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Research Article

Mapping the World Research Output on Wind Energy: A Scientometric Analysis

M. Dinakaran*, P. Gomathi

Department of Library and Information Science, Periyar University, Salem, Tamil Nadu, INDIA.

ABSTRACT

This scientometric study intends to analyze the number of contributions made by researchers in Wind energy worldwide from 2015 to 2019. The main objectives of the study are to explore the scientometric parameters: Authorship pattern, Degree of collaboration, Relative growth rate, Doubling time, Exponential growth rate, Year-wise contribution, Authors contribution, Keyword-wise contribution, Document-wise contribution, Country-wise contribution, Institute-wise contribution, Language-wise contribution. The required data has been retrieved from the Web of Science database. The retrieved data was analyzed through Histcite, VOSviewer, Microsoft Word and Microsoft Excel software. Between 2015 and 2019, 6129 records were published, 1463(25.14%) were published in 2019, and 1045(15.78%) were published in 2005. The author Wang ZL has identified the most prolific author who has published 46 articles, and the most productive country USA published 1185(19.3%) records. The relative growth rate value has been calculated with an increasing trend from 0.65 to 1.44, and the doubling time has been calculated with a decreasing trend from 1.07 to 0.49. The Degree of collaboration is computed as 0.93. The results of this study conclude that wind energy publications have gradually increased in the selected years.

Keywords: Scientometrics, Wind energy, Authorship pattern, Web of Science, VOSviewer, Degree of collaboration.

Correspondence:
M. Dinakaran
Department of Library and Information Science, Periyar University, Salem-636011, Tamil Nadu, INDIA.
Email: dinakaranphd@gmail.com

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INTRODUCTION

Wind energy is one of the fastest-growing renewable energy technologies throughout the world. Globally installed wind generation capacity onshore and offshore has increased by almost 1975 in the past two decades, jumping from 7.5 Giga Watts (GW) in 1997 to 546 GW by 2018. According to IRENA's latest data, wind electricity production doubled between 2009 and 2013; in 2016, wind energy accounted for 16% of electricity generated by renewable energies. Many parts of the world have substantial wind speeds, but the best locations for generating wind power are sometimes remote; offshore wind power offers tremendous potential. With the invention of the electronic generator in the 1830s, engineers started attempting to harness wind energy to produce electricity. Wind power generation occurred in the United Kingdom and the United States in 1887 and 1888. However, modern wind power is considered to have been first developed in Denmark, where horizontal-axis wind turbines were built in 1891, and 22.8 m wind turbines began operation in 1897. The growth of renewable energy sources is recognized as an essential component in providing integrated solutions for limiting greenhouse gas emissions. It is an opportunity to encourage innovation, promote economic growth, and improve access to safe, clean, and affordable Energy (Blanco, 2009). Therefore, this study has been conducted to understand the publication trends of wind energy publications.

The term scientometrics was first defined and suggested by two Russian scholars (Nalimov & Mulchinko, 1969). According to their definition, scientometrics is "The application of those quantitative methods which deal with the analysis of science viewed as an information process". On the other hand, (Hess, 1997) defined "Scientometrics as the study of the measurement of scientific and technological progress". Scientometrics is quantitative analytics used to assess and analyze the amount of research on a particular subject or field. Scientometrics deals mainly with science policy applications and strong application-oriented tradition; for instance, scientometric studies help governments and private sectors identify their competitive edges, make strategic plans for future research areas and allocate research funding to key research areas, identify several publications that appear the contributed to the development of scientometrics. Thus, this study has been conducted in scientometrics to identify the international collaboration patterns among the authors and the growth of wind energy publications globally.

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REVIEW OF LITERATURE

The Review of the previous study related to wind energy and renewable Energy, such as solar, geothermic, and biomass energy, gave an understanding of scholarly publications. A few similar pieces of literature are discussed. Acevedo-Prins *et al*. (2019) conducted a bibliometric study on energy and wind power policies from the Scopus and Web of Science databases. 121 Web of Science documents and 225 Scopus documents were collected from 1992 to 2017, respectively. The researchers analyzed the number of publications, journals, articles, and author's contributions. Their analysis has concluded that policy issues are divided between the acceptance public of technology and penetration costs. Venktesan Thanuskodi (2015) conducted a quantitative analysis of wind power generation across the globe from 1980 to 2014. The publication output is reflected in the Scopus database. A total of 20779 papers have been retrieved for the study. Among the publications, the subject category engineering has published 38% of documents, and the source Renewable Energy has been identified as a prominent source with 6% of publications. Moreover, China has produced the most, 16.21% of publication. The study concludes that wind power generation output consistently grew during the period. He Yu (2019) studied a bibliometric analysis of biomass energy of international cooperation. Their study analyzed academic papers collected from SSCI and SCI databases from 2007 to 2016. Bibliometric parameters are employed for the statistical outputs, and VOSviewer software is used to generate international cooperation network maps. Their findings reveal the context and direction of development in the global biomass energy field. The results of this study can provide a scientific basis and support for the development of other related research work**.** Rajendran (2018) evaluated the scientometric study on research publications on geothermia from the Scopus database from 1966 to 2016. The author analyzed the research output on Literature growth, Author productivity, Authorship pattern, the average length of articles and country collaboration of Geothermic research. Rahimi *et al*. (2019) explored scientometric analysis on scheduling in Renewable Energy. The extracted data were published from 2000 to 2017 by the Scopus database. VOSviewer and CiteSpace tools have been used for keyword and citation analysis. China and the US are two countries with high contributions. Two counselling methods have been applied, including full counting and fractional counting. Citation analysis based on countries, documents, sources, authors, and organizations have been addressed, and results have been presented in their study**.** Zhao *et al*. (2022) analyzed a scientometric insight on new developments in wind energy forecasting with artificial intelligence and big data preceding two decades. The authors can find trends and forecasts on wind energy, artificial intelligence, and big data by conducting research. The authors conclude that their study has been used for existing research opportunities, challenges and implications. Azam *et al*. (2021) scrutinized a scientometric-based analysis of knowledge structure and research progress in wind power generation from 2005 to 2020 using CiteSpace software. Web of Science bibliographic databases were used to collect the required data for their study. Most prominent authors, countries, and journals were found in this study. China has been identified as the most published county in the study, with a 29% contribution. Kumar and Narula (2017) assess the social network analysis of renewable energy research in India based on the dissertation database UGC/INDCAT provided by the University Grants Commission (Government of India). Used by Scopus database and the Pajek software employed for social network analysis and visualization. Farooq *et al*. (2018) have mapped past, current, and future energy research trends in Pakistan, a scientometric assessment used through the Scopus database from 1990 to 2016. The researcher analyzed the Publication type, major areas, journals, citations, authorship pattern, affiliations and keyword occurrence frequency. Romo-Fernández *et al*. (2012) explore the world's scientific production on renewable Energy, sustainability, and the environment based on the bibliometric indicators from 2003 to 2008. Moreover, the study results have shown that world production has increased during the period. Similarly, Sanz-Casado *et al*. (2014) scrutinized the bibliometric analysis of Chinese-Spanish collaboration in renewable energy research. Sivasami (2019) conducted a scientometric analysis of the research performance of solar cells from 2009 to 2018. Forty-six thousand six hundred seventy records have been retrieved from the Web of Science database for the study. The author, Kim J, has the first position with 505 contributions. "Chinese Academy Science" was in first place with 3153 contributions. The Peoples R China has occupied first place with 14356 contributions, the USA has second place with 7002 contributions, and India has seventh place with 2704 contributions. Solar cell research publications show a growing trend in the selected period. Similarly, Sanz-Zhang *et al*. (2015) evaluate the scientific relatedness in Solar Energy: a comparative study between the USA and China from 2000-2013. I conducted a study to investigate scientific relatedness at the topic level, like relatedness between topic and topic, and the country level, like relatedness between topic and country. The bibliometric analyses show that both publications and knowledge topics exhibit a significant rise, and China has exceeded the USA and developed into the largest scientific producer after 2010. The results also highlight differences between the research directions in the USA and China. In the USA, "energy efficiency and environment" prove more developed, while in China, "solar power" shows more centrality. The previous literature review has provided comprehensive findings and gaps in wind energy publications.

Significance of the study

Limited literature is published on wind energy, particularly in the scientometric approach of statistical technique. The study has been conducted worldwide in wind energy research publications

from the Web of Science database. This study has analyzed the scientometric statistical tools for understanding the growth of wind energy literature from 2015 to 2019.

Objectives of the study

This study aims to qualitatively evaluate the trend and research output on wind energy publications in a scientometric approach based on scientific papers published in the Web of Science database from 2015 to 2019. This study has been conducted to calculate the year-wise publication, relative growth rate and doubling time, exponential growth rate, authorship pattern and authors' productivity, document type-wise distribution, Degree of collaboration, keywords-wise contribution, language, cited references, geographical distribution, institutions and journals with significant contribution in the field of wind energy.

METHODOLOGY

The scientometric study of the keyword "Wind Energy" data has been collected from the Web of Science bibliographic database published by Thomson Reuters. The study has contained five years of data from 2015 to 2019. A total number of 6129 records were retrieved for this study. The retrieved data was analyzed using Histcite, VOSviewer, and Microsoft Excel software.

Data analysis and interpretation

Year-wise publication

Table 1 and Figure 1 depicts the contribution of year-wise published documents on wind energy publications from 2015 to 2019. The vast number of records was published in 2019, with 1,463 records (25.14%), and the lowest was published in 2015 with 1,045 (15.78%). In this Table 1, between 2016 and 2017, publications have fluctuated with percentages of 18.53 and 18.87. This observation confirms that Wind energy publications have constantly increased from 2015 to 2019.

Year-wise authorship pattern

Table 2 shows the year-wise authorship pattern from 2015 to 2019. Three authors have contributed, in the first place, with 1509 counts. Two and four authors scored the second and third places, with 1306 and 1269 counts. Moreover, fewer counts have last place; one author has 396 counts. Table 2 showed that the collaboration of the three authors contributed to the authorship pattern on Wind energy publications.

Single-author Vs Multi authors

Table 3 and Figure 2 indicate that the observed from the authorship pattern in terms of single authors and multi-authors during the study period from 2015 to 2019. Out of 6129 records, multi-authors have published the majority of 5733(93.5.0%) records, and single authors have published the rest of 396(6.5%) records. It is noted that most of the authors are interested in publishing their research work with collaborations.

Analysis of the Degree of Collaboration

Table 4 examined the Degree of collaboration, which indicates the trend in single and multiple authors from 2015 to 2019. The Degree of cooperation ranges from 0.93 to 0.94, and the average Degree of cooperation is 0.93. The DC is calculated by using the formula.

$$DC=Nm/Nm+Ns$$

Where, Nm=Number of Multi Authors, Ns=Number of Single Authors. This formula is suggested by (Subramanium, 1985).

$$DC = 5733/6129 = 0.93$$

The results of this study show that the Degree of collaboration in wind energy publications is 0.93, which shows the collaboration of multiple authors.

Relative Growth Rate (RGR) and Doubling time (DT)

The Relative Growth Rate (RGR) Table 5 measures the increase in several articles/pages per unit of articles/pages per unit of time (Mahapatra, 1985). The relative growth rate calculates a specific period or interval's growth rate in a specific field. It can be calculated from the following equation:

$$R(P) = \frac{Log_e 2P - Log_e 1P}{2^T - 1^T}$$

Here, R(P) = Relative growth rate of articles over the specific period

$Log_e 1P$ = Log of the initial number of articles

$Log_e 2P$ = Log of the final number of articles

Table 1: Year-wise publication.

Sl. No.	Publication year	Records	Percentage
1	2015	1045	15.78
2	2016	1136	18.53
3	2017	1132	18.47
4	2018	1353	22.07
5	2019	1463	25.14
Total		6129	100

2^T-1^T = The unit difference between the initial and final times.

Doubling time is directly related to the Relative Growth Rate. It has suggested by (Mahapatra, 1985), it has been calculated mathematically as follows:

$$Dt(p) = \frac{Log_e 2}{R(P)} = \frac{0.693}{R(P)}$$

Here, Dt (P = Average doubling time of the article.

This Table 5 shows the Relative growth rate and doubling time. The highest relative rate was calculated at 1.44 in 2019. The lowest close growth rate was 0.65 in 2016. The highest doubling time was 1.07 in 2016, and the lowest was 0.49 in 2019.

Exponential growth rate

Table 6 shows the exponential growth rate of wind energy publications. The highest exponential growth rate was 1.19 in 2018, and the lowest was 0.99 in 2017. The overall exponential growth rate is 4.18 out of 6129 records. It is confirmed that wind energy research has exponent selected years.

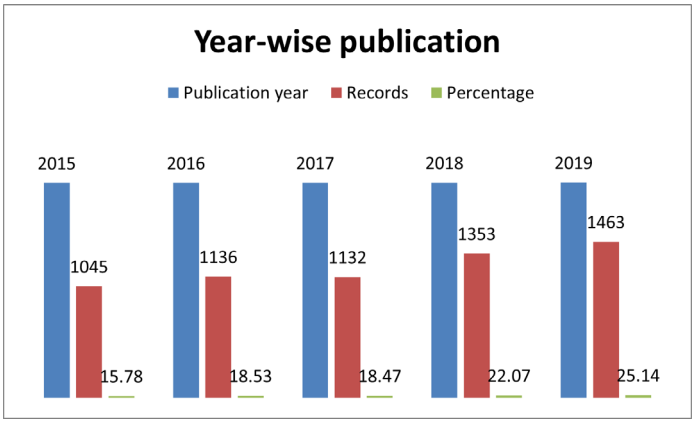

Figure 1: Year-wise publication.

Most productive authors (Top 15)

Among the top fifteen authors in Table 7 and Figure 3, we observed that the majority of the author Wang ZL had published 46(0.8%) records, followed by Wang J published 29(0.5%) records in second position. It is identified that the author Wang ZL has the most prominent author in the wind energy study.

Document Type-wise distribution

Table 8 indicates the document-wise distribution of wind energy publications. There are 17 documents published in the study. Articles were observed in 5310(86.6%) records out of 6129. Following the form of Review, it was published in second position among the 17 items. The other preferred forms followed by the study are article review, editorial material, proceeding paper, letter, book review, news item, book chapter, correction, data paper, biographical item, reprint and Retraction, published in wind energy publications.

Institution-wise distribution (Top 15)

Table 9 shows that only the top fifteen institutions are ranked in terms of research productivity based on the total number of institutions observed, which is 5159. It is noted that the Chinese Academy of Sciences is ranked first among the most productive institutions and published a maximum number of 126(2.1%),

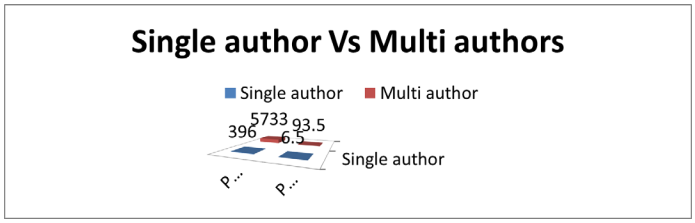

Figure 2: Single Vs Multi Authors.

Table 2: **Year-wise authorship pattern.**

Year	One Author	Two Authors	Three Authors	Four Authors	Five Authors	Above Five Authors	Total
2015	70	268	258	224	110	115	1045
2016	68	255	317	209	139	148	1136
2017	90	236	257	256	127	166	1132
2018	88	267	350	261	171	216	1353
2019	80	280	327	319	185	272	1463
Total	396	1306	1509	1269	732	917	6129

Table 3: **Single author Vs Multi authors.**

Sl. No.	Authorship pattern	Publications	Percentage
1	Single author	396	6.5
2	Multi-author	5733	93.5
Total		6129	100

Table 4: Analysis of the Degree of Collaboration.

Year	Single author (Ns)	Multi-author (Nm)	Total author (Nm+NS)	Degree of collaboration
2015	70	975	1045	0.93
2016	68	1068	1136	0.94
2017	90	1042	1132	0.92
2018	88	1265	1353	0.93
2019	80	1383	1463	0.94
Total	396	5733	6129	0.93

Table 5: Relative Growth Rate (RGR) and Doubling time (Dt).

Year	No of publications	Cumulative	$Log_e 1P$	$Log_e 2P$	$= \frac{R(P)}{Log_e 2P - Log_e 1P} / 2^T - 1^T$	Mean	$Dt(p) = \frac{0.693}{R(P)}$	Mean
2015	1045	1045		6.95	-		=	
2016	1136	2181	7.04	7.69	0.65		1.07	
2017	1132	3313	7.03	8.10	1.07	1.09	0.64	0.69
2018	1353	4666	7.21	8.44	1.23		0.56	
2019	1463	6129	7.29	8.73	1.44		0.49	
Total	6129							

Table 6: Exponential growth rate.

Sl. No.	Publication year	Records	Exponential growth rate
1	2015	1045	
2	2016	1136	1.08
3	2017	1132	0.99
4	2018	1353	1.19
5	2019	1463	1.08
Total		6129	4.18

Table 7: Most productive authors (Top 15).

Sl. No.	Author	Records	Percentage	Sl. No.	Author	Records	Percentage
1	Wang ZL	46	0.8	8	Li J	20	0.3
2	Wang J	29	0.5	9	Yang Y	20	0.3
3	Wang JZ	27	0.4	10	Rehman S	19	0.3
4	Zhang Y	24	0.4	11	Wang C	19	0.3
5	Chen J	21	0.3	12	Wang Y	19	0.3
6	Lundquist JK	21	0.3	13	Blaabjerg F	17	0.3
7	Iglesias G	20	0.3	14	Catalao JPS	17	0.3
				15	Chen Z	17	0.3

followed by Tech University Denmark, which produced 110 (1.8%) records, ranking second in the study period.

Country-wise distribution (Top 15)

Table 10 and Figure 4 reveals the country-wise distribution of publications output on wind energy publications. The USA has published 1185(19.3%) records and is considered the most productive country. The second-ranked country, Peoples R China, has published 1137(18.6%) publications. The third rank is to the UK. It has produced 550(9.0%) publications.

Language-wise distribution

The Language-wise distribution Table 11 shows ten different languages. The majority of scientists prefer their work to publish

Table 8: Document Type-wise distribution.

Sl. No.	Document Type	Records	%	Sl. No.	Document Type	Records	%
1	Article	5310	86.6	10	Review: Book Chapter	3	0.0
2	Review	504	8.2	11	Review: Early Access	2	0.0
3	Article; Proceedings Paper	167	2.7	12	Review; Retracted Publication	2	0.0
4	Article: Early Access	76	1.2	13	Article; Book Chapter	1	0.0
5	Editorial Material	38	0.6	14	Article; Data Paper	1	0.0
6	Correction	10	0.2	15	Article; Retracted Publication	1	0.0
7	Book Review	5	0.1	16	Meeting Abstract	1	0.0
8	Letter	4	0.1	17	Retraction	1	0.0
9	News Item	3	0.0	Total		6129	100

Table 9: Institution-wise distribution (Top 15).

Sl. No.	Institution	Records	Percentage
1	Chinese Academy Sciences	126	2.1
2	Tech university Denmark	110	1.8
3	North China Elect Power University	77	1.3
4	Aalborg University	71	1.2
5	Delft University of Technology	66	1.1
6	Tsinghua University	66	1.1
7	Natl Renewable Energy Lab	58	0.9
8	Georgia Inst Technology	55	0.9
9	Islamic Azad University	55	0.9
10	Chongqing University	53	0.9
11	Shanghai Jiao Tong University	52	0.8
12	University of Strathclyde	50	0.8
13	Zhejiang University	50	0.8
14	University of Chinese Academy Science	49	0.8
15	University of Lisbon	47	0.8
Others		5144	83.8
Total		6129	100

Table 10: Country-wise distribution (Top 15).

Sl. No.	Country	Records	Percentage	Sl. No.	Country	Records	Percentage
1	USA	1185	19.3	9	Denmark	237	3.9
2	Peoples R China	1137	18.6	10	Turkey	211	3.4
3	UK	550	9.0	11	Australia	203	3.3
4	Germany	450	7.3	12	France	195	3.2
5	India	401	6.5	13	Italy	191	3.1
6	Spain	354	5.8	14	Netherlands	188	3.1
7	Canada	300	4.9	15	South Korea	172	2.8
8	Iran	272	4.4	Others		83	1.4
				Total		6129	100

Table 11: Language-wise distribution.

Sl. No.	Language	Records	Percentage
1	English	6054	98.8
2	German	30	0.5
3	Portuguese	19	0.3
4	Spanish	15	0.2
5	Turkish	4	0.1
6	Chinese	2	0.0
7	French	2	0.0
8	Croatian	1	0.0
9	Czech	1	0.0
10	Welsh	1	0.0
Total		6129	100

Table 12: Keyword wise-distribution (Top 15).

Sl. No.	Word	Records	Percentage
1	Wind	4038	65.9
2	Energy	2593	42.3
3	Power	1153	18.8
4	Based	913	14.9
5	System	824	13.4
6	Turbine	662	10.8
7	Control	614	10.0
8	Using	584	9.5
9	Analysis	525	8.6
10	Renewable	466	7.6
11	Systems	466	7.6
12	Offshore	431	7.0
13	Speed	381	6.2
14	Hybrid	352	5.7
15	Assessment	340	5.5

in the English language. It is rated to be about 6054, and out of the total output of 6,129, it is calculated to be 98.8 per cent. The following language is German, accounting for 30(0.5%). The third position is Portuguese 19(0.3%) publications. Spanish and Turkish are appreciable, with about 15 and 4 publications, respectively.

Keyword wise-distribution (Top 15)

The keywords-wise distribution Table 12 and Figure 5 of the top fifteen keywords is used respectively. The highest time the wind keyword is using 40381(65.9%) out of 6129 records. The second keyword, Energy, uses 2593(42.3%) out of 6129 records, followed by power-based systems keywords, which publish reasonable publications during the study period.

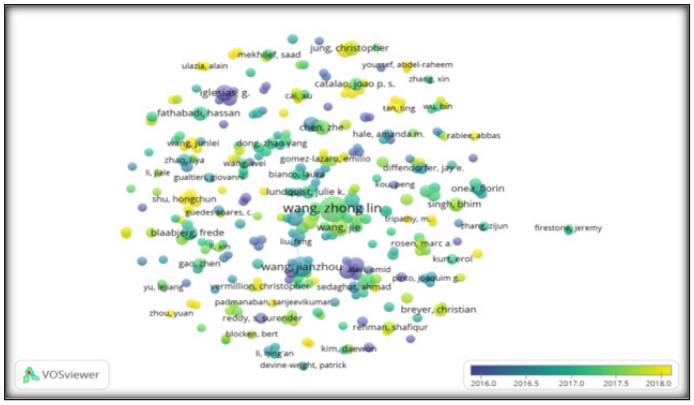

Figure 3: VOS viewer screenshot of the most productive authors.

Table 13: Journal-wise publication (Top 15).

Sl. No.	Journal	Records	Percentage
1	Renewable Energy	380	6.2
2	Energies	315	5.1
3	Renewable and Sustainable Energy Reviews	315	5.1
4	Energy	244	4.0
5	Applied Energy	217	3.5
6	Energy Conversion and Management	179	2.9
7	Wind Energy	137	2.2
8	Energy Policy	121	2.0
9	IEEE Transactions on Sustainable Energy	99	1.6
10	Sustainability	85	1.4
11	IET Renewable Power Generation	82	1.3
12	Journal of Cleaner Production	79	1.3
13	International Journal of Electrical Power and Energy Systems	77	1.3
14	IEEE Transactions on Power Systems	76	1.2
15	International Journal of Hydrogen Energy	72	1.2
Others		3651	59.7
Total		6129	100

Table 14: Cited references (Top 15).

Sl. No.	Author / Year / Journal	Records	Percentage
1	Devine-Wright P, 2005, wind energy, V8, P125	143	2.3
2	Wustenhagen R, 2007, energ policy V35CY, P2683	129	2.1
3	Gross C, 2007, energy policy, V35, P2727	120	2.0
4	Dee DP, 2011, q j roy meteor soc, V137, P553	118	1.9
5	Burton T, 2001, wind energy HDB	103	1.7
6	Wolsink M, 2007, renew sust energy rev, V11, P1188	96	1.6
7	Fan FR, 2012, nano energy, V1, P328	95	1.6
8	Carta JA, 2009, renew sust energy rev, V13, P933	93	1.5
9	Chen Z, 2009, i.e. t power electric, V24, P1859	88	1.4
10	Pena R, 1996, see p-elect pow appl, V143, P231	85	1.4
11	Warren CR, 2010, land use policy, V27, P204	82	1.3
12	Yang Y, 2013, acs nano, V7, P9461	82	1.3
13	Abdullah MA, 2012, renew sust energy rev, V16, P3220	81	1.3
14	Drewitt AL, 2006, ibis, V148, P29	81	1.3
15	Wolsink M, 2000, renew Energy, V21, P49	81	1.3

Figure 4: VOS viewer screenshot of the Country distribution.

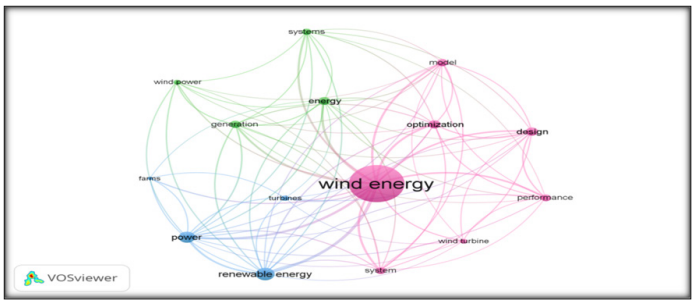

Figure 5: VOS viewer screenshot of the Keyword wise distribution.

Journal-wise publication (Top 15)

The journals have been ranked based on the number of publications on wind energy research in the Table 13. The Journal of Renewable Energy has published 380(6.2%) articles. It ranked first place in wind energy publications. The second position is taken by energies and renewable, sustainable energy review, accounting for 315(5.1%) papers on wind energy. The journal Energy published 244(4.0%) scaled papers in the publication's third position.

Cited references (Top 15)

The Table 14 result shows that Devine-Wright P, 2005, wind energy, V8, P125 is the most cited article. It has been mentioned 143 times, followed by Wustenhagen R, 2007, energy policy v35cy, P2683 129 times. The lowest number of cited articles have been cited 81 times by Wolsink M, 2000, Renewable Energy, V21, P49.

FINDINGS AND CONCLUSION

The study's findings reveal that year-wise distribution of 6129 published records, a high number of 1463 (25.14%) records were published in 2019, and the least number of 1045 (15.78%) records were published in 2015. Most of the records were contributed by multiple authors, especially triple authors, who contributed the most among the other collaborative authors. Single authors have contributed 396 (6.5%), and various authors, 5733 (93.5%), have contributed to the study. Based on this study, the Degree of collaboration has been calculated to be 0.93. The mean value of the relative growth rate was 1.09, and the growth rate was 0.65 in 2016, which increased to 1.44 in 2019. The doubling time value decreased from 2015 (1.07) to 2019 (0.49), and the mean value was 0.69. The most prolific author, according to the publications count, Wang ZL, has produced a high number of articles. The research is mainly occupied by articles published with 5310 (86.6%), followed by a review with 504 (8.2%) contributions. The Chinese Academy of Sciences has published 126 records among the top fifteen institutions, followed by Technology University Denmark, which has published 110 records. The United States of America is the most produced country with 1185 records. Authors have preferred the English language to publish their publications. A total of 6045 documents are published in this language. In the keyword analysis of wind energy, the word wind has the most occurrence by authors 4038 times. The scientometric study is the statistical method of counting, evaluating and measuring the growth of different field subjects. In the present study, an attempt has been made to bring out the statistical measurement of wind energy publications based on the scientometric approach.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ORCID ID

M. Dinakaran Orcid ID: https://orcid.org/0000=0003-2325-898X

P. Gomathi Orcid ID: https://orcid.org/0000=0001=7229-2784

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