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Scientometric Analysis of Non-Conventional Energy Research Literature

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Abstract - **Research on non-conventional energy has experienced significant global growth, with countries such as India playing a prominent role. Scientometric analyses of research trends in this field provide insights into productivity, impact, and collaboration patterns, which are essential for guiding future work and informing policy-making. This study aims to evaluate the contributions of Indian and global researchers to non-conventional energy research from 2003 to 2022, focusing on research productivity, citation impact, growth trends, and international collaborations. The analysis examined 13,378 publications from India and 164,586 publications globally in the non-conventional energy sector over the 2003-2022 period. Scientometric indicators, such as the average citation per paper, annual growth rate (AGR), exponential growth rate, activity index, publication efficiency index (PEI), relative growth rate (RGR), and doubling time (Dt), were employed. Bradford's law of scattering and Zipf's law were also tested to assess their applicability in this domain. In 2004, India achieved the highest average citation per paper, with 117.58 citations, while globally, the highest average citation per paper was 67.56 in 2005. The highest annual growth rate (AGR) of 114.26% was recorded in 2006, which also marked the peak exponential growth rate of 2.14, with 45 publications. In 2022, the highest activity index was 141.56. The maximum publication efficiency index (PEI) value was 4.38 in 2004, with 31 publications. The study identified Kumar, A., as the most prolific author, contributing 281 papers (12.87%) and highlighted the United States of America as the top international collaborator with 488 records. Bradford's law of scattering and Zipf's law did not align with the publication distribution patterns in this research area. Additionally, the study examined the mean relative growth rate (RGR), doubling time (Dt) for publications and citations, and other key scientometric indicators. The findings demonstrate strong growth and high citation impact in non-conventional energy research, with India and the global research community making significant contributions. Collaborative networks, particularly with the United States of America, play a substantial role in advancing this field. These insights underscore the importance of continued research and collaboration in non-conventional energy to address global energy challenges.**
Keywords: **Non-Conventional Energy, Scientometric Analysis, Research Productivity, Citation Impact, International Collaborations**

I. INTRODUCTION

Non-conventional energy sources, also known as renewable or alternative energy, have emerged as pivotal components in the global quest for sustainable development and environmental preservation. Non-conventional energy sources, such as solar, wind, hydropower, geothermal, biomass, and tidal energy, are renewable and offer a promising solution to climate change by reducing dependence on finite resources, unlike traditional fossil fuels. Each source presents unique advantages and challenges, but collectively, they have the potential to reshape the energy landscape and foster a more resilient and eco-friendly future. Solar power harnesses sunlight, wind turbines capture wind's kinetic energy, hydropower utilizes water's gravitational force, geothermal energy leverages Earth's core heat, and biomass uses organic materials like wood and crop residues. Collectively, these non-conventional energy sources hold the potential to generate electricity and drive a sustainable future.

Additionally, tidal energy captures the energy of ocean tides and currents to produce electricity. The adoption of non-conventional energy sources offers numerous benefits beyond environmental sustainability, including reduced greenhouse gas emissions, enhanced energy security through diversified energy sources, and stimulation of economic growth via job creation and technological innovation. Moreover, these energy sources often have lower operating costs and can be deployed in remote or rural areas, thereby expanding access to modern energy services for underserved communities worldwide. The benefits of these non-conventional energy sources are not only significant but also inspiring, motivating continued support and investment in these technologies.

This study also conducts a data analysis of research on non-conventional energy for scientometric purposes, providing direction for future researchers and improving the identity of this research domain. Specifically, it seeks to identify year-wise growth rates, institutions, core journals, authorship patterns, and productive authors in this field.

II. REVIEW OF LITERATURE

Konur (2012) examined the bio-oil literature published over the past three decades using the Science Citation Index Expanded (SCIE), the Social Sciences Citation Index (SSCI), and scientometric techniques. The results show that bio-oil research output and citations have grown exponentially over the last decade, following two decades of low performance. The USA, China, and Turkey were identified as the most prolific countries in bio-oil research. The most prolific institutions included the University of Science & Technology China and Park YK in South Korea. The most prolific journal was *Energy & Fuels*, with "energy fuels" being the most prolific subject area. A paper on the pyrolysis of wood biomass for bio-oil received the highest impact, with 567 citations. The scientometric analysis offers valuable insights into the evolution of bio-oil research, complementing studies in other renewable energies and dynamic research fields.

Penghui, Zhengheng, and Xiongfei (2012) observed scientometric and statistical research methods to analyze the development trends of green renewable energy standards. Data from the China Standard Service Net (CSSN) covering the period from 1980 to 2011 were analyzed, focusing on the number of renewable energy standards, emerging standards, and top productive institutes. The results indicate a significant increase in renewable energy standards in recent years, while emerging standards remained high due to industrialization and standardization trends in new energy sources worldwide.

Chatterjee and Dethlefs (2021) analyzed wind energy as a promising renewable energy source, highlighting operational inconsistencies in wind turbines that lead to significant costs and challenges in operations and maintenance (O&M). Condition-based monitoring (CBM) and performance assessment are crucial for efficient O&M planning and cost minimization.

Data-driven decision-making techniques have evolved rapidly in the wind industry, from signal processing methods in 2010 to artificial intelligence (AI) techniques, particularly deep learning, by 2020. This article uses statistical computing to present a scientometric review of AI's evolution in the wind energy sector, providing evidence-based insights into its strengths and limitations. It also addresses challenges such as data availability and quality, lack of transparency in AI models, and issues in real-time decision support. The goal is to encourage more organizations to adopt data-driven decision-making techniques in O&M to improve wind energy reliability and contribute to global climate change mitigation efforts.

Hulloli and Mani (2021) analyzed the growth and development of electric vehicle research publications and citations from India and the United States using Web of Science data from 2011 to 2020. The research focused on growth rates, author collaboration, co-authorship, and citation profiles. India's contribution to the field of biotechnology was significantly higher than that of the USA, with 3,131 papers and 21,057 citations. India also exhibited a higher growth rate (26.93%) compared to the USA's 7.74% and the global rate of 11.47%. Both countries had the most cited papers in the 11-50 citations range.

Rosokhata *et al.,* (2021) conducted a study on renewable energy, identifying influential publications, authors, and organizations. They analyzed 17,805 publications, with 51.7% published between 2016 and 2020. Major research areas included energy fuels, engineering, environmental sciences, and business economics. The study identified six main research clusters: optimization, renewable energy, biomass, CO2 emissions, modeling, and desalination. The findings provide insights for funding and risk assessment in renewable energy research.

Balz (2022) observed the MDPI's *Remote Sensing* journal from 2009 to 2021, revealing an increase in publication volume, a shift towards SAR sensor-based papers, and a decline in optical remote sensing research. The study also identified distinct writing styles across different subfields, countries, and cities. Additionally, it found growing scientific coupling between China and the USA in remote sensing research, offering insights into current trends and developments in the field.

Ghalambaz *et al.,* (2023) focused on solar thermal energy storage (STES), which has seen significant growth in recent years due to the potential of solar radiation for providing renewable and clean energy. This study explored STES research over the past 41 years by analyzing publications, citations, and dynamic network connections between authors, institutions, and countries. Bibliographic data were retrieved from the Web of Science database (WOS) between 1982 and 2022, with 1,835 papers collected.

Data analysis using VOSViewer software plotted, visualized, and mapped dynamic network connections between authors, institutions, and countries. The results showed that Cabeza, currently affiliated with Universitat De Lleida in Spain, was the most productive author with 47 publications, 2,954 total citations, and the highest TC/TP ratio of 62.9.

The top five productive and influential nations were China, the USA, India, Spain, and Germany, contributing 50% of total publications. Keyword analysis revealed that China and India focus on "phase change materials," while the USA and Spain emphasize "concentrated solar power" and "molten salt." France had a similar emphasis but paid less attention to "molten salt."

Bungau *et al.,* (2023) analyzed sustainable construction policies aimed at promoting environmentally friendly and resource-efficient building processes. The lack of bibliometric analyses in this field can hinder the effectiveness of research efforts, collaboration, and the dissemination of best practices. This study analyzed the impact of published data on building energy efficiency using the Web of Science core collection database.

A total of 28,555 papers were analyzed using the VOSviewer program, with data divided into two periods. The most prolific countries were China, the United States, and England. Collaboration maps revealed strong cooperation among these countries in paper development.

The most prominent papers were published in *Energy Policy* and *Energy and Buildings*, followed by *Energies*. The results demonstrate growing scientific interest in this area and serve as a valuable resource for researchers studying building energy efficiency.

Parida and Nayak (2023) investigated bifurcation research output in India from 2016 to 2020, focusing on prolific authors, document types, and research trends. The highest number of research papers (1,700) was recorded in 2017, while 2018 experienced the lowest growth rate at 19.65%. The study observed a strong trend toward collaborative research, with 137.8 single-authored papers, 1,564 multi-authored papers, and 1,701.8 collaborative papers.

Pandey, Chakraborty, and Khandal (2024) examined the increasing use of AI and machine learning in military applications, such as equipment, intelligence, cybersecurity, decision-making, operations, and medical systems. A review of 417 peer-reviewed articles from 1991 to 2023 revealed diverse research efforts integrating modern technologies into weapon development, strategic operations, and military society. The study also addressed legal and ethical concerns, examining authorship patterns, document types, and country-specific contributions.

III. OBJECTIVES OF THE STUDY

1. The study aims to analyze the year-wise growth pattern of non-conventional energy research in India and worldwide from 2003 to 2022.
2. To identify the relative growth rate and doubling time of publications in non-conventional energy research.
3. To identify the relative growth rate and doubling time of citations in non-conventional energy research.
4. To test the applicability of Bradford's Law of scattering journals and Zipf's Law of word occurrence in non-conventional energy research.
5. To study the exponential growth rate and annual growth rate in non-conventional energy research.
6. To examine the activity index and publication efficiency index in non-conventional energy research.
7. To determine the relative citation index in non-conventional energy research.
8. To identify the forms of communication used by researchers in non-conventional energy research.
9. To identify the top twenty authors, institutions, and highly cited articles in non-conventional energy research.

IV. METHODOLOGY

The research scope was defined as non-conventional energy. The search filters were configured to enable the retrieval of articles from the Web of Science Core Collection, which comprises over 21,100 peer-reviewed journals, books, and conference proceedings across more than 250 subject areas, including the sciences, social sciences, and arts and humanities.

The search strategy employed was ((TS = non-conventional energy*)) OR ((TS = renewable energy*)) OR ((TS = alternative source of energy*)), ensuring a comprehensive approach to data collection.

V. ANALYSIS AND INTERPRETATION

A. Year-Wise Research Output of Non-Conventional Energy

Table VI highlights the research productivity of non-conventional energy disciplines in terms of annual growth across India and the world, as indexed in the Web of Science (WoS) databases.

The publication output from India in non-conventional energy research during 2003-2022 comprised 13,372 papers, while the global publication output for the same period was 164,586 papers. In India, the year-wise analysis shows that 2022 was the most productive year, with 2,628 publications, followed by 2021 with 2,044 publications, and 2020 with 1,511 publications.

The least productive years were 2003 and 2005, with 21 (1.02%) papers each. Regarding citations, 2021 was the most cited year, with 47,734 citations, while the lowest citation count occurred in 2003, with only 968 citations. According to the table, India's highest average citation per paper was 117.58, recorded in 2004, and the lowest was 15.04, recorded in 2022. The highest h-index was 96 in 2020, and the lowest h-index was 10 in 2005.

Globally, 2022 was the most productive year, with 22,850 publications, followed by 2021 with 21,158 publications, and 2020 with 17,839 publications. The least productive year was 2003, with 739 (1.02%) papers. Regarding citations, 2019 was the most cited year, with 538,178 citations, while the lowest citation count was in 2003, with only 32,974 citations. The world's highest average citation per paper was 67.56, recorded in 2005, and the lowest was 14.94, recorded in 2022. The highest h-index was 237 in 2015, and the h-index for 2016-2022 was not available.

B. Relative Growth Rate and Doubling Time of Publication in Non-Conventional Energy Research: India

Table II indicates India's growth rate and doubling time of non-conventional energy literature publications. The growth rate decreased from 0.91 in 2004 to 0.18 in 2019, with a mean of 0.32 for the period from 2003 to 2022. The doubling time for publications ranged from 0.76 in 2004 to 3.94 in 2019, with a mean of 2.24 for the same period. However, the study found that the relative growth rate and doubling time were unstable throughout the study period.

TABLE I YEAR-WISE RESEARCH PUBLICATIONS OF NON-CONVENTIONAL ENERGY RESEARCH: INDIA V/S WORLD

	India					World				
Year	**TP**	**%**	**TC**	**ACPP**	**H-index**	**TP**	**%**	**TC**	**ACPP**	**H-Index**
2003	21	0.16	968	46.1	12	739	0.45	32974	44.62	95
2004	31	0.23	3645	117.58	17	795	0.48	45776	57.58	105
2005	21	0.16	1046	49.81	10	867	0.53	58574	67.56	119
2006	45	0.34	1600	35.56	19	1233	0.75	70672	57.32	122
2007	72	0.54	7100	98.61	29	1801	1.09	105546	58.6	151
2008	94	0.7	7235	76.97	36	2178	1.32	116898	53.67	167
2009	118	0.88	7950	67.37	40	3084	1.87	167581	54.34	192
2010	123	0.92	8284	67.35	41	3482	2.12	218646	62.79	205
2011	148	1.11	13644	92.19	49	4368	2.65	248812	56.96	209
2012	249	1.86	9222	37.04	41	5624	3.42	249508	44.36	205
2013	386	2.89	13972	36.2	64	6659	4.05	306389	46.01	227
2014	625	4.67	22017	35.23	62	8047	4.89	329296	40.92	226
2015	714	5.34	18464	25.86	71	9274	5.63	369480	39.84	237
2016	1063	7.95	24001	22.58	82	11232	6.82	429542	38.24	NA
2017	1069	7.99	27374	25.61	86	12939	7.86	469616	36.29	NA
2018	1251	9.36	32982	26.36	89	14358	8.72	490374	34.15	NA
2019	1159	8.67	29176	25.17	80	16059	9.76	538178	33.51	NA
2020	1511	11.3	42786	28.32	96	17839	10.84	532974	29.88	NA
2021	2044	15.29	47734	23.35	91	21158	12.86	507769	24	NA
2022	2628	19.65	39514	15.04	73	22850	13.88	341427	14.94	NA
Total	13372	100	358714			164586	100	5630032		

TP = Total Publications, % = Percentage, TC = Total Citations, ACPP = Average Citation per Paper, NA = Not Available

TABLE II RELATIVE GROWTH RATE AND DOUBLING TIME OF PUBLICATION IN NON-CONVENTIONAL ENERGY RESEARCH: INDIA

Year	**TP**	**CP**	**Log 1**	**Log 2**	**RGR (P)**	**Dt (P)**
2003	21	21		3.04		
2004	31	52	3.04	3.95	0.91	0.76
2005	21	73	3.95	4.29	0.34	2.04
2006	45	118	4.29	4.77	0.48	1.44
2007	72	190	4.77	5.25	0.48	1.45
2008	94	284	5.25	5.65	0.4	1.72
2009	118	402	5.65	6	0.35	1.99
2010	123	525	6	6.26	0.27	2.6
2011	148	673	6.26	6.51	0.25	2.79
2012	249	922	6.51	6.83	0.31	2.2
2013	386	1308	6.83	7.18	0.35	1.98
2014	625	1933	7.18	7.57	0.39	1.77
2015	714	2647	7.57	7.88	0.31	2.2
2016	1063	3710	7.88	8.22	0.34	2.05
2017	1069	4779	8.22	8.47	0.25	2.74
2018	1251	6030	8.47	8.7	0.23	2.98
2019	1159	7189	8.7	8.88	0.18	3.94
2020	1511	8700	8.88	9.07	0.19	3.63
2021	2044	10744	9.07	9.28	0.21	3.28
2022	2628	13372	9.28	9.5	0.22	3.17
Total	13372	Mean value			0.32	2.24

TP = Total Publication, Cum = Cumulative, RGR = Relative Growth Rate, Dt = Doubling Time

C. Relative Growth Rate and Doubling Time of Citations in Non-Conventional Energy Research: India

Table III reveals India's relative growth rates of citation output and doubling time, with a decrease from 1.56 in 2004 to 0.12 in 2022. The mean growth rate for 2003-2022 was 0.30, while the doubling time for citations ranged from 0.44 in 2004 to 5.94 in 2022.

The mean doubling time for citations for 2003-2022 was 3.07, indicating steady growth in non-conventional energy research publications. However, the relative growth rate and doubling time were unstable during the study period.

TABLE III RELATIVE GROWTH RATE AND DOUBLING TIME OF CITATION IN NON-CONVENTIONAL ENERGY RESEARCH: INDIA

Year	TC	CP	Log 1	Log 2	RGR (C)	Dt (C)
2003	968	968		6.88		
2004	3645	4613	6.88	8.44	1.56	0.44
2005	1046	5659	8.44	8.64	0.2	3.39
2006	1600	7259	8.64	8.89	0.25	2.78
2007	7100	14359	8.89	9.57	0.68	1.02
2008	7235	21594	9.57	9.98	0.41	1.7
2009	7950	29544	9.98	10.29	0.31	2.21
2010	8284	37828	10.29	10.54	0.25	2.8
2011	13644	51472	10.54	10.85	0.31	2.25
2012	9222	60694	10.85	11.01	0.16	4.2
2013	13972	74666	11.01	11.22	0.21	3.34
2014	22017	96683	11.22	11.48	0.26	2.68
2015	18464	115147	11.48	11.65	0.17	3.97
2016	24001	139148	11.65	11.84	0.19	3.66
2017	27374	166522	11.84	12.02	0.18	3.86
2018	32982	199504	12.02	12.2	0.18	3.83
2019	29176	228680	12.2	12.34	0.14	5.08
2020	42786	271466	12.34	12.51	0.17	4.04
2021	47734	319200	12.51	12.67	0.16	4.28
2022	39514	358714	12.67	12.79	0.12	5.94
Total	358714	Mean value			0.3	3.07

TC = Total Citations, Cum = Cumulative, RGR = Relative Growth Rate, Dt = Doubling Time

D. Annual Growth Rate of Non-Conventional Energy Research

Table IV depicts the annual growth rate output of non-conventional energy research. The study reveals that the annual growth rate fluctuated from 2003 to 2022. The highest AGR was 114.29 in 2006, and the lowest was 0.56 in 2017. During the sample period, 2005 and 2019 recorded negative AGR scores, while the remaining years exhibited favorable growth rates.

TABLE IV ANNUAL GROWTH RATE OF NON-CONVENTIONAL ENERGY RESEARCH

Year	TP	AGR
2003	21	
2004	31	47.62
2005	21	-32.26
2006	45	114.29
2007	72	60
2008	94	30.56
2009	118	25.53
2010	123	4.24
2011	148	20.33
2012	249	68.24
2013	386	55.02
2014	625	61.92
2015	714	14.24
2016	1063	48.88
2017	1069	0.56
2018	1251	17.03
2019	1159	-7.35
2020	1511	30.37
2021	2044	35.27
2022	2628	28.57
Total	13372	

TP = Total Publication, Cum = Cumulative Publications, AGR = Annual Growth Rate

E. Exponential Growth Rate of Non-Conventional Energy

Table V shows the exponential growth of publication output in non-conventional energy research from 2003 to 2022. The highest exponential growth rate was 2.14 in 2006, with 45 publications. The lowest exponential growth rate was 0.68 in 2005, with 21 publications. The study revealed an average exponential growth rate of 1.33, indicating fluctuating growth rates throughout the study period.

TABLE V EXPONENTIAL GROWTH RATE OF NON-CONVENTIONAL ENERGY RESEARCH

Year	TP	EGR
2003	21	
2004	31	1.48
2005	21	0.68
2006	45	2.14
2007	72	1.6
2008	94	1.31
2009	118	1.26
2010	123	1.04
2011	148	1.2
2012	249	1.68

2013	386	1.55
2014	625	1.62
2015	714	1.14
2016	1063	1.49
2017	1069	1.01
2018	1251	1.17
2019	1159	0.93
2020	1511	1.3
2021	2044	1.35
2022	2628	1.29
Total	13372	1.33

TP = Total Publication, EGR = Exponential Growth Rate

F. Activity Index of Non-Conventional Energy

Table VI shows the activity index of India's contribution to world output in non-conventional energy research from 2003 to 2022. The data reveal that the activity index for 19 out of the 15 years of study was less than 100, reflecting lower activity in non-conventional energy research output compared to the world average. The highest activity index was 141.56, observed in 2022; the next highest values were 118.91 in 2021 and 116.49 in 2016. The activity index was significantly lower in 2005, at 29.81, during the overall study period. Furthermore, the researcher observed that the activity index fluctuated during the study period.

TABLE VI ACTIVITY INDEX OF NON-CONVENTIONAL ENERGY RESEARCH

Year	World TP	India TP	AI
2003	739	21	34.98
2004	795	31	47.99
2005	867	21	29.81
2006	1233	45	44.92
2007	1801	72	49.21
2008	2178	94	53.12
2009	3084	118	47.09
2010	3482	123	43.48
2011	4368	148	41.7
2012	5624	249	54.49
2013	6659	386	71.35
2014	8047	625	95.6
2015	9274	714	94.76
2016	11232	1063	116.49
2017	12939	1069	101.69
2018	14358	1251	107.24
2019	16059	1159	88.83
2020	17839	1511	104.25
2021	21158	2044	118.91
2022	22850	2628	141.56
Total	164586	13372	

TP = Total Publication, AI = Activity Index

G. Publication Efficiency Index in Non-Conventional Energy

Table VII reveals the publication efficiency index of overall publications on non-conventional energy research output during the study period. The average publication efficiency index was 1.77 during this period. The highest publication efficiency index was 4.38 in 2004, with 31 publications, followed by 3.68 in 2007, with 72 publications, and 3.44 in 2011, with 148 publications. The lowest publication efficiency index was recorded at 0.56 in 2022, with 2,628 publications.

TABLE VII PUBLICATION EFFICIENCY INDEX IN NON-CONVENTIONAL ENERGY RESEARCH

Year	TP	TC	PEI
2003	21	968	1.72
2004	31	3645	4.38
2005	21	1046	1.86
2006	45	1600	1.33
2007	72	7100	3.68
2008	94	7235	2.87
2009	118	7950	2.51
2010	123	8284	2.51
2011	148	13644	3.44
2012	249	9222	1.38
2013	386	13972	1.35
2014	625	22017	1.31
2015	714	18464	0.96
2016	1063	24001	0.84
2017	1069	27374	0.95
2018	1251	32982	0.98
2019	1159	29176	0.94
2020	1511	42786	1.06
2021	2044	47734	0.87
2022	2628	39514	0.56
Total	13372	358714	1.77

TP = Total Publications, TC = Total Citations, PEI = Publication Efficiency Index

H. Relative Citation Index of Non-Conventional Energy Research

Table VIII lists the top 20 countries' relative citation indexes (RCIs), based on 4,063 papers, which range from 0.48 to 2.48. Pakistan has the highest relative citation index (2.48) with 142 documents. Vietnam ranks second with a relative citation index of 2.05 and 140 papers, while the People's Republic of China ranks third with a relative citation index of 2.01 and 384 papers. Ethiopia has 112 documents and the lowest relative citation index (0.48).

TABLE VIII RELATIVE CITATION INDEX OF NON-CONVENTIONAL ENERGY RESEARCH

Countries Name	TP	TC	ACPP	RCI	H-Index
USA	488	20726	42.47	1.32	75
Saudi Arabia	430	12205	28.38	0.88	52
People's Republic of China	384	24798	64.58	2.01	84
South Korea	314	16434	52.34	1.63	68
Malaysia	276	13408	48.58	1.51	60
Australia	254	10196	40.14	1.25	55
England	254	11608	45.7	1.42	50
Canada	171	7195	42.08	1.31	40
Japan	167	6723	40.26	1.25	43
Pakistan	142	11327	79.77	2.48	61
Vietnam	140	9229	65.92	2.05	54
Egypt	129	3298	25.57	0.79	32
Denmark	125	5516	44.13	1.37	37
Taiwan	125	5642	45.14	1.4	43
Singapore	119	4212	35.39	1.1	38
South Africa	113	4130	36.55	1.14	31
Ethiopia	112	1728	15.43	0.48	24
Turkey	110	6692	60.84	1.89	44
Germany	108	5262	48.72	1.51	36
Italy	102	4487	43.99	1.37	35
Total	4063	184816			
World Total	164586	5293367			

TP = Total Publications, TC = Total Citations, ACPP = Average Citation per Paper, RCI = Relative Citation of Index

I. Bradford's Law of Scattering of Journals

Bradford's Law of Scattering of Journals states that journals are distributed in decreasing productivity, with the most productive journals in the first zone and the less productive ones in the last zone. This law suggests dividing journals into zones, each producing a similar number of articles, with a 1:n² relationship between the zones. The total number of publications is 13,372, from 2,020 journals.

TABLE IX BRADFORD DISTRIBUTION OF JOURNAL IN NON-CONVENTIONAL ENERGY RESEARCH

Rank	No. of Journals	Cum No. of Journals	No. of Articles	Cum No. of Articles	Log (N)	Zones
1	1	1	534	534	0	Zone 1
2	1	2	482	1016	0.69	
3	1	3	239	1255	1.1	
4	1	4	214	1469	1.39	
5	1	5	183	1652	1.61	
6	1	6	175	1827	1.79	
7	1	7	156	1983	1.95	
8	1	8	153	2136	2.08	
9	1	9	151	2287	2.2	
10	1	10	135	2422	2.3	
11	1	11	133	2555	2.4	
12	1	12	129	2684	2.48	
13	1	13	123	2807	2.56	
14	1	14	121	2928	2.64	
15	1	15	117	3045	2.71	

16	1	16	116	3161	2.77	
17	1	17	112	3273	2.83	
18	1	18	97	3370	2.89	
19	1	19	91	3461	2.94	
20	1	20	90	3551	3	
21	2	22	166	3717	3.09	
22	1	23	82	3799	3.14	
23	1	24	77	3876	3.18	
24	1	25	76	3952	3.22	
25	1	26	73	4025	3.26	
26	2	28	140	4165	3.33	
27	1	29	67	4232	3.37	
28	1	30	64	4296	3.4	
29	1	31	63	4359	3.43	
30	1	32	62	4421	3.47	
31	1	33	61	4482	3.5	Zone 2
32	2	35	118	4600	3.56	
33	2	37	114	4714	3.61	
34	1	38	56	4770	3.64	
35	1	39	55	4825	3.66	
36	1	40	54	4879	3.69	
37	2	42	100	4979	3.74	
38	3	45	147	5126	3.81	
39	2	47	92	5218	3.85	
40	2	49	90	5308	3.89	
41	2	51	86	5394	3.93	
42	1	52	42	5436	3.95	
43	2	54	82	5518	3.99	
44	4	58	156	5674	4.06	
45	2	60	76	5750	4.09	
46	3	63	111	5861	4.14	
47	1	64	36	5897	4.16	
48	2	66	70	5967	4.19	
49	2	68	68	6035	4.22	
50	3	71	99	6134	4.26	
51	1	72	32	6166	4.28	
52	2	74	62	6228	4.3	
53	1	75	30	6258	4.32	
54	4	79	116	6374	4.37	
55	3	82	84	6458	4.41	
56	1	83	27	6485	4.42	
57	8	91	208	6693	4.51	
58	5	96	125	6818	4.56	
59	5	101	120	6938	4.62	
60	5	106	115	7053	4.66	
61	5	111	110	7163	4.71	
62	7	118	147	7310	4.77	

63	5	123	100	7410	4.81	
64	8	131	152	7562	4.88	
65	8	139	144	7706	4.93	
66	12	151	204	7910	5.02	
67	9	160	144	8054	5.08	
68	13	173	195	8249	5.15	
69	11	184	154	8403	5.21	
70	18	202	234	8637	5.31	
71	25	227	300	8937	5.42	Zone 3
72	18	245	198	9135	5.5	
73	23	268	230	9365	5.59	
74	23	291	207	9572	5.67	
75	50	341	400	9972	5.83	
76	46	387	322	10294	5.96	
77	45	432	270	10564	6.07	
78	60	492	300	10864	6.2	
79	108	600	432	11296	6.4	
80	171	771	513	11809	6.65	
81	314	1085	628	12437	6.99	
82	935	2020	935	13372	7.61	
Total	2020		13372			

Table IX presents the zonal distribution of journals on non-conventional energy research output. The scattering of 2,020 journals contributed 13,372 records from 2003 to 2022. Bradford's law describes a quantitative relationship between journals and papers. The study arranges the journals' productivity in descending order and divides the articles into three zones or groups: the first zone is highly productive, the second zone is moderately productive, and the third is the peripheral zone. The zone distribution follows a 1:n² ratio.

TABLE IX BRADFORD IN ZONES-WISE IN NON-CONVENTIONAL ENERGY RESEARCH

Zones	No. of Journals	%	No. of Articles	%	Bradford Multiplier
1	32	1.58	4421	33.06	
2	170	8.42	4216	31.53	5.31
3	1818	90	4735	35.41	10.69
Total	2020	100	13372	100	16.01 (8.00)*

*Bradford Multiplier

Table IX shows that zone one contains 32 (1.58%) journals, which account for 4,421 (33.06%) publications. Zone two consists of 170 (8.42%) journals that contribute 4,216 (31.53%) publications, and zone three contains 1,818 (90.00%) journals that contribute 4,735 (35.41%) publications. The Bradford multiplier factor between zone 1 and zone 2 is 5.31, between zones 2 and 3 is 10.69, and the average multiplier factor is 8.00.

J. Application of Zipf's Law of Word Occurrence

Table X shows the word occurrence according to Zipf's law. The word "Performance" ranks first with a frequency of 1,001, followed by "Design" (835) in second place, "Optimization" (786) in third, "System" (696) in fourth, and "Renewable Energy" (640) in fifth, and so on.

The relationships among the word occurrences in the dataset are not always related, and their multiplication does not equal the constant. Therefore, Zipf's law does not apply to the dataset.

K. Prolific Authors in Non-Conventional Energy Research

Table XI shows the authors' performance in the current study, which examined various citation score criteria, including TLCS, TGCS, and TLCR. In this context, Kumar, A, ranked first. His total number of research publications was 281 (12.87%), with a TLCS of 441, a TGCS of 10,794, and 396 cited references, with an average of 1.41 cited references per publication.

Kumar, S, ranked second, with a total of 202 research publications (9.25%). His TLCS was 246, his TGCS was 7,231, his cited references were 242, and his average cited reference was 1.20. Kumar, R, ranked third, with a total of 189 research publications (8.66%). His TLCS was 216, his TGCS was 8,604, his cited references were 248, and his average cited reference was 1.31.

TABLE X ZIPF'S LAW OF WORD OCCURRENCE IN NON-CONVENTIONAL ENERGY RESEARCH

Sl. No	Words	Frequency y(f)	Rank (r)	Log f	Log r	r*f=c	Log c
1	Performance	1001	1	3	0	1001	3
2	Design	835	2	2.92	0.3	1670	3.22
3	Optimization	786	3	2.9	0.48	2358	3.37
4	System	696	4	2.84	0.6	2784	3.44
5	Renewable Energy	640	5	2.81	0.7	3200	3.51
6	Energy	579	6	2.76	0.78	3474	3.54
7	Generation	492	7	2.69	0.85	3444	3.54
8	Systems	415	8	2.62	0.9	3320	3.52
9	Model	406	9	2.61	0.95	3654	3.56
10	Management	375	10	2.57	1	3750	3.57
11	Algorithm	357	11	2.55	1.04	3927	3.59
12	Power	353	12	2.55	1.08	4236	3.63
13	Storage	279	13	2.45	1.11	3627	3.56
14	Wind	266	14	2.42	1.15	3724	3.57
15	Biomass	249	15	2.4	1.18	3735	3.57
16	Water	216	16	2.33	1.2	3456	3.54
17	Impact	213	17	2.33	1.23	3621	3.56
18	Operation	207	18	2.32	1.26	3726	3.57
19	Efficiency	192	19	2.28	1.28	3648	3.56
20	Combustion	183	20	2.26	1.3	3660	3.56

TABLE XI TOP TWENTY PROLIFIC AUTHORS IN NON-CONVENTIONAL ENERGY RESEARCH

Author	TP	%	TLCS	TGCS	CR	Avg. CR
Kumar A	281	12.87	441	10794	396	1.41
Kumar S	202	9.25	246	7231	242	1.2
Kumar R	189	8.66	216	8604	248	1.31
Singh B	147	6.73	165	2839	124	0.84
Kumar P	117	5.36	165	4969	222	1.9
Singh S	111	5.08	147	4041	157	1.41
Sharma S	105	4.81	196	4272	142	1.35
Singh A	100	4.58	150	3131	140	1.4
Kumar N	94	4.31	156	2836	132	1.4
Kumar V	94	4.31	67	2946	102	1.09
Sharma A	94	4.31	107	2222	77	0.82
Mishra S	85	3.89	184	2136	91	1.07
Gupta A	79	3.62	42	1519	74	0.94
Ghosh S	77	3.53	60	2596	76	0.99
Singh R	73	3.34	68	1935	95	1.3
Kumar D	71	3.25	60	2180	66	0.93
Sharma R	69	3.16	67	1948	75	1.09
Singh P	67	3.07	29	1540	99	1.48
Das S	64	2.93	37	1349	65	1.02
Kumar M	64	2.93	54	1874	68	1.06
Total	2183	100				

TP= Total Publications, %= Percentage, TLCS= Total Local Citation Score, TGLS= Total Global Citation Score, CR= Cited Reference

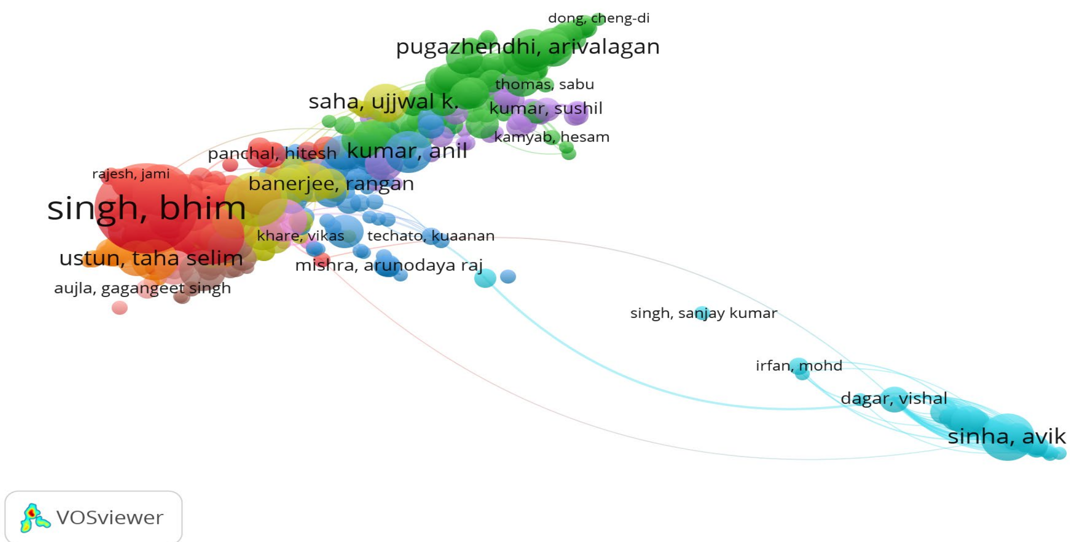

Fig. 1 Bibliographic coupling of authors in non-conventional energy research

L. Highly Productive Institutions in Non-Conventional Energy Research

Table XII illustrates the institution-based literature outputs in the field of non-conventional energy, extracted from the Web of Science between 2003 and 2022. The data show that the majority of research articles were published by the Indian Institute of Technology, New Delhi, with 917 (21.74%) publications, a TLCS score of 1,908, a TGCS score of 37,853, and the first-ranking position. The National Institute of Technology, New Delhi, ranked second with 617 (14.63%) publications, a TLCS score of 964, and a TGCS score of 17,627. Anna University, Chennai, ranked third with 294 (6.97%) publications, a TLCS score of 443, and a TGCS score of 13,653.

TABLE XII TOP TWENTY INSTITUTIONS IN NON-CONVENTIONAL ENERGY RESEARCH

Institutions	Place	TP	%	TLCS	TGCS
Indian Institute of Technology System	New Delhi	917	21.74	1908	37853
National Institute of Technology System	New Delhi	617	14.63	964	17627
Anna University	Chennai, Tamil Nadu	294	6.97	433	13653
Indian Institute of Technology	Delhi	282	6.69	565	12360
Vellore Institute of Technology	Vellore, Tamil Nadu	218	5.17	82	3692
Jadavpur University	Kolkata, West Bengal	182	4.31	169	3732
Indian Institute of Technology	Guwahati, Assam	149	3.53	138	4680
Indian Institute of Technology	Roorkee, Uttarakhand	142	3.37	394	4991
Indian Institute of Technology	Kharagpur, West Bengal	131	3.11	128	4792
Delhi Technological University	New Delhi	130	3.08	76	2571
Indian Institute of Science	Bangalore, Karnataka	130	3.08	233	5097
SRM Institute of Science & Technology	Chennai, Tamil Nadu	128	3.03	28	2543
Maulana Azad National Institute of Technology	Bhopal, Madhya Pradesh	116	2.75	432	4686
Aligarh Muslim University	Aligarh, Uttar Pradesh	114	2.7	103	3682
Jamia Millia Islamia	New Delhi	114	2.7	114	2958
Academy of Scientific and Innovative Research	Ghaziabad, Uttar Pradesh	113	2.68	69	4716
Visvesvaraya National Institute of Technology	Nagpur, Maharashtra	113	2.68	107	1892
Amrita Vishwa Vidyapeetham	Chennai, Tamil Nadu	110	2.61	35	828
Council of Scientific & Industrial Research	New Delhi	109	2.58	68	6801
Indian Institute of Technology Madras	Chennai, Tamil Nadu	109	2.58	52	2094
Total		4218	100		

TP = Total Publications, % = Percentage, TLCS = Total Local Citation Score, TGLS = Total Global Citation Score

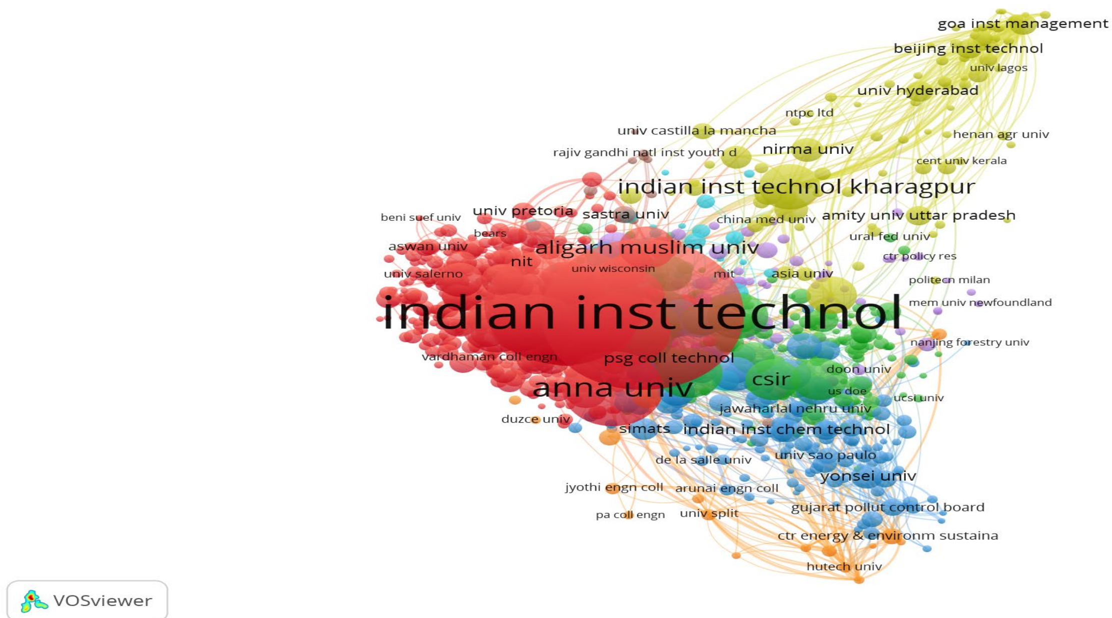

Fig. 2 Bibliographic coupling of institutions in non-conventional energy research

M. Highly Productive Journals in Non-Conventional Energy Research

Table XIII presents the most productive journal during the sample period, *Renewable & Sustainable Energy Reviews*, with 532 (15.42%) records. In terms of TLCS and TGCS, *Renewable & Sustainable Energy Reviews* has the highest total local citation score of 3,686 and a global citation score of 69,167, respectively. This is followed by *Materials Today: Proceedings*, with 482 (13.97%) records, and *Renewable Energy*, with 220 (6.37%) records. In contrast, *Sustainability* received zero local citations.

TABLE XIII TOP TWENTY JOURNALS IN NON-CONVENTIONAL ENERGY RESEARCH

Name of the Journals	TP	%	TLCS	TGCS
Renewable & Sustainable Energy Reviews	532	15.42	3686	69167
Materials Today-Proceedings	482	13.97	184	3943
Renewable Energy	220	6.37	1082	14527
Energies	214	6.2	7	3897
Environmental Science And Pollution Research	182	5.27	237	6084
International Journal of Hydrogen Energy	173	5.01	296	9779
Energy	152	4.4	526	7547
Journal of Cleaner Production	151	4.38	176	9534
Energy Sources Part A-Recovery Utilization and	146	4.23	90	1704
Fuel	135	3.91	94	6539
International Transactions on Electrical Energy Systems	133	3.85	10	1666
IEEE Access	129	3.74	273	3884
International Journal of Energy Research	123	3.56	193	3073
Sustainable Energy Technologies And Assessments	121	3.51	20	2733
Sustainability	117	3.39	0	2439
Journal of Energy Storage	116	3.36	100	4980
Bioresource Technology	96	2.78	144	8814
Energy Conversion and Management	79	2.29	379	5351
IEEE Transactions on Industry Applications	77	2.23	153	1987
International Journal of Electrical Power & Energy Systems	73	2.12	274	2672
Total	3451	100		

TP = Total Publications, % = Percentage, TLCS = Total Local Citation Score, TGLS = Total Global Citation Score

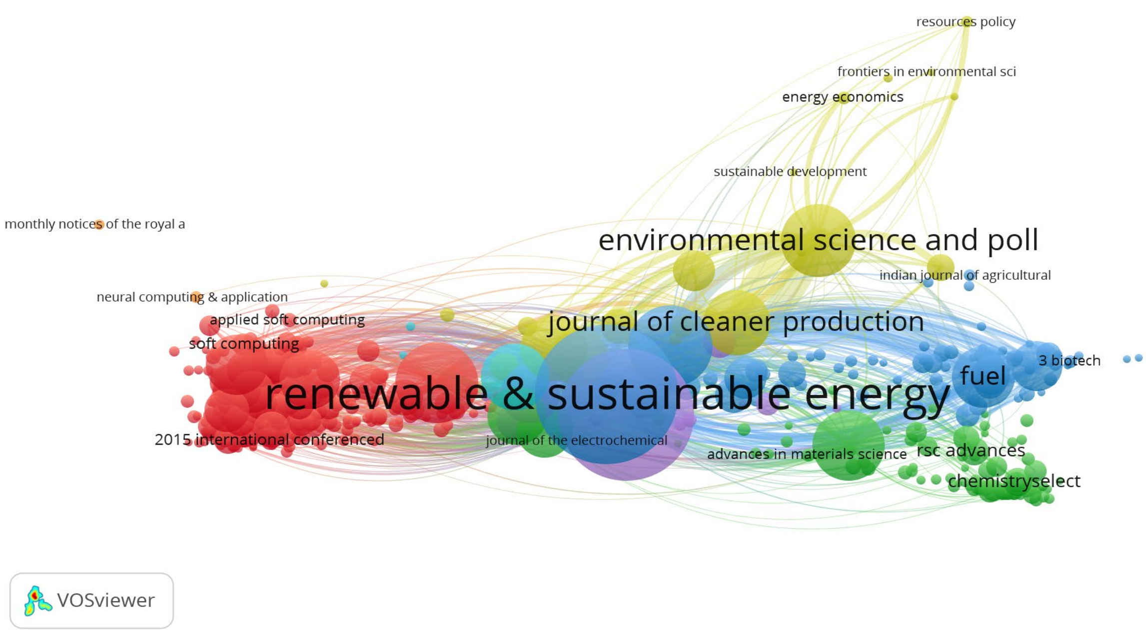

Fig. 3 Bibliographic coupling of journals in non-conventional energy research

N. Highly Uses Document Types in Non-Conventional Energy Research

Table XIV shows the preferred form of communication among researchers in non-conventional energy research. Articles are the most preferred form of communication among solar energy researchers. Out of 13,372 records, 6,579 (49.20%) are journal articles, which have obtained a TLCS of 7,114 and a TGCS of 177,516 - representing the highest number of local and global citations for this form of communication chosen by non-conventional energy researchers. This is followed by proceedings papers, with 4,657 (34.83%) records, reviews with 1,793 (13.41%), and articles/proceedings papers with 169 (1.26%) records. The remaining forms of documents are listed in the table below.

TABLE XIV TOP DOCUMENT TYPES IN NON-CONVENTIONAL ENERGY RESEARCH

Document Type	TP	%	TLCS	TGCS
Article	6579	49.2	7114	177516
Proceedings Paper	4657	34.83	780	18980
Review	1793	13.41	5005	150946
Article; Proceedings Paper	169	1.26	406	8558
Article; Early Access	81	0.61	0	769
Article; Retracted Publication	23	0.17	9	388
Editorial Material	23	0.17	7	398
Review; Early Access	14	0.1	0	233
Letter	9	0.07	8	49
Review; Book Chapter	6	0.04	3	535
Article; Early Access; Retracted Publication	3	0.02	0	23
Book Review	3	0.02	0	2
Correction	3	0.02	0	1
Proceedings Paper; Retracted Publication	3	0.02	0	1
Review; Retracted Publication	3	0.02	3	218
Article; Data Paper	1	0.01	0	10
Article; Early Access; Publication with Expression of Concern	1	0.01	0	0
Meeting Abstract	1	0.01	0	0
Total	13372	100		

TP = Total Publications, % = Percentage, TLSC = Total Local Citations Score, TGCS = Total Global Citation Score

O. Highly Cited Papers in Non-Conventional Energy Research

Table XV presents data on the top twenty highly cited research papers on non-conventional energy. The table reveals that the most highly cited article is by Kumari, R., Kumar, R., and Lynn, A., titled "g_mmpbsa-A GROMACS Tool for High-Throughput MM-PBSA Calculations," published in the *Journal of Chemical Information and Modeling* in 2014. This article has been cited 3,354 times by other researchers, ranking first among the selected highly cited articles. It is followed by Panwar, N.L., Kaushik, S.C., and Kothari, S., whose article "Role of Renewable Energy Sources in Environmental Protection: A Review," published in *Renewable & Sustainable Energy Reviews* in 2011, has been cited 2,378 times, ranking second. Next is the article by Agarwal, A.K., titled "Biofuels (Alcohols and Biodiesel) Applications as Fuels for Internal Combustion Engines," published in *Progress in Energy and Combustion Science* in 2007, with 2,223 citations.

TABLE XV TOP TWENTY HIGHLY CITED PAPERS IN NON-CONVENTIONAL ENERGY RESEARCH

Authors	Article Title	Source Title	TC	PY
Kumari, R., Kumar, R., Lynn, A.	g_mmpbsa-A GROMACS Tool for High-Throughput MM-PBSA Calculations	Journal of Chemical Information and Modeling	3359	2014
Panwar, N.L., Kaushik, S.C., Kothari, S.	Role of renewable energy sources in environmental protection: A review	Renewable & Sustainable Energy Reviews	2378	2011
Agarwal, A.K.	Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines	Progress in Energy and Combustion Science	2223	2007
Sudevalayam, S., Kulkarni, P.	Energy Harvesting Sensor Nodes: Survey and Implications	IEEE Communications Surveys and Tutorials	1362	2011
Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A., Kim, K.H.	Solar energy: Potential and future prospects	Renewable & Sustainable Energy Reviews	1314	2018
Parida, B., Iniyan, S Goic, R.	A review of solar photovoltaic technologies	Renewable & Sustainable Energy Reviews	1266	2011
Pohekar, S.D., Ramachandran, M.	Application of multi-criteria decision making to sustainable energy planning - A review	Renewable & Sustainable Energy Reviews	1231	2004
Menon, V., Rao, M.	Trends in bioconversion of lignocellulose: Biofuels, platform chemicals & biorefinery concept	Progress in Energy and Combustion Science	1112	2012
Khale, D., Chaudhary, R.	Mechanism of geopolymerization and factors influencing its development: a review	Journal of Materials Science	992	2007
Gupta, S., Tripathi, M	A review of TiO2 nanoparticles	Chinese Science Bulletin	961	2011
Kumar, A., Sah, B., Singh, A.R., Deng, Y., He, X.N., Kumar, P., Bansal, R.C.	A review of multi criteria decision making (MCDM) towards sustainable renewable energy development	Renewable & Sustainable Energy Reviews	941	2017
Dhyani, V., Bhaskar, T	A comprehensive review on the pyrolysis of lignocellulosic biomass	Renewable Energy	938	2018
Nazir, H., Batool, M., Osorio, F.J.B., Isaza-Ruiz, M., Xu, X.H., Vignarooban, K., Phelan, P., Inamuddin., Kannan, A.M.	Recent developments in phase change materials for energy storage applications: A review	International Journal of Heat and Mass Transfer	916	2019
Goyal, H.B., Seal, D., Saxena, R.C	Bio-fuels from thermochemical conversion of renewable resources: A review	Renewable & Sustainable Energy Reviews	800	2008
Suganthi, L., Samuel, A.A.	Energy models for demand forecasting-A review	Renewable & Sustainable Energy Reviews	786	2012
Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R., Maiti, S.	Recycled aggregate from C&D waste & its use in concrete - A breakthrough towards sustainability in construction sector: A review	Construction and Building Materials	764	2014
Jain, P.	Hydrogen the fuel for 21st century	International Journal of Hydrogen Energy	755	2009
Gollakota, A.R.K., Kishore, N., Gu, S.	A review on hydrothermal liquefaction of biomass	Renewable & Sustainable Energy Reviews	746	2018
Destek, M.A., Sinha, A.	Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries	Journal of Cleaner Production	732	2020
John, R.P., Anisha, G.S., Nampoothiri, K.M., Pandey, A.	Micro and macroalgal biomass: A renewable source for bioethanol	Bioresource Technology	715	2011

TC = Total Citations, PY = Publication Years

VI. FINDINGS OF THE STUDY

1. In 2022, 2,628 non-conventional energy research publications were published by Indian researchers, out of 13,372 in the sample period. The highest average number of citations per paper was 117.58 in 2004, and the highest h-index was 96 in 2020.
2. In 2022, 22,814 non-conventional energy research publications were published globally, out of 164,586 in 2005, with the highest average number of citations per paper at 67.56.
3. The relative growth rate and doubling time of publications vary in non-conventional energy, with a mean value of RGR was 0.32 and a doubling time of 2.24.
4. The study reveals fluctuating relative growth rates and doubling times of citations in non-conventional energy, with a mean value of RGR was 0.30 and a doubling time of 3.07.
5. The annual growth rate in non-conventional energy research was both positive and negative. The highest annual growth rate was 114.29, recorded in 2006.
6. The average exponential growth rate of non-conventional energy in the study was 1.32. Overall, the exponential growth rate fluctuated during the study period.
7. The average publication efficiency index is 1.77 during the said period.
8. Among the top 20 countries, Pakistan recorded the highest relative citation index at 2.28.
9. According to Bradford's law of journal scattering, the total number of journals cited in non-conventional energy research was analyzed in three zones based on the number of sources, records, and other factors. Each zone accounts for roughly one-third of the total citations. However, the journal distribution observed in this study, which follows a 32:170:1818 ratio, does not fit with Bradford's distribution law.
10. The frequency of keywords using Zipf's law was tested in non-conventional energy research. The study analyzed the top 20 keywords listed in the table. "Performance" is in first place with 1001 records.
11. The first place among the top 20 authors went to Kumar A, who has 281 research papers overall, 441 TLCS, 10794 TGCS, 396 cited references, and an average of 1.41 cited references in non-conventional energy.
12. The most research papers on non-conventional energy were published by the Indian Institute of Technology (917 publications), one of the top 20 institutions.
13. The most research articles on non-conventional energy were published in Renewable & Sustainable Energy Reviews, one of the top 20 journals, with 532 publications. This journal scored the highest in both local and global citation counts, with 3686 and 69167 citations, respectively.
14. The most popular communication medium among non-traditional energy researchers is journal papers, which have been submitted to by Indian researchers through 18 distinct channels. With a TLCS of 7114 and a TGCS of 177516, 6579 (49.20%) of the 13372 are journal articles.
15. This study analyzes the highly cited paper on nonconventional energy research.

VII. CONCLUSION

The study provides a comprehensive understanding of non-conventional energy research by analyzing data indexed in the Web of Science database from 2003 to 2022. A total of 13,372 research publications were published, receiving 323,919 citations. In comparison, global publications in non-conventional energy during the same period totaled 164,586 papers, which received 5,293,367 citations. A key finding of the study was the presence of fluctuations throughout the period, which are highly relevant to our understanding of this field.

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