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A Scientometric Analysis of Energy Management in the Past Five Years (2018–2022)

Soodabeh Ghalambaz [1] and Christopher Neil Hulme [2,*]

[1] Department of Management, Payame Noor University (PNU), Tehran P.O. Box 19395-4697, Iran
[2] Department of Materials Science and Engineering, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
* Correspondence: chrihs@kth.se

Abstract: Energy management is an essential part of the integration of renewable energy in energy systems, electric vehicles, energy-saving strategies, waste-heat recovery, and building energy. Although many publications considered energy management, no study addressed the connection between scientists, organizations, and countries. The present study provides a scientometric analysis that addresses the trend of publications and worldwide dynamic maps of connectivity and scientists, organizations, and countries and their contribution to energy management. The results showed that Javaid Nadeem published the most papers in the field of energy management (90) while Xiao Hu received the most citations (1394). The university with the highest number of publications in energy management is the Islamic Azad University (144 papers), while the Beijing Institute of Technology has received the most citations (2061 citations) and the largest h-index (28). China and the United States are in the first and second rank in terms of total publications, citations, and h-index. Pakistan has the most publications relative to the country's research and development investment level. The maps of co-authorship show islands of isolated groups of authors. This implies that the researchers in energy management are not well-connected. Bibliographic coupling of countries revealed China and USA are influential contributors in the field, and other countries were coupled mostly through these two countries.

Keywords: energy management; scientometric analysis; bibliographic coupling; connection network

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1. Introduction

Due to industrial growth and the exponential rise in population, energy demand is rising [1]. Energy management (EM) plays a major role in various energy aspects, including energy production [2], energy distribution [3], and energy storage [4], while emerging renewable energy sources provide an alternative long-term solution for energy demand to mitigate climate change and reduce carbon production [5,6].

In the past few decades, particular attention has been dedicated to EM in various technological fields such as renewable energy [7,8], hybrid renewable energy systems [9], electric vehicles [10], energy saving [11], waste-to-energy management strategies [12], and building energy [13,14]. Recently, EM has found important applications in renewable energy.

Within renewable energy, there are various EM challenges. For example, there are various sources of renewable energy but significant uncertainty in production [8]. Providing the required functionality between microgrids and consumers in the flow of information is another management challenge. Such a management system should ensure that generation and distribution systems provide energy at nominal operative budgets [7]. David et al. [15] utilized the Scopus database to find research published between 2000 and 2019 related to EM for photovoltaic cells. They used the search string '("solar" and "energy" and "management" and "photovoltaic")'. They found and reported ten trends that could assist

researchers in finding ideas for future studies on photovoltaic solar energy. Roslan et al. [16] explored the Scopus database to find the most cited papers (as of January 2021) in the subject of microgrid control methods for realizing sustainable EM. The most cited publications were from 30 different countries and were published in 33 different journals.

The uncertain and variable nature of renewable energy sources demands particular design considerations, such as backup energy sources and combinations of two or more renewable-energy sources. These considerations could raise capital and operational costs of energy systems. To counter this, the control of the flow of energy and management of energy storage systems and demand are ways that EM principles could help to reduce energy costs [9].

The recent growth in electric vehicles (EVs) created new challenges for energy management. The battery cost is very significant, as they account for approximately 33% of the cost of the vehicle [10]. Strategies for EM in EVs during driving cycles and energy source management expose new challenges that should be addressed in this industrial sector [10]. EM for fuel cells in EVs is a separate challenge that also requires attention [12]. Raboaca et al. [17] employed a bibliometric approach to address these issues. They found 127 EM strategies, which were analyzed and classified by multiple criteria. Miah et al. [18] utilized the Scopus database and explored the papers related to EM for EVs. They found 2704 papers and selected 100 of the most relevant for further analysis, of which 22 were published in 2020, reflecting the rapid increase in interest in the sector.

A building EM system consists of many parts, such as lighting, air conditioning, ventilation, heating, and refrigerating equipment. Statistical results show a notable increase in energy saving when EM systems are implemented [11]. Applicable control systems and software for building management is already commercially available. However, integrating building energy with novel energy storage systems and renewable energy sources opens new EM challenges that should be addressed. The integration of artificial intelligence with building EM systems is one potential area of development to meet this need.

There are various factors that contribute to waste: Environmental, social, technological, economic, and political. Analysis of and decision making related to waste in EM, therefore, requires multidisciplinary support and relies on multiple measures in the process of decision making. Since various measures are involved, some of these objectives typically conflict with each other and robust management strategies and decision analysis tools are required [12].

EM is a "hot topic" that has attracted the attention of many researchers [1–14]. Many papers and reviews have been published to address critical issues in different fields of energy production [2], distribution [3], storage [4], savings [11], renewable [7,8], hybrid renewable [9], EVs [10], waste management [12], and buildings [13,14]. These reviews investigated the trend of progress and advancement in technological aspects of energy. Existing bibliometric studies are available in EM systems related to solar energy management [15], microgrid control [16], and EVs [17,18]. However, the communication between scientists, organizations and countries for EM is lacking. A scientometric analysis can address the statistics of publications, citations, and worldwide dynamic maps of the connectivity and contribution of scientists, organizations, and countries on energy management.

The present study aims to analyze the topic of EM using a scientometric analysis approach for the first time. The results of the current research answer the following questions: What are the most significant scientists, countries, and organizations advancing energy management in the field? What are the papers with the most citations? What are the organizations and countries with the most publications? What are the characteristics of EM's global dynamic and thematic map? How are scientists, papers, organizations, and countries coupled?

2. Methods

In the current research, data relating to publications in the field of EM were mined from Web of Science (WoS) Core Collection, a leading database for ranking and collection of

scientific publications. WoS was searched on the 5th of May 2022 for the papers published since January 2018. Here, 2018 was selected as the initial year since WoS provides impact factor reports for journals based on the most recent five years of citations. Similarly, Scopus CiteScore (a competitor to WoS) also provides a citation impact report based on a four-year citation impact and use of that database would be more suited to a period of 2019–2022. The data were analyzed automatically using a bespoke MATLAB code. Moreover, the software VOSviewer (Centre for Science and Technology Studies (CWTS), Leiden, The Netherlands) was utilized for bibliographic mapping and cluster illustration. The following search string was used to extract data related to energy and management from WoS: '(energy* (Title) AND management* (Title))'. This string combines two important terms related to EM: energy and management that must appear in the title of each article. The asterisk ensures words such as energies or managements are also included in the search domain. The MATLAB code itself is contained in 47 separate files, which are inconvenient to use without guidance. Readers are encouraged to contact the lead author if they wish to obtain copies of the exact codes used in this study. A more user-friendly version of the analysis code will be developed and distributed once ready.

The first 500 records returned by WoS were checked manually for any irrelevant results, of which five such records were identified. Thus, we estimate that 1% of the sample is inappropriate. Table 1 in [19] reports the required sample size for a population of 7000 with 95% confidence is 378. Thus, the number of relevant records in the adopted sample size of 500 in the current research is above the 378 records threshold and can represent the total sample with a confidence level in excess of 95%.

Table 1. Yearly report of total publications and citations.

Year	TP	TC	>200	>100	>50	>25	>10	>5	>1
2018	1616	21,662	5	32	102	242	492	674	1028
2019	1659	17,608	0	9	68	195	489	716	1061
2020	1649	12,244	0	4	22	102	374	617	1038
2021	1584	4528	0	0	2	22	91	220	697
2022	522	301	0	0	0	0	3	7	52
Total	7030	56,343	5	45	194	561	1449	2234	3876
%	100%	-	0.07%	0.64%	2.76%	7.98%	20.62%	31.79%	55.15%

TP = total publications, and TC = total citations.

During the anlaysis, a threshold of 100 EM citations was applied for entries on the dynamic maps. The tables and graphs are sorted by the highest publication counts and citations. Thus, the samples with a 1% error seem to be adequate for statistical analysis and graphical representation of the outcome. It is also likely that inappropriate articles are from several fields of study. Since the current research aims to provide statistical analysis and worldwide dynamic maps of connectivity and scientists, organizations, and countries within the field of EM, it is likely that the inappropriate articles will not be represented strongly and so the 1% error would effectively diminish further in the computations and maps. Based on these factors, the data collected by the automated procedure were accepted without and manual screening.

3. Bibliometric Analysis

Using the search string explained in the Section 2, a total of 7030 documents were found and analyzed to reveal the most productive authors, organizations and countries, as well as links between them.

3.1. Publications and Citations by Year

Table 1 and Figure 1 report the yearly number of the total publications (TP) and the total citations (TC). As can be seen, about 1600 publications were published each year except for 2022, which is still ongoing. The maximum number of citations for any given year was approximately 21,000, which occurred in 2018; then, the number of publications

fell slowly each year. This is reasonable and simple to explain, as an older publication has more time to receive citations compared to a more recent one. Table 1 categorizes the papers with thresholds higher than 1, 5, 10, 25, 50, 100, and 200 citations.

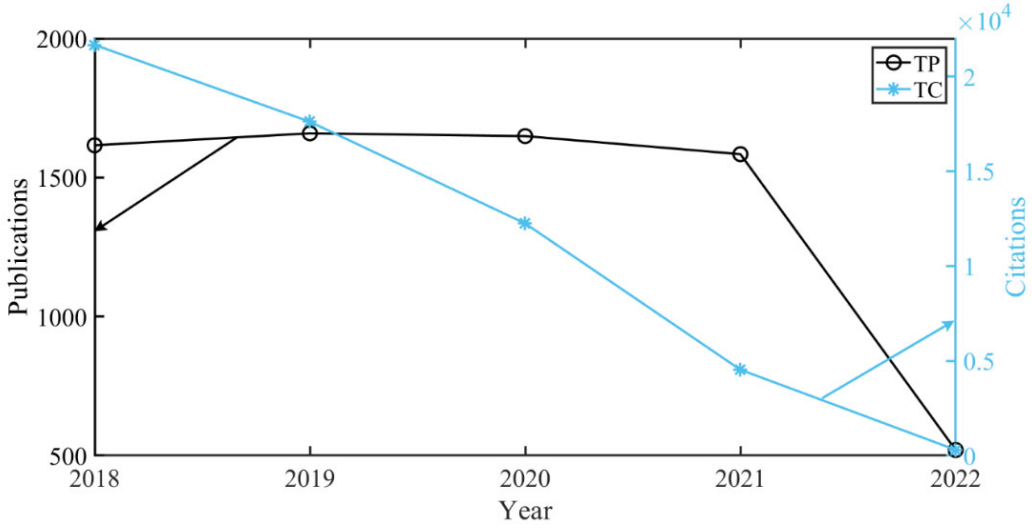


Figure 1. Number of total publications (TP) and total citations (TC) during the past five years related to EM.

Table 1 suggests that approximately 55% (3876/7030) of articles received at least one citation and nearly 32% (2234/7030) of articles received at least five. The highest number of publications occurred in 2019, after which the number of publications decreased, but has remained at a similar level throughout the period studied.

During the 5-year period that was surveyed in the current study, the number of papers per year that received more than 10, 25, 50, 100, and 200 citations each was the highest in 2018. The number of papers in these categories dropped in subsequent years, which may be due to the time delay between a publication and accumulation of many citations from future papers, especially for publications in 2021 and 2022.

3.2. The Most Productive and Influential Authors

The top authors with publications in EM are analyzed here. It should be noted some authors may have more than one affiliation, and some authors may change their affiliations several times or change their name. Thus, providing a unique affiliation for authors was not feasible. Some authors also use different formats for writing their names in different studies. Similarly, two or more different authors may have similar names and affiliations. There is no concrete automated way of distinguishing such authors. Recently, WoS started to assign a researcher ID to publications so that they are attributed to the correct author(s) reliably and regardless of affiliation or name at the time of writing. However, the researcher ID has not been provided for all authors of the WoS records, so it cannot be used in the current study.

Table 2 lists the top 40 authors who are sorted according to TP. Nadeem Javaid, with 90 publications, is at the top of the list. This author published 60% more additional articles than the next author on the list. After Nadeem, there are six authors with 35 or more papers: Ji Li (56 articles); Yu Wang (52); Xiao Hu (39); Josep M. Guerrero. (38); Xi Li (38); and Yu Zhang (37). All of the authors on this list have published 16 or more papers. Xiao Hu is the most cited author in the field of EM with 39 papers and 1394 citations.

Table 2. Forty leading authors in EM.

R	Author Name	Country	TP	TC	h-Index	TC/TP
1	Nadeem, Javaid	Pakistan	90	712	14	7.9
2	Li, Ji	China	56	538	13	9.6
3	Wang, Yu	China	52	604	13	11.6
4	Hu, Xiao	China	39	1394	20	35.7
5	Guerrero, Josep M.	Denmark	38	428	10	11.3
6	Li, Xi	China	38	551	12	14.5
7	Zhang, Yu	North Ireland	37	414	12	11.2
8	Wang, Li	China	34	354	9	10.4
9	Li, Qi	China	31	488	11	15.7
10	Catalao, Joao P. S.	Portugal	30	487	12	16.2
11	Li, Yan	China	30	162	7	5.4
12	Mohammadi-Ivatloo, Behnam	Iran	28	302	8	10.8
13	Boulon, Loic	Canada	27	173	7	6.4
14	Hu, Xiaosong	China	27	1266	18	46.9
15	Chen, Xi	England	26	184	7	7.1
16	He, Hongwen	China	26	477	11	18.3
17	Vale, Zita	Portugal	26	104	6	4.0
18	Wang, Wei	China	26	223	8	8.6
19	Zhang, Yi	China	26	387	10	14.9
20	Chen, Zhe	Denmark	24	353	12	14.7
21	Zhang, Jian	Australia	22	289	9	13.1
22	Li, Li	China	21	341	10	16.2
23	Li, Wei	Australia	21	423	9	20.1
24	Wu, Yu	China	21	385	10	18.3
25	Zhang, Qi	China	21	197	5	9.4
26	Liu, Yan	China	19	119	4	6.3
27	Wang, Peng	China	19	275	6	14.5
28	Zhang, Yan	China	19	461	7	24.3
29	Li, Xu	China	18	144	5	8.0
30	Peng, Jiankun	China	18	424	9	23.6
31	Thollander, Patrik	Sweden	18	252	9	14.0
32	Wang, Hao	China	18	119	6	6.6
33	Wang, Xin	China	18	83	4	4.6
34	Dong, Zhao Yang	Australia	17	218	8	12.8
35	Liu, Hui	China	17	166	6	9.8
36	Wang, Shu	China	17	273	7	16.1
37	Anvari-Moghaddam, Amjad	Denmark	16	177	6	11.1
38	Chen, Weirong	China	16	421	11	26.3
39	Chen, Zheng	China	16	284	11	17.8
40	Khan, Zahoor Ali	U Arab Emirates	16	114	6	7.1

The second most cited author is Xiaosong Hu, with 1266 and the third is Javaid Nadeem with 712 citations. Each of the first ten authors in Table 2 received 350 citations or more.

The h-index (*h* papers cited at least *h* times, HI) of 21 out of 40 most prolific authors in EM is at least 10 (Table 2). These h-indices are solely computed based on EM publications. The top h-indexes belong to Xiao Hu (20) and Xiaosong Hu (28).

Cole and Cole [20] considered two criteria of *citations* and *productivity* and defined four categories for authors. Authors with many publications and citations were identified as *prolific*. Authors with high TP but low TC were identified as *mass producers*. Authors with low TP but high TC were identified as *perfectionists*. Finally, authors with low TP and low TC were identified as *silent* (Figure 2). Mas-Tur et al. recently applied these classifications [21]. Here, the dashed lines shows the mean values of TP and TC in this study.

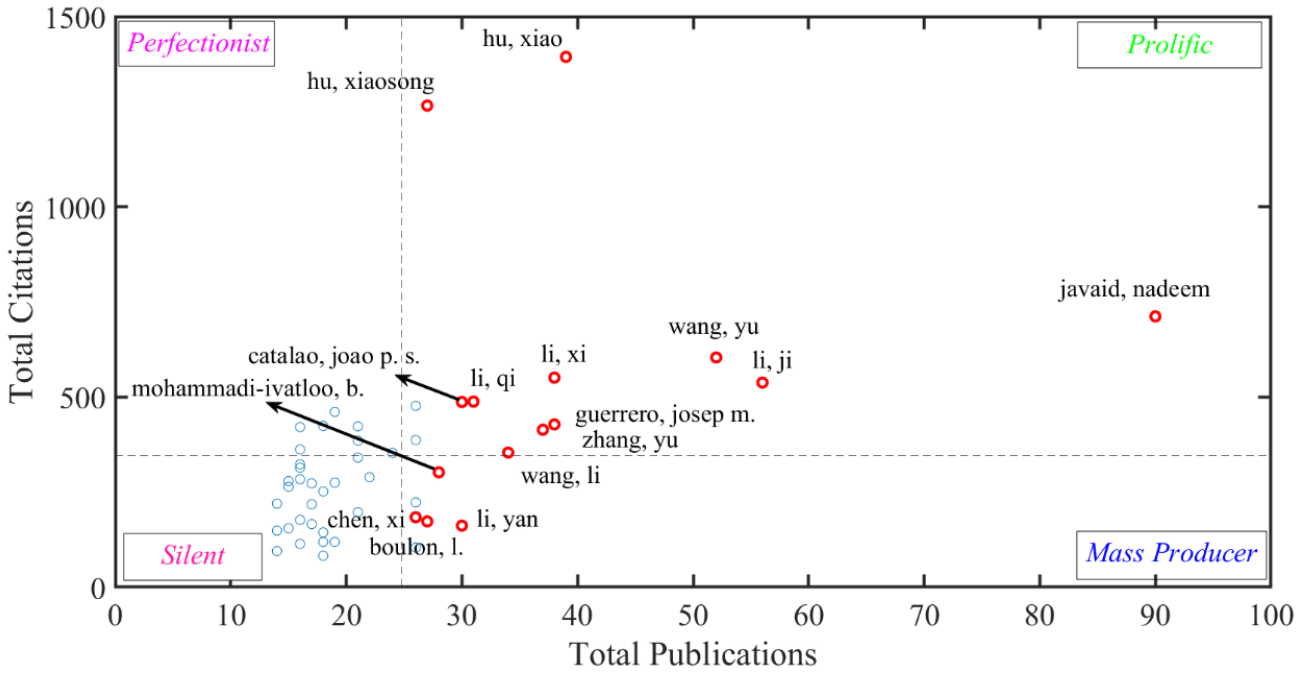


Figure 2. A TP-TC map for authors published in EM.

Xiao Hu, Xiaosong Hu and Nadeem Javaid are placed firmly in the prolific zone based on TC. Although the first two are relatively close to the perfectionist, based on TP. Xiao Hu and Xiaosong Hu are in the prolific zones, these two authors are very close to the border of the perfectionist zone. In terms of quality (measured by the number of citations per publication), Xiaosong Hu is ranked first by receiving 1266 citations and publishing 27 papers (TC/TP = 46.9). In second place is Xiao Hu receiving 1394 citations for 39 papers (TC/TP = 35.7). There is a limited number of authors in the mass producer and perfectionists' zone, and most of the authors are silent.

3.3. The Most Productive and Influential Universities

Table 3 reports a list of the top 40 universities sorted based on TP. Considering TP, the top five universities are: Islamic Azad University, Beijing Institute of Technology, Aalborg University, North China Electric Power University, and Tsinghua University. Beijing Institute of Technology has the highest number of citations (TC = 2061), followed by Chongqing University (1907), Islamic Azad University (1813) and Nanyang Technological University (1319). According to the h-index, the top four universities are: Beijing Institute of Technology (h = 28), Chongqing University (h = 23), Islamic Azad University (h = 22), and Tsinghua University (h = 22). The University of Waterloo (TC/TP = 22), Chongqing University (TC/TP = 21.9), and Nanyang Technological University (TC/TP = 21.6) have the highest average quality.

Considering these indicators together, no university is clearly superior. In terms of total citations, the top three universities show intense competition: the first-rank university (Beijing Institute of Technology) has a number of citations that is only 14 percent higher than that of the third-rank university (Islamic Azad University). However, the latter has 37% more citations than the fourth rank university (Nanyang University of Technology).

Islamic Azad University, Beijing Institute of Technology, and Aalborg University are amongst the top five universities in terms of three different metrics (TP, TC, and h-index). According to Table 3, Chongqing University has achieved an excellent performance in terms of two indicators, TC and h-index, but is ranked seventh in terms of TP (87), this university is ranked second in terms of TC and HI after the Beijing Institute of Technology and is ranked second rank in terms of TC/TP.

Table 3. List of universities with highest TP in EM.

R	Name	Country	TP	TC	h-Index	TC/TP
1	Islamic Azad Univ	Iran	144	1813	22	12.6
2	Beijing Inst Technol	China	119	2061	28	17.3
3	Aalborg Univ	Denmark	107	1289	20	12.0
4	North China Elect Power Univ	China	91	1006	16	11.1
5	Tsinghua Univ	China	88	1227	22	13.9
6	Chongqing Univ	China	87	1907	23	21.9
7	Shanghai Jiao Tong Univ	China	79	747	16	9.5
8	Chinese Acad Sci	China	71	1036	16	14.6
9	Comsats Inst Informat Technol	Pakistan	68	595	11	8.8
10	Nanyang Technol Univ	Singapore	61	1319	18	21.6
11	Southeast Univ	China	54	627	14	11.6
12	Zhejiang Univ	China	53	654	14	12.3
13	Huazhong Univ Sci and Technol	Australia	52	764	16	14.7
14	Jilin Univ	China	50	387	11	7.7
15	Comsats Univ Islamabad	Pakistan	47	571	14	12.1
16	Univ Waterloo	Canada	47	1033	18	22.0
17	King Saud Univ	Saudi Arabia	45	663	16	14.7
18	Univ New South Wales	Australia	45	784	17	17.4
19	Univ Tabriz	Iran	45	585	15	13.0
20	Tongji Univ	China	42	419	12	10.0
21	King Abdulaziz Univ	Saudi Arabia	41	416	11	10.1
22	Univ Sydney	China	40	530	13	13.3
23	Politecn Milan	Italy	39	267	9	6.8
24	Shandong Univ	China	38	231	9	6.1
25	Tianjin Univ	China	37	295	8	8.0
26	Univ Technol Sydney	Australia	37	524	14	14.2
27	Univ Bourgogne Franche Comte	France	36	452	11	12.6
28	Univ Porto	Iran	35	543	12	15.5
29	Aalto Univ	Finland	34	527	11	15.5
30	Amirkabir Univ Technol	Iran	34	289	11	8.5
31	Southwest Jiaotong Univ	China	34	554	12	16.3
32	Hunan Univ	China	33	305	10	9.2
33	Politecn Torino	Turkey	33	203	7	6.2
34	Univ Quebec Trois Rivieres	Canada	33	184	7	5.6
35	Beijing Jiaotong Univ	China	32	267	7	8.3
36	Natl Inst Technol	India	32	359	12	11.2
37	Univ Tehran	Iran	32	384	11	12.0
38	Xi An Jiao Tong Univ	China	32	136	5	4.3
39	Delft Univ Technol	The Netherlands	31	182	8	5.9
40	Northwestern Polytech Univ	China	31	301	7	9.7

Figure 3 illustrates a map of TC-TP for universities. There seems to be a direct relationship between TP and TC. Figure 3 shows that many of the universities are in the silent zone. Most of the universities placed at the top of Table 3 appear in the prolific zone. Jilin University and COMSATS University Islamabad are close to being classified as mass producers. Almost no university from the top of Table 3 is located in the perfectionist zone, indicating that TC is heavily dependent on TP, i.e., no university achieved high TC with low TP.

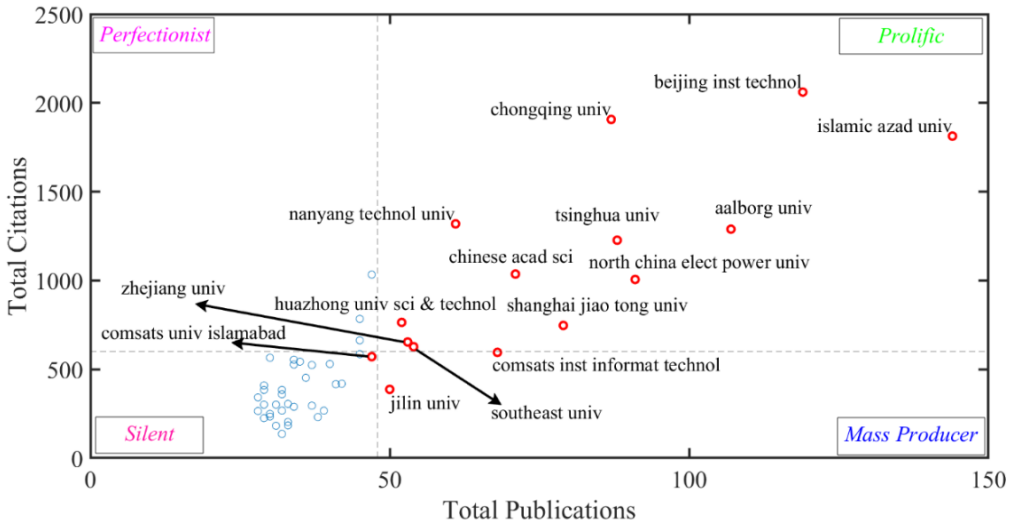


Figure 3. A TC-TP map for universities.

3.4. The Most Productive and Influential Countries

Table 4 reports a list of top countries sorted by TP, limited to the top 40. Each country's population and research and development (R&D) investment is also reported for the sake of normalization. Regarding TP, China leads the ranking, followed by the USA, India, Iran, and England. In terms of total citations and h-index, these countries, except India, are in the top 5 countries in Table 4. According to Table 4, China and the United States are first and second in terms of three indicators: TP, TC, and HI. In terms of total publications and total citations, China leads the ranking, and it is almost twice as large as the United States (second rank) in terms of TP and TC. Pakistan also has the highest TP/R&D. Denmark, Singapore, Finland, and Portugal have the highest publication per million population (TP/POP).

Figure 4 illustrates a map of TP-TC for the top countries. This figure shows that many of the countries are in the silent zone. There are few countries in the Prolific zone. This figure also shows a strong direct relationship between TP and TC for each country in the prolific zone, except India. Although India does not follow the trend of the results, it received a fair number of TC.

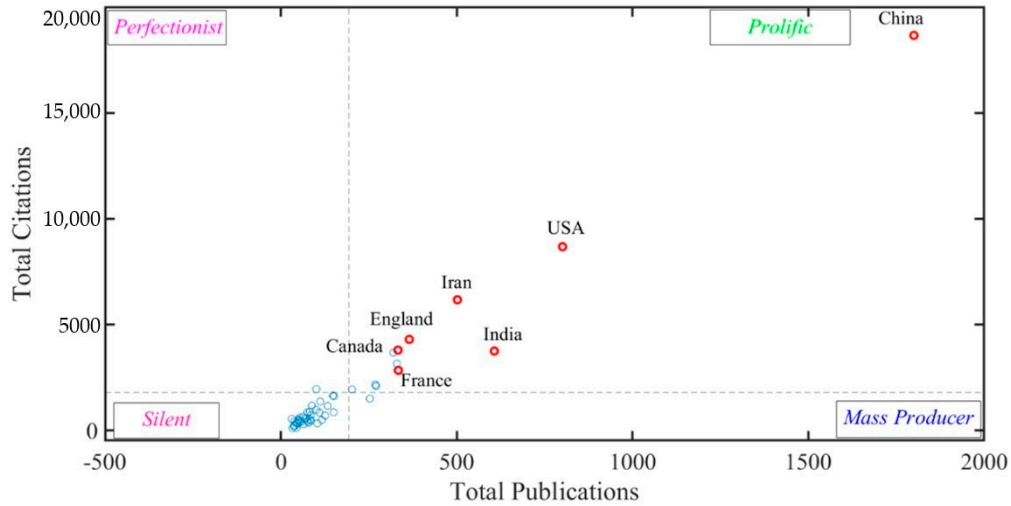


Figure 4. Countries mapped by total publications (TP) and total citations (TC).

Table 4. Most productive and influential countries in EM. Pop = population in millions. R&D = annual research and development budget as a percentage of total gross domestic product (GDP).

R	Country	TP	TC	HI	TC/TP	Pop	TP/Pop	TC/Pop	R&D	TP/R&D	TC/R&D (K)
1	China	1800	18,658	58	10.4	1411	1.28	13.2	2.14	841	8716
2	USA	801	8668	45	10.8	329	2.43	26.3	2.83	283	3060
3	India	607	3732	30	6.1	1380	0.44	2.7	0.65	930	5717
4	Iran	502	6158	38	12.3	84	5.98	73.3	0.83	605	7417
5	England	365	4285	34	11.7	67	5.43	63.8	1.70	214	2517
6	France	334	2821	26	8.4	67	4.96	41.9	2.19	152	1286
7	Canada	333	3778	35	11.3	38	8.76	99.4	1.54	216	2449
8	Italy	330	3138	26	9.5	60	5.54	52.7	1.39	237	2255
9	Australia	320	3658	30	11.4	26	12.46	142.4	1.87	171	1951
10	Pakistan	271	2080	23	7.7	221	1.23	9.4	0.24	1147	8803
11	Spain	271	2084	20	7.7	47	5.72	44.0	1.24	218	1676
12	South Korea	268	2146	22	8.0	52	5.18	41.4	4.53	59	474
13	Germany	253	1483	18	5.9	83	3.04	17.8	3.13	81	473
14	Saudi Arabia	202	1921	23	9.5	35	5.80	55.2	0.00	0	0
15	Portugal	151	1596	21	10.6	10	14.65	154.9	1.35	112	1184
16	Japan	150	836	16	5.6	126	1.19	6.6	3.28	46	255
17	Denmark	148	1636	22	11.1	6	25.38	280.5	3.03	49	539
18	Egypt	133	1141	20	8.6	102	1.30	11.1	0.72	184	1576
19	Turkey	126	688	15	5.5	84	1.49	8.2	0.96	131	717
20	Poland	116	472	12	4.1	38	3.06	12.4	1.21	96	390
21	Malaysia	112	1349	18	12.0	32	3.46	41.7	1.04	108	1296
22	Brazil	109	831	18	7.6	213	0.51	3.9	1.16	94	716
23	Russia	104	320	10	3.1	144	0.72	2.2	0.98	106	326
24	Singapore	101	1932	22	19.1	6	17.76	339.8	1.92	52	1004
25	Greece	100	954	17	9.5	11	9.33	89.0	1.18	85	810
26	Sweden	88	1154	19	13.1	10	8.50	111.5	3.31	27	348
27	South Africa	86	439	12	5.1	59	1.45	7.4	0.83	103	528
28	The Netherlands	85	704	13	8.3	17	4.87	40.4	2.16	39	325
29	Algeria	83	495	12	6.0	44	1.89	11.3	0.54	153	912
30	Finland	82	870	16	10.6	6	14.83	157.3	2.76	30	316
31	Morocco	79	346	9	4.4	37	2.14	9.4	0.00	0	0
32	Tunisia	75	431	11	5.7	12	6.35	36.5	0.60	125	717
33	U Arab Emirates	75	827	15	11.0	10	7.58	83.6	1.28	59	647
34	Taiwan	71	549	13	7.7	0	0	0	0.00	0	0
35	Austria	64	268	8	4.2	9	7.18	30.1	3.21	20	83
36	Vietnam	63	627	14	10.0	97	0.65	6.4	0.53	120	1190
37	Ireland	57	370	11	6.5	5	11.41	74.1	1.15	50	323
38	Norway	54	591	13	10.9	5	10.04	109.9	2.07	26	285
39	Romania	53	463	9	8.7	5	10.38	90.7	0.22	241	2108
40	Thailand	53	394	8	7.4	70	0.76	5.6	1.00	53	393

3.5. Distribution of Authors, Institutions, and Countries

Table 5 and Figure 5 show the distribution trend of countries, institutions, and authors over the past five years. There is only a slight difference in the number of articles published between 2018 and 2021. Table 5 shows that the trend in the number of institutions and authors has experienced an upward trend from 2018 to 2021. The number of publications, countries, and institutions shows a drop in 2022, since the data are incomplete for that year (the current year at the time of writing).

Table 5. Distribution trend of total number of publications, countries, institutions, and authors during the past five years.

Year	TP	Countries	Institutions	Authors
2018	1616	91	1860	5594
2019	1659	87	1970	5952
2020	1649	94	2025	5969
2021	1584	97	2203	6132
2022	520	76	1094	2267

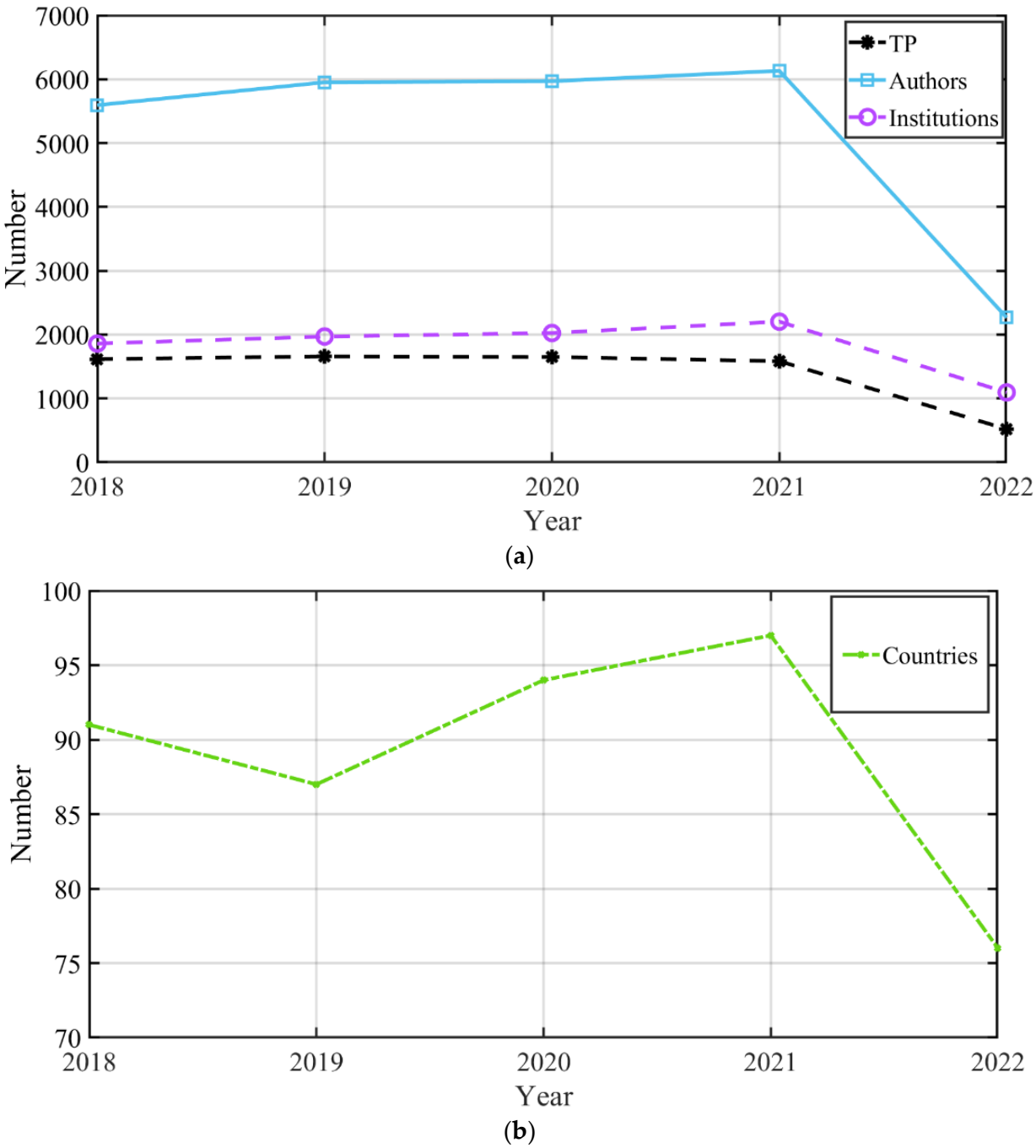


Figure 5. The number of yearly contributions to EM: (**a**) institutions, authors, and total publications (TP) and (**b**) countries.

4. Network Visualization

The dynamic maps of connections in network visualization were plotted for the author's co-citation, co-authorship, and authors' bibliographic coupling, organizations, and countries.

4.1. Author's Co-Citation

Co-citation occurs when two documents receive a citation from the same third document [22]. Thus, the authors of cited articles are related, and, hence, they can be clustered in a co-citation map. A threshold of 100 EM citations was applied to filter the authors before analyzing the co-citation data for plots. There were 93,614 authors in the overall dataset, and applying this filter reduced the number of authors to 120. In the network visualization map, authors are indicated by circles, while the lines between the circles denote the co-citation relationships (Figure 6). The distance between two authors on the map approximately indicates the relatedness of the two authors in terms of co-citations [23]. The total overall strength of links for each author determines the size of the circle and the author's name.

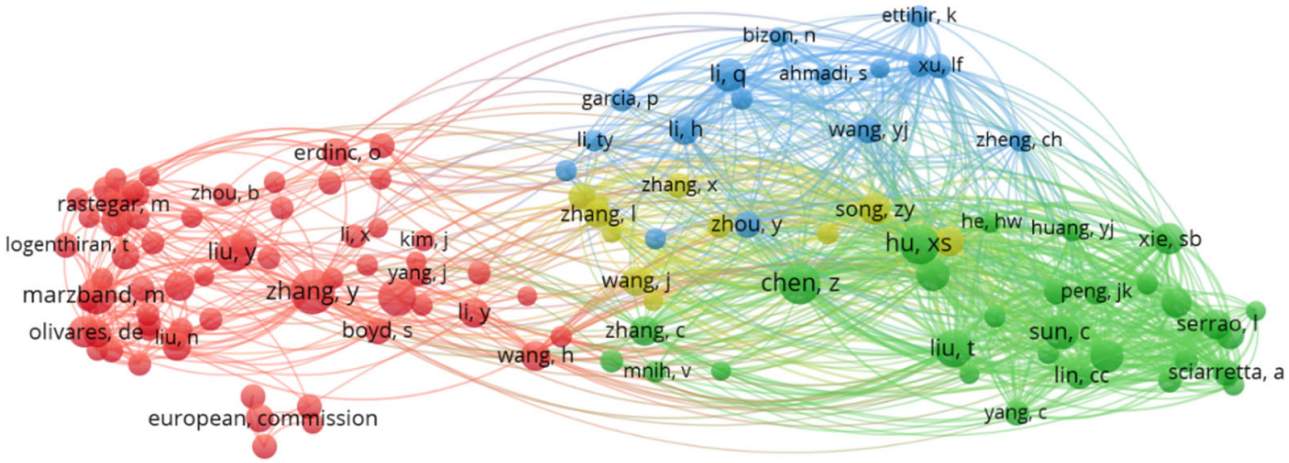


Figure 6. Co-citation map for EM authors.

Figure 6 illustrates four clusters. A first cluster (red), with 64 authors, is anchored by authors Sb Xie and Y Zhang, with total link strength of 3193 and 2527, respectively. The second cluster (green), with 29 authors, is anchored by authors Xs Hu and Z Chen. The second cluster contains the top four researchers in terms of total link strength. Xs Hu had the highest total link strength in the second cluster with a link strength of 4522, followed by Z Chen (4105), T Liu (3755), and C Sun (3336). The third cluster (blue), with 16 authors, is anchored by authors Q Li with total link strength (2384) and Lf Xu (2007).

The fourth cluster (yellow), with 11 authors, is anchored by authors R Xiong and Zy Song with total link strength of 2694 and 2635, respectively. Among the top ten authors with the highest total link strength, there are six authors from the second cluster (green). This means that 60% top ten authors' highest total link strength belongs to the second cluster in EM. According to Figure 6, the connections between the first cluster (red) and the second cluster (green) are fragile. The fourth cluster (yellow) is located in the middle of the map and has a good relationship with all clusters.

4.2. Co-Authorships

Co-authorship is one of the most tangible forms of research association. A co-authorship network is a way in which the authors are linked to each other through joint participation in one or more publications either directly or via third parties. The VOSviewer software was utilized to plot the network visualization maps of co-authorship for a group of authors (Figure 7). Authors with TC $\geq$ 100 and TP $\geq$ 10 (52 authors) were selected for the

co-authorship visualization map. The size of the text and circles shows the overall co-authorship link strength of an author, while the line thickness denotes the connection strength between authors. The authors with the strongest relationships are clustered together and illustrated by a color.

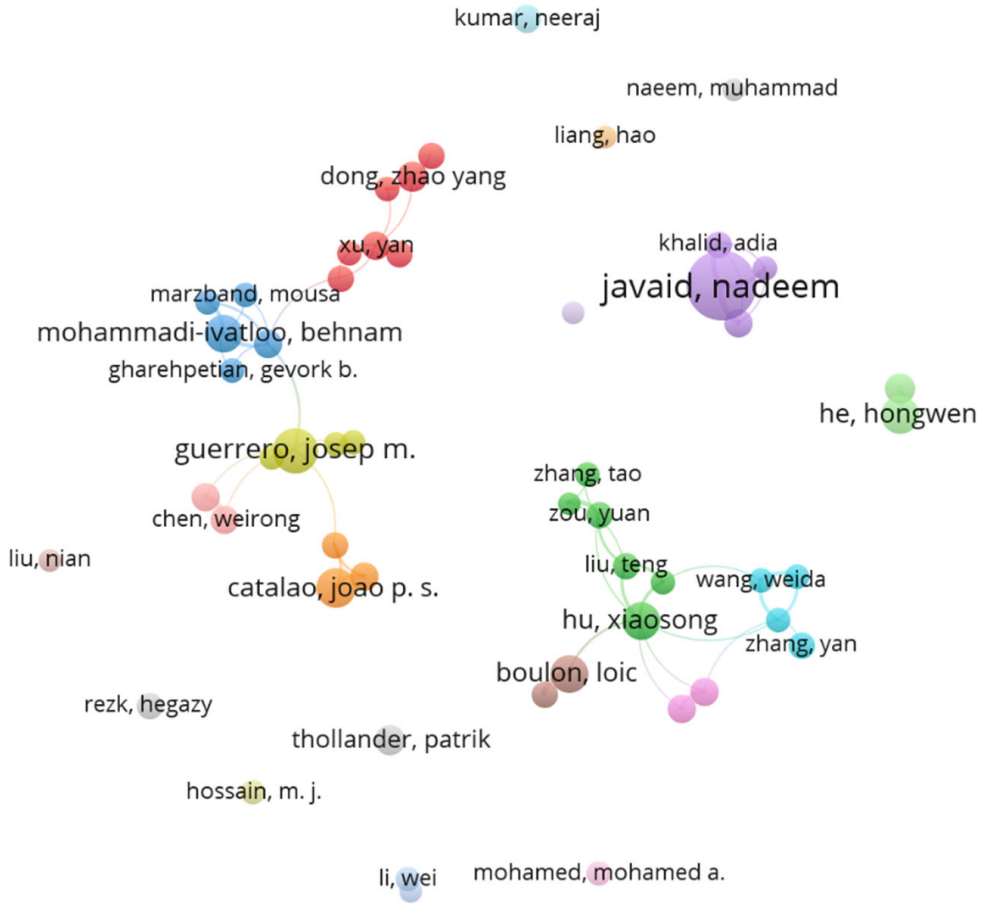


Figure 7. Co-authorship of authors publishing in EM.

In Figure 7, the authors are divided into 21 zones. Many zones include only one researcher. A large group of seven authors can be identified in a research network (the zone illustrated in red). These groups of authors are termed clusters. This means they work together in the same area and combine their publishing efforts. No Author in the red cluster dominates the others because their total link strengths are approximately the same. Freed Blaabjerg was the connection point between the res and the blue clusters.

The purple cluster is dominated by Javaid Nadeem, Javaid, who is the best connected author in this study (40 total links to other authors in this network).

Javaid Nadeem is the most productive author and established uniform links with other members of the cluster in which he is represented. However, there is no link between the cluster centered on him and any other clusters. This indicates that Javaid Nadeem and other members of that cluster are isolated from the community in terms of co-authorship.

4.3. Bibliographic Coupling of Authors, Institutions, and Countries

A bibliographic coupling occurs in cases where two articles cite the same third article. As explained by Martyn [24], "two papers that share one reference contain one unit of coupling, and the value of a relationship between two papers having one or more references in common is stated as being of strength one, two, etc., depending on the number of shared references". Bibliographic coupling utilizes citations to explain the similarities between two items. In the case of authors' bibliographic coupling, two articles citing the third article are closely linked, and they should be denoted by similar colors and placed in a cluster. A

bibliographic coupling strength was evaluated by the total citations or references of the other third documents they share.

Figure 8 illustrates the map of the authors' bibliographic coupling map. The authors with TC $\geq$ 100 and TP $\geq$ 10 were selected (52) for the bibliographic coupling analysis. Distance between the nodes in the network is directly proportional to their subject relatedness. The thickness of the lines between the network nodes represents the bibliographic coupling strength between them. Figure 8 shows three clusters, in red, green, and blue. The first cluster (red) consists of 31 researchers, the second cluster (green) consists of 15 researchers, and the third cluster (blue) cluster consists of 6 researchers. The most important authors in this metric were Xiaosong Hu from the second cluster, who was assessed to have the highest link total strength (9215), followed by Javaid Nadeem from the first cluster (8907). According to Figure 8, it can be seen that the whole system is heterogeneous. This heterogeneity has led the red cluster to establish a strong bibliographic pair with itself and weaker integration with the other two clusters. The green cluster also establishes a strong internal bibliographic pairing, but it is somewhat integrated with the blue cluster.

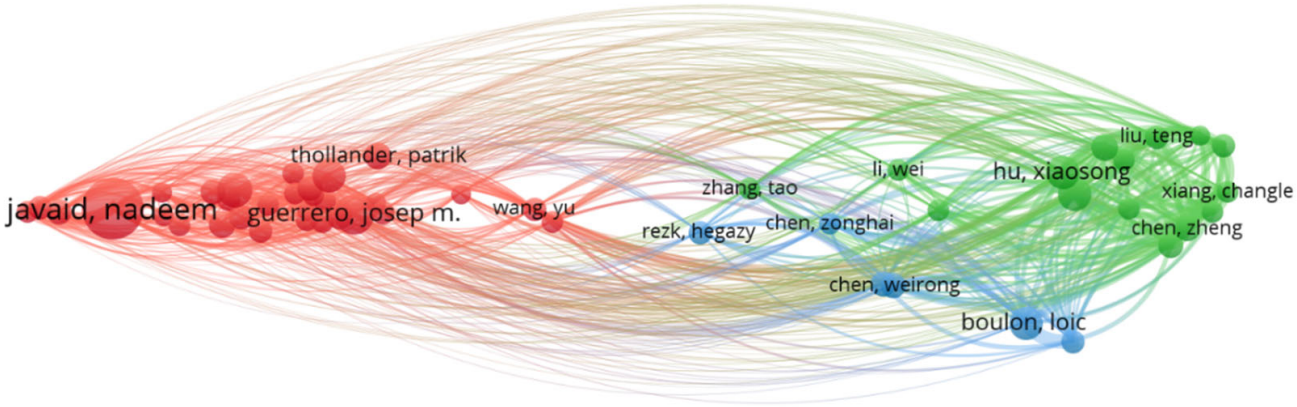


Figure 8. The map of EM authors' bibliographic coupling.

The institutions' bibliographic coupling happens when articles affiliated to two institutions cite a publication of a third institution. Figure 9 depicts the map of institutions' coupling for institutions with TC $\geq$ 300 and TP $\geq$ 10 (63). There are four clusters (Figure 9): The red cluster with 38 institutions, the green cluster with 15 institutions, the blue cluster with seven institutions, and the yellow cluster with three institutions. Table 6 lists the papers, citations, and total link strength of the top ten institutions. Beijing Institute of Technology from China received the highest link strength (52,584), followed by Chongqing University from China (163,925), Tsinghua University from China (21,322), and University Waterloo from Canada (20,335), and Jilin university from China, which received 20,251 total link strength. Four of the top five of universities in terms of bibliographic coupling in EM belong to China, as are two of the next top five (to make a total of six of the top ten).

Figure 10 illustrates the bibliographic coupling for countries with TP $\geq$ 10 and TC $\geq$ 300 (126This reduced the total of 126 countries in the study to 46. In this map, countries are divided into five clusters. Cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (yellow), and cluster 5 (purple) consist of 15, 12, 11, 6, and 2 countries, respectively. The most important two countries (China and USA) with the highest total link strength in EM are in cluster 2 (green). Table 7 reveals the papers, citations, and the total link strength of the top ten countries. China received the highest total link strength (517,865), followed by the USA (223,921), Iran (178,641), India (165,583), and Canada (165,476). In addition, China is almost twice as large as the next country (United States) in total link strength, publications, and citations.

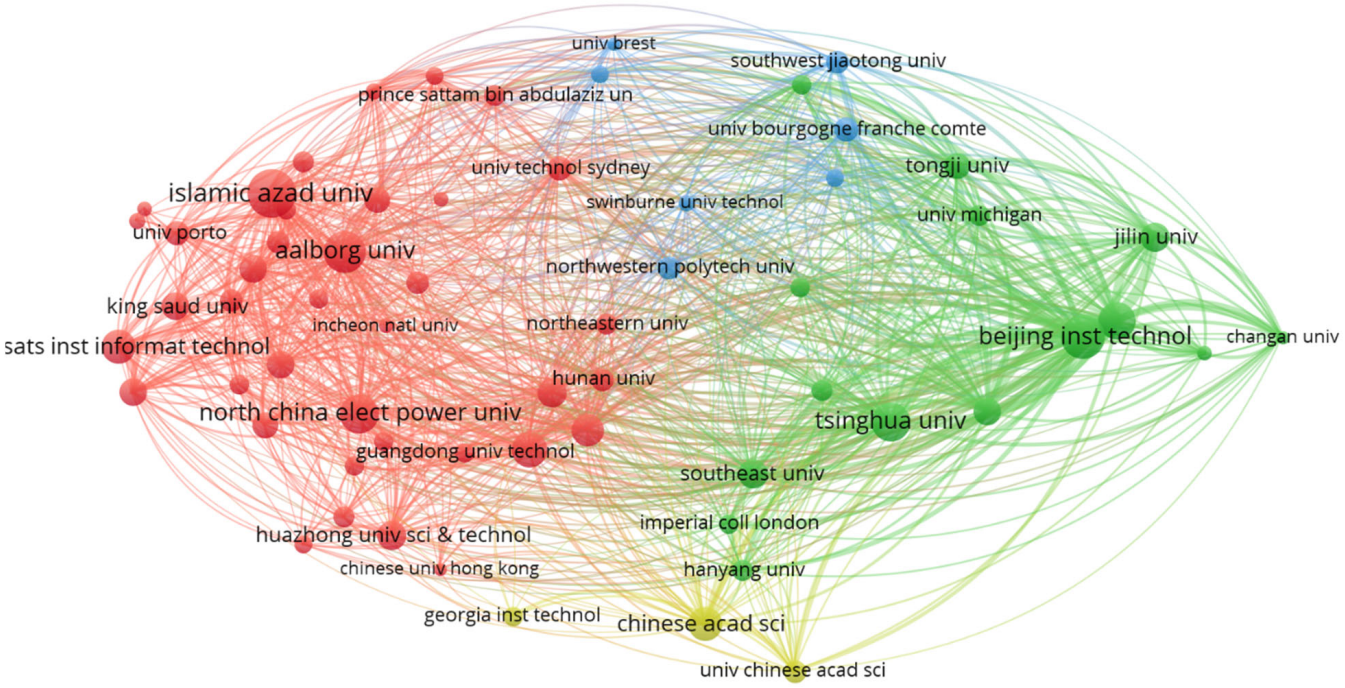


Figure 9. The map of EM bibliographic coupling for institutions.

Table 6. Top-10 most linked institutions based on the total link strength.

R	Organization	Documents	Citations	Total Link Strength
1	Beijing Inst Technol, China	119	2061	52,584
2	Chongqing Univ, China	87	1907	40,249
3	Tsinghua Univ, China	88	1227	21,322
4	Univ Waterloo, Canada	47	1033	20,335
5	Jilin Univ, China	50	387	20,251
6	Aalborg Univ, Denmark	107	1289	19,221
7	Islamic Azad Univ, Iran	144	1813	14,845
8	Nanyang Technol Univ, Singapore	61	1319	13,449
9	North China Elect Power Univ, China	91	1006	12,627
10	Southeast Univ, Bangladesh	54	627	12,151

Table 7. Top-10 most linked countries based on the total link strength.

R	Country	Documents	Citations	Total Link Strength
1	China	1800	18,658	517,865
2	USA	801	8668	223,921
3	Iran	502	6158	178,641
4	India	607	3732	165,583
5	Canada	333	3778	165,476
6	England	365	4285	140,066
7	Australia	320	3658	133,950
8	France	334	2821	125,665
9	Italy	330	3138	104,888
10	Pakistan	271	2080	97,819

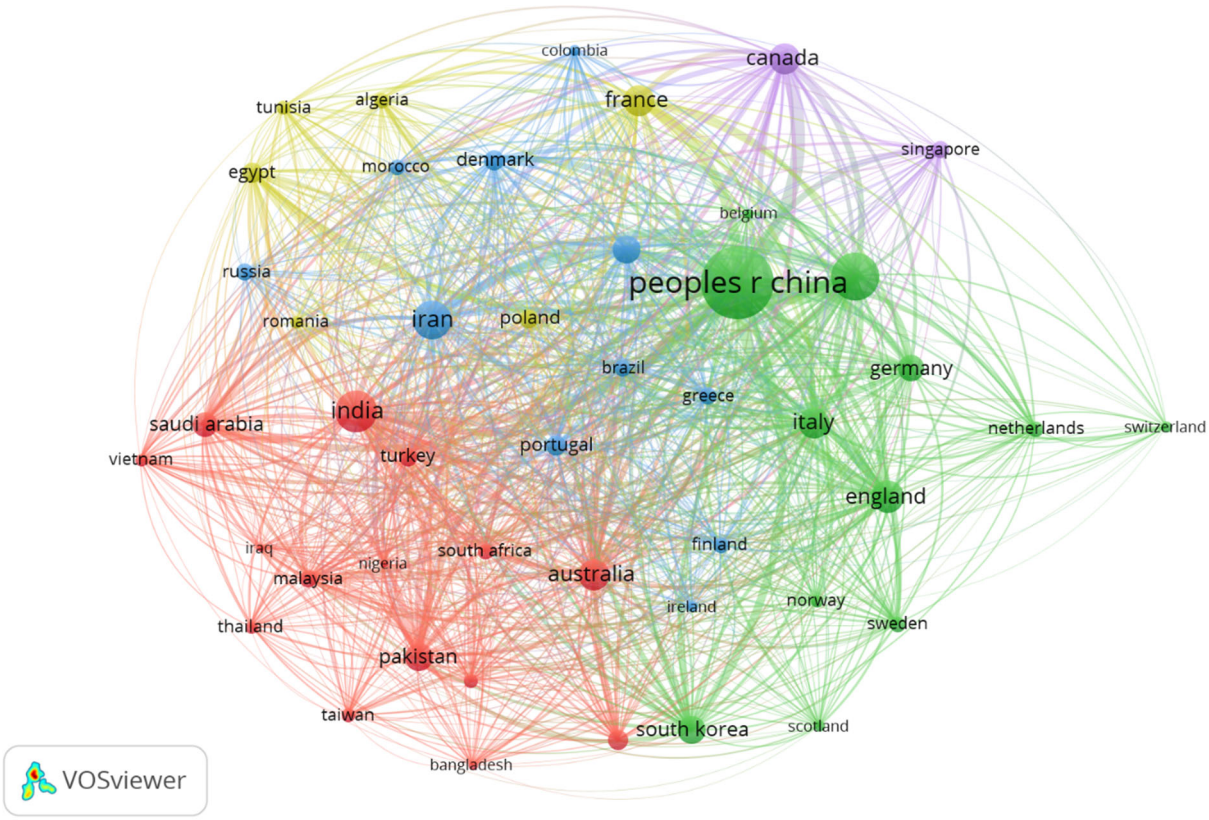


Figure 10. The map of EM bibliographic coupling for countries.

The top 20 articles with the most citations published in EM are presented in Table 8. The Web of Science category of each paper is also summarized in the table. As seen, most of the papers are in the categories of engineering and energy.

Table 8. Top-15 most cited publication in EM.

R	Ref.	CA	Year	TC	Title	Web of Science Category
1	[25]	Benbouzid, M	2018	297	"microgrids energy management systems: a critical review on methods, solutions, and prospects"	energy and fuels; engineering, chemical
2	[26]	Anghel, I	2018	243	"blockchain based decentralized management of demand response programs in smart energy grids"	chemistry, analytical; engineering, electrical and electronic; instruments and instrumentation
3	[27]	Yu, Qq	2018	236	"reinforcement learning-based real-time power management for hybrid energy storage system in the plug-in hybrid electric vehicle"	energy and fuels; engineering, chemical
4	[28]	Ghadimi, N	2018	228	"multi-objective energy management in a micro-grid"	energy and fuels
5	[29]	Hannan, Ma	2018	214	"state-of-the-art and energy management system of lithium-ion batteries in electric vehicle applications:issues and recommendations"	computer science, information systems; engineering, electrical and electronic; telecommunications
6	[30]	Shojafar, M	2019	185	"energy-efficient adaptive resource management for real-time vehicular cloud services"	computer science, information systems; computer science, software engineering; computer science, theory and methods
7	[31]	Mahmood, A	2018	174	"prosumer based energy management and sharing in smart grid"	green and sustainable science and technology; energy and fuels

Table 8. *Cont.*

R	Ref.	CA	Year	TC	Title	Web of Science Category
8	[32]	Tang, Y	2018	173	"a battery/ultracapacitor hybrid energy storage system for implementing the power management of virtual synchronous generators"	engineering, electrical and electronic
9	[33]	Asadi, A; Rezaniakolaei, A	2018	166	"heat transfer efficiency of al2o3-mwcnt/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: an experimental and theoretical investigation"	thermodynamics; engineering, mechanical; mechanics
10	[34]	Jost, M; Albrecht, S	2018	157	"textured interfaces in monolithic perovskite/silicon tandem solar cells: Advanced light management for improved efficiency and energy yield"	chemistry, multidisciplinary; energy and fuels; engineering, chemical; environmental sciences
11	[35]	Kim, Hm	2018	155	"a multiagent-based hierarchical energy management strategy for multi-microgrids considering adjustable power and demand response"	engineering, electrical and electronic
12	[36]	Ahmadi, S	2018	151	"improving fuel economy and performance of a fuel-cell hybrid electric vehicle (fuel-cell, battery, and ultra-capacitor) using optimized energy management strategy"	thermodynamics; energy and fuels; mechanics
13	[37]	Morstyn, T	2019	146	"multiclass energy management for peer-to-peer energy trading driven by prosumer preferences"	engineering, electrical and electronic
14	[38]	Xie, S	2019	145	"intelligent edge computing for iot-based energy management in smart cities"	computer science, hardware and architecture; computer science, information systems; engineering, electrical and electronic; telecommunications
15	[39]	Wang, X	2018	144	"energy demand side management within micro-grid networks enhanced by blockchain"	energy and fuels; engineering, chemical
16	[40]	Thomas, D	2018	139	"optimal operation of an energy management system for a grid-connected smart building considering photovoltaics' uncertainty and stochastic electric vehicles' driving schedule"	energy and fuels; engineering, chemical
17	[41]	Arcos-Aviles, D	2018	137	"fuzzy logic-based energy management system design for residential grid-connected microgrids"	engineering, electrical and electronic
18	[42]	Hu, Xs	2019	134	"energy management strategies of connected hevs and phevs: recent progress and outlook"	thermodynamics; energy and fuels; engineering, chemical; engineering, mechanical
19	[43]	Shareef, H	2018	134	"review on home energy management system considering demand responses, smart technologies, and intelligent controllers"	computer science, information systems; engineering, electrical and electronic; telecommunications
20	[44]	Lu, X	2020	131	"energy management of hybrid electric vehicles: a review of energy optimization of fuel cell hybrid power system based on genetic algorithm"	thermodynamics; energy and fuels; mechanics

5. Conclusions

The recent publications on energy management (EM) were analyzed using a scientometric analysis approach. WoS bibliographic data for publications in the date range 2018–2022 were employed, and a dataset of papers related to EM and their citations and metadata details was created. The dataset was analyzed using a bespoke code, and visualization maps of connectivity were plotted using VOSviewer. After analyzing the data, the most influential individual authors, organizations, and countries were identified, and the dynamic network maps of connection between them were explained. Finally, the most cited articles in EM were identified and their WoS categories were reported. The major findings of this research can be summarized as follows:

Considering top authors, Javaid Nadeem published the most papers (90). Javaid Nadeem published 60% more articles in EM than the second-ranked author, Xiao Hu (1394). The top h-indexes belong to Xiao Hu (h = 20) and Xiaosong Hu (h = 18).

Islamic Azad University was the institution that published the most articles. Beijing Institute of Technology has the highest rank considering combined TC and h-index. In terms of citations per paper, the University of Waterloo (22), the Chongqing University (21.9), and Nanyang Technological University (21.6) are ranked highest. Authors affiliated with these universities have significantly influenced EM compared to other universities.

From the countries' point of view, China and the United States are in the first and second rank in terms of TP, TC, and h-index, respectively. China is almost twice as large as the United States (second rank) in terms of TP and TC. Pakistan has the most TP relative to its R&D investment level.

In terms of the co-citation of authors, there were four clusters, each of which was anchored by a specific researcher. Among all the researchers surveyed, the most cited researcher, the most productive researcher. The most highly cited researcher, and the researcher with the highest citations per paper were in the green cluster. The connections between the red and the green clusters were poor. In addition, the yellow cluster is located in the middle of the map and has a good relationship with all the clusters.

The co-authorship network of authors and publishing in EM was examined in this study. Authors are divided into 21 clusters, and among all authors, Javaid Nadeem showed the highest total link strength. In addition, cluster 5, including Javaid Nadeem, Javaid, was isolated from the community regarding co-authorship. In addition, the bibliographic coupling of the authors revealed that the most influential author is Xiaosong Hu. The other important author was Javaid Nadeem.

Bibliographic coupling of institutions showed that Beijing Institute of Technology from China received the highest link strength, followed by Chongqing University (China), Tsinghua University (China), the University of Waterloo (Canada), and Jilin University (China).

Bibliographic coupling of countries revealed five clusters. China received the highest total link strength, followed by USA, Iran, India, and Canada. China established almost twice the link strength, TP, and TC compared to the United States (second rank). Moreover, China and USA are influential contributors to EM, and other countries were coupled through these countries.

There is not yet a good explanation for why researchers are badly connected to each other. It is conceivable that the broadness of the field contributes to this, as authors do not consider other authors that work on EM to be in the same part of the field and so do not feel it necessary to cite them or consider their work. Future studies could address this question and analyze what parts of the EM field are most active, or the most cited.

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