

On Visual Data Analysis of IEEE Xplore Bibliometric Records on Machine Learning and Artificial Intelligence for Power Systems

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Abstract — This paper addresses the lack of analytical tools for visual data analysis in IEEE Xplore, an abstract database of publications on technical problems in electronics and electrical engineering. The openness of the platform and the good fillability of a large number of bibliometric record fields make it attractive for visual data analysis. The topic of machine learning and artificial intelligence applied to power systems, which are critical issues in the energy transition process, is chosen as an example for visual data analysis. The programs and utilities used for data analysis were VOSviewer, Scimago Graphica, FP-Growth algorithm, Inkscape, and MultiDendrograms. The use of IEEE Terms field data to identify publication topics in the exported data is analyzed in the most comprehensive way. This paper can be considered a reference for professionals interested in bibliometric analysis and visualization of IEEE Xplore data.

Index Terms — IEEE Xplore, IEEE Terms, bibliometric analysis, visualization, VOSviewer, Scimago Graphica, FP-Growth algorithm, MultiDendrograms.

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I. INTRODUCTION

A. Objectives of the Study

IEEE Xplore is an open platform of interest to address engineering challenges in energy transition and digitalization. It contains qualitative bibliometric data but does not provide analytical tools for visual data analysis.

The primary objective of this paper is to bridge this gap by showing experts the potential of freeware for visually analyzing data exported from IEEE Xplore. The topic “Machine learning and Artificial intelligence applied to Power Systems and Energy Systems,” as part of the theme of energy transition and digitalization of the Fuel and Energy Complex, besides being topical, reflects the interest of the author of this paper and the center in which he works.

B. Motivation for Selecting a Source of Bibliometric Data and Designing a Query Reason for Choosing IEEE Xplore

Electrification and digitalization are critical issues in the energy transition, as they affect technological, social, and economic aspects. The technological integration of diverse energy sources requires the use of smart grids to improve their efficiency and security [1, 2].

The objectives listed above are largely within the purview of the IEEE, the largest professional engineering organization in the world (<https://www.ieee.org/about/vision-mission.html>)

IEEE and its publishing partners deliver their scientific and technical content on the IEEE Xplore digital platform. IEEE Xplore contains more than 6 million of the world's most cited publications in **electrical engineering, computer science,** and related areas (<https://ieeexplore.ieee.org/Xplorehelp/overview-of-ieee-xplore/about-ieee-xplore>).

TABLE 1. Top Searches and Matching Documents

Top Searches	Matching Documents
Image Processing	416 453
Machine Learning	324 970
Deep Learning	234 558
Artificial Intelligence	220 871

A distinctive feature of the IEEE Xplore platform is its openness and good fillability of a large number of fields of bibliometric records. The data exported from IEEE Xplore contain the following fields available for bibliometric analysis: Document Title, Authors, Author Affiliations, Publication Title, Publication Year, Abstract, DOI, Funding Information, Author Keywords, IEEE Terms, Mesh_Terms, Article Citation Count, Patent Citation Count, Reference Count, and Publisher. This information surpasses the data of bibliometric records of Elsevier's ScienceDirect platform, which includes the fields such as Title, Authors, Year, DOI, Author Keywords, and Abstract. That is, the citation, affiliation, and system keyword fields are missing in the data exported from ScienceDirect. In addition, the "IEEE Terms" of IEEE Xplore can be seen as an analog of the "Index Keywords" of Scopus.

Note: Within this paper, single quotes are used to emphasize a particular substring, such as a term consisting of several words, and double quotes are used to cite text.

IEEE Xplore Query Selection

To confirm the thesis that the engineering issues of IEEE Xplore publications are relevant to the challenges of digitalization, the most common topics of publications are shown in Table 1. It is difficult to imagine the process of digitalization without solving problems of image processing, machine learning, deep learning, and artificial intelligence.

Data are current as of August 9, 2024. The verification showed that the data in the Table align with the queries to the fields: "All Metadata" for all years of publications indexing.

The terms "Machine Learning" and "Artificial Intelligence" are chosen for this study. Image Processing and Deep Learning are also relevant terms worthy of a separate study in the context of energy transition. Again, the main objective of this paper is to demonstrate the possibilities of visual analysis of bibliometric data of IEEE Xplore platform using free software, and the topic is chosen simply as an example of the current issue of digitalization and energy transition.

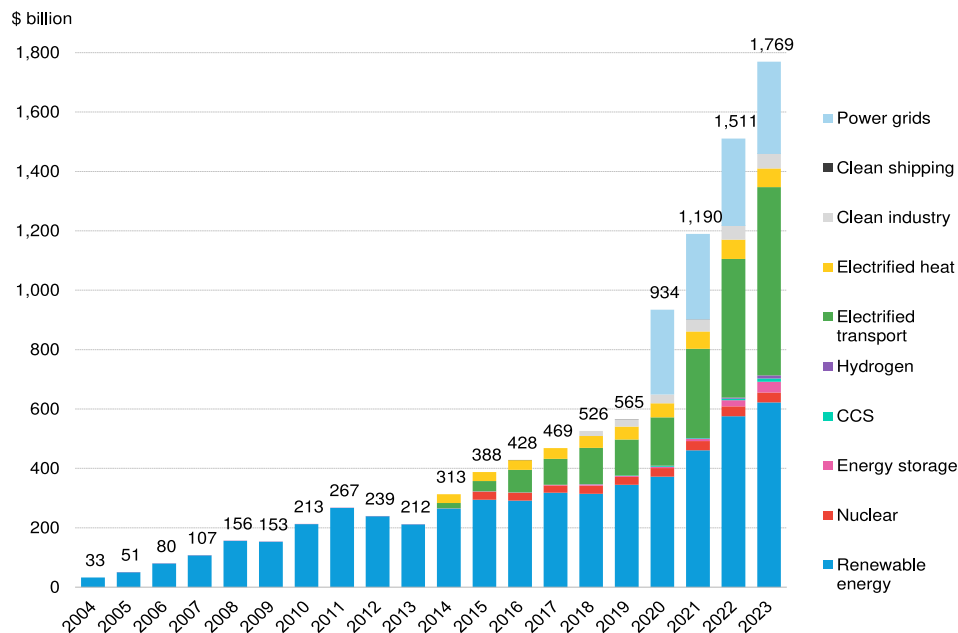


Fig. 1. Global investment in energy transition, by sector. Source: BloombergNEF. Energy transition investment grew 17% in 2023.

Investment is a good indicator of the relevance of the issue under study, so Fig. 1 shows a diagram of global investment in key areas of the energy transition as presented in a Bloomberg Agency report <https://data.bloomberglp.com/professional/sites/24/Energy-Transition-Investment-Trends-2024.pdf>.

The power grid is an essential part of the energy systems, in which intensive investments have been made since 2020. This is quite logical, since the further development of the other areas shown in the diagram is not possible without the development of the power grid. The most common concepts that include the term “power grid” are “Power Systems” and “Energy Systems.” Therefore, they are chosen as keywords for the final query to the bibliometric database IEEE Xplore: (“All Metadata”: Power Systems) OR (“All Metadata”: Energy Systems)) AND (“All Metadata”: Machine learning OR “All Metadata”: Artificial intelligence)); Filters Applied: Journals, Years 2020–2024.

TABLE 2. Top 30 Authors with the Largest Number of Publications

Author	Count	Author	Count	Author	Count
Y. Li	141	X. Zhang	69	J. Chen	50
Y. Wang	120	J. Li	68	X. Liu	49
Y. Liu	109	J. Zhao	68	H. Liu	48
Y. Zhang	94	J. Liu	63	Z. Chen	46
X. Wang	92	J. Zhang	61	J. Yang	41
H. Zhang	87	X. Li	60	C. Wang	40
Z. Wang	80	Y. Xu	60	L. Zhang	40
J. Wang	79	S. Wang	59	S. Li	39
H. Wang	76	Z. Zhang	58	Z. Liu	39
Y. Chen	74	L. Wang	51	S. Liu	38

II. MATERIALS AND METHODS

This study uses bibliometric records exported from the IEEE Xplore platform using the query: “((“All Metadata”: Power Systems) OR (“All Metadata”: Energy Systems)) AND (“All Metadata”: Machine learning OR “All Metadata”: Artificial intelligence)); Filters Applied: Journals, Years 2020–2024”. Consideration is given to 1 000 records for each year, sorted by their relevance to the

TABLE 3. Top 30 Examples of Frequently Occurring Affiliations

Author Affiliations	M1	M2
School of Electrical and Information Engineering, The University of Sydney, Sydney, NSW, Australia	102	38
School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China	151	58
School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore	96	54
Department of Electrical Engineering, Tsinghua University, Beijing, China	84	38
School of Computer Science and Engineering, Nanyang Technological University, Singapore	61	31
College of Electrical Engineering, Zhejiang University, Hangzhou, China	52	27
State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications, Beijing, China	52	14
Department of Energy Technology, Aalborg University, Aalborg, Denmark	50	27
Department of Electrical and Computer Engineering, Texas A&M University, College Station, TX, USA	48	21
College of Electrical and Information Engineering, Hunan University, Changsha, China	47	20
Pacific Northwest National Laboratory, Richland, WA, USA	64	15
School of Electrical Engineering, Southeast University, Nanjing, China	44	20
State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing, China	44	15
China Electric Power Research Institute, Beijing, China	65	33
College of Artificial Intelligence, Nankai University, Tianjin, China	54	13
College of Electrical Engineering, Sichuan University, Chengdu, China	41	15
College of Electrical Engineering and New Energy, China Three Gorges University, Yichang, China	40	12
College of Energy and Electrical Engineering, Hohai University, Nanjing, China	39	12
School of Electrical Engineering, Northeast Electric Power University, Jilin, China	37	15
IBM T. J. Watson Research Center, Yorktown Heights, NY, USA	36	4
School of Control and Computer Engineering, North China Electric Power University, Beijing, China	38	18
School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ, USA	39	15
School of Artificial Intelligence, University of Chinese Academy of Sciences, Beijing, China	36	10
State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, China	34	10
Department of Computer Science and Engineering, Institute of Technology, Nirma University, Ahmedabad, Gujarat, India	33	7
Department of Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China	41	17
Department of Electronic and Electrical Engineering, University of Bath, Bath, U.K.	39	13
School of Electric Power Engineering, South China University of Technology, Guangzhou, China	33	13
School of Electrical and Information Engineering, Tianjin University, Tianjin, China	38	18
State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, China	35	16

query. The analysis encompassed 5 thousand records containing fields such as Document Title; Authors; Author Affiliations; Publication Title; Publication Year; Abstract; DOI; Funding Information; Author Keywords; IEEE Terms; Mesh_Terms; Article Citation Count; Patent Citation Count; Reference Count; Publisher. Data is current as of August 8, 2024.

The topic analyzed further in this paper is “Machine Learning OR Artificial Intelligence for Power Systems OR Energy Systems.”

A. Programs and Utilities Used

VOSviewer is a widely used software application for building and visualizing bibliometric networks. Developed by Nees Jan van Eck and Ludo Waltman at Leiden University's Centre for Science and Technology Studies [3].

Scimago Graphica is a free data visualization tool developed by SCImago LAB that makes it easy to explore data without any programming knowledge [4].

The **FP-Growth algorithm** is a data mining technique that can detect frequent itemsets without the need to generate candidates, making it more efficient than traditional algorithms such as Apriori [5].

Inkscape is a free and open source vector graphics editor for creating and editing vector images such as illustrations, diagrams, logos, and complex paintings. It primarily uses the Scalable Vector Graphics (SVG) format.

MultiDendrograms is a hierarchical data clustering software distributed under an Open Source license [6].

III. RESULTS AND DISCUSSIONS

A. General Record Characteristics

The total number of authors in records is 24 098, the average number of authors per publication is 4.8. The number of unique authors is 12 324.

Table 2 shows the list of 30 authors and the number of their publications in the exported bibliometric records.

The Table shows the predominance of Chinese authors, which is consistent with the fact that China is experiencing high growth in energy consumption due to economic development [7]. China is a leader in renewable energy. Its policy is aimed at economic growth, environmental protection, and reduction in reliance on imports [8, 9].

Below is the list of countries with the highest publication activity. Affiliation was assessed by the number of records in which the name of the country appeared, i.e. the number of publications in which at least one author was affiliated with that country.

China|Hong Kong → 1 962, USA → 1 072, UK|U.K. → 377, Canada → 327, India → 299, Saudi Arabia → 286, South Korea → 272, Singapore → 191, Italy → 170, Germany → 160, Iran → 125, Taiwan → 127, Japan → 110, Malaysia → 98, Brazil → 90, France → 83, Finland → 78, Switzerland → 67, Portugal → 50, South Africa → 31, Russian Federation|Russia → 26. The low number of affiliations with Russia is most often explained by two factors: many Russian authors publish in Russian journals, many Russian journals only accept articles in Russian.

The predominance of Chinese affiliations is consistent with the data on authors. In addition, authors with Chinese surnames may also appear with the USA, UK, Canada, and Singapore affiliations.

The Author Affiliations field in the bibliometric records of the IEEE Xplore platform is fairly uniformly populated, but there may be slightly different spellings, e.g., “5GIC and 6GIC, Institute for Communication Systems (ICS), University of Surrey, Guildford, U. K.” and “5GIC and 6GIC, Institute for Communication Systems, University of Surrey, Guildford, U. K.” and “5GIC and 6GIC, Institute for Communication Systems, University of Surrey, Guildford, U.K.”, therefore Table 3 was compiled in two stages: first, the occurrence of affiliations was counted, and then the possibility of their different spellings was checked for the most frequent ones. Other option: the author may have multiple affiliations, e.g. “National Key Laboratory of Science and Technology on Multispectral Information Processing, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China.”

Below are examples of the three most frequent affiliations with different spellings, with → followed by the frequency of occurrence.

School of Electrical and Information Engineering, The University of Sydney, Sydney, NSW, Australia → 100;

School of Electrical and Information Engineering, The University of Sydney, Sydney, NSW, Australia → 2.

School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 78;

Key Laboratory of Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 19;

National Key Laboratory of Science and Technology on Multispectral Information Processing, School of Artificial

Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 12;

Key Laboratory of Ministry of Education for Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 9;

National Key Laboratory of Science and Technology on Multispectral Information Processing and Key Laboratory of Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 6;

Key Laboratory of Imaging Processing and Intelligence Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 5;

Key Laboratory of Image Processing and Intelligent Control of Ministry of Education, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 4;

Key Laboratory of Image Processing and Intelligent Control, Ministry of Education, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 3;

Key Laboratory of Imaging Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 3;

Key Laboratory of the Ministry of Education for Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 3;

Image Processing and Intelligent Control Key Laboratory of Education Ministry of China, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 2;

Key Laboratory of Image Information Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 2;

Key Laboratory of Image Processing and Intelligent Control of Education Ministry, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 2;

Key Laboratory on Image Information Processing and Intelligent Control of Ministry of Education, School of Artificial Intelligence and Automation, Huazhong

University of Science and Technology, Wuhan, China → 2;

Engineering Research Center of Autonomous Intelligent Unmanned Systems, Key Laboratory of Image Processing and Intelligent Control, School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China → 1.

School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore → 69;

School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, Singapore → 22;

Delta-NTU Corporate Laboratory for Cyber-Physical Systems, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore → 3;

Department of School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore → 2.

Note: for the first 30 most frequent affiliations, variants containing abbreviations in parentheses and differences in word case were not found.

Considering the above, Table 3 was compiled as follows: the number of matches was checked by a direct search for the shortest spelling of the affiliation, e.g., “School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, China.” Two values were calculated: the number of records in which the affiliation spelling occurred (reflecting the number of publications with this affiliation N_2) and the total number of occurrences of the affiliation (reflecting the number of authors with this affiliation N_1).

The data show the predominance of Chinese affiliations in the Table: China → 20 lines, followed by the U.S. → 4 lines, Singapore → 2, U.K., Australia, India, and Denmark → 1.

A well populated “Author Affiliations” field in the bibliometric data of IEEE Xplore platform allows for other studies, such as tracking scholarly collaborations by matching author affiliations. But this is beyond the scope of this study.

B. Main Topics of Institutions

In order to assess the predominant themes of the institutions, the “IEEE Terms” were used. The choice of “IEEE Terms” is due to their normalized spelling and peer review, unlike the Author keywords, which require preprocessing, such as lemmatization and the use of a list of synonyms.

TABLE 4. Top 30 “IEEE Terms” Obtained for The First 10 Affiliations from Table 3. N is Occurrence of the Term in The List of 2 262 Results

Term	N	Term	N
Optimization	53	Generators	22
Power system stability	52	Reinforcement learning	21
Data models	43	Feature extraction	20
Computational modeling	40	Task analysis	20
Training	37	Deep learning	19
Load modeling	34	Forecasting	19
Predictive models	30	Security	19
Uncertainty	30	Power grids	18
Power systems	28	Resource management	18
Costs	26	Wind power generation	18
Real-time systems	26	Internet of Things	17
Stability criteria	26	Power system dynamics	17
Voltage control	26	Games	16
Machine learning	25	Microgrids	15
Renewable energy sources	24	Reactive power	15

TABLE 5. Top 30 Journals with the Largest Number of Publications on the Topic Under Study

Publication Title	N	Publication Title	N
IEEE Access	1774	IEEE Transactions on Industry Applications	56
IEEE Internet of Things Journal	236	IEEE Transactions on Sustainable Energy	56
IEEE Transactions on Power Systems	213	IEEE Transactions on Industrial Electronics	50
IEEE Transactions on Smart Grid	148	CSEE Journal of Power and Energy Systems	47
IEEE Transactions on Industrial Informatics	136	IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems	47
IEEE Sensors Journal	105	IEEE Transactions on Biomedical Circuits and Systems	41
IEEE Transactions on Intelligent Transportation Systems	91	IEEE Transactions on Power Delivery	40
IEEE Transactions on Neural Networks and Learning Systems	85	IEEE Transactions on Systems, Man, and Cybernetics: Systems	40
IEEE Systems Journal	83	IEEE Transactions on Power Electronics	36
IEEE Transactions on Circuits and Systems I: Regular Papers	72	IEEE Transactions on Green Communications and Networking	34
IEEE Transactions on Vehicular Technology	69	IEEE Transactions on Transportation Electrification	32
IEEE Transactions on Circuits and Systems II: Express Briefs	67	IEEE Open Journal of the Communications Society	31
IEEE Transactions on Instrumentation and Measurement	64	IEEE Transactions on Fuzzy Systems	29
Journal of Modern Power Systems and Clean Energy	59	IEEE Transactions on Communications	28
IEEE Transactions on Wireless Communications	57	IEEE Transactions on Consumer Electronics	28

TABLE 6. Top 30 “IEEE Terms” in The 10 Journals with The Highest Number of Publications on The Topic Under Study

IEEE Term	N	IEEE Term	N	IEEE Term	N
Machine learning	477	Load modeling	251	Batteries	175
Optimization	427	Task analysis	236	Uncertainty	164
Predictive models	412	Artificial intelligence	228	Power systems	153
Data models	345	Real-time systems	217	Resource management	149
Training	331	Renewable energy sources	213	Monitoring	147
Feature extraction	304	Energy consumption	199	Security	147
Deep learning	263	Sensors	197	Generators	144
Power system stability	261	Forecasting	195	Reinforcement learning	141
Computational modeling	258	Support vector machines	183	Mathematical models	138
Internet of Things	251	Costs	178	Microgrids	137

The data in Table 3 were used as queries on the “Author Affiliations” field of the general table of exported data. The query results defined “IEEE terms” corresponding to this affiliation.

Alluvial diagrams are a handy way to visualize many-to-many mapping data such as “Author Affiliations” and “IEEE terms.” To construct them, we need to build a correspondence table “Author Affiliations” and “IEEE terms.” In order to place Alluvial diagrams in the paper, it

is necessary to decrease the number of entries in the table. Even for the first 10 affiliations from Table 3, the total occurrences of “IEEE Terms” were 2 262, of which 608 were unique terms. Given such a large number of terms, constructing an Alluvial diagram for a printed article is not feasible. It is essential to select the terms. The easiest way is to use the frequency of terms from the total list of 2 263 results and identify the top 30 most frequently occurring terms. The list of such terms is shown in Table 4.

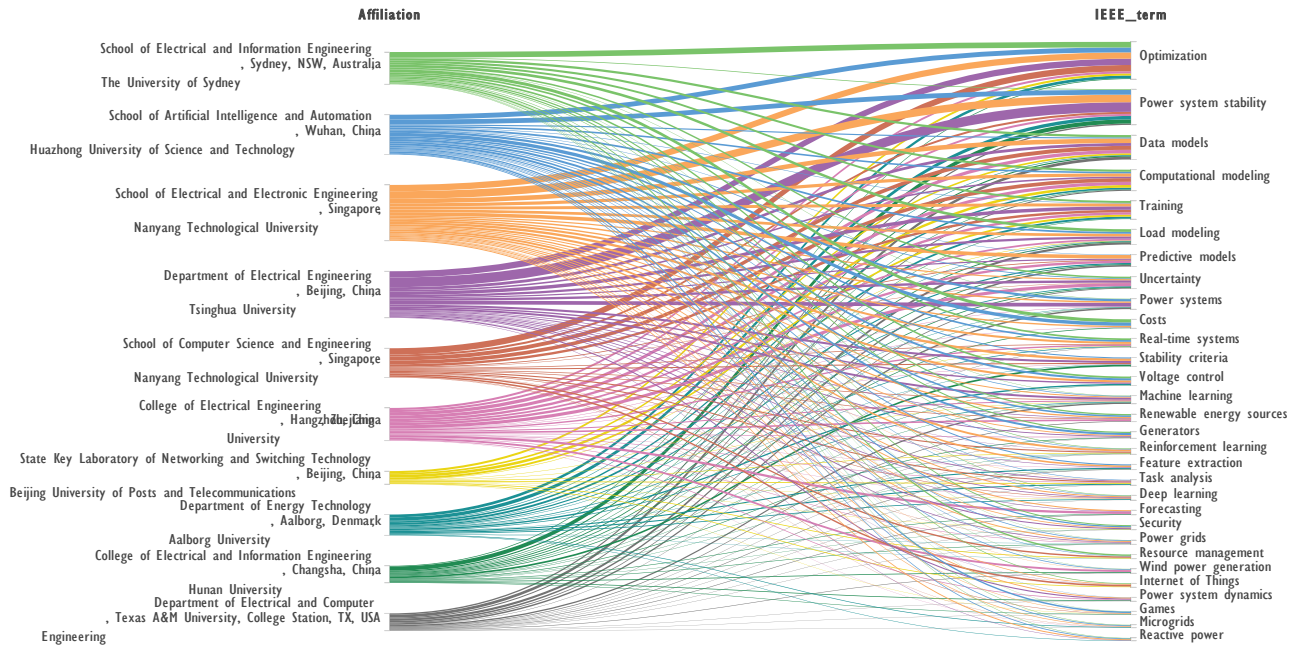


Fig. 2. Alluvial diagram for 10 affiliations and 30 “IEEE Terms.”

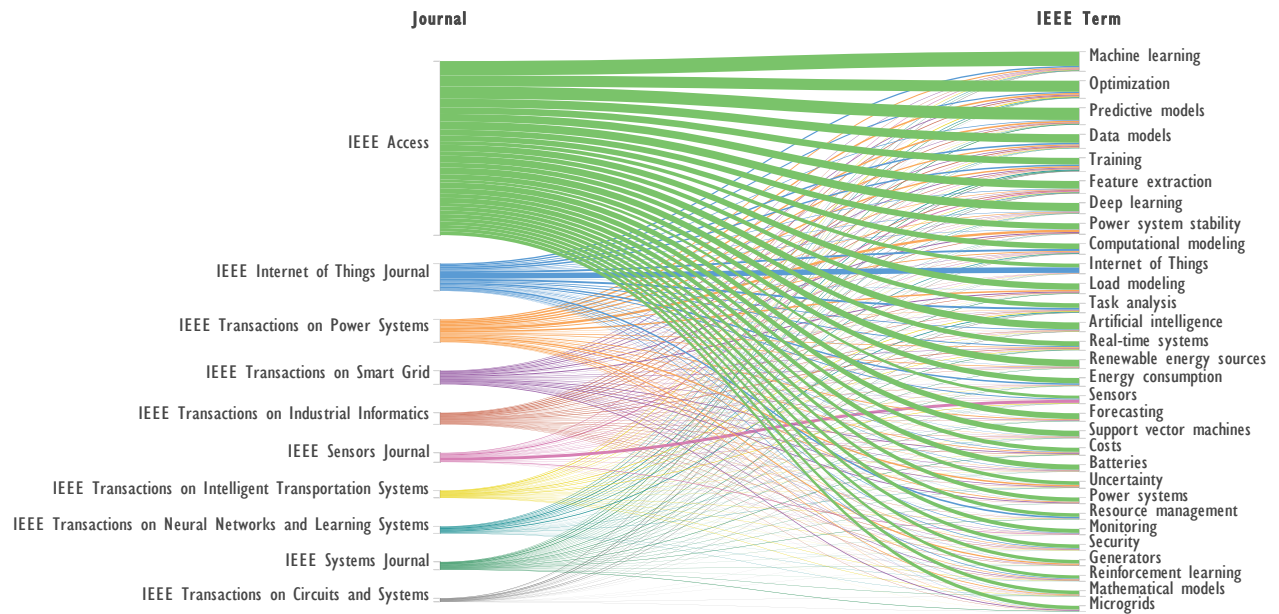


Fig. 3. Alluvial diagram for 10 journals and 30 “IEEE Terms.”

After these steps, out of 2 262 “IEEE Terms” records and the first 10 affiliations from Table 3, 620 rows remain to construct the Alluvial diagram shown in Fig. 2.

C. Main Topics of Journals

Of particular interest to experts may be the subject matter of the journals represented in IEEE Xplore on the topic under study (“Machine Learning OR Artificial Intelligence for Power Systems OR Energy Systems,” “Machine Learning OR Artificial Intelligence for Power

Systems OR Energy Systems”) expressed in “IEEE Terms.” Such knowledge can simplify query composition using “IEEE Terms,” e.g., (“IEEE Terms”: Random forest).

A total of 179 unique terms occur in the “Publication Title” field in the sample examined. The 30 journals with the highest number of articles are presented in Table 5.

The subject matter expressed in the most frequent “IEEE Terms” was determined for the top 10 journals from Table 5. These 10 journals represent 2 943 entries out of a

total of 5 000. The converted file containing one “IEEE Terms” per line contains 21 709 entries and 1 654 unique “IEEE Terms.” The top 30 of them are shown in Table 6.

In the main query, the term “Machine learning” → 477

occurs more often than the term “Artificial intelligence” → 228. “Power system stability” → 261 and “Power systems” → 153 indicate that in this topic the term “Power systems” and its combinations are more common than “Energy

TABLE 7. Pivot table of occurrence of 30 'IEEE Terms' in 10 journals

IEEE Term	IEEE Access	IEEE Internet of Things Journal	IEEE Sensors Journal	IEEE Systems Journal	IEEE Transactions on Circuits and Systems	IEEE Transactions on Industrial Informatics	IEEE Transactions on Intelligent Transportation Systems	IEEE Transactions on Neural Networks and Learning Systems	IEEE Transactions on Power Systems	IEEE Transactions on Smart Grid
Machine learning	349	33	14	6	9	8	10	10	27	11
Optimization	270	29	4	11	3	19	18	14	39	20
Predictive models	297	16	3	15		17	6	8	39	11
Data models	208	38	7	5		20	10	9	31	17
Training	162	36	10	15	13	14	5	21	35	20
Feature extraction	185	13	25	6	12	18	10	13	14	8
Deep learning	197	10	6	5	2	6	5	9	15	8
Power system stability	145	9		4	3	14		5	58	23
Computational modeling	134	46	10	5	7	6	5	15	22	8
Internet of Things	91	135	8	3	4	4	5	1		
Load modeling	153	6	2	11		13	3	3	36	24
Task analysis	111	47	5	6	9	11	15	18	8	6
Artificial intelligence	169	18	7	3	8	10	7	1	3	2
Real-time systems	118	22	7	11	2	15	11	4	17	10
Renewable energy sources	163	6	1	7		7	1	1	16	11
Energy consumption	130	36	5	7	2	7	6	2	1	3
Sensors	69	22	72	4	3	4	12	3	3	5
Forecasting	141	4		7		6	2	3	21	11
Support vector machines	134	6	8	2	4	8	5	6	6	4
Costs	99	13		10	2	10	5	2	18	19
Batteries	125	10	5	4	1	7	4	2	7	10
Uncertainty	87	4		5		6	4	6	36	16
Power systems	98	4	1	5		5		1	19	20
Resource management	85	40	1	8		6	6	1		2
Monitoring	96	14	15	3	1	5	3	1	2	7
Security	87	16	4	2	1	10	6	1	12	8
Generators	82	5		4	1	8	2	2	31	9
Reinforcement learning	75	16	2	2		8	7	4	13	14
Mathematical models	84	6	2	6	2	4	7	4	19	4
Microgrids	87	5		9	2	6	1		7	20

TABLE 8. Top 30 “IEEE Terms” for All 5 Clusters Selected by Their Occurrence

IEEE Term	N	IEEE Term	N	IEEE Term	N
Machine learning	739	power system stability	357	Batteries	260
Optimization	688	Real-time systems	349	Costs	252
Training	663	Load modeling	328	Monitoring	241
Predictive models	598	Internet of things	318	Forecasting	237
Data models	592	Resource management	315	Wireless communication	228
Computational modeling	493	Energy consumption	313	Security	226
Feature extraction	483	Sensors	291	Reinforcement learning	225
Task analysis	456	Renewable energy sources	279	Power systems	224
Artificial intelligence	404	Support vector machines	272	Neural networks	222
Deep learning	378	Uncertainty	262	Mathematical models	215

systems.” For the terms “Deep learning” → 263 and “Reinforcement learning” → 141, a separate study is advisable.

The Alluvial diagram shown in Fig. 3 is constructed for the top 10 journals and the 30 most frequent “IEEE Terms” in them.

In the journal list, the full title, “IEEE Transactions on Circuits and Systems I: Regular Papers,” is replaced by the short one, “IEEE Transactions on Circuits and Systems.”

As an alternative, the data from Alluvial diagram can be represented as pivot Table 7.

The choice between the Alluvial diagram and the Pivot table depends on the specific objectives and personal preference.

D. Using the VOSviewer Program for Clustering “IEEE Terms”

“IEEE Terms” can be used similarly to Scopus Index Keywords to identify the subject matter of the collected bibliometric data using the VOSviewer program.

Figure 4 shows the clustering of “IEEE Terms.” The graph is constructed with the following parameters: the total unique “IEEE Terms” amount to 2 608, including 918 that occur 5 or more times. The co-occurrence network is constructed for 400 terms that exhibit the highest total strength. At the same time, 5 clusters were obtained and visualized using the LinLog/modularity algorithm.

The most common “IEEE Terms” for all 5 clusters are summarized in Table 8.

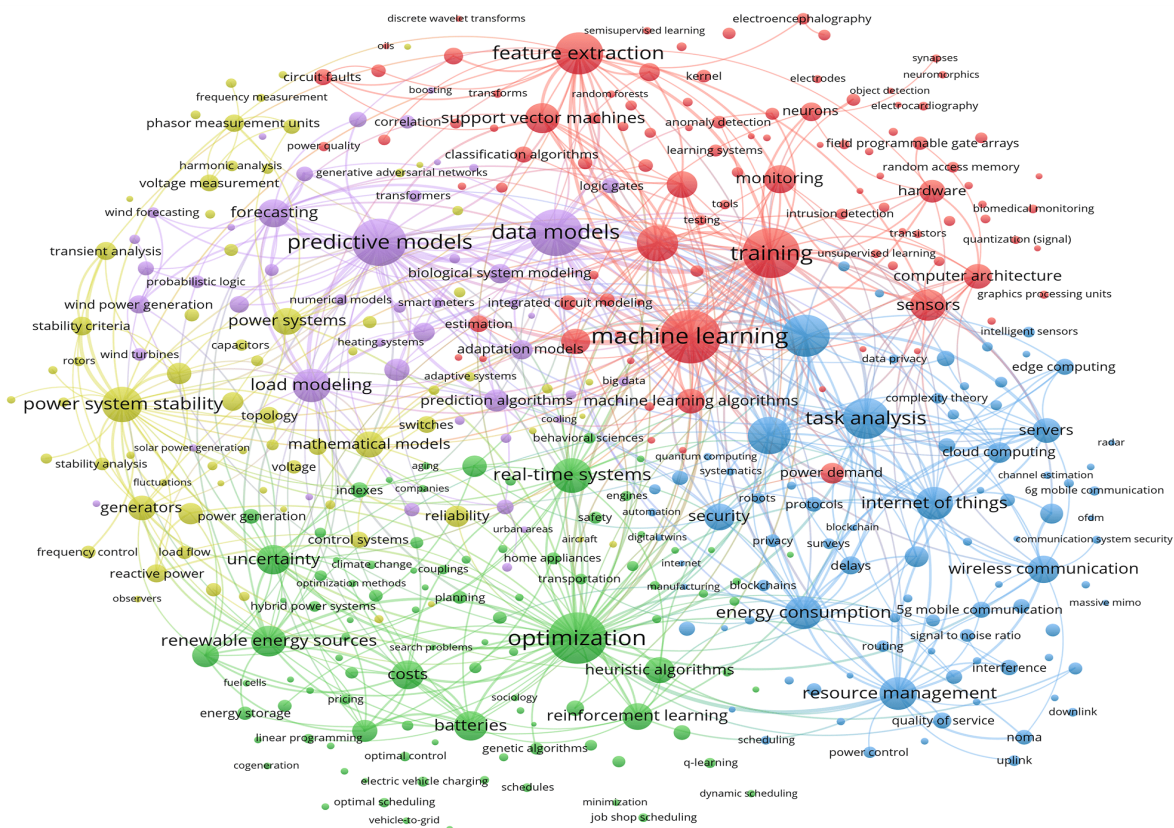


Fig. 4. Co-occurrence network of “IEEE Terms” for the collected bibliometric data built using VOSviewer.

TABLE 9. Top 10 “IEEE Terms” by Frequency of Occurrence for Each of The 5 Clusters

Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5
Machine learning	Optimization	Computational modeling	Power system stability	Predictive models
Training	Real-time systems	Task analysis	Power systems	Data models
Feature extraction	Renewable energy sources	Artificial intelligence	Mathematical models	Load modeling
Deep learning	Uncertainty	Internet of things	Generators	Forecasting
Sensors	Batteries	Resource management	Voltage control	Prediction algorithms
Support vector machines	Costs	Energy consumption	Reliability	Mathematical model
Monitoring	Reinforcement learning	Wireless communication	Power system dynamics	Adaptation models
Neural networks	Heuristic algorithms	Security	Power grids	Biological system modeling
Artificial neural networks	Microgrids	Servers	Stability criteria	Analytical models
Computer architecture	Energy management	Cloud computing	Transient analysis	Wind power generation

TABLE 10. Top 10 “IEEE Terms” By Occurrence in New Publications (Avg.pub.year Score) For Each of The 5 Clusters

Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5
Accuracy	Reviews	Surveys	Regulation	Long short term memory
Computational efficiency	Electricity	Federated learning	Mathematical models	Transformers
Random forests	Deep reinforcement learning	Autonomous aerial vehicles	Voltage	Solar power generation
Transfer learning	Metaheuristics	Digital twins	Contingency management	Extreme learning machines
Convolutional neural networks	Behavioral sciences	Blockchains	Aircraft	Solar energy
Memristors	Optimization methods	Energy efficiency	Numerical stability	Urban areas
Wearable computers	Climate change	Quantum computing	Perturbation methods	Adaptation models
Location awareness	Q-learning	Industrial internet of things	Impedance	Production
Transistors	Sustainable development	Systematics	Capacitors	Analytical models
Quantization (signal)	Costs	Artificial intelligence	Steady-state	Boosting

TABLE 11. Top 10 “IEEE Terms” By Occurrence in Highly Cited Publications (Avg.norm.citations Score) For Each of The 5 Clusters

Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5
Pipelines	Power supplies	Blockchain	Regulation	Market research
Signal processing algorithms	Job shop scheduling	Medical services	Maximum power point trackers	Covid-19
Intrusion detection	Dynamic scheduling	Manufacturing	Computer crime	Big data
Integrated circuit modeling	Climate change	Collaborative work	Nonlinear dynamical systems	Load forecasting
Temperature sensors	Autonomous vehicles	Communication system security	Power electronics	Maintenance engineering
Location awareness	Vehicle-to-grid	6G mobile communication	Frequency control	Smart meters
Diseases	Transportation	5G mobile communication	Cyberattack	Wind turbines
Fault diagnosis	Optimal control	Digital twins	Reliability	Data models
Power quality	Vehicle dynamics	Solid modeling	Thermal stability	Forecasting
Quantization (signal)	Peer-to-peer computing	Automation	Computer security	Biological system modeling

Table 9 presents the top 10 “IEEE Terms” for each of the 5 clusters. These terms reveal the main themes of the clusters.

The trend of change in the topics of publications described by the terms of each cluster over time can be assessed by comparing the data in Table 9 and Table 10, which present the terms most frequently occurring in new publications. The assessment was made by the parameter Avg.pub.year, which reflects the average year of the publication in which the term appears.

Using the combination of terms from the two Tables, we

can refine queries for publications described by terms from each cluster.

For example, for the term “machine learning” of the first cluster, the relevant issues can be represented by the terms: “accuracy,” “computational efficiency,” and “random forests,” while for the term “predictive models” of the fifth cluster from Table 9 – by the terms “long short term memory” and “transformers.”

Another important criterion for selecting terms to identify relevant research topics may be the citation rate of publications with “IEEE Terms” in their bibliometric

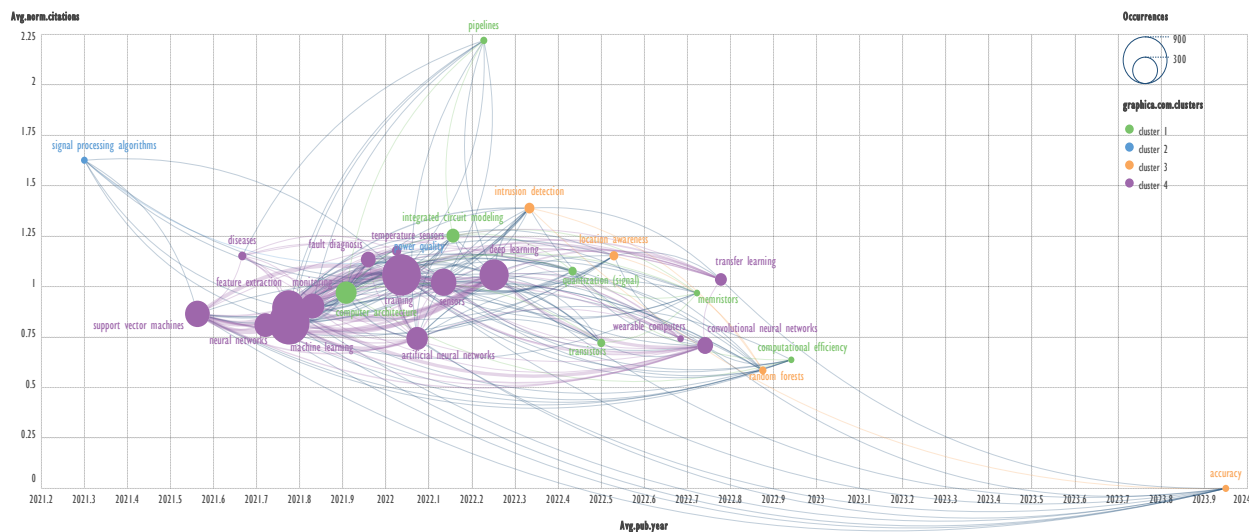


Fig. 5. Co-occurrence network of “IEEE Terms” in coordinates Avg.pub.year and Avg.norm.citations for the first cluster of data from Tables 9–11.

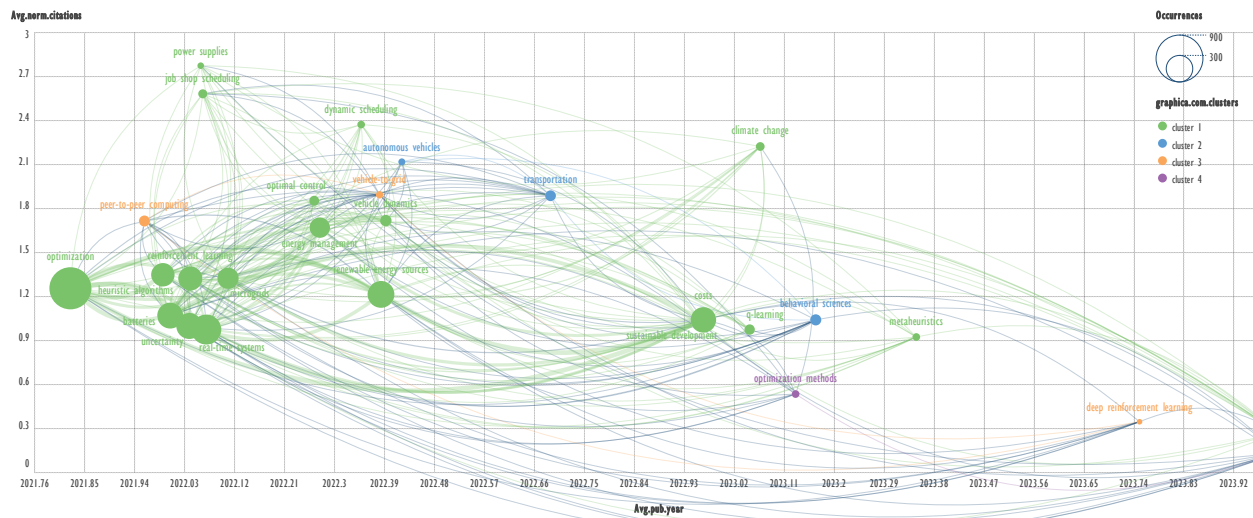


Fig. 6. Co-occurrence network of “IEEE Terms” in coordinates *Avg.pub.year* and *Avg.norm.citations* for the second cluster of data from Tables 9–11.

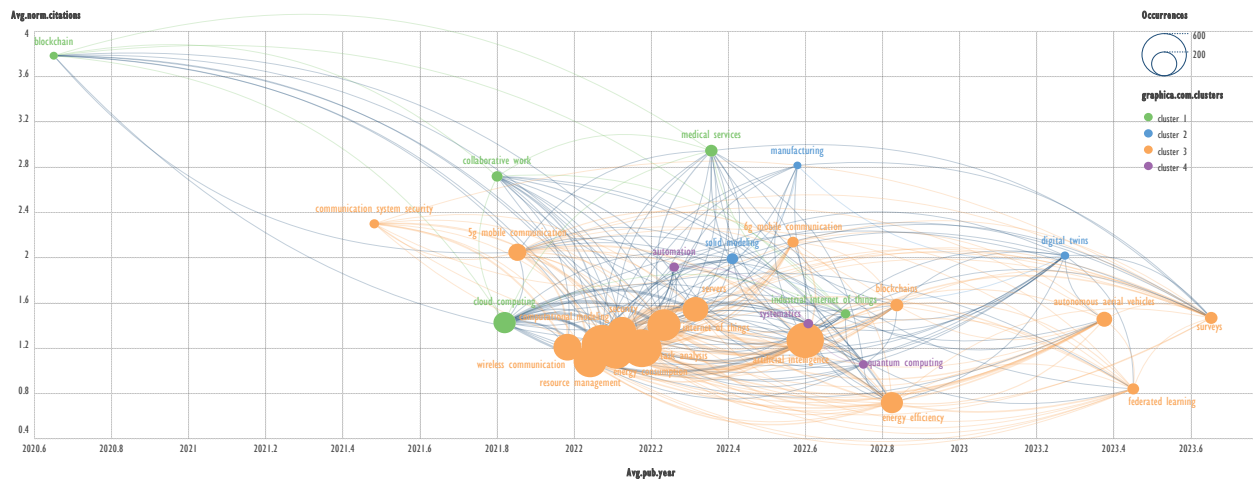


Fig. 7. Co-occurrence network of “IEEE Terms” in coordinates *Avg.pub.year* and *Avg.norm.citations* for the third cluster of data from Tables 9–11.

records. According to the VOSviewer guidelines, this indicator is proposed to be evaluated by the parameter *Avg.norm.citations* (average normalized citations). The data for the top 10 “IEEE Terms” for each of the 5 clusters with the highest *Avg.norm.citations* are presented in Table 11.

Example of using terms from the three Tables for the first cluster is feature extraction, computational efficiency, signal processing algorithms, and intrusion detection. For the fourth cluster, an interesting topic can be described by the terms: power system stability, mathematical models, nonlinear dynamical systems, and frequency control.

Considering that “a picture is worth a thousand words” (https://en.wikipedia.org/wiki/A_picture_is_worth_a_thousand_words), we use the terms presented in Tables 9–11

and their parameters to graphically display the network of these terms in the coordinates *Avg.pub.year* and *Avg.norm.citations* using the program Scimago Graphica. The results are shown in Fig. 5–9.

There are repetitions in Tables 9 to 11, for example, a term may be “highly cited” and “frequently occurring.” These repetitions were eliminated during the graph construction process, resulting in a total of fewer than 30 datasets, specifically 28 to 26, being used for construction.

Note: For each cluster obtained by VOSviewer, “IEEE Terms” were taken, and in Fig. 5–9, the four clusters obtained by Scimago Graphica for each cluster obtained by VOSviewer are highlighted in color.

In the fourth and largest cluster in Fig. 5, the term “transfer learning” is found in new publications and has a

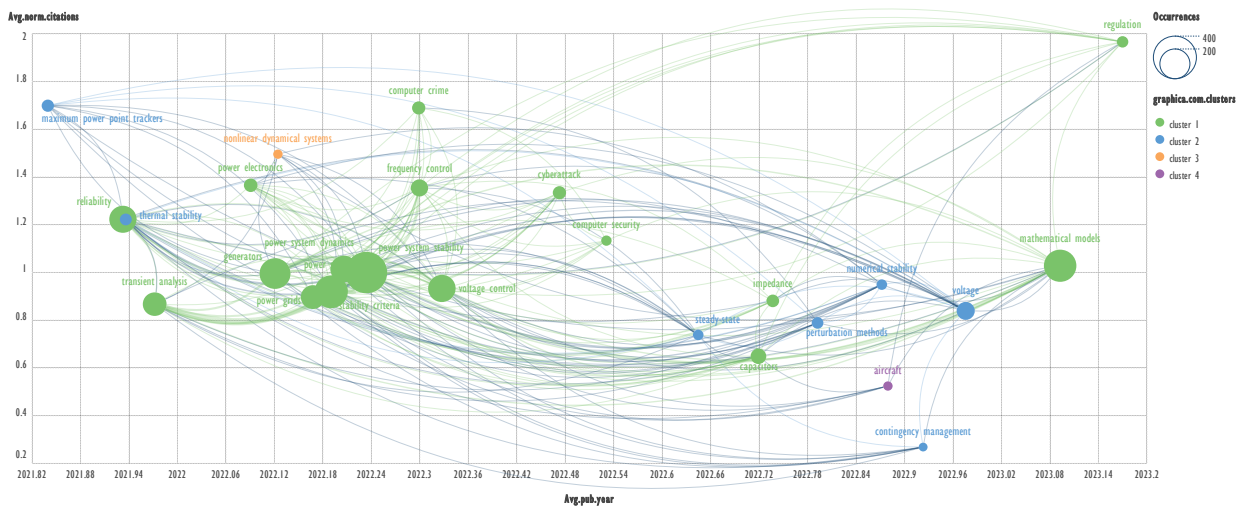


Fig. 8. Co-occurrence network of “IEEE Terms” in coordinates *Avg.pub.year* and *Avg.norm.citations* for the fourth cluster of data from Tables 9–11.

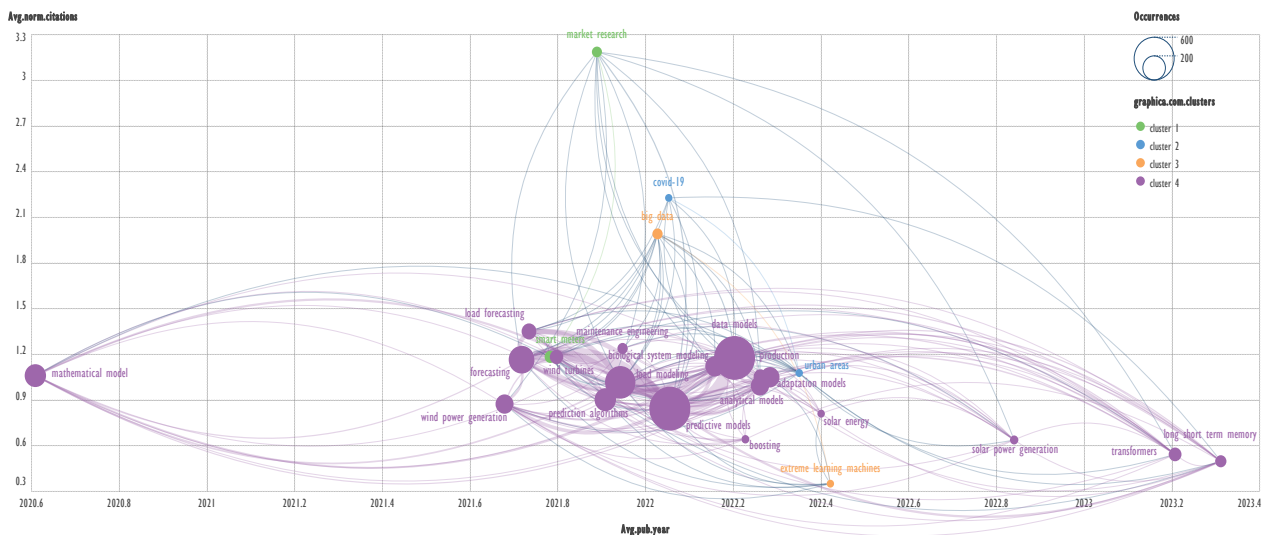


Fig. 9. Co-occurrence network of “IEEE Terms” in coordinates *Avg.pub.year* and *Avg.norm.citations* for the fifth cluster of data from Tables 9–11.

relatively high citation rate compared to the terms in this cluster. Here is a publication in which this term appears in a quote: “this article proposes a novel phasor measurement unit (PMU) measurements-based STVSA method by using deep **transfer learning**” [10]. In the third cluster, the topic described by the terms “intrusion detection” and “accuracy” described by the quotation from the publication [11] may be of interest: “Cyber **intrusion detection** systems ... power system protection schemes. The **accuracy** and time to detect cyber-attacks ... are two key factors for reliable ... smart grids.” For the terms “pipelines” and “computational efficiency,” we can suggest the paper [12] with the quote, “In this paper ... a **computationally efficient** framework ... to rank the importance of filters and thus converting a three-step

pipeline.”

Let us take the non-obvious combination of terms – metaheuristics and q-learning for which an interesting publication can be found [13]. Explanatory quote from the abstract: “Embedding Q-Learning in the selection of metaheuristic operators...”

The terms “digital twins” and “federated learning” reflect the topical aspect of learning models without violating data privacy, an example of such an approach is presented in the paper [14]. Explanatory quote from the abstract: “Federated learning (FL) based digital twin (DT) model framework could be seen as an emerging paradigm to avoid large communication loads and high data leakage.”

For the terms “regulation” and “mathematical models,” a quote “... voltage regulation applications ... based on a

developed mathematical model to control the output voltage ...” can be given from the paper [15].

The fourth cluster's emerging theme (Fig. 9), expressed in terms “transformers” and “long short term memory” can be represented by a quote “Incipient Faults in Power Transformers ... Bi-Directional Long Short-Term Memory Network” from the paper [16].

E. Convex Hull Chart for “IEEE Terms” as an Indicator of Research Fronts

Research fronts form when a small fraction of previous publications are cited in new ones, indicating common concepts, hypotheses, experimental data, or methods in similar articles (https://clarivate.com/cis/blog/research_fronts_2021).

IEEE Terms are defined as Keywords assigned to IEEE journal articles and conference papers from a controlled vocabulary created by the IEEE vocabulary created by the IEEE (<https://ieeexplore.ieee.org/Xplorehelp/searching-ieee-xplore/command-search#summary-of-data-fields>). That is, a dictionary compiled by experts based on the use of terms in already published works, meaning these terms have been widely used in publications from previous years.

To determine something similar to a research front, but not based on publications, rather on “IEEE Terms,” one can do it as follows – select the terms with the highest average citation rates and display them in the coordinates of Avg.pub.year and Avg.norm.citations in the form of a “Convex hull chart.” The diagram for the top 30 “IEEE Terms” from all clusters is presented in Fig. 10.

The right border of the green area can be interpreted as the actual thematic front described by the terms: “medical services,” “manufacturing,” “6G mobile communication,” “array signal processing,” “privacy,” and “wireless communication.”

Modern search engines, for example, scite.ai, when used for scientific publications, make it possible to get a proposal for a highly cited article that best reflects the topic described by the above terms. Unlike “classical” search, where the output must match the terms in the query with logical operators, the output in AI search indicates that the article is more likely to be “relevant” to the terms listed compared to other publications. An example of such an article is [17], suggested by scite.ai for the set of terms listed above, but containing only the terms “6G” and “wireless communication” in the title and abstract, but due to the review nature of the article it may be useful in a

broader context relevant to the terms listed.

Figure 11 shows the 30 “IEEE Terms” with the highest “Total Link Strength,” i.e. the terms most frequently co-occurring with other terms. These terms encapsulate the overall context of the subject in question. An interesting query can be composed of terms reflecting the general context (field of application) and, for example, terms with high citation rates, which may reflect the relevance of the issue under study.

There is a significant difference between Fig. 10 and 11. In the latter, the term “mathematical models” is found in new publications, while in highly cited articles, the term refers to the dominance of earlier publications.

In contrast to Fig. 11, which contains frequently co-occurring terms, a “Convex hull chart” can be constructed for rarely co-occurring terms, see Fig. 12.

In our context, “nonlinear dynamical systems” and “observers” rarely co-occur with other terms. But in a general search for the terms “nonlinear dynamical systems” and “observers,” a search for (“(All Metadata”: nonlinear dynamical systems) AND (“All Metadata”: observers)” for 2020–2024 yields 5 736 results, including 3 789 for Conferences and 1 875 – for Journals. Thus in a broad context, this topic is relevant. For example, the article [18] was cited 205 times (current as of August 20, 2024). A quote revealing the content of the publication “A new approach to the design of nonlinear disturbance observers (DOBs) for a class of nonlinear systems described by input-output differential equations is presented in this paper.” It can be seen that the topic studied in this paper and the topic described by the terms “nonlinear dynamical systems” and “observers” have little overlap, but the topics themselves are extensive. In such cases, by looking closely at their intersection, it is possible to formulate a promising problem that is not yet well represented in publications but has the potential for development. For example, for the “observers for nonlinear dynamical systems” problem, one can explore the use of “Machine learning” to find the optimal parameters of “observers for nonlinear dynamical systems,” and “nonlinear dynamical systems” can be narrowed down to “Power Systems OR Energy Systems.”

F. Applying The FP-Growth Algorithm to Detect Co-Occurrence of “IEEE Terms”

As the previous analysis reveals, it is most interesting to create queries containing multiple terms. The use of multiple term co-occurrence estimation can be

accomplished using the well-known FP-growth algorithm. Figure 13 shows the result of applying this algorithm to identify the co-occurrence of “IEEE Terms” in the records with the highest citations as an Alluvial diagram. Records with 20 or more citations from the “Article Citation Count” column were used. Individual words in “IEEE Terms” are joined by underscores.

“Load modeling,” “Deep learning,” “Forecasting,” and “Predictive models” are an example of the co-occurrence

of four “IEEE Terms” in highly cited records. The 2021 article [19], cited 143 times (current as of August 21, 2024), was found in IEEE Xplore. This publication, retrieved using the search query “(“All Metadata”: “Load modeling”) AND (“All Metadata”: “Predictive models”) AND (“All Metadata”: “Forecasting”) AND (“All Metadata”: “Deep learning”),” exemplifies the topic described by these terms.

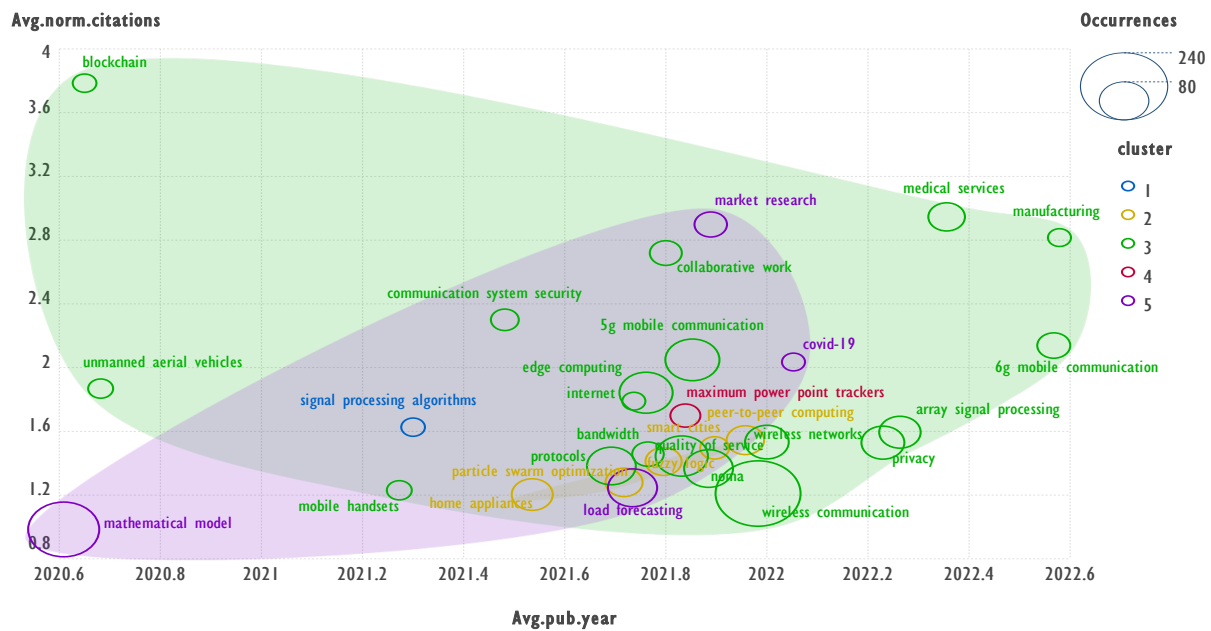


Fig. 10. Top 30 “IEEE Terms” with the highest average citation common to all clusters mapped as “Convex hull chart.”

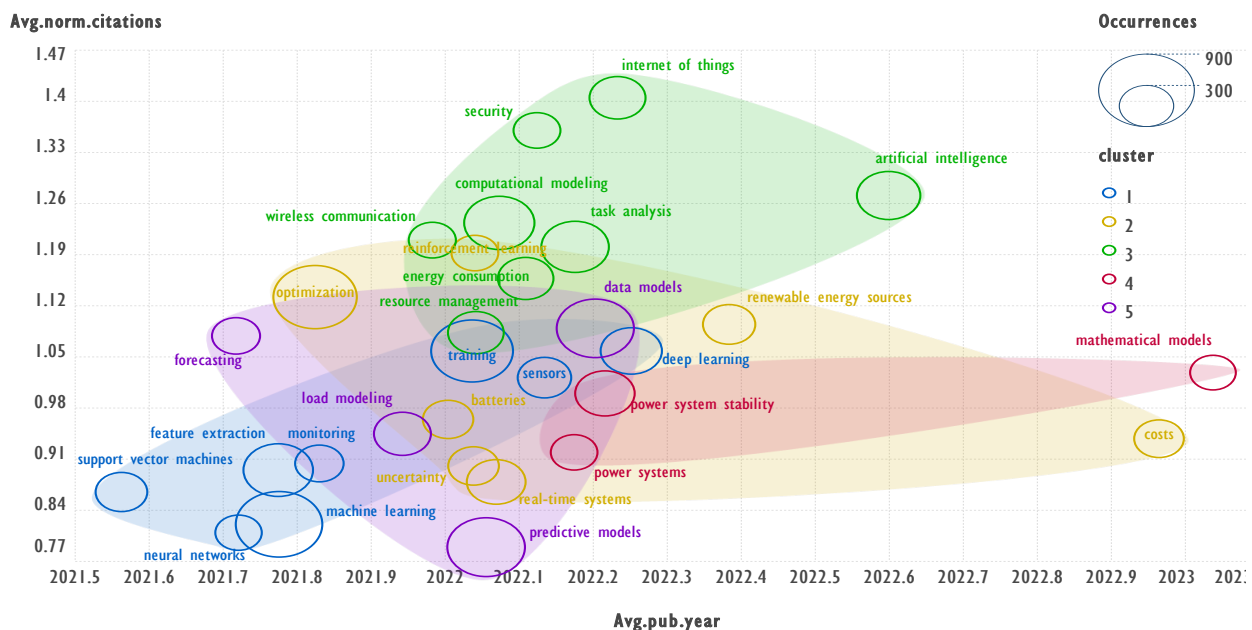


Fig. 11. Top 30 “IEEE Terms” with the highest “Total Link Strength” for all clusters mapped as “Convex hull chart.”

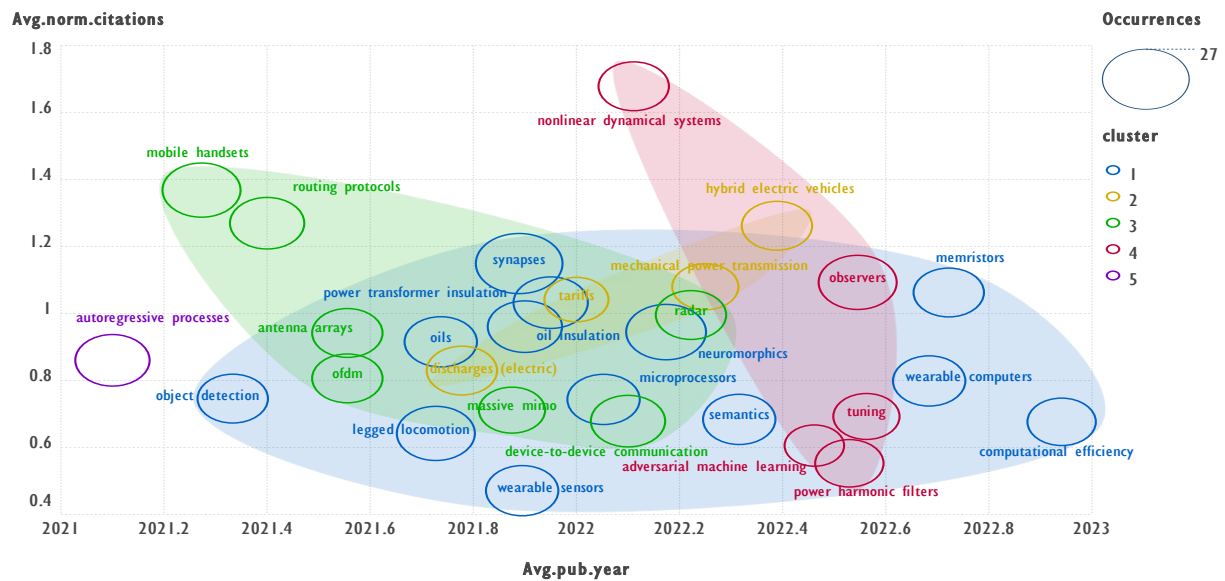


Fig. 12. Top 30 “IEEE Terms” with the lowest “Total Link Strength” for all clusters mapped as “Convex hull chart.”

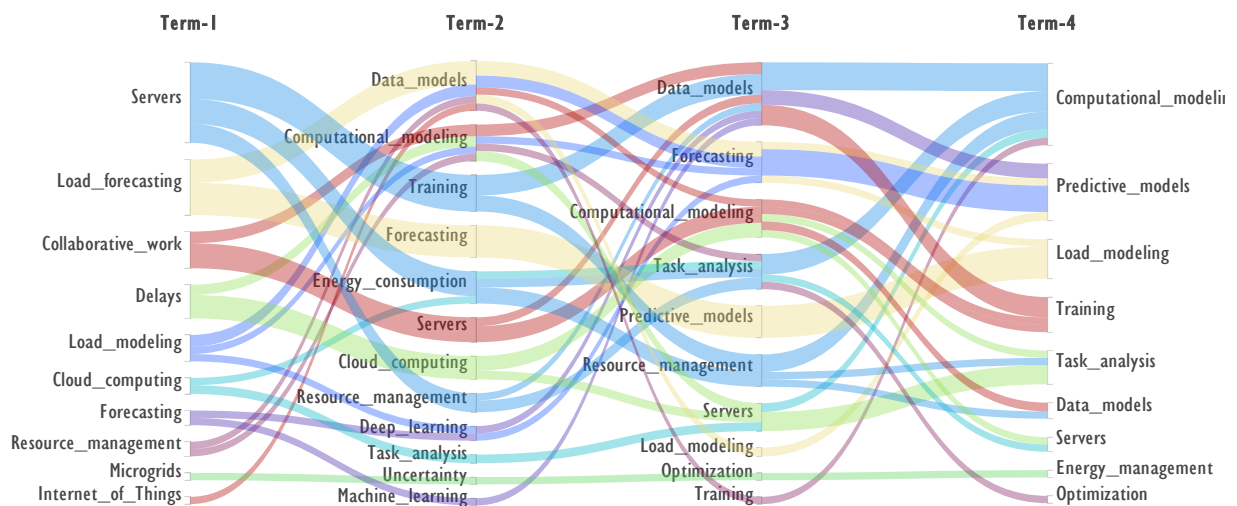


Fig. 13. Co-occurrence of four terms in the “IEEE Terms” field for records cited 20 or more times.

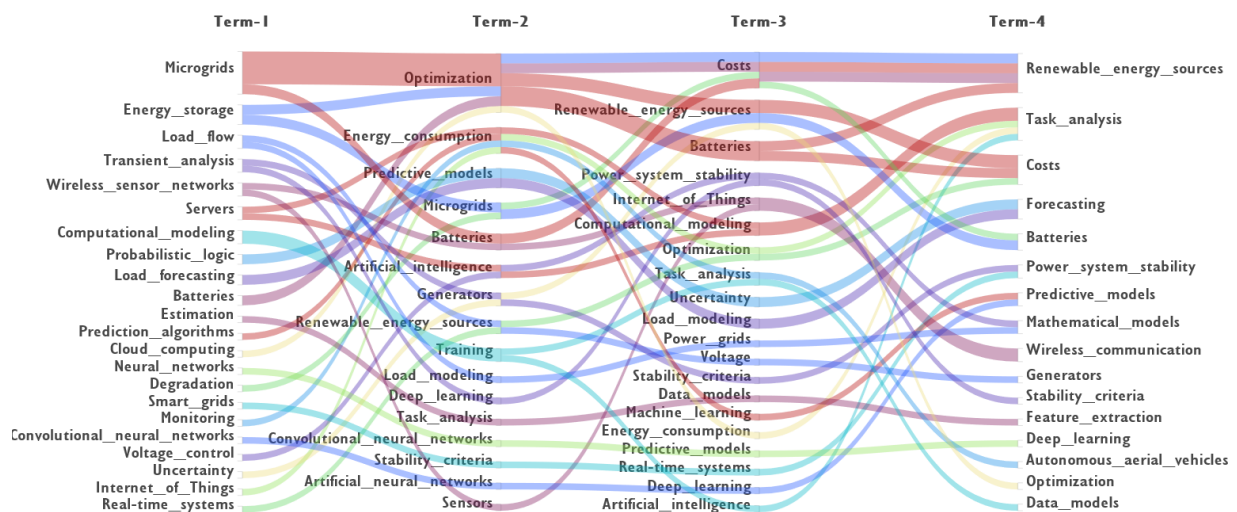


Fig. 14. Co-occurrence of the four terms in the “IEEE Terms” field for 2024 records with citations.

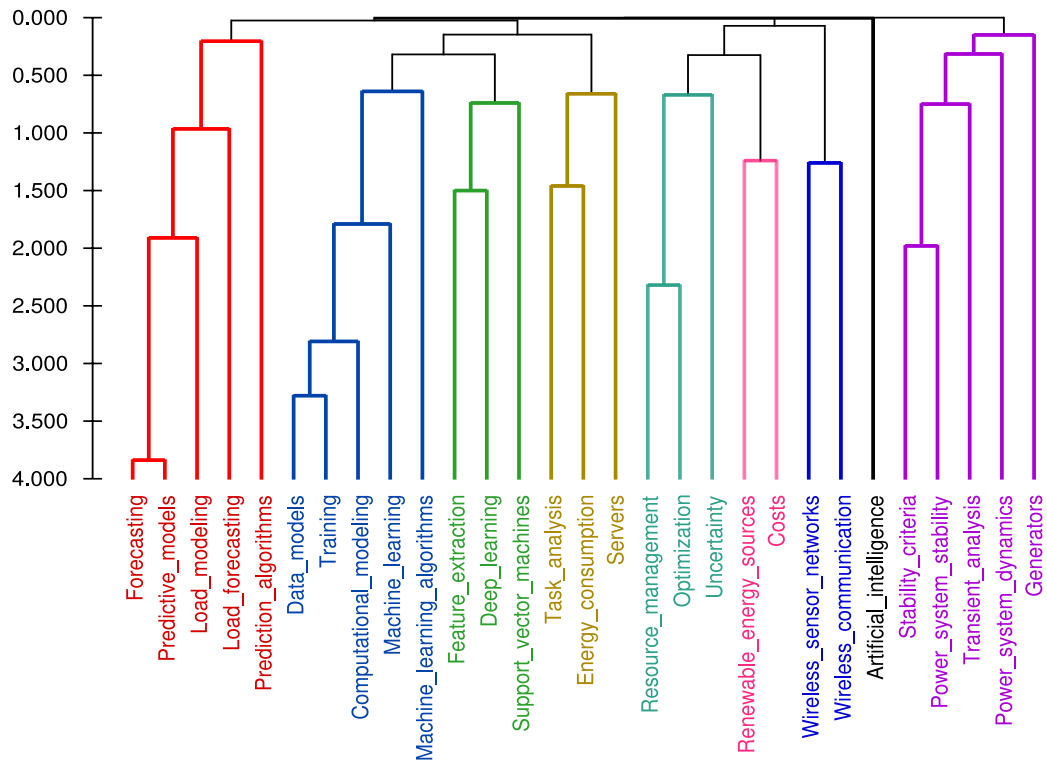


Fig. 15. Dendrogram constructed for the 50 most frequently co-occurring terms defined for all bibliometric records.

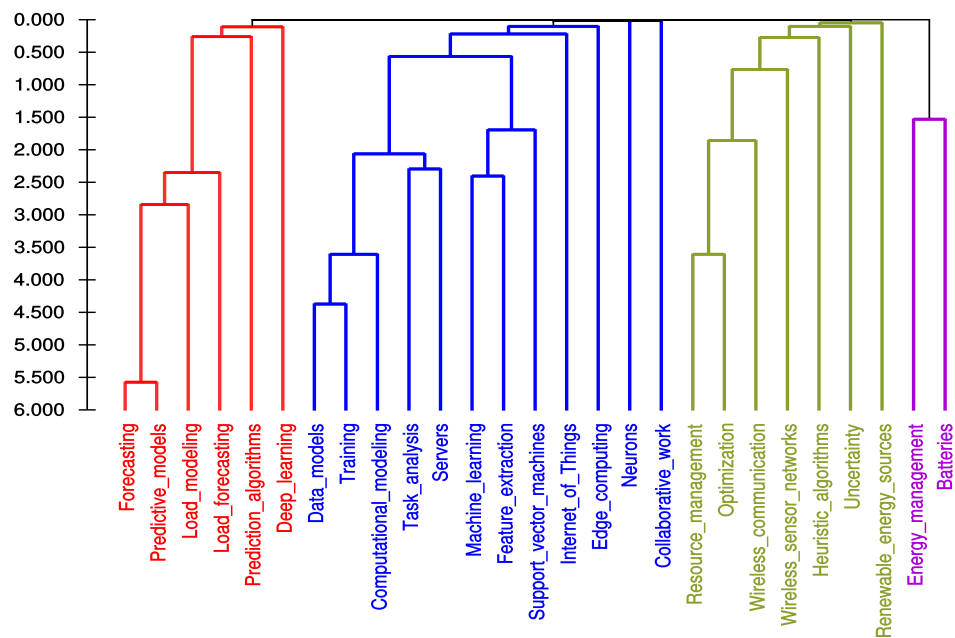


Fig. 16. Dendrogram constructed for the 50 most frequently co-occurring terms defined for bibliometric records with citations of 30 times and higher.

those for 2024 with citations, see Fig. 14.

Figure 14 displays the dominant theme described by the terms: “Microgrids,” “Optimization,” “Renewable energy sources,” and “Costs.” Example of a publication disclosing this topic and corresponding to the query: “(“All Metadata”: Microgrids) AND (“All Metadata”: Costs) AND (“All Metadata”: Renewable energy sources) AND (“All Metadata”: Optimization)” is [20]. A quote revealing the topic is: “The generation sources of a microgrid system mainly include distributed generators and renewable energy sources. The improved artificial bee colony (ABC) algorithm is proposed to solve this generation cost optimization.”

G. Hierarchical Clustering of “IEEE Terms”

Hierarchical clustering is the most easily interpretable clustering algorithm.

The plots shown in Fig. 15 and 16 are obtained using Multidendrograms-5.2.1 with clustering parameters: Type of measure → Similarity; Precision → 3; Clustering algorithm → “Beta Flexible” and “Weighted.” Inkscape was used to add color to the dendrograms. The co-occurrence of “IEEE Terms” was determined using the FP-growth utility.

These dendrograms facilitate comparing the total co-occurrence of “IEEE Terms” and “IEEE Terms” inherent in the most cited publications.

IV. CONCLUSIONS

IEEE Xplore provides open, exportable, and very high-quality data that include the fields: “Document Title, Authors, Author Affiliations, Publication Title, Publication Year, Abstract, DOI, Funding Information, Author Keywords, IEEE Terms, Mesh_Terms, Article Citation Count, Patent Citation Count, Reference Count, Publisher.” This comprehensive dataset enables in-depth bibliometric analysis. There is no “Reference” field, but if necessary, the “Reference” field can be taken from another open reference database, e.g. The Lens.

The results of the analysis presented in this paper show that the lack of built-in and open source analytical tools in the IEEE Xplore platform can be overcome by using free software that allows bibliometric analysis and visualization of the results obtained.

The use of the IEEE Terms field data to identify field-specific publication topics in the exported data was most fully analyzed.

V. Possible Applications of The Findings

This paper can also be considered as a recommendation for professionals interested in bibliometric analysis of IEEE Xplore data.

VI. ACKNOWLEDGMENT

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