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Research Article

Scientometrics Analysis of Biomass Energy Research Literature

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Abstract

Research on biomass energy has witnessed substantial growth, fueled by the rising global emphasis on sustainable and renewable energy solutions. In this context, scientometric studies serve as a valuable tool, offering critical insights into research trends, knowledge gaps, and potential future directions for advancing biomass energy technologies. The study examines the scientometric trends and impact of biomass energy research between 1998 and 2022, focusing on key indicators such as citation rates, growth rates, publication efficiency, and authorship patterns. The analysis was conducted on 5,186 publications from India and 72,641 publications globally in the biomass energy sector during the period 1998–2022. Scientometric indicators, including average citations per paper, annual growth rate (AGR), exponential growth rate, activity index, publication efficiency index (PEI), relative growth rate (RGR), and doubling time (Dt), were used. In 2006, India achieved the highest average citations per paper (182.34), while globally, the highest average citations per paper (93.11) were recorded in 2002. The highest AGR of 80.00 was recorded in 2004, which also marked the peak exponential growth rate of 1.80, with 36 publications. In 2022, the highest activity index was recorded at 141.56. The maximum PEI value (4.85) was observed in 2006, with 32 publications. The study identified the top 25 contributing authors and journals in the field of biomass energy research. Additionally, it discussed the mean RGR and Dt for publications and citations, along with other key scientometric indicators. The findings demonstrate strong growth and a high citation impact in biomass energy research, with India and the global research community making significant contributions. Collaborative networks, particularly with developed countries, play a substantial role in advancing this field. These insights underscore the importance of continued research and collaboration in biomass energy to address global energy challenges.

I. INTRODUCTION

A key renewable energy source for addressing the twin challenges of rising energy demand and climate change is biomass energy, which is derived from organic materials such as microalgae, forestry by-products, municipal solid waste, and agricultural residues. As a carbon-neutral alternative to fossil fuels, biomass enhances energy security, reduces greenhouse gas emissions, and supports rural economies through efficient resource utilization. Over the past two decades, biomass energy has received increasing attention from policymakers, industry, and researchers, leading to a substantial rise in scientific publications and collaborative projects worldwide. Owing to advances in conversion technologies and interdisciplinary approaches, diverse research areas—including carbon management, biofuels, biogas, and biochar—have made significant progress. Given the expanding scope of biomass research, scientometric methods provide a systematic approach to evaluating research productivity, collaboration patterns, thematic evolution, and global trends in the field. By analyzing bibliographic data, scientometric studies offer insights into key contributors, influential institutions, funding patterns, and emerging research hotspots, thereby mapping the knowledge structure of biomass energy research. Such analyses not only highlight the contributions of India and other countries but also identify gaps between theoretical advancements and practical applications. In this context, a scientometric assessment of biomass energy research is timely and necessary to understand its growth trajectory, assess its scientific impact, and guide future research directions aligned with sustainable development goals.

II. LITERATURE REVIEW

Dhawan *et al.* (2017) evaluated the research publication output on digital libraries in India and reported significant advancement, based on an analysis of 424 publications indexed in Scopus between 2007 and 2016. The study indicated a growth rate of 10.95% in research output within this domain, along with an average citation impact of 2.53 citations per paper. Furthermore, 12.03% of the publications involved international collaboration, placing India seventh worldwide in terms of publication share. The study also observed that 53.54% of the papers received at least one citation, reflecting moderate visibility and impact within the research community. The disciplinary distribution of research showed computer science leading with 60.14% of the output, followed by social sciences at 40.57% and engineering at 14.86%. Contributions originated from 159 organizations and 226 authors, with the top 25 institutions and 20 authors significantly influencing both publication output and citation performance. Additionally, publication venues were notably concentrated, with the top 15 journals accounting for 53.29% of total output. The *DESIDOC Journal of Library and Information Technology* ranked as the leading journal, publishing 23 papers during this period.

Rahimi, Behmanesh, and Ahmadi (2019) carried out a study on "scheduling in renewable energy" and "unit commitment in renewable energy." They examined 1,009 articles identified in the Scopus database and used keyword and citation methods to derive their findings, which indicate a relatively high research impact from China and the USA. Co-authorship and co-citation analyses were also demonstrated. The most active publication venues in this sector were *IEEE Transactions*, with "energy" and "engineering" identified as the most prominent research topics. The paper also provides detailed citation and co-citation maps related to various influencing factors.

Wang and Asniza (2023) conducted a scientometric review of 148 studies on writing motivation published between 2001 and 2022 and indexed in the Web of Science and Scopus databases. Their analysis indicates significant trends in this research area. CiteSpace analysis revealed a consistent increase in research output since 2011. Key themes in influential studies include motivation theory, writing performance, gender, grade level, and instructional strategies. Notably, Pajares and the United States emerged as key contributors, reflecting influential authorship and a geographical concentration of scholarship. The identified research hotspots span educational research, psychology, and linguistics, highlighting the interdisciplinary positioning of writing motivation studies. Jahanshahi *et al.* (2023) conducted a study evaluating bioenergy as a viable alternative to fossil fuels, driven by policy initiatives from governments and international organizations promoting energy recovery from bio-based materials. These initiatives have resulted in significant financial and scientific advancements over the past two decades. A comprehensive scientometric analysis of bioenergy research from 1966 to 2022, encompassing 51,905 scientific documents indexed in the Web of Science, illustrates extensive global engagement in the field, with contributions from more than 96,000 authors across 162 countries. The study examined ten parameters, including publication trends, document types, subject categories, institutional affiliations, citation patterns, co-authorship dynamics, and keyword networks. The findings reveal a consistent growth in research output, particularly marked by a sharp increase in the latter half of the 2000s. Furthermore, keyword evolution indicates a shift from early-stage, first-generation bioenergy technologies to more advanced, fourth-generation innovations, signaling a transformative progression within the sector. However, despite these advances, the literature indicates that sustainability challenges have constrained the widespread commercial adoption of certain feedstocks and technologies.

Chaparwal and Rajput (2024) conducted a scientometric analysis of biomass research in India from 2013 to 2022 using Scopus data, revealing substantial growth in scholarly activity within the field. Research output increased markedly, reflecting the growing recognition of biomass as a sustainable energy alternative in India. Key themes identified through Multiple Correspondence Analysis (MCA) include biofuels, microalgae, and carbon management, underscoring the sector's focus on renewable fuel development and environmental sustainability. An analysis of author impact highlights a core group of influential researchers who have played a pivotal role in shaping biomass research. Institutional leadership is prominently represented by Banaras Hindu University and the Indian Institutes of Technology, both of which have been instrumental in advancing this domain. Co-authorship network analysis further indicates strong collaborations among Indian institutions and international partners, strengthening the global knowledge base and reinforcing India's position in biomass research.

III. OBJECTIVES OF THE STUDY

1. To measure the year-wise distribution of publications and citations in biomass energy research from 1998 to 2022.
2. To determine the relative growth rate and doubling time of publications.
3. To analyse the exponential growth rate and annual growth rate of biomass energy research publications.
4. To conduct a time-series analysis of biomass energy research publications.
5. To examine the Activity Index and Publication Efficiency Index in biomass energy research publications.
6. To identify authorship patterns in the research area, such as the average number of authors per paper and productivity per paper.

IV. METHODOLOGY

Researchers extracted data for this study from the Web of Science Core database, covering the period from 1998 to 2022. The search string used to retrieve all publications on biomass energy research in India and worldwide was as

follows: TS = (biomass energy*). The researchers employed scientometric indicators such as the Publication Efficiency Index (PEI), Activity Index, Exponential Growth Rate, Annual Growth Rate, and other relevant indicators for the analysis. The study also utilized HistCite, BibExcel, and Microsoft Excel 2010 software.

V. ANALYSIS AND INTERPRETATION

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

India						World					
Year	**TP**	**%**	**TC**	**ACCP**	**H-Index**	**Year**	**TP**	**%**	**TC**	**ACCP**	**H-Index**
1998	18	0.35	1001	55.61	13	1998	524	0.72	23092	44.07	78
1999	20	0.39	785	39.25	11	1999	520	0.72	23692	45.56	77
2000	15	0.29	727	48.47	10	2000	416	0.57	26022	62.55	80
2001	12	0.23	764	63.67	9	2001	440	0.61	31650	71.93	91
2002	20	0.39	1056	52.80	13	2002	444	0.61	41340	93.11	93
2003	20	0.39	522	26.10	10	2003	574	0.79	38757	67.52	98
2004	36	0.69	1791	49.75	22	2004	537	0.74	47633	88.70	103
2005	23	0.44	2761	120.04	17	2005	612	0.84	47395	77.44	110
2006	32	0.62	5835	182.34	20	2006	814	1.12	63052	77.46	127
2007	41	0.79	3162	77.12	23	2007	1006	1.38	82853	82.36	137
2008	59	1.14	8373	141.92	36	2008	1310	1.80	108901	83.13	157
2009	75	1.45	5937	79.16	37	2009	1758	2.42	129117	73.45	163
2010	82	1.58	8966	109.34	41	2010	1948	2.68	144909	74.39	173
2011	115	2.22	8864	77.08	47	2011	2494	3.43	148966	59.73	172
2012	113	2.18	6565	58.10	38	2012	2935	4.04	150836	51.39	167
2013	153	2.95	12145	79.38	49	2013	3144	4.33	156200	49.68	164
2014	195	3.76	10273	52.68	54	2014	3747	5.16	163810	43.72	161
2015	240	4.63	11171	46.55	60	2015	4200	5.78	171126	40.74	160
2016	315	6.07	11943	37.91	60	2016	4639	6.39	178007	38.37	158
2017	331	6.38	13187	39.84	59	2017	5170	7.12	174572	33.77	149
2018	390	7.52	15594	39.98	61	2018	5647	7.77	184399	32.65	151
2019	468	9.02	14623	31.25	58	2019	6442	8.87	185678	28.82	138
2020	634	12.23	19670	31.03	70	2020	7173	9.87	174322	24.30	125
2021	783	15.10	18071	23.08	58	2021	8075	11.12	140362	17.38	106
2022	996	19.21	11237	11.28	41	2022	8072	11.11	70503	8.73	66
Total	5186	100	195023				72641	100	2707194		

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

Table I highlights the research productivity of the biomass energy discipline in terms of annual growth across India and the world, based on publications indexed in the Web of Science database. India's biomass energy research output from 1998 to 2022 totals 5,186 papers, compared to a global output of 72,641 papers during the same period. Both India and the global research community exhibit an increasing trend in research output over these years. India's annual publication count fluctuated between 18 and 996 papers, whereas the global count ranged from 524 to 8,072 papers. India recorded 19,670 citations in 2020, while the global total reached 185,678 citations, the highest number recorded in 2019. In terms of citation metrics, India's peak average citations per paper were highest at 182.34 in 2006, whereas the global peak average was 93.11 in 2002. India's highest H-index was recorded in 2020 at 70 and the lowest in 2001 at 9. Globally, the highest h-index was recorded in 2010 at 173, while the lowest was recorded in 2022 at 66. Table II indicates India's relative growth rate and doubling time of publications in biomass energy research during the period 1998–2022. The relative growth rate of research output declined from 0.75 in 1999 to 0.15 in 2005. Over the period 1998–2022, the mean relative growth rate was found to be 0.23. The doubling time for publications increased from 0.93 in 1999 to 4.59 in 2005. The mean doubling time for publications from 1998 to 2022 was 3.10, indicating a consistent increasing trend in the field of biomass energy research. This section also presents the world's relative growth rate and doubling time of publications in biomass energy research during 1998–2022. The relative growth rate of research output decreased from 0.69 in 1999 to 0.12 in 2022. Over the period 1998–2022, the mean relative growth

rate was 0.20. The doubling time for publications increased from 1.01 in 1999 to 5.88 in 2022. The mean doubling time for publications from 1998 to 2022 was 3.69, indicating a consistent increasing trend in the number of publications in the field of biomass energy research.

TABLE II RELATIVE GROWTH RATE AND DOUBLING TIME OF PUBLICATION IN BIOMASS ENERGY INDIA: INDIA V/S WORLD

India							World					
Year	**TP**	**Cum**	**Log 1**	**Log 2**	**RGR**	**Dt**	**TP**	**Cum**	**Log 1**	**Log 2**	**RGR**	**Dt**
1998	18	18		2.89			524	524		6.26		
1999	20	38	2.89	3.64	0.75	0.93	520	1044	6.26	6.95	0.69	1.01
2000	15	53	3.64	3.97	0.33	2.08	416	1460	6.95	7.29	0.34	2.07
2001	12	65	3.97	4.17	0.20	3.40	440	1900	7.29	7.55	0.26	2.63
2002	20	85	4.17	4.44	0.27	2.58	444	2344	7.55	7.76	0.21	3.30
2003	20	105	4.44	4.65	0.21	3.28	574	2918	7.76	7.98	0.22	3.16
2004	36	141	4.65	4.95	0.29	2.35	537	3455	7.98	8.15	0.17	4.10
2005	23	164	4.95	5.10	0.15	4.59	612	4067	8.15	8.31	0.16	4.25
2006	32	196	5.10	5.28	0.18	3.89	814	4881	8.31	8.49	0.18	3.80
2007	41	237	5.28	5.47	0.19	3.65	1006	5887	8.49	8.68	0.19	3.70
2008	59	296	5.47	5.69	0.22	3.12	1310	7197	8.68	8.88	0.20	3.45
2009	75	371	5.69	5.92	0.23	3.07	1758	8955	8.88	9.10	0.22	3.17
2010	82	453	5.92	6.12	0.20	3.47	1948	10903	9.10	9.30	0.20	3.52
2011	115	568	6.12	6.34	0.23	3.06	2494	13397	9.30	9.50	0.21	3.36
2012	113	681	6.34	6.52	0.18	3.82	2935	16332	9.50	9.70	0.20	3.50
2013	153	834	6.52	6.73	0.20	3.42	3144	19476	9.70	9.88	0.18	3.94
2014	195	1029	6.73	6.94	0.21	3.30	3747	23223	9.88	10.05	0.18	3.94
2015	240	1269	6.94	7.15	0.21	3.31	4200	27423	10.05	10.22	0.17	4.17
2016	315	1584	7.15	7.37	0.22	3.13	4639	32062	10.22	10.38	0.16	4.43
2017	331	1915	7.37	7.56	0.19	3.65	5170	37232	10.38	10.52	0.15	4.64
2018	390	2305	7.56	7.74	0.19	3.74	5647	42879	10.52	10.67	0.14	4.91
2019	468	2773	7.74	7.93	0.18	3.75	6442	49321	10.67	10.81	0.14	4.95
2020	634	3407	7.93	8.13	0.21	3.37	7173	56494	10.81	10.94	0.14	5.10
2021	783	4190	8.13	8.34	0.21	3.35	8075	64569	10.94	11.08	0.13	5.19
2022	996	5186	8.34	8.55	0.21	3.25	8072	72641	11.08	11.19	0.12	5.88
Total	5186	Mean Value			0.23	3.10	72641	Mean Value			0.20	3.69

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

Table III: This section indicates India's relative growth rate and doubling time of citations in biomass energy research during 1998–2022. The relative growth rate of citations declined from 0.58 in 1999 to 0.06 in 2020. Over the period 1998–2022, the mean relative growth rate was found to be 0.21. The doubling time for citations increased from 1.20 in 1999 to 11.68 in 2022. The mean doubling time for citations from 1998 to 2022 was 4.09, indicating a consistent increasing trend in the number of citations in biomass energy research. This section also presents the world's relative growth rate and doubling time of citations in biomass energy research during 1998–2022.The relative growth rate of citations decreased from 0.71 in 1999 to 0.03 in 2022. Over the period 1998–2022, the mean relative growth rate was 0.19. The doubling time for citations increased from 0.98 in 1999 to 26.26 in 2022. The mean doubling time for citations from 1998 to 2022 was 5.48, indicating consistent growth in the number of citations in the field of biomass energy research. The annual growth rate of biomass energy research output is presented in Table V. In Table IV From 1998 to 2022, variations were observed in the annual growth rate. The highest AGR (80.00) was recorded in 2004, while the lowest was recorded in 2003 (0.00). Further analysis revealed that the years 2000, 2001, 2005, and 2012 exhibited negative annual growth rates.

TABLE III RELATIVE GROWTH RATE AND DOUBLING TIME OF CITATION IN BIOMASS ENERGY INDIA: INDIA V/S WORLD

India							World					
Year	**TC**	**Cum**	**Log 1**	**Log 2**	**RGR**	**Dt**	**TC**	**Cum**	**Log 1**	**Log 2**	**RGR**	**Dt**
1998	1001	1001	-	6.91	-	-	23092	23092	-	10.05	-	-
1999	785	1786	6.91	7.49	0.58	1.20	23692	46784	10.05	10.75	0.71	0.98
2000	727	2513	7.49	7.83	0.34	2.03	26022	72806	10.75	11.20	0.44	1.57
2001	764	3277	7.83	8.09	0.27	2.61	31650	104456	11.20	11.56	0.36	1.92
2002	1056	4333	8.09	8.37	0.28	2.48	41340	145796	11.56	11.89	0.33	2.08
2003	522	4855	8.37	8.49	0.11	6.09	38757	184553	11.89	12.13	0.24	2.94
2004	1791	6646	8.49	8.80	0.31	2.21	47633	232186	12.13	12.36	0.23	3.02
2005	2761	9407	8.80	9.15	0.35	1.99	47395	279581	12.36	12.54	0.19	3.73
2006	5835	15242	9.15	9.63	0.48	1.44	63052	342633	12.54	12.74	0.20	3.41
2007	3162	18404	9.63	9.82	0.19	3.68	82853	425486	12.74	12.96	0.22	3.20
2008	8373	26777	9.82	10.20	0.37	1.85	108901	534387	12.96	13.19	0.23	3.04
2009	5937	32714	10.20	10.40	0.20	3.46	129117	663504	13.19	13.41	0.22	3.20
2010	8966	41680	10.40	10.64	0.24	2.86	144909	808413	13.41	13.60	0.20	3.51
2011	8864	50544	10.64	10.83	0.19	3.59	148966	957379	13.60	13.77	0.17	4.10
2012	6565	57109	10.83	10.95	0.12	5.67	150836	1108215	13.77	13.92	0.15	4.74
2013	12145	69254	10.95	11.15	0.19	3.59	156200	1264415	13.92	14.05	0.13	5.26
2014	10273	79527	11.15	11.28	0.14	5.01	163810	1428225	14.05	14.17	0.12	5.69
2015	11171	90698	11.28	11.42	0.13	5.27	171126	1599351	14.17	14.29	0.11	6.12
2016	11943	102641	11.42	11.54	0.12	5.60	178007	1777358	14.29	14.39	0.11	6.57
2017	13187	115828	11.54	11.66	0.12	5.73	174572	1951930	14.39	14.48	0.09	7.40
2018	15594	131422	11.66	11.79	0.13	5.49	184399	2136329	14.48	14.57	0.09	7.68
2019	14623	146045	11.79	11.89	0.11	6.57	185678	2322007	14.57	14.66	0.08	8.32
2020	19670	165715	11.89	12.02	0.13	5.48	174322	2496329	14.66	14.73	0.07	9.57
2021	18071	183786	12.02	12.12	0.10	6.70	140362	2636691	14.73	14.79	0.05	12.67
2022	11237	195023	12.12	12.18	0.06	11.68	70503	2707194	14.79	14.81	0.03	26.26
Total	195023	Mean Value			0.21	4.09	2707194	Mean Value			0.19	5.48

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

Table V shows the exponential growth rate of publication output in biomass energy research from 1998 to 2022. The study identified the highest exponential growth rate of 1.80 in 2004, with 36 publications, and the lowest rate of 0.64 in 2005, with 23 publications. The table indicates that the average exponential growth rate was 1.16. Overall, the study observed fluctuations in the exponential growth rate during the sample period. Table VI reveals the publication efficiency index of overall biomass energy research output during the study period. The average publication efficiency index during the sample period was 1.67. The highest publication efficiency index was recorded in 2006 at 4.85, with 32 publications, followed by 2008 with an index of 3.77 and 59 publications, and 2005 with an index of 3.19 and 23 publications. The lowest publication efficiency index was recorded in 2022 at 0.30, with 996 publications.

TABLE IV ANNUAL GROWTH RATE OF BIOMASS ENERGY RESEARCH

Year	TP	Cum Publications	AGR
1998	18	18	-
1999	20	38	11.11
2000	15	53	-25.00
2001	12	65	-20.00
2002	20	85	66.67
2003	20	105	0.00
2004	36	141	80.00
2005	23	164	-36.11
2006	32	196	39.13
2007	41	237	28.13
2008	59	296	43.90
2009	75	371	27.12
2010	82	453	9.33
2011	115	568	40.24
2012	113	681	-1.74
2013	153	834	35.40
2014	195	1029	27.45
2015	240	1269	23.08
2016	315	1584	31.25
2017	331	1915	5.08
2018	390	2305	17.82
2019	468	2773	20.00
2020	634	3407	35.47
2021	783	4190	23.50
2022	996	5186	27.20
Total	5186		

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

TABLE V EXPONENTIAL GROWTH RATE OF BIOMASS ENERGY RESEARCH

Year	TP	EGR
1998	18	-
1999	20	1.11
2000	15	0.75
2001	12	0.80
2002	20	1.67
2003	20	1.00
2004	36	1.80
2005	23	0.64
2006	32	1.39
2007	41	1.28
2008	59	1.44
2009	75	1.27
2010	82	1.09
2011	115	1.40
2012	113	0.98
2013	153	1.35
2014	195	1.27
2015	240	1.23
2016	315	1.31
2017	331	1.05

2018	390	1.18
2019	468	1.20
2020	634	1.35
2021	783	1.24
2022	996	1.27
Total	5186	1.16

TP= Total Publication, EGR= Exponential Growth Rate

TABLE VI PUBLICATION EFFICIENCY INDEX IN BIOMASS ENERGY RESEARCH

Year	TP	TC	PEI
1998	18	1001	1.48
1999	20	785	1.04
2000	15	727	1.29
2001	12	764	1.69
2002	20	1056	1.40
2003	20	522	0.69
2004	36	1791	1.32
2005	23	2761	3.19
2006	32	5835	4.85
2007	41	3162	2.05
2008	59	8373	3.77
2009	75	5937	2.11
2010	82	8966	2.91
2011	115	8864	2.05
2012	113	6565	1.54
2013	153	12145	2.11
2014	195	10273	1.40
2015	240	11171	1.24
2016	315	11943	1.01
2017	331	13187	1.06
2018	390	15594	1.06
2019	468	14623	0.83
2020	634	19670	0.83
2021	783	18071	0.61
2022	996	11237	0.30
Total	5186	195023	1.67

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

Table VII shows the activity index of India's contribution to global biomass energy research output from 1998 to 2022. The data reveal that, for twenty-one out of the twenty-five years studied, the activity index was below 100, reflecting India's research output being lower than the world average in biomass energy literature. The highest activity index was 172.83 in 2022, followed by 135.82 in 2021, 123.80 in 2020, and 101.76 in 2019. The lowest activity index was recorded in 2001 at 38.20 during the study period. Overall, the activity index exhibited a fluctuating trend throughout the study period.

Table VIII depicts the relative citation index of the top twenty-five countries, which ranges from 2.15 to 0.51 across 2,255 documents during the sample period. According to the table, Germany has the highest relative citation index at 4.20 with 57 documents, followed by Norway in second place with an index of 4.08 and 38 documents, and Japan in third place with an index of 3.26 and 52 documents. Ethiopia recorded the lowest relative citation index at 0.42 with 37 documents.

TABLE VII ACTIVITY INDEX OF BIOMASS ENERGY RESEARCH

Year	World TP	India TP	AI
1998	524	18	48.12
1999	520	20	53.87
2000	416	15	50.51
2001	440	12	38.2
2002	444	20	63.1
2003	574	20	48.81
2004	537	36	93.9
2005	612	23	52.64
2006	814	32	55.06
2007	1006	41	57.09
2008	1310	59	63.09
2009	1758	75	59.76
2010	1948	82	58.96
2011	2494	115	64.59
2012	2935	113	53.93
2013	3144	153	68.16
2014	3747	195	72.9
2015	4200	240	80.04
2016	4639	315	95.11
2017	5170	331	89.68
2018	5647	390	96.74
2019	6442	468	101.76
2020	7173	634	123.8
2021	8075	783	135.82
2022	8072	996	172.83
Total	72641	5186	

TP= Total Publication, AI= Activity Index

Table IX shows the time-series data for biomass energy research output from 1998 to 2022. The following formula was used to calculate the straight-line equation model.
Straight Line equation $Yc = a + bX$ Since $\Sigma X = 0$
Y- Publications
X- Unit of time
a & b constants to be calculated
Since $\sum X = 0$
$a = \Sigma Y/N = 5186/25 = 207.44$
$b = \Sigma XY/\Sigma X2 = 42993/1300 = 33.07$

Estimated literature in 2027 = 207.44+(33.07*(2027-2010)=769.66
Estimated literature in 2032 = 207.44+(33.07*(2032-2010)=935.01
Estimated literature in 2040 =207.44+(33.07*(2040-2010)=1576.26
Estimated literature in 2050 = 207.44+(33.07*(2050-2010)=2004.85
Therefore, the predicted biomass energy research output for the years 2027,2032, 2040 and 2050 is 769.66, 935.01, 1199.59 and 1530.30 respectively.

Table X shows the authorship pattern of papers in biomass energy research during the study period. A total of 5,186 articles were published, involving contributions from 22,345 authors. The table indicates that 131 research papers (2.53%) out of 5,186 publications were authored by single authors. This is followed by papers authored by two authors, who published 1,059 research papers (20.42%) involving 2,118 authors; three authors, who published 1,227 research papers (23.66%) involving 3,681 authors; four authors, who published 923 research papers (17.80%) involving 3,692 authors; and five or more authors, who together published 1,846 research papers (35.60%) involving 12,723 authors.

TABLE VIII RELATIVE CITATION INDEX OF BIOMASS ENERGY RESEARCH

S.No.	Country	TP	TC	ACCP	RCI	H-Index
1	USA	297	23751	79.97	2.15	64
2	South Korea	272	11338	41.68	1.12	57
3	Peoples Republic of China	207	13566	65.54	1.76	49
4	Saudi Arabia	143	4354	30.45	0.82	33
5	Australia	127	7782	61.28	1.64	48
6	Malaysia	121	4821	39.84	1.07	37
7	Vietnam	112	5775	51.56	1.38	44
8	England	111	9295	83.74	2.25	35
9	Taiwan	104	5266	50.63	1.36	36
10	Canada	100	10131	101.31	2.72	42
11	Thailand	61	3404	55.80	1.50	28
12	Germany	57	8918	156.46	4.20	29
13	Egypt	52	1291	24.83	0.67	21
14	Japan	52	6309	121.33	3.26	25
15	Sweden	46	3444	74.87	2.01	27
16	Pakistan	45	3715	82.56	2.22	27
17	Netherlands	43	2680	62.33	1.67	21
18	Russia	41	2591	63.20	1.7	17
19	South Africa	40	3110	77.75	2.09	24
20	Brazil	39	2276	58.36	1.57	22
21	Norway	38	5771	151.87	4.08	20
22	Scotland	38	3928	103.37	2.77	23
23	Ethiopia	37	584	15.78	0.42	14
24	France	37	2954	79.84	2.14	24
25	Oman	35	662	18.91	0.51	15
	Total	2255	147716			
	World TP	72641	2707194			

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

TABLE IX FUTURE GROWTH TREND (TIME SERIES) OF BIOMASS ENERGY RESEARCH

Year	TP	X	X2	XY
1998	18	-12	144	216
1999	20	-11	121	220
2000	15	-10	100	150
2001	12	-9	81	108
2002	20	-8	64	160
2003	20	-7	49	140
2004	36	-6	36	216
2005	23	-5	25	115
2006	32	-4	16	128
2007	41	-3	9	123
2008	59	-2	4	118
2009	75	-1	1	75
2010	82	0	0	0
2011	115	1	1	115

2012	113	2	4	226
2013	153	3	9	459
2014	195	4	16	780
2015	240	5	25	1200
2016	315	6	36	1890
2017	331	7	49	2317
2018	390	8	64	3120
2019	468	9	81	4212
2020	634	10	100	6340
2021	783	11	121	8613
2022	996	12	144	11952
Total	5186		1300	42993

TP= Total Publication

TABLE X AUTHORSHIP PATTERN IN BIOMASS ENERGY RESEARCH

Year	**SA**	**TA**	**TA**	**FA**	**MFA**	**TP**
1998	1	2	7	4	4	18
1999	2	9	3	3	3	20
2000	0	6	5	2	2	15
2001	0	6	4	1	1	12
2002	1	4	6	5	4	20
2003	2	7	2	5	4	20
2004	3	8	12	4	9	36
2005	1	4	9	4	5	23
2006	1	8	13	4	6	32
2007	4	13	9	9	6	41
2008	6	11	22	11	9	59
2009	6	20	32	7	10	75
2010	5	17	29	13	18	82
2011	12	31	30	18	24	115
2012	0	28	41	17	27	113
2013	1	36	50	27	39	153
2014	6	61	54	33	41	195
2015	9	55	64	45	67	240
2016	9	96	91	58	61	315
2017	6	80	85	61	99	331
2018	10	87	87	81	125	390
2019	5	106	111	107	139	468
2020	12	121	147	111	243	634
2021	12	122	143	131	375	783
2022	17	121	171	162	525	996
TP	131	1059	1227	923	1846	5186
%	2.53	20.42	23.66	17.8	35.6	100
TA	131	2118	3681	3692	12723	22345

TP= Total Publication, %=Percentage, SA= Single Authors, TA= Two Authors, TA= Three Authors, FA= Four Authors, MFA= More Than Five Authors.

TABLE XI AVERAGE AUTHOR PER PAPER AND PUBLICATION PER PAPER OF BIOMASS ENERGY RESEARCH

Year	TP	TA	AAPP	PPA
1998	18	63	3.50	0.29
1999	20	57	2.85	0.35
2000	15	46	3.07	0.33
2001	12	33	2.75	0.36
2002	20	67	3.35	0.30
2003	20	62	3.10	0.32
2004	36	124	3.44	0.29
2005	23	93	4.04	0.25
2006	32	113	3.53	0.28
2007	41	134	3.27	0.31
2008	59	207	3.51	0.29
2009	75	224	2.99	0.33
2010	82	289	3.52	0.28
2011	115	388	3.37	0.30
2012	113	435	3.85	0.26
2013	153	616	4.03	0.25
2014	195	713	3.66	0.27
2015	240	955	3.98	0.25
2016	315	1086	3.45	0.29
2017	331	1329	4.02	0.25
2018	390	1648	4.23	0.24
2019	468	1886	4.03	0.25
2020	634	2729	4.30	0.23
2021	783	3777	4.82	0.21
2022	996	5271	5.29	0.19
Total	5186	22345	3.68	0.28

TP= Total Publication, TA= Total Authors, AAPP=Average Author Per Paper, PPA= Productivity Per Author

Table XI depicts data on the average number of authors per paper in biomass energy research during the sample period from 1998 to 2022. The table reveals that the average number of authors per article was 3.68 across 5,186 published articles, with a total of 22,345 authors contributing during the study period. It also shows that the highest average number of authors per article was 5.29 in 2022, while the lowest was 2.75 in 2001. The average productivity per author for the period 1998–2022 was 0.28. The highest author productivity was recorded in 2001 at 0.36, whereas the lowest productivity per author was 0.19 in 2022.

Table XII shows the research productivity of highly prolific authors in biomass energy research during the period 1998–2022. Kumar, S., is the most productive author, with 122 records (9.20%). Based on the total local citation score, Banu, J. R. has the highest score, topping the table with 315 citations, while Varjani, S. has the lowest local citation score among the most productive authors, with 8 citations. In terms of total global citation scores, Pandey, A. has emerged as the top recipient, with 4,522 global citations, whereas Mishra, S. has the lowest global citation score among the most productive authors, with 991 citations. With respect to cited references, Kumar, G. leads with 310 cited references included in the bibliographies of his publications, while Sharma, S. has the fewest cited references, with 33 references across 34 publications. Regarding the average number of cited references per publication, calculated by dividing total cited references by the number of publications, Kavitha, S. has the highest average cited reference score of 5.28. In contrast, Sharma, S., recorded the lowest average cited reference score of 0.97 across 34 publications. Among the most productive authors, Kumar, S., achieved the highest h-index of 36, whereas Mishra, S., recorded the lowest h-index of 14.

TABLE XII TOP TWENTY FIVE PROLIFIC AUTHORS IN BIOMASS ENERGY RESEARCH

Sl. No	Author	TP	%	TLCS	TGCS	CR	Avg. CR	H-Index
1	Kumar S	122	9.2	222	4044	232	1.9	36
2	Kumar A	119	8.97	210	3879	211	1.77	31
3	Kumar G	67	5.05	173	2917	310	4.63	30
4	Kumar V	67	5.05	53	1672	166	2.48	23
5	Banu JR	64	4.83	315	2204	306	4.78	29
6	Kumar R	63	4.75	119	1896	113	1.79	28
7	Pandey A	62	4.68	150	4522	98	1.58	31
8	Kumar M	55	4.15	57	1379	115	2.09	21
9	Singh S	54	4.07	92	2074	102	1.89	23
10	Kumar P	51	3.85	37	2539	112	2.2	20
11	Das D	49	3.7	246	2970	76	1.55	26
12	Pugazhendhi A	48	3.62	64	2479	145	3.02	30
13	Singh R	48	3.62	70	1756	85	1.77	24
14	Sharma A	47	3.54	34	1441	82	1.74	16
15	Singh A	44	3.32	108	2145	117	2.66	21
16	Varjani S	44	3.32	8	1249	137	3.11	21
17	Ghosh S	41	3.09	58	1146	94	2.29	20
18	Bhaskar T	39	2.94	195	2754	65	1.67	21
19	Kumar P.S	38	2.87	22	1320	105	2.76	20
20	Kavitha S	36	2.71	252	1454	190	5.28	24
21	Mohanty K	35	2.64	174	1739	131	3.74	20
22	Sharma S	34	2.56	98	1573	33	0.97	19
23	Singh R.K	34	2.56	91	1550	83	2.44	18
24	Mishra S	33	2.49	42	991	60	1.82	14
25	Dasappa S	32	2.41	221	1385	130	4.06	21
	Total	1326	100					

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

Table XIII presents the most productive journals in biomass energy research. *Bioresource Technology* published the highest number of records, with 270 publications (12.43%), while *ChemistrySelect* had the lowest number, with 33 publications (1.52%). In terms of total local citation score (TLCS), *Renewable & Sustainable Energy Reviews* leads with a TLCS of 1,361, whereas *Science of the Total Environment* recorded a TLCS of zero. Regarding total global citation score (TGCS), *Renewable & Sustainable Energy Reviews* also ranks highest, with a global citation score of 29,894, while *ChemistrySelect* recorded the lowest TGCS, with 324 citations. In terms of the h-index, *Renewable & Sustainable Energy Reviews* achieved the highest value at 94, whereas *ChemistrySelect* recorded the lowest h-index of 9.

TABLE XIII TOP TWENTY FIVE JOURNALS IN BIOMASS ENERGY RESEARCH

Sl. No.	Journal	TP	%	TLCS	TGCS	H-Index
1	Bioresource Technology	270	12.43	944	16427	71
2	Renewable & Sustainable Energy Reviews	200	9.2	1361	29894	94
3	Fuel	176	8.1	188	7046	45
4	Biomass Conversion and Biorefinery	162	7.46	210	2151	24
5	International Journal of Hydrogen Energy	128	5.89	361	5105	42
6	Journal of Cleaner Production	111	5.11	187	5641	44
7	Energy	110	5.06	345	3940	39
8	Renewable Energy	109	5.02	505	5733	39
9	Biomass & Bioenergy	107	4.92	394	4747	39
10	Materials Today-Proceedings	94	4.33	45	667	14
11	Energy Sources Part A-Recovery Utilization and Environmental Effects	92	4.23	119	988	18
12	Environmental Science and Pollution Research	70	3.22	48	1487	22
13	Chemosphere	55	2.53	12	1899	26
14	Energy Conversion and Management	55	2.53	208	2948	30
15	Sustainable Energy Technologies and Assessments	48	2.21	3	660	16
16	Energy & Fuels	45	2.07	239	5507	19
17	Desalination and Water Treatment	42	1.93	21	614	14
18	RSC Advances	42	1.93	128	1808	23
19	Waste and Biomass Valorization	39	1.79	47	460	12
20	International Journal of Energy Research	38	1.75	70	591	15
21	Science of the Total Environment	38	1.75	0	1643	24
22	Journal of Environmental Management	37	1.7	47	1219	20
23	Clean Technologies and Environmental Policy	36	1.66	50	609	13
24	Journal of Energy Storage	36	1.66	6	1089	20
25	Chemistryselect	33	1.52	20	324	9
	Total	2173	100			

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

TABLE XIV TOP DOCUMENT TYPES IN BIOMASS ENERGY RESEARCH

Sl. No.	Document Type	TP	%	TLCS	TGCS
1	Article	2644	50.9	5400	93244
2	Article; Early Access	1180	22.8	420	17283
3	Review	545	10.5	2301	69178
4	Proceedings Paper	366	7.1	92	1548
5	Review; Early Access	309	6	166	8504
6	Article; Proceedings Paper	66	1.3	312	4168
7	Proceedings Paper; Early Access	59	1.1	22	361
8	Editorial Material	7	0.1	4	265
9	Review; Book Chapter	4	0.1	5	259
10	Article; Retracted Publication	3	0.1	0	7
11	Editorial Material; Early Access	1	0	0	1
12	Letter	1	0	1	58
13	Review; Retracted Publication	1	0	4	151
	Total	5186	100		

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

Table XIV shows the preferred communication channels among researchers in the field of biomass energy research. Journal articles are the most preferred form of communication. Out of 5,186 records, 2,644 documents (50.90%) are journal articles, which have obtained a total local citation score (TLCS) of 5,400 and a total global citation score (TGCS) of 93,244, representing the highest number of local and global citations among the communication channels used by biomass energy researchers. Approximately three-fourths of the communication channels employed by biomass energy researchers to disseminate their research findings are journal articles.

TABLE XV TOP TEN HIGHLY CITED PAPERS IN BIOMAS ENERGY RESEARCH

Sl. No.	Authors	Article Title	Source Title	TC	PY
1	Mohan, D., Pittman, C.U.,Steele, P.H	Pyrolysis of wood/biomass for bio-oil: A critical review	Energy & Fuels	4030	2006
2	Naik, S.N *et.al.*	Production of first and second generation biofuels: A comprehensive review	Renewable & Sustainable Energy Reviews	1972	2010
3	Smith, P *et.al.*	Greenhouse gas mitigation in agriculture	Philosophical Transactions of the Royal Society Biological Sciences	1523	2008
4	Dutta, S., Bhaumik, A., Wu, K.C.W	Hierarchically porous carbon derived from polymers and biomass: effect of interconnected pores on energy applications	Energy & Environmental Science	1157	2014
5	Menon, V., Rao, M	Trends in bioconversion of lignocellulose: Biofuels, platform chemicals & biorefinery concept	Progress In Energy And Combustion Science	1062	2012
6	Thomas, B., *et.al.*	Nanocellulose, a Versatile Green Platform: From Biosources to Materials and Their Applications	Chemical Reviews	850	2018
7	Dhyani, V., Bhaskar, T	A comprehensive review on the pyrolysis of lignocellulosic biomass	Renewable Energy	833	2018
8	Goyal, H.B., Seal, D., Saxena, R.C	Bio-fuels from thermochemical conversion of renewable resources: A review	Renewable & Sustainable Energy Reviews	772	2008
9	Jaleel, C.A., *et.al.*	Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition	International Journal Of Agriculture And Biology	737	2009
10	John, R.P., *et.al.*	Micro and macroalgal biomass: A renewable source for bioethanol	Bioresource Technology	699	2011

Table XV presents data on the top ten highly cited research papers in biomass energy. The table shows that the most highly cited article is by Mohan, D., Pittman, C. U., and Steele, P. H., published in the journal *Energy & Fuels*, titled "Pyrolysis of wood/biomass for bio-oil: A critical review" in 2006. This article received 4,030 citations from other researchers, securing the first rank among the selected highly cited articles.

VI. FINDINGS OF THE STUDY

1. In the year-wise publication of biomass energy research in India, 996 research papers were published in 2022 out of a total of 5,186 during the sample period. In 2006, the highest average number of citations per paper was 182.34, and the highest h-index of 70 was recorded in 2020.
2. In the year-wise publication of biomass energy research worldwide, 8,075 research papers were published in 2021 out of a total of 72,641 during the sample period. In 2002, the highest average number of citations per paper was 93.11, and the highest h-index of 173 was recorded in 2010.
3. The relative growth rate and doubling time of publications in India vary in biomass energy research, with a mean relative growth rate of 0.23 and a mean doubling time of 3.10. Globally, the relative growth rate and doubling time of publications also vary, with a mean relative growth rate of 0.20 and a mean doubling time of 3.69.
4. The study reveals fluctuating relative growth rates and doubling times of citations in India's biomass energy research, with a mean relative growth rate of 0.21 and a doubling time of 4.09. Globally, the mean relative growth rate of citations was 0.19, and the doubling time was 5.48.
5. The year 2004 recorded the highest annual growth rate (AGR) at 80.00, while the lowest AGR was recorded in 2003 at 0.00.
6. The average exponential growth rate of biomass energy research was 1.16 during the study period.
7. The average publication efficiency index during the sample period was 1.67.

8. The highest activity index was 172.83 in 2022, while the lowest activity index was 38.20 in 2001.
9. Based on the relative citation index, Germany recorded the highest value at 4.20 with 57 documents, whereas Ethiopia recorded the lowest value at 0.42 with 37 documents.
10. The study found that the expected future growth rate of biomass energy research shows an increasing trend.
11. During the study period, a total of 5,186 articles were published, with contributions from 22,345 authors. The study further observed that multi-authored papers were more prevalent than single-authored papers.
12. The average number of authors per article was 3.68, and the average productivity per author was 0.28 in biomass energy research.
13. The study analyzed the contributions of the top 25 authors in biomass energy research based on research output, total local citation score, total global citation score, cited references, average cited references, and h-index.
14. The study examined the contributions of the top 25 journals in biomass energy research based on research output, total local citation score, total global citation score, and h-index.
15. Journal articles are the most popular communication medium among biomass energy researchers. Out of 5,186 records, 2,644 documents (50.90%) are journal articles, which obtained a total local citation score of 5,400 and a total global citation score of 93,244.
16. The study analyzed highly cited papers in biomass energy research.

VII. CONCLUSION

Scientometric analysis plays a vital role in formulating appropriate strategies to enhance research activities. A comprehensive scientometric evaluation of biomass energy research performance in India and worldwide is crucial for developing a clear understanding of the field and identifying measures to strengthen future research efforts. In particular, assessing the research output of leading biomass energy journals and examining the contributions and impact of top authors provide valuable insights into the overall progress, strengths, and gaps within this domain. The study provides a comprehensive overview of biomass energy research by analyzing data indexed in the Web of Science database from 1998 to 2022. During this period, a total of 5,186 research publications were produced in India, receiving 195,023 citations. In comparison, 72,641 research papers worldwide received 2,707,194 citations in the same period. One of the key findings of the study is the presence of fluctuations in research output and impact over time, which is highly relevant to understanding the dynamics of biomass energy research.

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The authors confirm that no AI-assisted technologies were used in the preparation or writing of the manuscript, and no images were altered using AI.

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