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Research Article

Evolution of steam turbines: A bibliometric approach

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ABSTRACT

This study investigates the contribution from researchers around the world in the field of steam turbines during the period 2000-2020. A bibliometric approach has been applied to illustrate the scientific publications on steam turbines and related topics using the Scopus database, which has 11,751 publications published by 652 authors from more than 500 organizations scattered over 101 countries. Various aspects of the studies have been analyzed such as publication type, fundamental research areas, journals, citations, authorship patterns, affiliations, and most used keywords. In addition, the impact factor, h-index, and Paper İmpact Parameter (PIP) for the number of total citations have been used to reveal the power of countries, institutes, authors, and journals in the field of steam turbines. The results show that the most productive journal or proceedings, author, and country according to PIP are Energy, Ibrahim Dincer, and Singapore, respectively. The results also indicate turbomachinery to cover more papers than other core research areas and engineering subjects to also have the highest ratio.

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INTRODUCTION

From Charles Parson's first ideas of the modern steam turbine to Aurel Stodola's contributions and to the present day, steam turbines have had a wide range of usage areas and are mostly used to rotate generators and generate electricity or provide propulsion for ships, aircraft, and missiles. Steam turbines fundamentally convert heat energy in the form of evaporated water into motion using pressure over spinning blades. Despite some countries' use of nuclear power, the steam turbines of fossil fuel power plants still make up a large part of the production capacity for most industrially developed and developing countries [1]. In this context, numerous studies are found on a wide range of issues concerning steam turbines. In general, the studies principally focus on: general equipment configurations; the design of steam paths, blades, gland seals, and valves; improving operating performance and efficiency and power cycle configurations; experimental research into turbine transients; fault diagnostics and monitoring; lifetime extensions for aging and refurbishment; and computational fluid dynamics

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(CFD) analysis. In fact, these study areas can be further expanded.

Hodgkinson [2] carried out a review study in 1935 on steam turbines. Ryley [3] performed a review study in 1962 focusing on the thermodynamic and mechanical interactions of water globules and steam in the wet steam turbine. Beebe [4] summarized some condition monitoring techniques that contribute to keeping certain large fossil-steam turbine machines in service for up to 17 years without opening high-pressure sections. Since then, studies have continued without slowing down. Thiemann et al. [5] carried out the application of a modern CFD method in the design process of high-efficiency steam turbines. Medina-Flores and Picón-Núñez [6] presented a thermodynamic model to estimate the operating performance of single- and multiple-extraction back pressure steam turbines. The validity of the model was demonstrated by comparing the results with those from the commercial turbines reported in the open literature.

When examining current studies, Tanuma [7] focused on recent advances in steam turbines for new power plants. Almstedt et al. [8] contributed to the discussion on acceptance criteria for applying advanced design methods for steam turbine components from the industrial point of view. Aliabadi et al. [9] examined the appropriate location for hot steam injection in the steam turbine blade and found the suction side to be more effective regarding condensation loss and erosion ratios. Pondini et al. [10] described the control valve and operating systems of a steam turbine in their study, which also highlighted the requirements that new operating technologies must allow for to meet the control valve system performance criteria. Fuzzy logic, which has been used in almost all sectors recently, has also been used for some purposes in steam turbines. Dettori et al. [11] proposed an adaptive fuzzy logic PID approach for controlling steam turbines. Comprehensive research activities have been conducted in the field of steam turbines between 2000 and 2020. Undoubtedly, both research articles and review studies on steam turbines have been studied non-stop for years from a very broad perspective. Bibliometric studies provide a great opportunity for viewing the trend in publications in the field of steam turbines and information such as which author has been most productive or which topics are working in this field. Karakurt and Gunes [12] have been carried out the effects of different flow rate or the effects of the partial load conditions on steam turbine isentropic efficiency and power plant performance.

Bibliometrics is a term Alan Pritchard used to refer to the older and less-used term of statistical bibliography, which was penned by E. Wyndham Hulme to cover the art of counting documents "to shed light on the processes of written communication and of the nature and course of development of a discipline (in so far as this is displayed through written communication), by means of counting and analysing the various facets of written communication"[13]. Bibliometrics uses mathematics and statistics to analyze books, articles, and publications using three types of indicators: quantity, performance, and structural. Quantity indicators measure the productivity of a researcher or group, most commonly by counting the number of articles published over a period of time. Quality is not addressed by this simple method. Quantity indicators' use of the number of publications in top-ranked journals helps address the quality issue but still does not address the variations in results for different group sizes.

Performance indicators measure an author's or group's quality of work and are useful for measuring the effect a study or journal has on a scientific field. Journal performance indicators include the impact factor (IF) for measuring a journal's importance in its field, but multidisciplinary journals usually have higher IFs than specialized journals. Popularity, citation habits, and 5-year journal IFs all help deal with the individual factors affecting journal performance indicators' accuracy. The immediacy index measures current importance of a journal's publications. Cited Half-Life considers how many years one must go back before reaching 50% of the total citations; this can reflect editorial policies focused on current issues or a rapidly changing field for short half-lives, compared to an emphasis on archival literature or a slowly evolving field for longer half-lives [14].

The most cited paper was published by van Eck [15] in the field of bibliometrics. Although it was published in 2010, it has already been cited 1,453 times currently. Many successful bibliometric studies have occurred. Su et al. [16] performed a bibliometric study that focused on carbon emissions and environmental management. Secinaro et al. [17] carried out a bibliometric study for identifying business models for electric cars. Andreo-Martínez et al. [18] examined the production of biodiesel under supercritical conditions by using bibliometric analysis. Kumar et al. [19] revealed a quantitative analysis of artificial neural network applications in materials and engineering issues. Imran et al. [20] studied organic Rankine cycle technology from the point of view of bibliometric analysis. Omoregbe et al. [21] carried out a bibliometric study for 20 years in the field of carbon capture technologies for mitigating climate change. Laengle et al. [22] performed a bibliometric study over approximately 40 years' worth of fuzzy sets and systems. Bodnariuk and Melentiev [23] used various databases for performing a bibliometric analysis of micro-nanomanufacturing technologies. Amin et al. [24] studied a bibliometric review of process safety and risk analysis.

When examining the literature in detail, many different researchers have studied a variety of different subjects that are directly and closely related to steam turbines. In fact, finding where studies have concentrated on steam turbines and where studies will evolve in the near future can be obtained through a comprehensive bibliometric analysis.

Therefore, apart from previous studies, the main purpose of this study is to evaluate the global trend of research activities in the field of steam turbines quantitatively and qualitatively by taking into account the scientific research articles published in the period 2000-2020. We have researched publications statistics, the geographical distribution of authors and institutions, author lists, institutions that have important contributions in the field of steam turbines technology, citations, and authorship patterns and selected effective performance parameters for comparatively evaluating the contributions from authors, institutions, and countries. This is a comprehensive review study on steam turbine technology that takes a bibliometric approach and has the potential to influence future research aspects for researchers active in this field by providing them with a very useful overview.

METHODS

Important indicators are found that are mostly used in bibliometric studies. The h-index, also known as the Hirsch index or Hirsch number, is a way of measuring both the productivity and citation impact a researcher's publications have had. This index takes the scientist's most cited articles and the number of times they have been cited in other publications. CiteScore (CS) measures an academic journal's average number of citations received in that year for articles published in that journal during the previous three years. It is useful for determining the relative importance a journal has within its field and allows journals to be ranked by percentage in terms of subject category [25]. The SCImago Journal Rank (SJR) indicator measures the scientific influence scholarly journals have by taking into account the number of citations a journal receives and the importance/prestige of the journals from where the citations come [26]. Source Normalized Impact per Paper (SNIP) also measures the number of citations but intrinsically accounts for the variations in different fields' citation methods. It is useful for comparing journals within the same field as well as across disciplines by comparing individual journal's citations for each publication against the potential set of publications citing that journal. SNIP measures citation impact within a field-specific context that allows for the direct comparison of journals in different subject fields [27].

As shown in Equation 1, we have developed a new indicator, the Paper Impact Parameter (PIP) in order to illustrate realistic productivity and impact for authors, organizations and countries.

$$PIP = \frac{\sum_{F}^{L} C}{\sum_{F}^{L} P} \quad (1)$$

where F is the first year, L is the last year, C is the number of citations, and P is the number of publications.

By dividing the total number of all current citations by the total number of all publications for an entity, we've created a new benchmark for comparing the overall impact a country, institution, journal, or author/group of authors have had over a specific period of time. This comparison is a general indicator of performance and productivity over time and can be used internally to show performance growth patterns by comparing different time periods or between entities to measure overall impact on a field; it can also be used to rank two or more entities by productivity over time. Higher values indicate higher performance/productivity.

The data used in this bibliometric analysis is provided by Scopus. In May 2020, we accessed the Scopus database records dated between 2000 and 2020 using the keyword "steam turbines". As a result, 11,751 publications were obtained and analyzed. Bibliometric networks have been created and visualized. These data include journals, researchers, and individual publications as examples. Quantitative analysis of the literature on steam turbine articles can demonstrate the international status of global steam turbine research from a macro perspective and provide an overview of the study topics for steam turbines.

The importance and power this study has is in evaluating steam turbine trends and state-of-the-art information on steam turbines. Adding bibliometric graphics to this trending topic of study enables us to evaluate classic articles from a multi-faceted perspective. Meanwhile, conducting citation-based bibliometric analysis is a subjective constraint to prove the quality of a study, to determine the number of publications by year, and also to evaluate the scientific efficiency or h-index of authors. We have also performed our analysis in this article using the Scopus database; using another database may provide different results.

RESULTS AND DISCUSSION

The analysis for determining the trend of recent studies on steam turbines first determined the number of articles on the subject for the period 2000-2020, and the total number of citations given to these articles is shown in Figure 1. Although, similar numbers of articles were produced annually between 2000 and 2020, this number increased significantly in 2017, with over 1,000 papers being produced. The number of citations has reached over 10,000 annually, steadily increasing from 2000 to 2020.

When analyzing the number of publications by type, more than half are seen to be research articles, followed respectively by conference papers, reviews, and then book chapters (Figure 2). The remaining types of publication, described as others, include notes, conference reviews, business articles, short surveys, books, abstract reports, editorial errata, and letters.

Figures 3a, 3b, and 3c respectively show by country the number of publications, citations, and PIPs regarding the steam turbine. When analyzing Figure 3a (darker colors describe higher numbers of publications/citations/PIPs), China performs the highest with 3,001 publications, then the USA with 1,376 publications and Germany with 796 publications. These countries with the greatest number of publications on steam turbines are followed respectively by Russia, Japan, the United Kingdom, India, Italy, Poland, and the Czech Republic. When analyzing Figure 3b, China similarly performs highest with 12,301 citations and 18.07% of the total, followed by the USA with 7,934 citations and 11.65% of the total and the United Kingdom with 4,638 citations and 6.81% of the total.

In Figure 3c, the density map is given in terms of PIP numbers. Countries with at least 15 articles on steam turbines were taken into account while making this calculation. Accordingly, Singapore leads the PIP ranking with 18 publications and 414 citations (PIP = 23), followed by Australia with 95 publications and 1,849 citations (PIP = 19.46), Norway with 50 publications and 761 citations (PIP = 15.22), and Spain with 131 publications and 1,826 citations (PIP = 13.94), respectively. China ranks 40th with 3,001 publications and 12,301 citations (PIP = 4.10). As an important note, stating that the total number of publications and citations for some countries in all these analyses is thought to be low because they mostly prefer to publish articles in their own language rather than English may be helpful.

Figure 4. shows the universities/institutes that produced the most publications related to steam turbines. As can be seen, this figure shows the geographical distribution of the number of publications; China has 74.5% of the publications while Japan has nearly 9% and Germany and Polish have nearly the same at 8%. While China's Xi'an Jiaotong University ranks first among the universities, the Russia's Moscow Power Engineering Institute (National

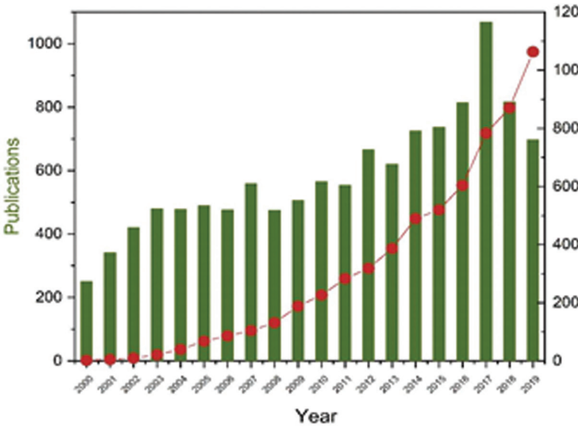


Figure 1. Timeline of publications and citations in the steam turbine field from 2000 to 2020.

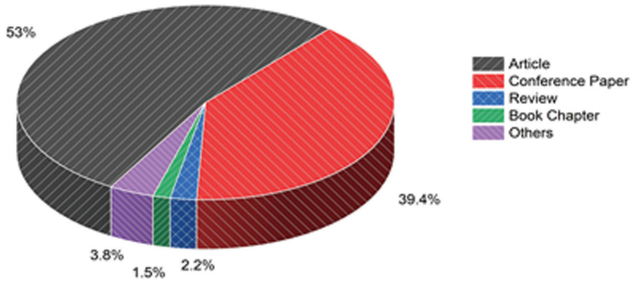
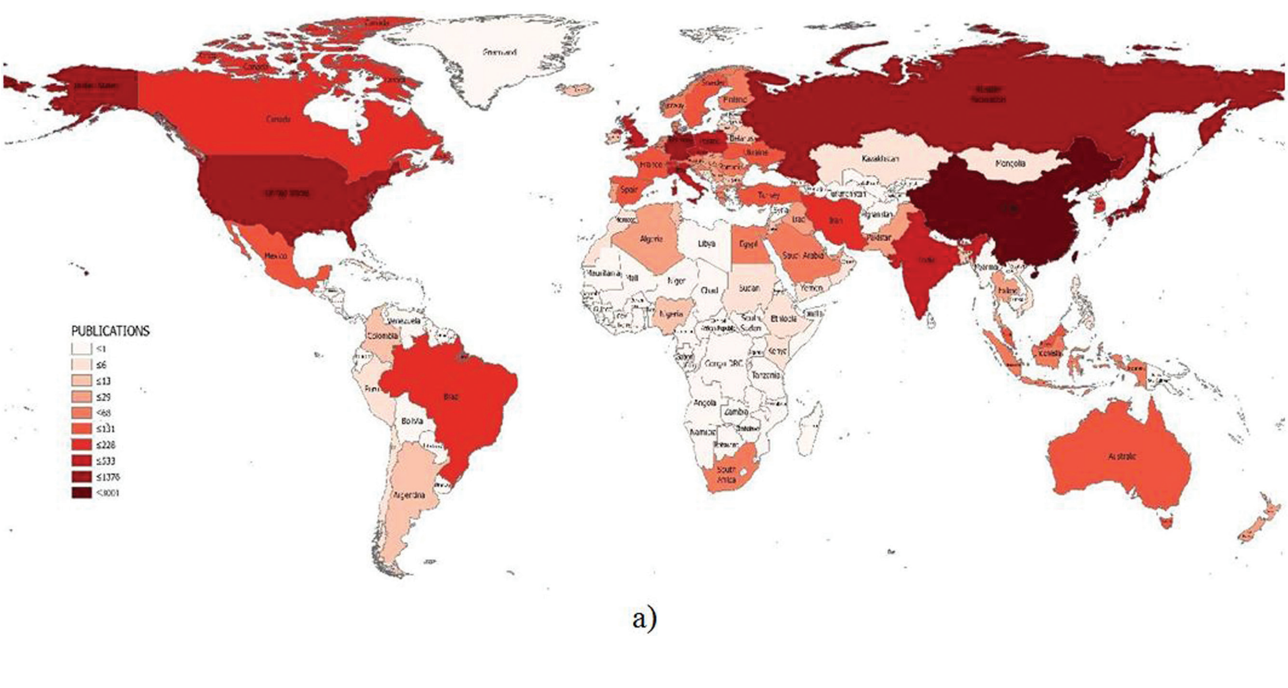
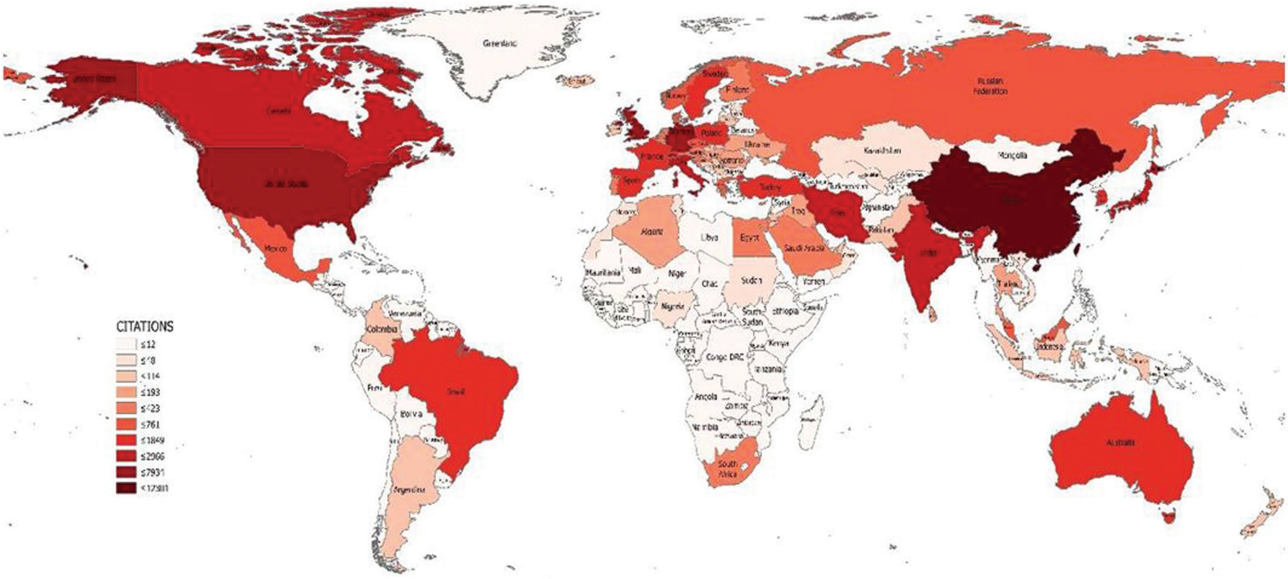


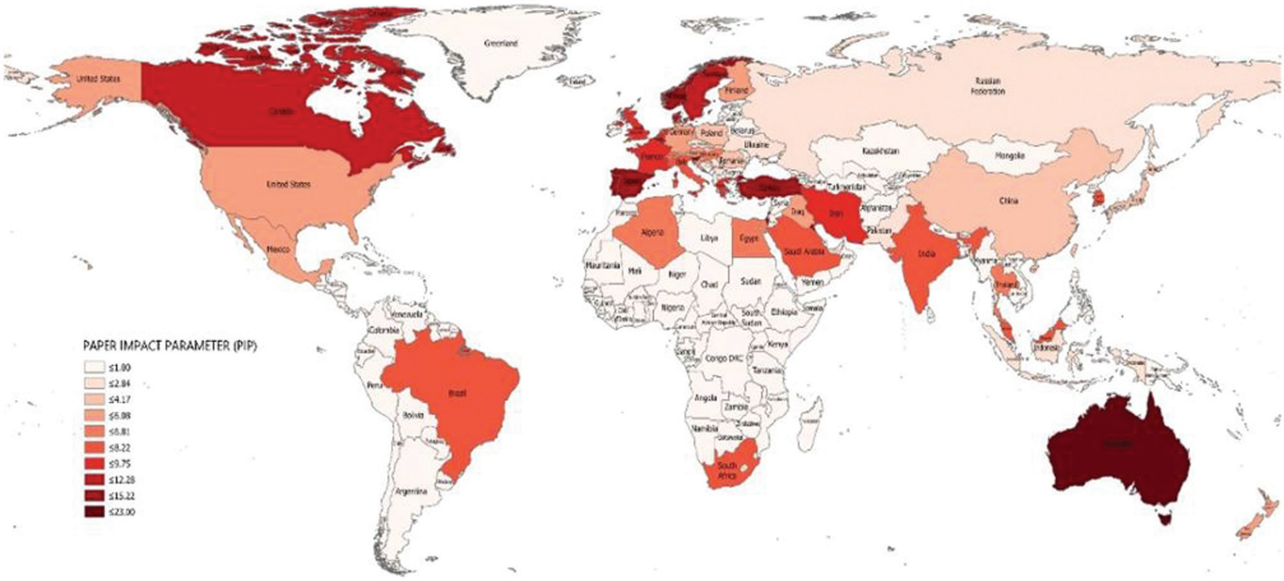
Figure 2. Types of publications in the steam turbine field from 2000 to 2020.



a)



b)



c)

Figure 3. Distribution of publications with respect to country in the steam turbine field from 2000 to 2020 by number of a) publications, b) citations, and c) Paper Impact Parameter.

Research University) is seen to be the most productive when looking at institutes. Also, Siemens AG ranks first among companies, followed respectively by Mitsubishi Heavy Industries and Toshiba Heavy Industries. Most of the steam turbine power plants in many countries of the world, nearly 50% [28], are thought to have been produced by these three companies, which is why these companies have needed to do R&D and provide scientific contributions.

The top 20 journals that have published the most articles on steam turbines and the number of articles they publish and cite are shown in Table 1. A list of the top three journals can be created with respect to the number of publications as Proceedings of the ASME Turbo Expo, Thermal Engineering, and Reneng Dongli Gongcheng Journal of Engineering for Thermal Energy and Power, with respect to the number of citations as Energy, Proceedings of the ASME Turbo Expo, and Energy Conversion and Management, and with respect to PIP as Energy, Energy Conversion and Management, and Applied Thermal Engineering. The most cited journals can also be seen to have the highest PIP, which shows the number of quality papers they have.

As conferences on mechanical engineering issues involving steam turbines are held almost every year, publications have been featured mostly in the American Society of Mechanical Engineers (ASME) proceedings as shown in Figure 5. Apart from this, journals such as Thermal Engineering and Journal of Engineering for Thermal Energy and Power are understood to publish the most publications on steam turbines, as seen in Figure 5. This figure also shows the effect ASME proceedings have had on the total number of publications, having doubled in number in 2006 and 2012.

When considering the simple Rankine cycle, one of the most important ways for steam turbines to produce more net power is to set the turbine inlet temperature (TIT) as high as possible. However, this TIT temperature should not exceed the maximum temperature that the turbine blades or material can withstand. Therefore, in order to increase the net power, studies have been carried out on turbine blades and materials that can withstand higher temperatures through methods such as ceramic coating. Thus, when examining in Figure 7, most studies are seen to focus on turbomachinery and power generation (32.3% and 26.3%, respectively). In addition to all these problems, other main study topics can be listed as: mechanical issues (14.6%), modeling and simulation (13.9%), and design and optimization (12.9%).

The core research areas consist of five main topics formed from the over 100 different keywords that show the relevance of the papers. The number of publications with respect to core research areas between 2000 and 2020 is given in Figure 6, where all topics are seen significantly to have a nearly steady increase in practically the same ratio until 2017.

As Figure 8. examines the subject categories from Scopus, the study areas on steam turbines, which are engineering works of wonder, are seen to be mostly on engineering (41.4%) and energy (20.6%). In addition, some studies focused on materials science issues for reasons such as finding materials that are more resistant to higher temperatures or problems such as corrosion cracking and fatigue.

The most productive authors are shown in Figure a-9b with their publications, citations, h-indexes, and PIP numbers related to steam turbines. The most productive authors according to the number of publications are J. Li, Y. Li, and Y.M. Brodov with 57, 53, and 39 publications respectively. In terms of number of citations, the most productive authors are M. Schatz, I. Dincer, and M.A. Darwish with 458, 353, and 340 citations; respectively.

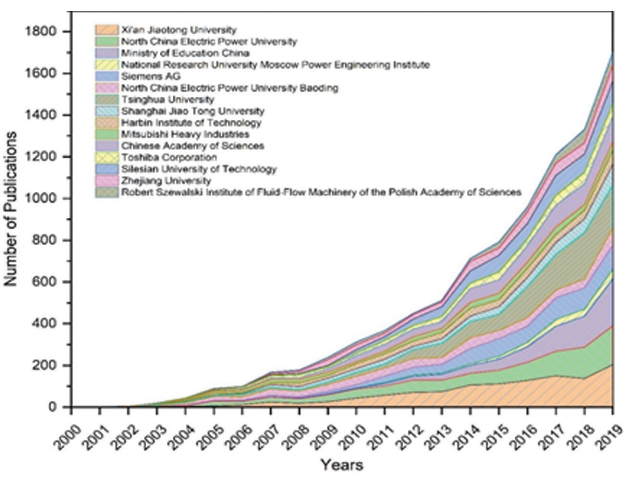


Figure 4. Origins of steam turbine articles by institution.

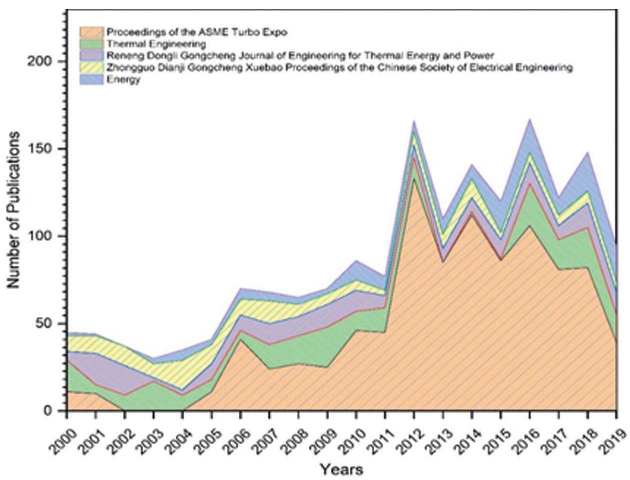


Figure 5. Most productive journals or proceedings in the steam turbine field.

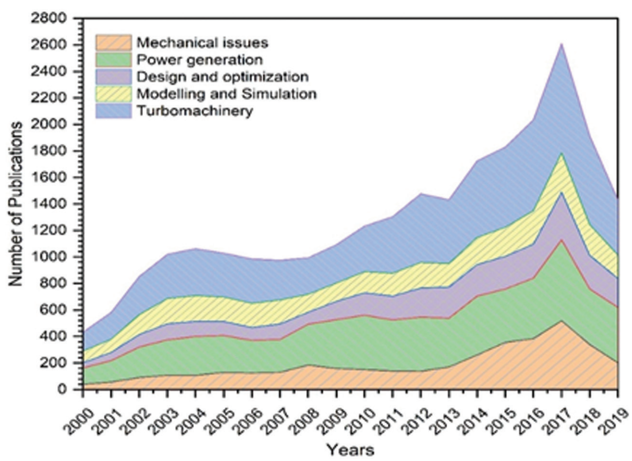


Figure 6. Core research areas and publication timeline from 2000 to 2020.

Table 1. Top 20 Productive Journals in the Steam Turbine Field from 2000 to 2020

Publication Name	Number of Publications	Citations	PIP	h index	CS 2018	SJR 2018	SNIP 2018
Proceedings of the ASME Turbo Expo	964	2,259	2.34	38	NA	NA	NA
Thermal Engineering	243	225	0.93	15	0.79	0.44	1.23
Reneng Dongli Gongcheng Journal of Engineering for Thermal Energy and Power	199	252	1.27	13	0.18	0.16	0.25
Zhongguo Dianji Gongcheng Xuebao / Proceedings of the Chinese Society of Electrical Engineering	166	1,116	6.72	89	2.79	0.92	1.24
Energy	164	3,844	23.44	158	6.20	2.05	1.82
Power	158	58	0.37		0.01	0.10	0.00
Journal of Engineering for Gas Turbines and Power	155	1,391	8.97	75	1.98	0.60	1.21
ASME Power Division Publications: Power	151	110	0.73	8	NA	NA	NA
Dongli Gongcheng Xuebao Journal of Chinese Society of Power Engineering	147	327	2.22	13	0.51	0.27	0.54
Applied Thermal Engineering	132	1,997	15.13	129	4.58	1.77	1.73
Dongli Gongcheng Power Engineering	132	337	2.55	16	NA	0.20	0.55
Advanced Materials Research	116	54	0.47	31	0.08	0.12	0.18
Energy Conversion and Management	105	2,239	21.32	163	7.87	2.73	2.15
VGB Powertech	103	83	0.81	13	NA	0.13	0.31
Applied Mechanics and Materials	92	42	0.46	28	0.07	0.11	NA
Power Technology and Engineering	86	69	0.80	10	0.18	0.16	0.40
Teploenergetika	82	17	0.21	6	NA	0.10	NA
Proceedings of the Institution of Mechanical Engineers Part A: Journal of Power and Energy	79	701	8.87	53	1.72	0.62	1.00
Power Engineering	77	32	0.42	9	0.02	0.10	NA
Energy Procedia	75	586	7.81	63	1.30	0.47	0.58

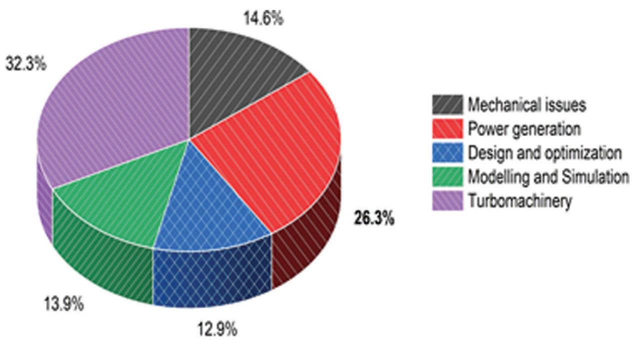


Figure 7. Distribution of the core research areas on steam turbines.

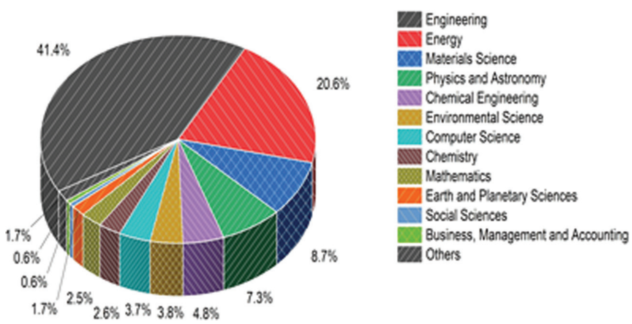


Figure 8. Publication distribution by subjects as classified by Scopus.

In terms of the h-index, the most productive authors are I. Dincer, M.A. Rosen, and Y. Yang with h-index values of 90, 70, and 49, respectively. Sorting by the number of publications or citations individually can actually give misleading information about the productivity of these authors. For this reason, we feel the PIP should also be taken into consideration in addition to the number of publications and citations, just like the h-index, because some

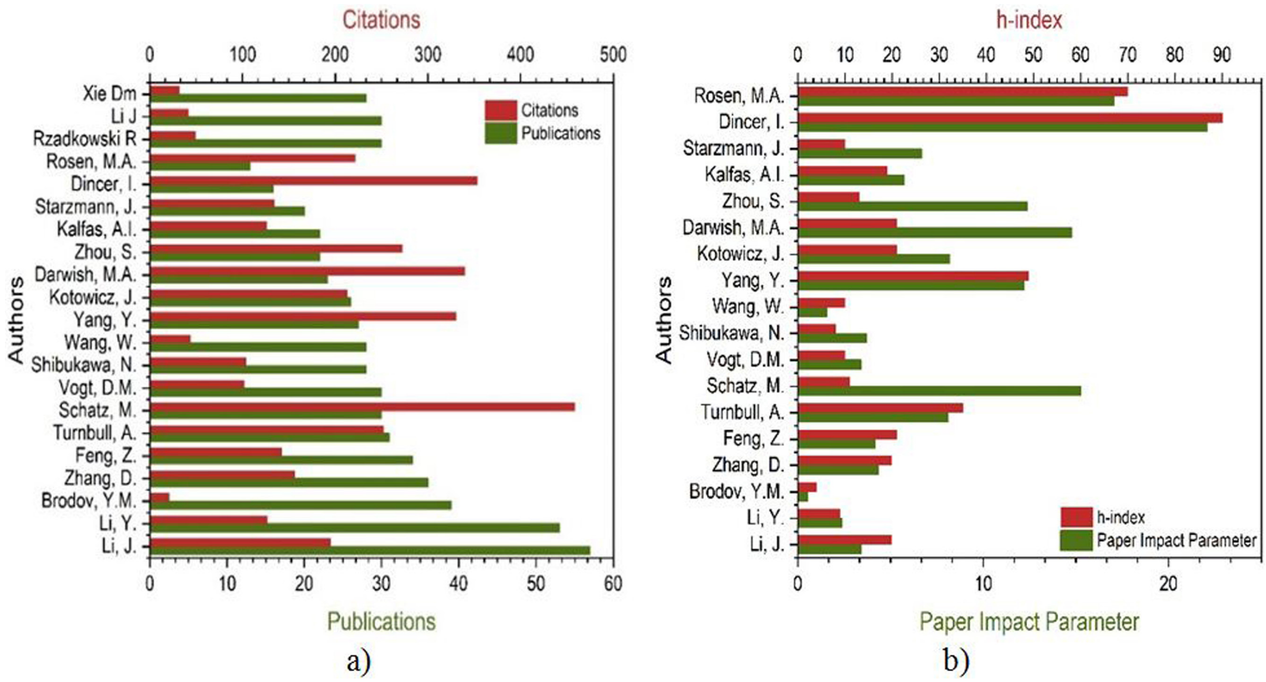


Figure 9. The most productive authors and their scores from 2000 to 2020 by a) numbers of citations and publications and, b) h-index and Paper Impact Parameter values.

Table 2. The Most Cited Publications in the Steam Technology Field from 2000 to 2020

Ref.	Year	Document Title	Journal Title	Total Citations
[29]	2004	Advances in solar thermal electricity technology	Solar Energy	567
[30]	2009	Current status and technical description of Chinese 2 × 250 MWth HTR-PM demonstration plant	Nuclear Eng. and Design	365
[31]	2001	Materials for ultrasupercritical coal power plants - boiler materials: Part 1	Journal of Materials Eng. and Performance	361
[32]	2008	Temporary primary frequency control support by variable speed wind turbines - Potential and applications	IEEE Transactions on Power Systems	358
[33]	2005	Reversible thermoelectric nanomaterials	Physical Review Letters	296
[34]	2001	Distributed generation: The power paradigm for the new millennium	CRC Press	263
[35]	2009	Cooling techniques for improved productivity in turning	International Journal of Machine Tools and Manufacture	256
[36]	2004	Advances, aging mechanisms and lifetime in solid-oxide fuel cells	Journal of Power Sources	250
[37]	2013	Progress in solid oxide fuel cells with nickel-based anodes operating on methane and related fuels	Chemical Reviews	250
[38]	2013	Application of solid oxide fuel cell technology for power generation - A review	Renewable and Sustainable Energy Reviews	239
[39]	2008	Transport and deposition of particles in turbulent and laminar flow	Annual Review of Fluid Mechanics	227
[40]	2006	Boiler materials for ultra-supercritical coal power plants - Steamside oxidation	Journal of Materials Eng. and Performance	221
[41]	2005	An overview of current and future sustainable gas turbine technologies	Renewable and Sustainable Energy Reviews	203
[42]	2004	Porous materials as open volumetric solar receivers: Experimental determination of thermophysical and heat transfer properties	Energy	200

authors are found who have few publications but many citations. This situation can be seen in detail in Figure , where I. Dincer, M.A. Rosen, and M.A. Darwish appear as the most productive authors with PIPs of 22.06, 17.08, and 14.78, respectively.

Table 2. shows the most cited publications, over 200 citations, (articles and books) on steam turbines. Looking at these articles, solar energy, power plants, materials science (especially nanomaterials and boiler materials), cooling technologies, performance analysis and sealing elements are generally seen to be emphasized.

CONCLUSION

By burning fossil fuels such as coal and natural gas or using nuclear power, water is heated at high temperatures and transformed into steam. The obtained superheated steam enters the section where the turbine blades are located within the isolated pipe systems. Pressurized steam, being superheated and having a high movement potential, rotates the turbine blades and creates mechanical energy. The mechanical energy obtained from the steam turbine is generally converted into electrical energy with the help of a generator connected to the turbine via a gearbox and can sometimes be used to drive a pump (e.g., in tanker ships). When considering the simple working logic of steam turbines, their sub-topics are seen to focus on issues such as cycle efficiency, materials, design, modeling, and simulations. Thanks to bibliometric analysis, we have indicated which directions steam turbines have evolved toward over the years, which countries are more active in this regard, and which authors are deemed more effective and highly cited. In this way, we shine a guiding light for researchers who want to study this subject. Researchers who want to work on steam turbines are able to quickly access pioneering works on the subject and can easily understand which directions the technological advances and studies have evolved toward.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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