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Trends and Research Directions in Electricity Load Forecasting: A Bibliometric Analysis

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ABSTRACT

Electricity load forecasting plays a critical role in strategic decision-making processes within the energy sector. Accurate and reliable forecasts are essential for ensuring the efficient operation of energy companies, distribution networks, and energy markets. Due to the complexity and dynamic nature of traditional forecasting methods, electricity load forecasting has become an increasingly challenging topic. In recent years, alongside traditional methods, there has been a growing use of novel and advanced techniques such as Empirical Mode Decomposition and Support Vector Regression in this field. These techniques offer effective alternatives for addressing complex data structures and nonlinear relationships. However, a comprehensive bibliometric analysis of studies and the application of these techniques in literature is yet to be conducted. This study aims to identify trends and future research directions in electricity load forecasting. To this end, a bibliometric analysis was performed using the Visualization of Similarities Viewer software. The findings of this study will serve as a valuable resource for researchers and industry professionals in the field of electricity load forecasting by guiding future research and shedding light on upcoming studies. This research encompasses articles containing the keywords "electrical," "load," and "estimation" published in scientific journals between 2015 and 2024.

1. Introduction

Electricity load forecasting is crucial for key decision-making processes like strategic planning, operational management, and resource allocation in the energy sector. Accurate and reliable forecasts are essential for the efficient operation of energy companies, distribution networks, and energy markets [1]. Accurate forecasts help electricity producers and distributors plan production and distribution while ensuring that the necessary resources are allocated properly to meet consumer needs [2]. However, electricity load forecasting is a challenging task due to its complex and dynamic nature. The accuracy of these forecasts depends on the forecasting methods and modeling techniques used.

In recent years, the use of new and advanced techniques in electricity load forecasting has significantly increased alongside traditional methods. Notably, methods such as Empirical Mode Decomposition (EMD) and Support Vector Regression (SVR) have been effectively utilized to handle complex data structures and nonlinear relationships [3]. These techniques offer an alternative approach to overcome the limitations of traditional methods, such as overfitting and network setup issues [4]. EMD is particularly effective for analyzing non-stationary and non-linear time series. SVR, on the other hand, improves forecast accuracy by reducing the complexity and noise in data sets [5]. Despite these advances, a comprehensive bibliometric analysis of the research and the application of such techniques have yet to be conducted. Therefore, the aim of this study is to visualize this analysis using

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VOSviewer to better understand the current state of research in electricity load forecasting and identify future research trends. VOSviewer software is used to map the data [6], and bibliometric analysis is considered effective in providing datasets that can be used to enhance research quality [7]. The results of this study will serve as an important reference source for researchers and industry experts working in the field of electricity load forecasting.

2. Related Works

The literature review on electricity load forecasting reveals a growing interest in utilizing advanced techniques such as Empirical Mode Decomposition and Support Vector Regression to improve prediction accuracy [8]. Traditional methods like Artificial Neural Networks (ANN) and Auto-Regressive (AR) models have been popular, but shortcomings such as overfitting and network construction issues have led researchers to explore alternative approaches. Studies have shown that SVM outperforms ANN and ARIMA models in load forecasting, with SVM-based models demonstrating superior prediction results. Hybrid models incorporating EMD have gained traction for handling non-linear and non-stationary signals, with EMD-based methods showing promise in various domains including electricity load forecasting, wind speed prediction, and financial time series forecasting. The proposed EMD-SVR method, as presented by Yaslan and Bican, stands out for its innovative integration of EMD for denoising and SVR for prediction, showcasing improved forecasting accuracy compared to traditional SVR models [9].

Gasparin et al., explored deep learning models for electric load forecasting, finding LSTM's effectiveness in capturing long-term dependencies for day-ahead predictions. GRU architectures showed promise for daily consumption forecasts. The study underscored the significance of varied computing architectures and input data sources for improved accuracy in load forecasting. Standardized evaluation metrics and reproducibility were identified as crucial for advancing deep learning applications in this domain [10].

Papadopoulos and Karakatsanis highlighted Two main types of forecasting models: time series models (like ARIMA) and casual models (like ARIMAX). Machine learning methods, including ANN, SVM, RF, and GB, have been studied for load forecasting. Previous comparisons favored SARIMAX over ANN and RF for accuracy. Temperature is noted as a significant predictor, enhancing model performance. GB has emerged as a powerful algorithm, ranking high in load forecasting competitions due to its automatic variable selection. The authors compare four models—Seasonal ARIMA, Seasonal ARIMAX, RF Regressor, and GBRT—for day-ahead load prediction in the New England Electricity Market. GBRT performs best for 24-hour forecasts, suggesting its suitability for load forecasting [11].

Amjady introduced a new method merging time series modeling with operator insights to enhance short-term load forecasting. It outperforms conventional methods like ANN and pure time series models. Furthermore, it successfully forecasts both hourly loads and daily peak loads, a critical aspect often neglected by traditional approaches, validated through rigorous testing on Iran's power system network [12].

Lee and Hong introduced a new hybrid model for forecasting electric power load several months in advance. This model combines dynamic and fuzzy time series approaches, separately applied to various load sectors. Tested with actual data from the Seoul metropolitan area, the hybrid model outperforms two typical dynamic models, with less than 3% absolute error in four-month forecasting. Mid-term load forecasting is crucial for power plant maintenance scheduling and energy conservation, particularly in rapidly growing cities facing increasing power demands [13].

Hagan and Behr discussed the application of time series analysis methods, particularly Box and Jenkins models, to short-term load forecasting. They reviewed the suitability of these models for the task and introduced a procedure to address the challenge of accurately representing nonlinear relationships between load and temperature. The article compared these models with a forecasting procedure currently used by a utility company. The nonlinear extension model outperformed the other models, showing improvements of 14%, 26%, and 35% compared to the conventional method in different seasons [14].

Nguyen and Hansen discussed the significance of load forecasting in the utility industry, particularly in the context of Smart Grid technologies. They introduced time series models like ARIMA and SARIMA for short-term electricity load forecasting based on data from ERCOT in Texas. The study aims to generate accurate forecasts to support various aspects of system health management for utility companies, such as financial planning, rate design, power system operation, and grid maintenance [15].

3. Data Sources and Analytical Methods

The term "bibliometrics" was coined by Alan Pritchard in 1969. Pritchard defined bibliometrics as the use of mathematical and statistical methods to analyze the progress of a scientific field [8]. This definition emphasizes that bibliometrics serves as a tool for understanding scientific discoveries and academic developments [16].

Bibliometrics is a methodology that provides an in-depth look at the literature in academic research and profiles a specific scientific field through the analysis of published works. This method, through the steps of

description, classification, and analysis, helps us understand the development and trends of scientific studies by focusing on relevant knowledge areas [17]. In this study, the Web of Science (WoS) database was preferred during the data collection phase, and bibliometric analysis techniques were employed during the analysis process. This approach allowed for the determination of the study's primary data source and analysis methods, enabling the evaluation of academic trends and developments in the literature [18].

Web of Science, initially known as Web of Knowledge, is the first bibliographic database established in the 1960s by Eugene Garfield at the Institute for Scientific Information (ISI). In 1992, when ISI was acquired by Thompson Reuters, ISI changed its name to Web of Science, abbreviated as WoS [19]. Web of Science is a multidisciplinary and selective database consisting of various specialized indexes grouped by indexed content type or subject. The main section of the Web of Science platform is called the Core Collection (WoS CC), which includes six primary citation indexes: Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), Conference Proceedings Citation Index (CPCI), Book Citation Index (BKCI), and the recently established Emerging Sources Citation Index (ESCI) [20]. In this context, the Web of Science database is frequently preferred for bibliometric analysis.

3.1. Data Sources and Screenings

Although there are various data providers for bibliometric analysis, the Web of Science database was preferred in this study. The analysis process utilized the VOSviewer 1.6.20 software. A search conducted on Web of Science on March 19, 2024, using the keyword "electrical load estimation" in the "all fields" category yielded 2,545 results. These results form the core data of the study, providing an overview of the academic literature in the field of electricity load forecasting. When articles were selected from the 2,545 results, the number decreased to 1,546. By selecting the Web of Science indexes Science Citation Index Expanded (SCI-EXPANDED) or Social Sciences Citation Index (SSCI), the number of articles further narrowed to 1,395. English-language publications were the focus of the study, with a total of 1,391 articles being analyzed in detail using bibliometric analysis methods. This approach demonstrates that the research is based on international literature and that the bibliometric analysis was conducted on a substantial dataset. When the criteria were set from 2015 to 2024 (including March 19, 2024), a total of 963 articles were obtained.

Figure 1 illustrates the selection of documents from the Web of Science database based on predefined criteria (document type, index, language, and publication years) and the subsequent use of VOSviewer for analysis. The workflow includes filtering steps, the number of resulting documents, and the main types of bibliometric analyses conducted (e.g., co-authorship, co-occurrence, and citation-based mappings).

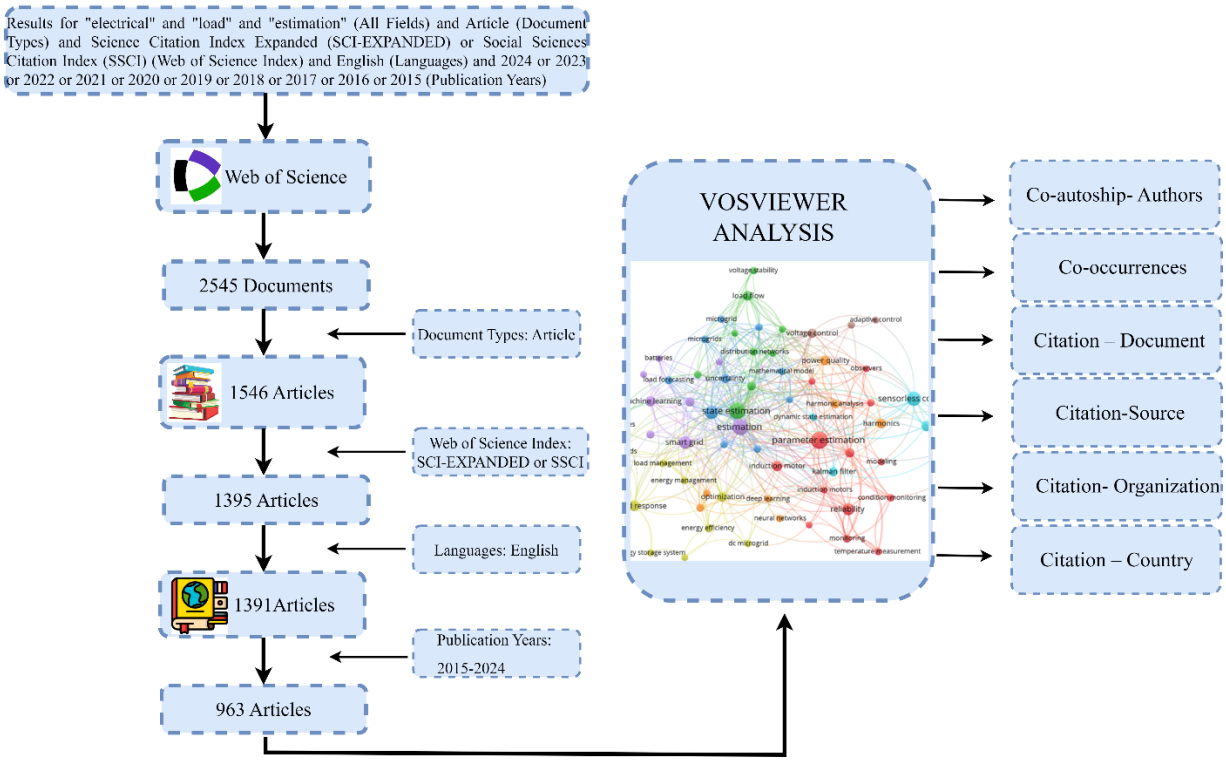

Figure 1. Flowchart of the bibliometric data collection and analysis process

3.2. Analytical Method

VOSviewer is a software tool specifically designed for creating and exploring maps based on network data. Initially developed for analyzing academic records, it has a wide range of applications and can be used on various types of network data, such as social networks. VOSviewer employs three different representations—network, overlay, and density visualization—to examine relationships between networks. Through these representations, it uncovers significant relationships, such as co-authorship, co-citation, bibliographic coupling, and co-occurrence of keywords. This allows researchers to gain deeper insights into and analyze interactions and connections within scientific studies [21].

4. Results of Bibliometric Analysis

The 963 articles in the dataset were published between 2015 and 2024. When the articles on electricity load forecasting are analyzed by year, the following number of publications was observed: 58 articles in 2015, 66 in 2016, 75 in 2017, 108 in 2018, 96 in 2019, 139 in 2020, 133 in 2021, 149 in 2022, 118 in 2023, and 21 in 2024. Figure 2 presents the number of publications and citation counts for each year.

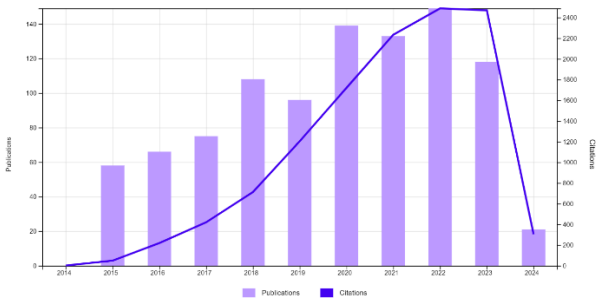

Figure 2. Year-wise article and citation counts

When analyzing the graph in Figure 2, a clear trend of increasing article numbers is observed. Since 2015, citation counts have risen parabolically. Although there are small decreases in some years, there is a noticeable increase in interest in the research field. For example, despite a decrease in the number of articles in 2023, the peak of citation counts occurred between 2022 and 2023, reflecting the trend from 2022. This suggests the development of discipline and continued interest from researchers in the topic. Research in electricity load forecasting has focused on articles in the field of renewable energy, and the findings are presented in Figure 3.

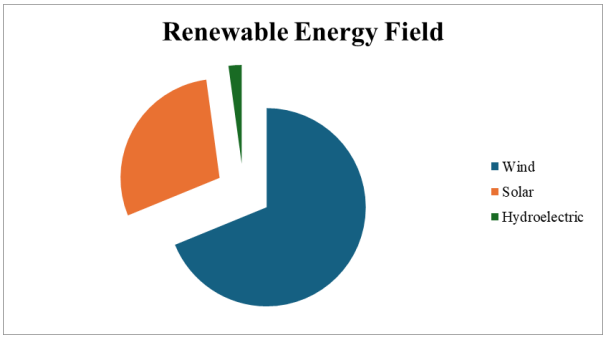

Figure 3. Some topics in the field of renewable energy

When Figure 3 is examined, it is evident that among the articles focusing on key terms such as wind, solar, and hydroelectric energy in the field of renewable energy, wind energy is the most chosen topic. This analysis was conducted by adding the criterion "AND wind (Topic)" to the dataset. As a result, 128 articles related to the keyword "wind" were found. In Figure 4, the number of articles on wind energy by year is presented.

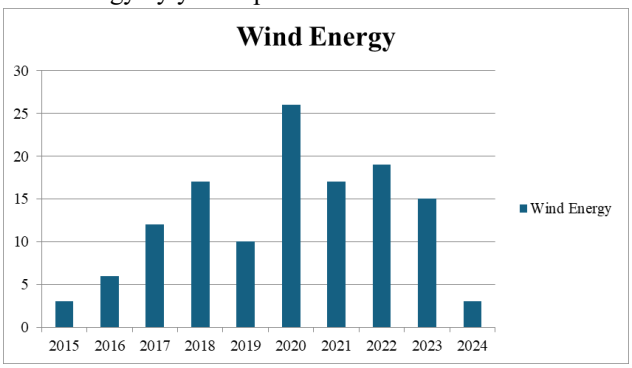

Figure 4. Number of articles in the field of wind energy

When analyzing the graph in Figure 4, it is observed that the number of articles on wind energy published each year varies, reflecting changing climate conditions and environmental factors. In 2015, there were 3 articles, in 2016 there were 6, in 2017 there were 12, in 2018 there were 17, in 2019 there were 10, in 2020 there were 26, in 2021 there were 17, in 2022 there were 19, in 2023 there were 15, and in 2024 there were 3 articles. The number of articles peaked in 2020.

To access research in the field of solar energy, another branch of renewable energy included in the dataset, the criterion "AND solar (Topic)" was added. This resulted in 54 articles related to the keyword "solar." These were published as follows: 1 in 2015, 4 in 2016, 4 in 2017, 3 in 2018, 6 in 2019, 10 in 2020, 7 in 2021, 11 in 2022, 7 in 2023, and 1 in 2024.

To access research in the field of hydroelectric energy, the "AND hydroelectric (Topic)" criterion was added. This search resulted in 4 articles related to the keyword "hydroelectric," published in the following years: one in 2016, one in 2019, and two in 2020.

4.1. Co-authorship- Authors

In this study, data were obtained using the VOSviewer_1.6.20 program to perform a Co-authorship – Authors analysis. Co-authorship analysis highlights the authors of a research paper and their collaboration status. This is important for demonstrating collaboration and multidisciplinary approaches in the process of academic publication. In this study, when the criteria were set to a minimum of 3 documents and 3 citations per author, out of 3,291 authors, 61 contributed. Table 1 lists the top 5 authors with the highest number of articles.

Table 1. Authors with the highest number of articles

ID	AUTHOR	ARTICLE	CITATIONS
1	Fei Wang	8	335
2	Pragasen Pillay	8	152
3	Kangping Li	7	335
4	Vladimir Terzija	7	40
5	Mehdi Karrari	6	73

Fei Wang, with the highest number of articles (8 articles) and 335 citations, stands out as the author with the most citations, while Vladimir Terzija, despite having 7 articles, is the author with the least citations among the top 5. This highlights the importance of the content of the articles and the method used. Some of the 61 nodes in the network are not connected to each other. The largest connected cluster consists of 8 nodes. Instead of showing all the nodes, this cluster of connected nodes has been displayed.

The Co-authorship networks shown in Figure 5 are typically represented by nodes and edges. Each node represents a source (usually an article or an author), and edges show the co-authorship relationships between nodes. These types of networks are used to visualize key figures in scientific communities, major research areas, and interdisciplinary interactions. When examining the co-authorship (author) in Figure 5, two different clusters in different colors can be observed. The central publications indicate frequent citations from different fields, with more detailed connections to several clusters. Fei Wang and Kangping Li are positioned centrally due to being the most cited authors.

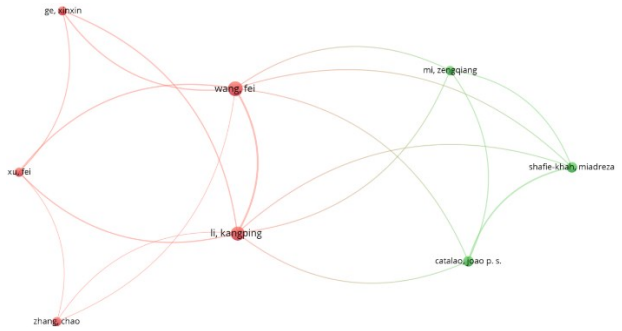

Figure 5. Co-authorship (Author) Network

4.2. Co-occurrences Analysis

Co-occurrence analysis examines the frequency with which specific words or terms appear together in texts or datasets, revealing the relationships between these terms. This method can be used in various applications such as information extraction, identifying word relationships, content analysis, and topic modeling [22]. It is an effective tool, especially in large datasets and text data, for identifying meaningful relationships and defining important concepts. In this study, a minimum of 7 keywords were selected. As a result, 69 out of 4023 keywords surpassed the threshold value. Table 2 presents the top 5 most frequently used keywords. According to the keywords used in articles related to electricity load forecasting, the most common terms are induction motor with 3952 occurrences, wireless power transfer with 3884, voltage stability with 3778, voltage measurement with 3766, and voltage measurement with 3751, ranking at the top.

Table 2. Top 5 Co-occurring relationships with keywords

ID	KEYWORD	OCCURRENCES
3952	Induction Motor	18
3884	Wireless Power Transfer	8
3778	Voltage Stability	9
3766	Voltage Measurement	12
3751	Voltage Control	12

In the network map of Figure 6, a network map based on keywords has emerged with 8 clusters, 399 connections, and a total connection strength of 570, utilizing the VOSviewer program in the research

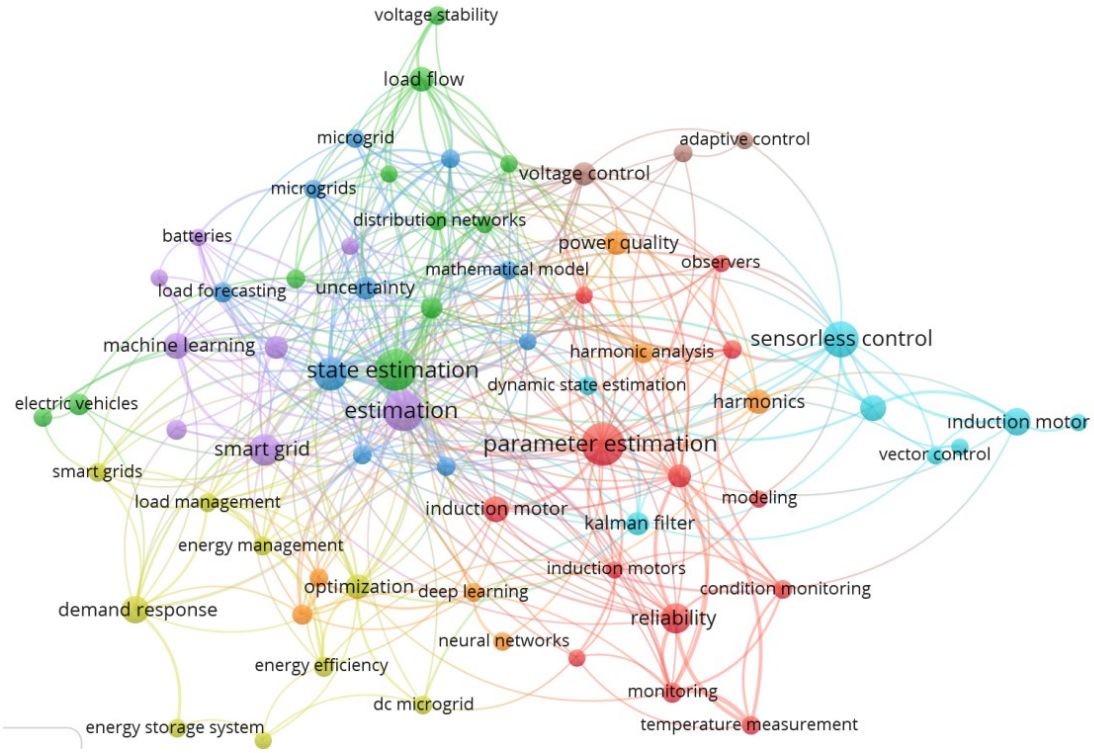

Figure 6. Most frequently used keyword network

4.3. Citation – Document

Citation – Document citation analysis refers to documents in scientific literature that are analyzed for citations. These documents are typically used to evaluate citation relationships and the impact of one or more scientific works. In the analysis, the minimum citation count for a document was set to 40. As a result, 61 out of 963 documents surpassed this threshold. According to Table 3, the document with 613 citations ranked first [23].

Table 3. Top 5 most cited documents

ID	DOCUMENT	CITATIONS
805	[23]	613
614	[24]	196
194	[25]	140
916	[26]	137
704	[27]	128

In VOSviewer, the largest connected item cluster was selected with 5 elements from the 61 items [25]. It can be observed that there is only a single connection.

Figure 7. Citation network of cited documents

4.4. Citation-Source

Citation-Source analysis refers to the sources cited by a document or study. In other words, it is the list of references or bibliography where one source cites another [28]. In the study, when the minimum number of documents for a source was set to 3, 61 out of 214 sources exceeded the threshold.

Table 4. Most cited sources

ID	SOURCE	DOCUMENTS	CITATIONS	IMPACT FACTOR (IF) 2024
205	International Journal of Electrical Power & Energy Systems	148	2243	5.0
176	IEEE Transactions on Power Electronics	16	935	6.5
178	IEEE Transactions on Smart Grid	19	772	9.8
183	IEEE Transactions on Industry Applications	26	476	4.5
49	Energies	64	448	3.2

The most significant values in the table highlight a distinct difference between the impact and publishing strategies of the journals. The IEEE Transactions on Smart Grid emerges as the most prestigious and highest-impact journal on the list, boasting a remarkable Impact Factor (IF) of 9.8. This indicates that despite its limited number of published documents, the articles within it receive an exceptionally high volume of citations [29]. In contrast, the International Journal of Electrical Power & Energy Systems is the most highly cited source overall, with 2,243 citations, yet its IF is lower. This suggests that the journal contributes fundamentally to the field through a high volume of publications, which accounts for its elevated

total citation count.

In VOSviewer, a selection was made with the largest connected component consisting of 37 items from 61 elements. As a result, the citation network of sources is shown in Figure 8. The International Journal of Electrical Power & Energy Systems source is the focal point, with the highest number of nodes.

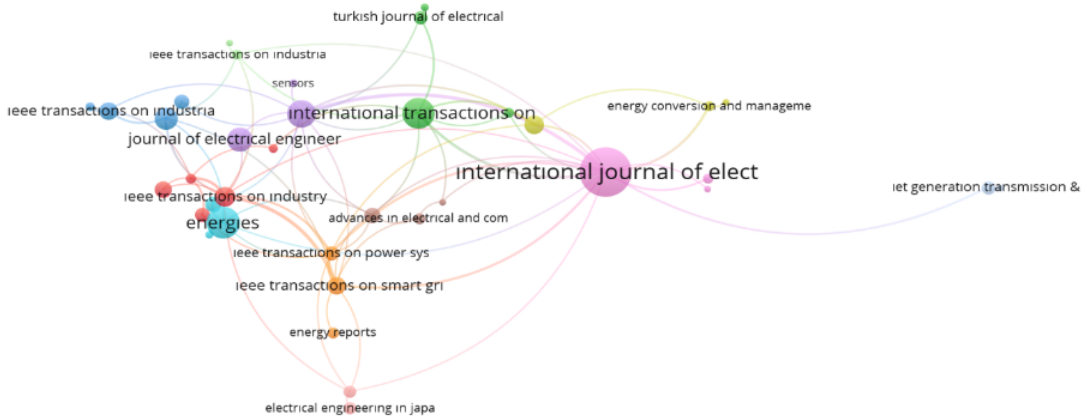

Figure 8. Cited source network

4.5. Citation- Organization

Citation-Organization" analysis refers to the organizations or institutions that a document (article, report, book, etc.) cites [30]. In this study, when the minimum number of organizations cited by a source was set to 4, 74 out of 1254 organizations exceeded the threshold. The organizations with the most citations are listed in Table 5.

Table 5. Most cited organizations

ID	ORGANIZATION	DOCUMENTS	CITATIONS
553	North China Electric Power University	22	472
822	Tsinghua University	16	270
1178	Zhejiang University	8	237
494	Nanyang Technological University	9	217
872	University of Beira Interior	4	202

In VOSviewer, a selection was made with the largest connected component consisting of 24 elements out of 74. As a result of this selection, the network of cited organizations is presented in Figure 10. The source "North China Electric Power University" is the focal point with the most nodes.

Figure 9. Citation network between organizations

4.6. Citation – Country

Citation – Country analysis refers to the number of citations or references made by a specific country in scientific publications [31]. It measures a country's contribution to scientific research and reflects its scientific impact and contribution level [32]. In the study, when the minimum number of countries per source is set to 2, 67 out of 82 countries exceeded the threshold. In Table 6, the country with the highest number of publications is also the one that receives the most citations.

Table 6. Countries with the most citations

ID	COUNTRY	DOCUMENTS	CITATIONS
46	Peoples R China	202	2679
71	Usa	119	2639
76	India	105	1086
78	Iran	77	894
24	Germany	42	689

In VOSviewer, a selection was made with the largest connected component of 55 out of 67 elements. As a result, the network of cited countries is shown in Figure 11. In this diagram, each circle represents a country. Larger circles indicate the dominance of those countries in the research. If a line exists between two country names, it indicates collaboration between those two countries. Additionally, the proximity of the lines between the countries shows the strength and breadth of their connections. People's Republic of China is the country represented by the largest circle.

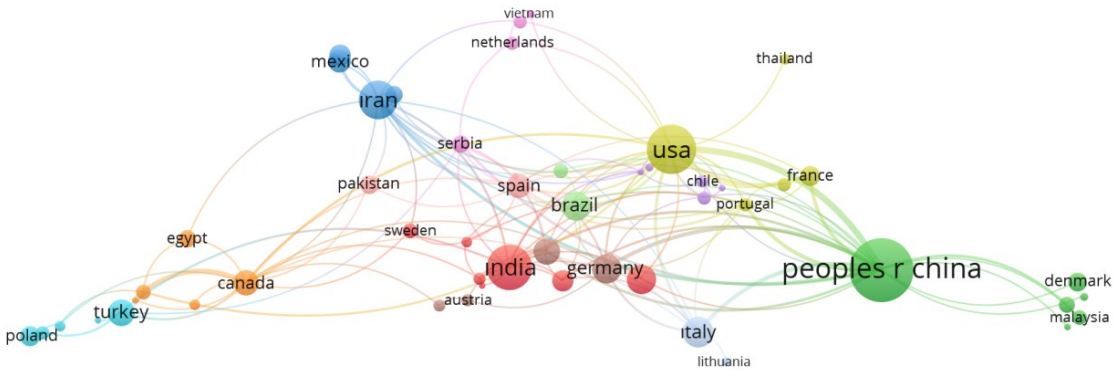

Figure 10. Citation network between countries

5. Discussion

The bibliometric results demonstrate not only the quantitative growth of electricity load forecasting research but also qualitative shifts in methodological approaches and thematic priorities. The increasing number of publications and citations after 2020 reflects the rising importance of accurate load forecasting in the context of renewable energy integration and smart grid management. However, the results also reveal fragmentation across subdomains, indicating that despite rapid growth, the field remains uneven in terms of thematic focus and methodological adoption.

One of the striking findings concerns the limited integration of advanced forecasting techniques such as Empirical Mode Decomposition and Support Vector Regression, which were highlighted in the introduction as effective tools for handling non-linear and non-stationary time series. While these methods appear in selected influential works, their bibliometric visibility remains modest compared to traditional approaches. This suggests that although advanced methods are being explored, they have not yet become mainstream in electricity load forecasting literature, creating an opportunity for future research to bridge this gap.

Another important insight emerges from the keyword co-occurrence analysis. Terms related to renewable energy-particularly wind and solar-are increasingly frequent, underscoring the growing intersection between load forecasting and renewable integration. Yet, hydroelectric forecasting remains underrepresented, reflecting a potential research gap in diversifying energy-specific forecasting approaches. This imbalance highlights the need for more comprehensive studies that address different renewable sources in forecasting models.

Collaboration networks also provide valuable implications. While authors such as Fei Wang and Kangping Li dominate co-authorship clusters, the presence of disconnected nodes suggests that research collaborations are still fragmented across regions and institutions. This indicates the potential for strengthening international and interdisciplinary cooperation, particularly in combining expertise from computer science, energy engineering, and climate science. Such cross-disciplinary efforts are likely to improve both methodological innovation and practical applicability.

The source and citation analysis further points to the dominance of a few high-impact journals, particularly the International Journal of Electrical Power & Energy Systems. While this concentration reflects strong publication outlets, it may also limit the diversity of perspectives. Future studies could benefit from expanding to multidisciplinary journals and conferences where hybrid modeling and AI-based approaches are being discussed, thus capturing emerging methodological innovations earlier.

6. Conclusions and Future Work

6.1. Conclusions

This study provides a comprehensive bibliometric overview of electricity load forecasting research using Web of Science data and VOSviewer. The findings demonstrate a steady increase in publications and citations, particularly after 2020, with China and the USA as leading contributors. Prominent authors such as Fei Wang and Kangping Li, along with institutions like North China Electric Power University and Tsinghua University, play a central role in shaping collaborative research networks. Keyword analysis further emphasizes the integration of renewable energy, especially wind and solar, into forecasting models. Influential journals such as the International Journal of Electrical Power & Energy Systems were identified as the most impactful publication outlets in the field. Overall, the results confirm the growing importance of advanced methods and interdisciplinary collaboration in advancing electricity load forecasting.

6.2. Future Work

Future research could expand the scope of bibliometric analysis by incorporating publications indexed in Scopus and IEEE Xplore, enabling cross-database comparisons

and broader coverage. The application of advanced text-mining and topic modeling techniques would provide deeper insights into thematic structures and emerging research gaps. Another promising avenue is the integration of bibliometric findings with performance benchmarking of forecasting models, bridging the gap between scholarly output and methodological effectiveness. Finally, stronger interdisciplinary collaborations-linking electricity load forecasting with climate science, renewable energy integration, and smart grid technologies-will be essential to address the complex challenges of future energy systems.

Declaration of Ethical Standards

The authors affirm that they have adhered to all applicable ethical standards in the preparation and submission of this manuscript. This includes compliance with policies concerning authorship, proper citation of sources, accurate data reporting, and the presentation of original research. No part of this manuscript has been plagiarized or submitted elsewhere. All research procedures, including data handling and analysis, were conducted responsibly and with academic integrity.

Credit Authorship Contribution Statement

The contributions of each author are detailed according to the CRediT (Contributor Roles Taxonomy) as follows: Oya Kılcı contributed to the conceptualization, methodology design, extensive literature search, data curation, and drafting of the manuscript. Abdulkadir Öztürk was involved in methodology design, validation, and manuscript review. Muslume Beyza Yıldız played a significant role in bibliometric analysis, data interpretation, preparation of figures and tables, and manuscript editing. Sude Nur Atik contributed to software implementation and data processing. Elham Tahsin Yasin assisted with literature review and reference organization. Zeki Berk Tonguç provided statistical validation, quality checks. Murat Koklu supervised the project, ensured funding acquisition, contributed to review and editing, and gave the final approval of the manuscript.

All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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