Research Article

Journal of Marine and Engineering Technology (JOINMET) 4(2), 44-53, 2024

Received: 13-Nov-2024 Accepted: 15-Dec-2024

homepage: https://dergipark.org.tr/tr/pub/joinmet

https://doi.org/10.58771/joinmet.1584084

SAKARYA UNIVERSITY OF APPLIED SCIENCES

Trends and Emerging Themes in Thermal Energy Storage: A Bibliometric Study

Malik Karadag[1], Idris Tan Akçay[2], Asim Sinan Karakurt[3*]

[1] Naval Architecture and Marine Engineering Department, Yildiz Technical University, malik.karadag@std.yildiz.edu.tr
[2] Naval Architecture and Marine Engineering Department, Yildiz Technical University, tan.akcay@std.yildiz.edu.tr
[3] Naval Architecture and Marine Engineering Department, Yildiz Technical University, asinan@yildiz.edu.tr

ABSTRACT

Thermal energy storage (TES) systems play a pivotal role in the efficient integration of renewable energy sources into the global energy landscape. This bibliometric analysis delves into the evolving research landscape of TES systems, focusing on nearly 19000 scientific papers from the Scopus database as the primary source to identify key research trends, influential authors, and leading institutions shaping the field between 2000 and 2023. The analysis reveals a substantial surge in TES research over the past two decades due to factors such as advancing technology and increasing incentives. China has emerged as a global leader in this domain, followed closely by the United States and India. Xi'an Jiaotong University, De Lleida University, and Tsinghua University are the most prolific institutions in this field. The Journal of Energy Storage is the most frequently paper-published, followed by Applied Thermal Engineering and Applied Energy. Key research themes identified include the development, design, and optimization of heat storage systems, TES system integration with renewable energy sources, and the exploration of phase change materials for efficient energy storage. The analysis also highlights the contributions of prominent researchers in the field. Cabeza LF, Li Y, and Wang Y are identified as the most prolific authors, having made significant contributions to the advancement of TES technology. The increasing demand for sustainable and efficient energy solutions has spurred significant interest in TES systems. As the world transitions towards a low-carbon future, TES systems offer a promising solution for storing excess renewable energy and ensuring a reliable and sustainable energy supply.

Keywords: Bibliometric analyses, scopus, thermal energy storage

[3*] Corresponding Author's email: asinan@yildiz.edu.tr

Termal Enerji Depolamada Trendler ve Temalar: Bibliyometrik Bir Çalışma

ÖZ

Termal enerji depolama (TES) sistemleri, yenilenebilir enerji kaynaklarının küresel enerji sistemine verimli bir şekilde entegre edilmesinde önemli bir rol oynamaktadır. Bu bibliyometrik analiz, 2000 ile 2023 yılları arasında TES sistemleri üzerine şekillenen araştırma eğilimlerini, etkili yazarları ve alandaki önde gelen kurumları belirlemek amacıyla Scopus veri tabanındaki yaklaşık 19.000 bilimsel makaleyi incelemektedir. Analiz, son yirmi yılda gelişen teknoloji ve artan teşvikler gibi nedenlerden dolayı TES araştırmalarında önemli bir artış olduğunu ortaya koymaktadır. Bu alanda, Çin küresel bir lider olarak öne çıkarken, onu Amerika Birleşik Devletleri ve Hindistan takip etmektedir. Xi'an Jiaotong Üniversitesi, De Lleida Üniversitesi ve Tsinghua Üniversitesi, bu alandaki en üretken kurumlar olarak öne çıkmaktadır. Journal of Energy Storage, bu konuda en fazla makalenin yayımlandığı dergi olurken, onu Applied Thermal Engineering ve Applied Energy dergileri takip etmektedir. Ana araştırma temaları arasında ısı depolama sistemlerinin geliştirilmesi, tasarımı ve optimizasyonu; TES sistemlerinin yenilenebilir enerji kaynaklarıyla entegrasyonu; ve verimli enerji depolaması için faz değişim malzemelerinin araştırılması yer almaktadır. Analiz ayrıca, alandaki önde gelen araştırmacıların katkılarını da vurgulamaktadır. Cabeza LF, Li Y ve Wang Y, TES teknolojisinin ilerlemesine önemli katkılar sağlayan en üretken yazarlar olarak öne çıkmaktadır. Sürdürülebilir ve verimli enerji çözümlerine olan artan talep, TES sistemlerine olan ilgiyi önemli ölçüde artırmıştır. Dünya düşük karbonlu bir geleceğe doğru ilerlerken, TES sistemleri, fazla yenilenebilir enerjinin depolanması ve güvenilir, sürdürülebilir bir enerji arzının sağlanması için umut verici bir çözüm sunmaktadır.

Anahtar Kelimeler: Bibliyometrik analiz, scopus, termal enerji depolama

1 Introduction

Due to developing technology and increasing needs, we are becoming increasingly dependent on energy today. A large portion of the energy used, although it varies by geography, is obtained from fossil-based energy sources. Due to the decrease in known fossil resources and environmental restrictions, not every energy source can be used everywhere. In addition, energy supply is a major problem in places that are out of the grid or have no access to the grid. One of the solutions offered to such problems is energy storage systems. The operating logic of energy storage systems is to store the production difference in cases where excess energy emerges or when operating at lower loads than efficient working conditions and then use it where or when it is needed. Thus, it is possible to provide reliable and sustainable energy. In this context, energy can be stored as mechanical, chemical, electrical, electrochemical and thermal energy. The energy stored with these methods can be used as electricity or heat when needed (Dincer & Ezan, 2022).

Sensible, latent, and thermochemical systems are the commonly used mainly Thermal energy storage (TES) systems whose selection depends on some variables such as using period, storage period, and economics (Dincer, 2002). Peak load shifting, increased energy economy, integrating renewable energy sources, increased system reliability, and less environmental impact are just a few of the many benefits that TES provides. From an economic perspective, TES systems have a great deal of promise for increasing the effectiveness of thermal energy equipment and facilitating widespread energy substitution (Dincer & Ezan, 2018). The validity of thermodynamic principles, the importance of temperature differences, the relationship between heat and work, cyclic processes, and principles such as conservation of energy form the basis of thermal energy conversion and are important for understanding how systems work. These principles can be applied in many areas from machine design to energy efficiency evaluation. Thermal energy conversion is the process of converting naturally occurring energy flows into usable forms based on temperature differences. This process usually occurs via a heat engine and involves doing work by directing heat flows originating from temperature gradients (Dincer & Rosen, 2021).

There have been many studies in different fields using the bibliometric analysis method. A general literature summary is given below to show both the different areas of use of bibliometric analysis and especially the studies related to energy storage systems. As mentioned above, analyses related to almost every academic field with data can be made with the bibliometric analysis method. For example, using Scopus data, the changes in the subject headings of the

articles in the database over the years were examined (Al-Khoury et al., 2022), the studies published in the field of maritime English in a 40-year period were examined (Li et al., 2023), the studies related to both the physical and mental health of seafarers were examined (Masalacı, 2024), the studies related to Workloads in the Maritime Sector were examined (Arslan & Paker, 2023), the studies in the Scopus database related to steam turbines, which have an important place in energy production, were examined (Karakurt et al., 2022), the data of the 100 most cited studies in the field of hydrogen energy worldwide were examined (Bashan & Ust, 2022), the research conducted by researchers in this field in the 30-year period from 1992 to 2022 related to hydrogen energy and storage. There are studies examining the contributions of the authors, institutions and countries worldwide in the field of ocean engineering between 1989 and 2021 (Gunes, 2021). In addition to these, there are studies examining the studies on the intelligent control of TES systems (Tarragona et al., 2020), examining the studies conducted with latent TES between 2000-2019 (Mustapha et al., 2021), examining the studies conducted on sand-based TES systems (Odoi-Yorke et al., 2024), and examining the studies conducted on TES systems proposed for Renewable energy communities (Brunelli et al., 2024). However , what is shared here is a very small part in terms of both scope and quantity. In this study, the studies conducted between 2000-2023 related to TES systems in general will be examined and a projection will be provided regarding the development of the process and its future course.

2 Modeling

Bibliometric analyses are statistical tools that provide information about the course of academic studies prepared on a subject, in a publication or in a publication type (Donthu et al., 2021). In the light of this information, it is possible to access information such as which individuals, institutions and countries stand out, which terms and subject headings are used over the years, and which publications are more effective.

In this study, statistical data belonging to nearly 19000 articles for the “Thermal Energy Storage” subject title in the Scopus database (Scopus, 2024) related to TES systems between the years 2000-2023 were processed using Bibliometrix and MS Excel programs and the results were shared. Since bibliometric analyses are qualitative research tools, no clear mathematical model exists. Instead, the processing steps of data obtained from the database are generally shared, as in the example of Bibliometrix an R tool for science mapping (Aria & Cuccurullo, 2017). Three main steps (data collection, data analysis, and data visualization) in the system are shown in Figure 1.

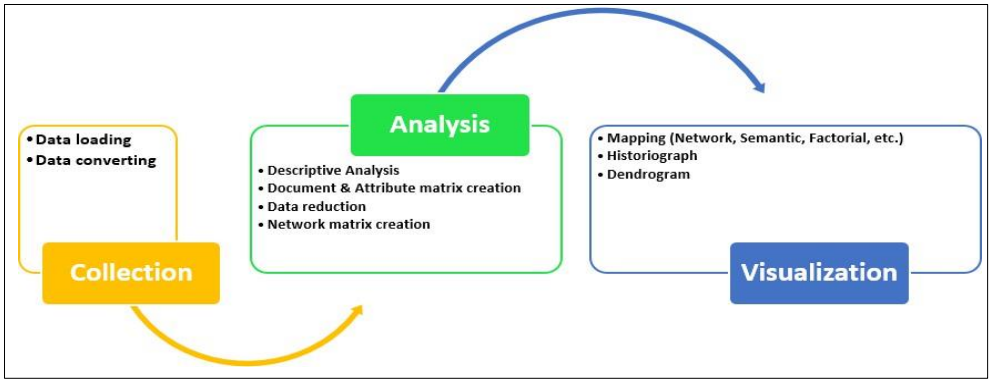

Figure 1: Data processes in the Bibliometrix (Aria & Cuccurullo, 2017)

3 Analysis and Evaluation

According to Scopus data, graphs related to the distribution of studies according to their types, subjects, keywords used in the studies, countries, institutions and journals, and the number of studies and citations were shared. In the biometric analysis, the TES part covers the years 2000-2023, and the number of data obtained without specifying the type of study was determined as 18322. Then, without any restriction in terms of the type of study examined, the number of studies to be investigated was calculated as stated by only restricting the year, and the types of these studies are indicated as percentages in Figure 2. 70% of the studies written are articles, and this number is determined as 12788 in total. The number of conference papers, which constitute 20% of the studies, is determined as 3704.

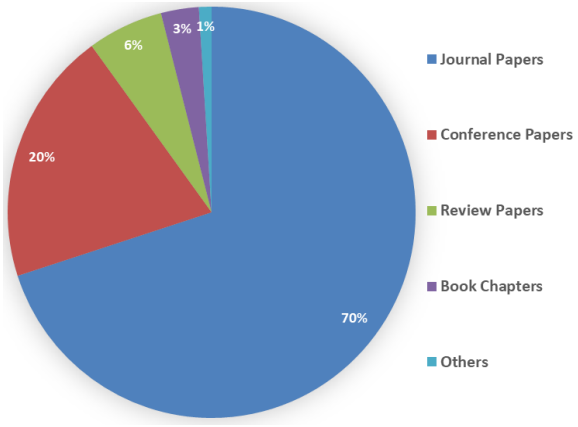

Figure 2: Types of publications on TES systems between 2000-2023.

Figure 3 displays the statistics when the data is assessed in terms of subjects. With almost half of the papers, energy and engineering are the most prevalent fields, suggesting that thermal energy storage technology application is a major area of interest. A sizeable portion (10%) goes to materials science, which highlights the significance of creating new materials for effective thermal energy storage. Together, chemical engineering, chemistry, and physics make up 20%, emphasizing the importance of basic knowledge in improving thermal energy storage systems. 10% comes from the environmental and earth sciences, most likely as a result of research into sustainable energy storage methods and natural materials. The remaining 8% is made up of math, computer science, and other subjects, indicating areas for more multidisciplinary study in thermal energy storage.

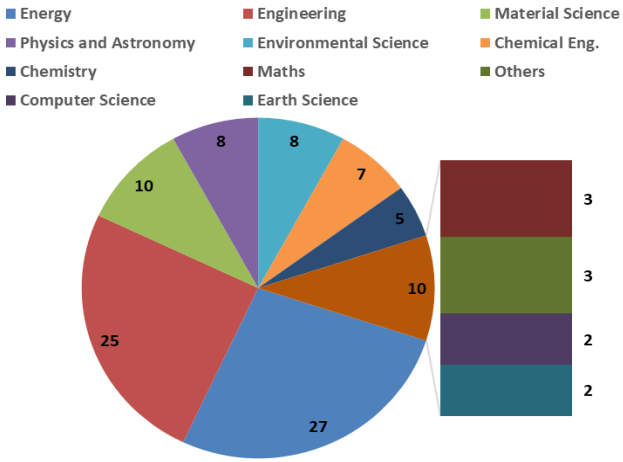

Figure 3: Distribution of studies on TES systems by area between 2000-2023.

Figure 4 shows the citation numbers of the 10 countries with the highest number of citations. As a result of the research on TES, the citations created were created by many countries and China came first with 125834 citations. China took its place at the top of the list with a clear difference compared to the other countries on the list and due to its high population density. China is followed by the United States with 37872 citations. With these values, it can be said that they have a level of citation numbers that can be considered proportional to their population. However, Spain is in third place on the list with a high rate of 29772 articles. In addition to these countries, Turkey is at a very good level in terms of the number of citations compared to its population values; the total number of citations was calculated as 20210 in total for the years 2000-2023 and is in 6th place in the list.

Figure 4 also shows the number of studies written by 10 countries on TES between 2000-2023. The country that has written the most studies on this subject is China with 5075. China is followed by the United States with 2355 studies and India with 1771 studies. Turkey ranks 10th in the ranking with 659 studies.

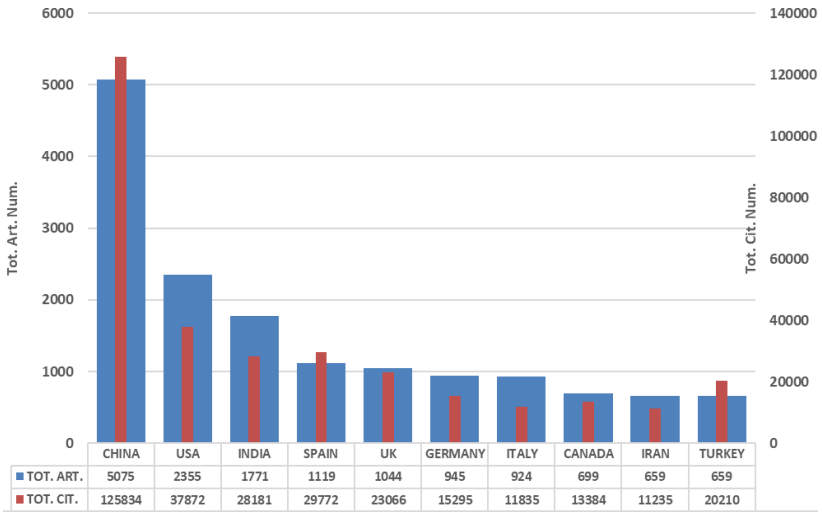

Figure 4: Number of articles and citations written in the field of TES systems by country.

The number of studies written by scientists conducting research on TES systems are given in Figure 5. In this table, the expression indicated by SCP shows the number of studies written by scientists of the country as singular without scientists from other countries, while the expression MCP shows the number of studies written by scientists of the specified country together with scientists from other countries. China ranks first and there are 3742 studies in this ranking. 3069 of these are singular and 673 are multiple studies. Here, the MCP rate, that is, the ratio of studies written multiple to the total studies written on behalf of the country, is calculated as 17.99%.

According to the values understood from here, countries other than China have written a total of 3266 studies and this can be easily understood from the graph. India follows China which consists of 956 studies written singularly and 163 studies written multiple . Here, the MCP rate is calculated as 14.57%. The United States is ranked third with 861 single studies and 170 multiple studies written, the MCP rate was calculated as 16.49%. Turkey ranked 8th in the ranking. With 310 single studies and 103 multiple studies written, it has a 24.94% MCP rate.

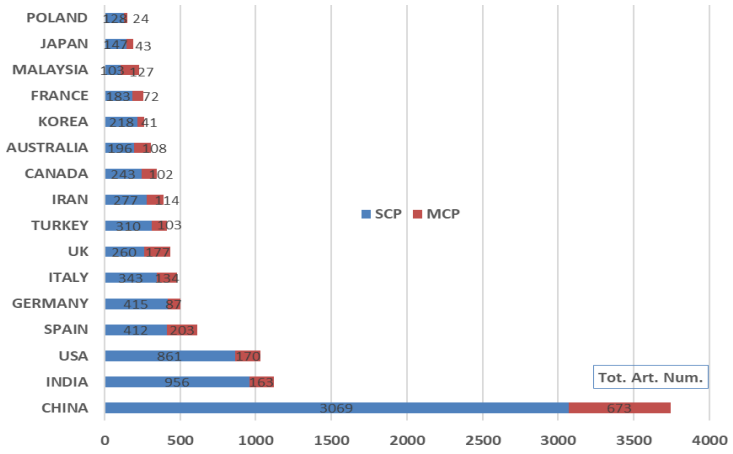

Figure 5: Number of single and multiple articles written by countries on TES systems.

The study numbers of the top 5 countries with the most studies on TES systems are given in Figure 6, depending on the annual increase rate. It can be figured out the exponential characteristics of curves very clearly, especially the last ten years. The general pattern is encouraging for all countries, suggesting that interest in thermal energy storage research is rising internationally. The growing need for effective and sustainable energy solutions is probably what's causing this.

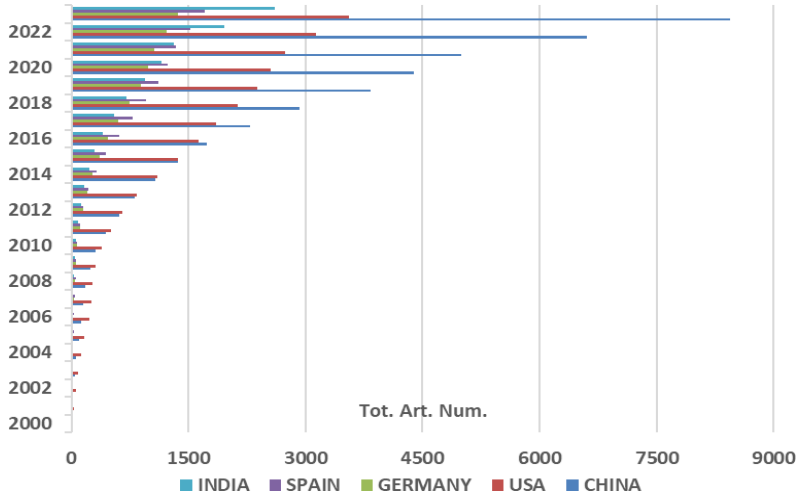

Figure 6: Annual study numbers of the top 5 countries with the most studies on TES systems.

Figure 7 visually represents the global landscape of research activity in TES systems. The color intensity of each country reflects the level of research output, with darker shades indicating higher activity. China stands out as a clear leader in TES research. Its dark blue color highlights its significant contribution to the field. This is likely due to China's strong focus on renewable energy integration and its large-scale energy infrastructure projects. The United States shows substantial research activity, particularly in areas like solar thermal energy storage and building-integrated TES systems. Several European countries have active research communities in TES. India and South Korea also exhibit significant research efforts, driven by their growing energy demands and renewable energy initiatives.

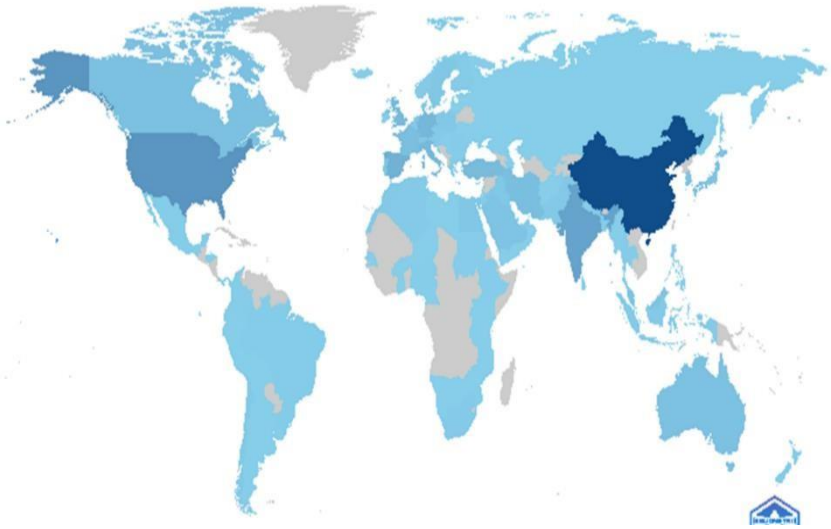

Figure 7: Geographic distribution of research on TES systems.

In the evaluation of TES analysis as an author are shown in Figure 8 as shown. Cabeza LF ranks first with 307 studies. Cabela LF is followed by Li Y with 275 studies in the second place. Wang Y is in the third place with 263 studies. The H index is based on the most cited articles of a scientist and the number of citations received in other publications. According to the table given in the studies written about TES, Cabeza LF has the highest H index of 70. Another person with a high H index on this subject, Sarı A, has an index of 59.

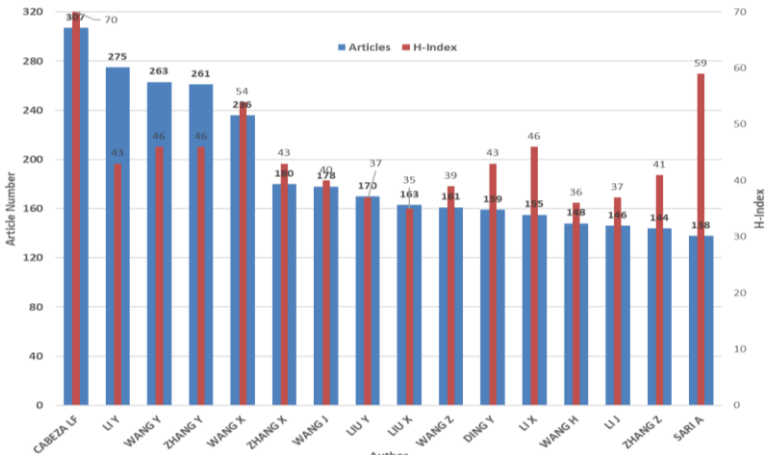

Figure 8: Number of authors' studies on TES systems.

Authors who created studies on TES generally started to create products after 2014. Cabeza LF, who created the most studies, created the most studies in 2016. Cabeza LF created 40 studies in 2016. Li Y, who is second in the number of studies, created an average of 20 studies every year between 2016 and 2020. Li Y, on the other hand, increased the number of articles he wrote after 2020. These values are as shown in Figure 9 .

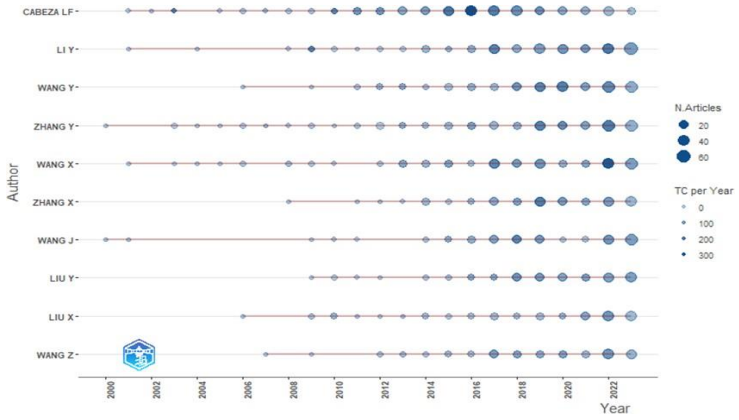

Figure 9: Number of studies conducted by authors on TES systems over the years.

After classifying the citation numbers on a country basis, the classification on an academic basis was also examined. Here, Sharma A. is in the first place with 4432 citations, followed by Zalba B. with 3913 citations. Chen C. is in the third place with 2842 citations. The graph showing the first 10 people on this list is shown in Figure 10.

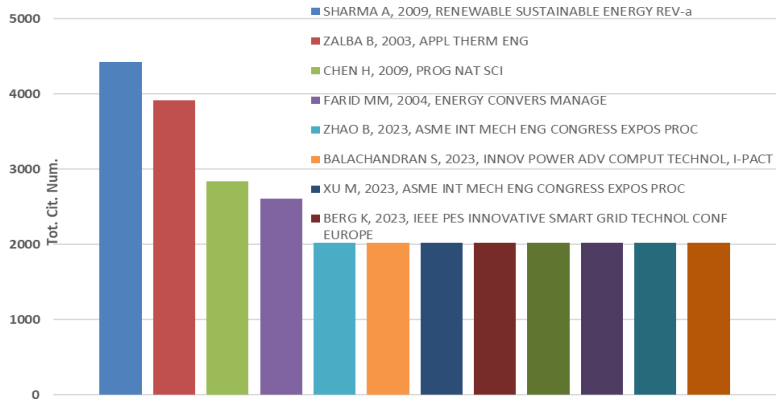

Figure 10: Analysis of the references written on TES systems by authors.

In addition to the extensive research conducted by certain universities on TES, many universities have begun to conduct extensive research on systems that can store energy in the future. Research on TES was first started in 1964, but the first article written on this subject was published by Tsinghua University in 1999. Figure 11 shows the number of studies by year for the top 5 universities that have conducted the most research and have the most studies. The university that conducts the most research is Xi'an Jiaotong University. This university, which has a total of 315 studies, is located in China. Then comes De Lleida University which took the second place on the list with 267 studies. Tsinghua University is in the third place on the list. It managed to write its name on the list of universities that are quite ambitious in this regard with 243 studies written. In Figure 11, the number of articles for a total of 10 universities is compared and given in a graphic form. In Turkey, as mentioned, Karadeniz Technical University is the university that has written the most articles on this subject. The number of studies is 112 and it has taken the 17th place in the world in terms of research conducted on this subject.

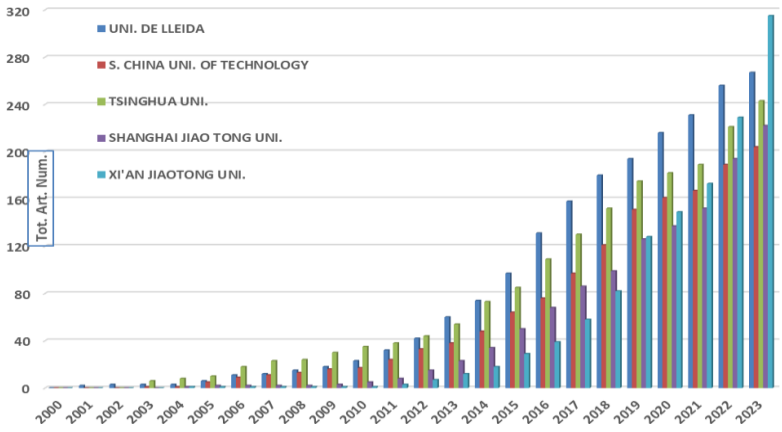

Figure 11: Analysis of universities publishing articles on TES systems by year.

Figure 12 shows the number of studies written on certain topics. In the table given for the TES section, there has been an increase in creating studies on solar energy materials and solar batteries, especially after 2012. 632 studies were written about energy storage, especially in 2022. When we look at the table given, the study creation situation has increased in the topics taken as basis after 2012.

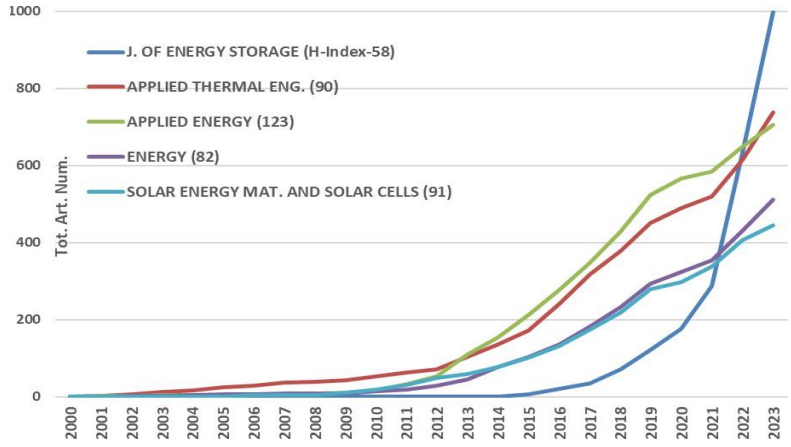

Figure 12: Number of studies on TES systems by specific topics.

Figure 13 shows a map of words used together in articles. Heat storage, thermal energy and phase change materials are the most commonly used word groups together. Since the words used in the research on TES do not differ much in general, this event gave us the need to make a graph and subsequently, these words were included in the literature in this way. The concept of “Heat Storage” took its place at the top of the list and when the change in the frequency of the word used over the years was examined, it was used 13268 times (15%) in 2023 alone and took its place at the top of the list. Following this group of words, the concept of “Thermal Energy”, which was written 8607 times (10%),

is in second place on the list, followed by the concept of “Phase Change Materials”, which is used 6938 times (8%), in third place. These words are only in the first three places of the list, and are used with increasing numbers every year, without exception.

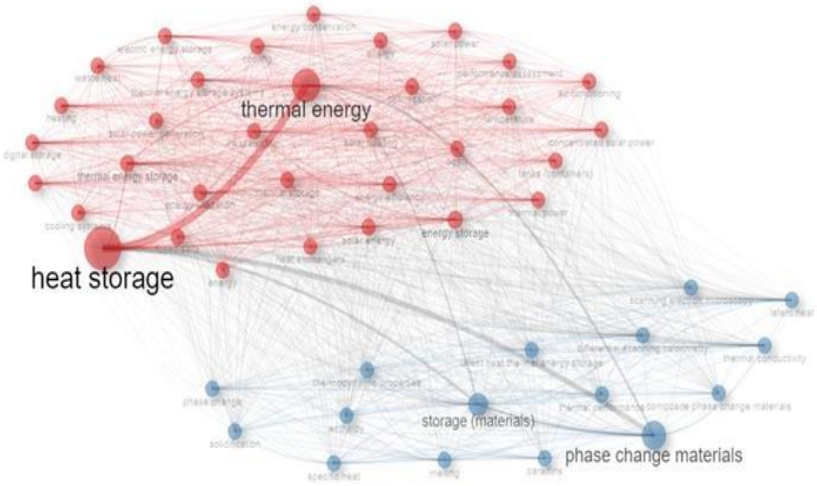

Figure 13: Words used together in the article type written for TES systems.

4 Conclusions

This bibliometric analysis provides a comprehensive overview of the research landscape of Thermal Energy Storage (TES) systems over the past two decades with using almost 19000 studies. The increasing global demand for sustainable and efficient energy solutions has driven significant growth in TES research. The escalating demand for renewable energy sources and efficient energy storage solutions, coupled with advancements in materials science enabling the development of advanced thermal energy storage technologies, has spurred significant growth in research and development activities in this field. Consequently, a notable increase in both the quantity and quality of publications in recent years has been observed. A notable surge in TES research, particularly in thermal energy storage and phase change materials, has been observed. China has emerged as a leading nation in TES research, followed by the United States and India. Xi'an Jiaotong University, De Lleida University, and Tsinghua University are the most popular three centers in terms of the number of publicaitons. The Journal of Energy Storage is the most-published journal, which has been aggressively increasing in the last 5 years, and then Applied Thermal Engineering and Applied Energy journals have come. In order to develop thermal energy storage solutions, engineers, materials scientists, chemists, physicists, environmental scientists, and computer scientists must work together, as evidenced by the wide range of disciplines involved. By understanding the current state-of-the-art and future trends in TES research, researchers and policymakers can make informed decisions to accelerate the deployment of TES technologies and contribute to a more sustainable energy future.

5 Declarations

5.1 Competing Interests

All authors of the manuscript have no conflict of interest to declare.

5.2 Authors’ Contributions

Malik KARADAG: Contributed to the literature summary creation, model design, analysis and interpretation.

Idris Tan AKCAY: Contributed to the literature summary creation, model design, analysis and interpretation.

Asım Sinan KARAKURT: Contributed to the topic proposal, consultancy, literature summary creation, model design, analysis and interpretation.

References

Al-Khoury, A., Hussein, S. A., Abdulwhab, M., Aljuboori, Z. M., Haddad, H., Ali, M. A., Abed, I. A., & Flayyih, H. H. (2022). Intellectual Capital History and Trends: A Bibliometric Analysis Using Scopus Database. Sustainability, 14(18), Article 18. https://doi.org/10.3390/su141811615

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Arslan, E., & Paker, S. (2023). Bibliometric and Qualitative Analysis of Workload Studies in the Maritime Sector. Journal of Marine and Engineering Technology, 3(2), Article 2. https://doi.org/10.58771/joinmet.1400314

Bashan, V., & Ust, Y. (2022). A Bibliometric Analysis and Evaluation of Hydrogen Energy: The Top 100 Most Cited Studies. El-Cezeri, 9(2), Article 2. https://doi.org/10.31202/ecjse.1001900

Brunelli, L., Borri, E., Pisello, A. L., Nicolini, A., Mateu, C., & Cabeza, L. F. (2024). Thermal Energy Storage in Energy Communities: A Perspective Overview through a Bibliometric Analysis. Sustainability, 16(14), Article 14. https://doi.org/10.3390/su16145895

Dincer, I. (2002). On thermal energy storage systems and applications in buildings. Energy and Buildings, 34(4), 377–388. https://doi.org/10.1016/S0378-7788(01)00126-8

Dincer, I., & Ezan, M. A. (2018). Heat Storage: A Unique Solution For Energy Systems. Springer International Publishing. https://doi.org/10.1007/978-3-319-91893-8

Dincer, İ., & Ezan, M. A. (Eds.). (2022). Energy: Concepts and Applications (1st ed.). Turkish Academy of Sciences. https://doi.org/10.53478/TUBA.978-625-8352-00-9

Dincer, I., & Rosen, M. A. (2021). Thermal Energy Storage: Systems and Applications. John Wiley & Sons.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Gunes, Ü. (2021). Bibliometric Analysis for the Field of Ocean Engineering. Gemi ve Deniz Teknolojisi, 219, Article 219.

Karakurt, A. S., Özsari, İ., Başhan, V., & Güneş, Ü. (2022). Evolution of steam turbines: A bibliometric approach. Journal of Thermal Engineering, 8(5), Article 5. https://doi.org/10.18186/thermal.1187839

Li, T., Chen, Q., Xi, Y., & Lau, Y.-Y. (2023). A 40-Year Bibliometric Analysis of Maritime English Research: Insights and Implications. Sustainability, 15(5), Article 5. https://doi.org/10.3390/su15054348

Masalacı, B. Ç. (2024). A Bibliometric Analysis of Mental Health and Wellbeing of Seafarers. Marine Science and Technology Bulletin, 13(1), Article 1. https://doi.org/10.33714/masteb.1404370

Mustapha, A. N., Onyeaka, H., Omoregbe, O., Ding, Y., & Li, Y. (2021). Latent heat thermal energy storage: A bibliometric analysis explicating the paradigm from 2000–2019. Journal of Energy Storage, 33, 102027. https://doi.org/10.1016/j.est.2020.102027

Odoi-Yorke, F., Opoku, R., Davis, F., & Obeng, G. Y. (2024). Employing bibliometric analysis to identify the trends, evolution, and future research directions of sand-based thermal energy storage systems. Journal of Energy Storage, 94, 112343. https://doi.org/10.1016/j.est.2024.112343

Scopus. (2024). Document search. Scopus. https://www.scopus.com/search/form.uri#basic

Tarragona, J., de Gracia, A., & Cabeza, L. F. (2020). Bibliometric analysis of smart control applications in thermal energy storage systems. A model predictive control approach. Journal of Energy Storage, 32, 101704. https://doi.org/10.1016/j.est.2020.101704