 |
| 6    | computer science, information systems                                          | 14 | 10.69  | 92 | 0.79 |
| 7    | computer science, interdisciplinary applications                               | 14 | 10.69  | 152| 0.77 |
| 8    | energy and fuels                                                               | 11 | 8.40   | 263| 2.07 |
| 9    | physics, multidisciplinary                                                      | 11 | 8.40   | 145| 0.86 |
| 10   | automation and control systems                                                 | 8  | 6.11   | 178| 1.10 |
| 11   | thermodynamics                                                                 | 8  | 6.11   | 269| 4.27 |
| 12   | computer science, software engineering                                         | 7  | 5.34   | 29 | 0.26 |
| 13   | telecommunications                                                               | 7  | 5.34   | 56 | 1.19 |
| 14   | computer science, theory and methods                                           | 6  | 4.58   | 11 | 0.29 |
| 15   | engineering, mechanical                                                        | 5  | 3.82   | 51 | 2.15 |
| 16   | management                                                                     | 5  | 3.82   | 83 | 0.69 |
| 17   | mechanics                                                                      | 5  | 3.82   | 150| 4.63 |
| 18   | computer science, hardware and software architecture                           | 4  | 3.05   | 6  | 0.13 |
| 19   | engineering, civil                                                             | 4  | 3.05   | 4  | 0.19 |
| 20   | mathematics, applied                                                           | 4  | 3.05   | 38 | 0.90 |
Table 5  Top 5 journals publishing articles in entropy-based dispatching field

| Rank | Journal title |
|------|---------------|
| 1    | International Of Production Research |
| 2    | European Journal Of Operational Research |
| 3    | Entropy |
| 4    | Energies |
| 5    | International Journal Of Advanced Manufacturing Technology |
| 6    | Electric Power Systems Research |
| 7    | Energy Conversion And Management |
| 8    | International Journal of Electrical Power & Energy Systems |
| 9    | IEEE Transactions on Smart Grid |
| 10   | Energy |
| 11   | Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture |
| 12   | Water Resources Management |
| 13   | Applied Soft Computing |
| 14   | PLOS ONE |
| 15   | Journal of Computing in Civil Engineering |
| 16   | Neurocomputing |
| 17   | Information Sciences |
| 18   | IEEE Access |
| 19   | Computers and Industrial Engineering |
| 20   | Journal of Modern Power Systems and Clean Energy |

Table 6  Contribution of the top 10 authors in entropy-based dispatching field

| Rank | Author        | TA | TPR, % | TC | ACP | h-index | Institution                                      | References |
|------|---------------|----|--------|----|-----|---------|-------------------------------------------------|------------|
| 1    | Zhang, Chaoyong | 2  | 100    | 85 | 2.57| 2       | Huazhong University of Science & Technology       | [9, 31]    |
| 2    | Zhang, Zhifeng | 2  | 100    | 19 | 1.55| 1       | Nanchang Hangkong University                      | [28, 32]   |
| 3    | Weng, Shengxuan | 2  | 100    | 26 | 1.25| 1       | Nanjing University of Posts & Telecommunications  | [33, 34]   |
| 4    | Xie, Xiangpeng | 2  | 100    | 26 | 1.25| 1       | Nanjing University of Posts & Telecommunications  | [33, 34]   |
| 5    | Hu, Songlin    | 2  | 100    | 26 | 1.25| 1       | Nanjing University of Posts & Telecommunications  | [33, 34]   |
| 6    | Yue, Dong      | 2  | 100    | 26 | 1.25| 1       | Nanjing University of Posts & Telecommunications  | [33, 34]   |
| 7    | Lv, Shengping  | 2  | 100    | 17 | 0.58| 2       | South China Agricultural University              | [35, 36]   |
| 8    | Li Xuebin      | 2  | 100    | 23 | 0.55| 2       | China Ship Design & Research Center              | [37, 38]   |
| 9    | Lukas, Ladislav | 2  | 100    | 7  | 0.5 | 2       | University of West Bohemia Pilsen                | [39, 40]   |
| 10   | Zhong, Denghua | 2  | 100    | 5  | 0.34| 2       | Tianjin University                               | [41, 42]   |

Table 7  Top five journals categorised in ‘Entropy-based Dispatching’ by web of science

| JCR year Rank | Journal title                                      | TC | IF |
|---------------|---------------------------------------------------|----|----|
| 2018 1        | European Journal of Operational Research           | 48466| 3.806|
| — 2           | International Journal of Production Research       | 17,976| 3.199|
| — 3           | ENERGIES                                          | 19,625| 2.707|
| — 4           | International Journal of Advanced Manufacturing Technology | 30,520| 2.496|
| — 5           | Entropy                                            | 7232 | 2.419|
| 2017 1        | European Journal of Operational Research           | 43,505| 3.428|
| — 2           | International Journal of Production Research       | 14,799| 2.623|
| — 3           | Energies                                           | 11,350| 2.676|
| — 4           | International Journal of Advanced Manufacturing Technology | 25,357| 2.601|
| — 5           | Entropy                                            | 4812 | 2.305|

3.6 Contribution of leading authors

Table 6 lists the ten most prolific authors based on the number of articles they published. As it is observed from the table, the number of published literatures in the field of entropy-based dispatching is relatively small, and the attention is not very high. The top ten authors in Table 7 all published two articles. As it is ranked by ACP in Table 6, Zhang Chaoyong (2.57) from Huazhong University of Science and Technology is ranked first, and Zhang Zhifeng (1.55) from Nanchang University is ranked second. The top ten authors accounted for 15.3% of the total publications, which means there are a large number of researchers in the field who have contributed to the 131 articles.

3.7 Analysis of the most cited articles

Although the total number of citations of articles is affected by many factors, it is still a widely accepted evaluation index of scientific papers to some extent [37]. Table 8 lists the top ten references in the total number of citations related to the field of entropy-based dispatching. First, ‘Environmental/economic power dispatch problem using multi-objective differential evolution algorithm ‘ published by Wu et al. [8] in ‘Electric Power Systems Research’ was cited 121 times, ranked the first. Second, ‘A multi-objective genetic algorithm based on immune and entropy principle for flexible job-shop scheduling problem’ (85) [56] and ‘ Hybrid genetic algorithm for economic dispatch with valve-point effect ‘ (83) [27] came in second and third, respectively. In addition, it

3.806. In addition ‘International Journal of Production Research’ (3.199) was ranked second. Clearly, these two journals are more valuable in this area.
can be known from the table that the annual reference quantity (TCY) of ‘The role of demand response in single and multi-objective wind-thermal generation scheduling: A stochastic programming ’ [46] written by Falsafi Hananeh and co-workers in the journal ‘ENERGY’ in 2014 was 12.5, which is the largest among the related journals in the field of entropy-based dispatching.

4 Implications

4.1 Research perspectives and trends

The three fields of Engineering Electrical and Electronics, Operations Research Management Science and Engineering Manufacturing are most closely related to entropy-based dispatching. From the correlation analysis of dispatching problems in different research fields and different entropy theories, the research interest and research value of Information entropy and Entropy weight are the highest. Information entropy has good research prospects in power system noise processing [10], soft information processing involved in dispatching systems [25], channel rate prediction and quantification in opportunistic dispatching algorithms [41], and improving the certainty of vehicle tracking position [19]. Entropy weight is of great research value in the Pareto solution of the dispatching model [20, 49]. Information entropy and Entropy weight are also often used to measure the complexity of manufacturing systems [16]. Relative Entropy (KL-divergence) has greater research potential in measuring flexibility and quantifying dynamic information in manufacturing systems [55]. Cross-entropy shows a good research prospect in the problem of economic load distribution [48, 70, 75]. Crowding entropy can be used to maintain the diversity of Pareto optimality [8], and has high research value in the field of improved intelligent algorithms in power systems and manufacturing systems. The mixed use of fuzzy entropy and some dispatching algorithms may be a good research direction [30]. The overlap of different research fields provides more possibilities for the entropy-based dispatching. In addition, besides the electrical, operations research and computer science, there are also promising research perspectives in less exposed areas, such as energy [77–79] and automatic control [56, 75, 80–86].

5 Conclusion and discussions

Given the present research on entropy-based scheduling, there is no doubt that the attention in this field has steadily increased in recent years, and the research vacancy is huge. Chinese researchers are paying the most attention to the field, and making the strongest contributions. In the ‘WoS research area’, Engineering, Electrical and Electronic and Operations research and Management Science are the most closely combined with the entropy-based scheduling research. Their total number of articles published is significantly higher than that of other research areas. ‘International Journal of Production Research’ and ‘European Journal of Operational Research’ are two of the most noteworthy journals for researchers in the field. From the frequently cited literatures, it can be predicted that the combination of entropy theory with economic scheduling, power scheduling and job-shop scheduling will be the development trend of this field in the future.

This study uses bibliometrics to study and analyse the content of entropy scheduling from qualitative and quantitative aspects. This study can provide an overview of the research on the entropy-based dispatching and help relevant scholars determine future research directions and potential collaborators. However, there are still some limitations. First of all, this method fails to delve into the root causes behind the research results. Second, the data collected from the database and related indicators should be updated over time, such as the H-index and impact factors. In addition, the data are not inclusive enough, and valuable literature could possibly be
yon of more comprehensive data, more accurate analysis of research features and trends, and more in-depth examination of the causes of the analysis results.

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