International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-8, Issue-7, July 2022
ISSN: 2395-3470
www.ijseas.com

Solar Cell Research Output in India: A Scientometric Study

***S. Ravichandran, ** Dr.S.Vivekanandhan *** G.VinitaAngeline**

*Library Assistant Grade-1, SRM Institute of Science and Technology, Kattankolathur, Chengalpet, Tamilnadu, India. Pin- 603203, Mobile: 9952054226, Mail:ravichas2@srmist.edu.in
Corresponding author: S. Ravichandran

**Assistant Librarian, SRM Institute of Science and Technology, Kattankolathur, Chengalpet, Tamilnadu, India. Pin: 603203, Mobile: 9840133850, Mail: vivekans@srmist.edu.in

***Assistant Librarian, Nehru Arts and Science College, Thiumalayam palayam, Coimbatore, Tamilnadu, India, Pin- 641105, Mobile: 9790750681,

Mail- Nascgvinitaangeline@nehrucolleges.com

Abstract

This paper discusses the scientometric analysis of solar cell research publications in India during 2010-2019 with a total number of 8017 publications from the SCOPUS multidisciplinary online database. During the study period, it is identified the year-wise distribution of the maximum of 1416(17.66%) research publications. the maximum author-wise contribution of Sharma, G.D. S. 181 (21.65%) research publications. Global publications are increasing from 5.67 percent to 12.37 percentage, and Indian output also increasing from 0.18 to 1.26 percent. The authorship pattern amongst six and above authors' contributions is 1783(22.24%) papers. CAI is decreasing trend for more than three authors from 1st block year (102.60) to 2nd block year (99.03). The average degree of collaboration is 0.98. The highest collaboration coefficient is 0.70 in the most of years and the lowest CC is 0.67 in the year 2013, the average CC is 0.69. The collaboration index observed the maximum of collaboration Index is 4.31 in the year 2014, a minimum of 4.02 in the year 2011, and average CI is 4.17. The Modified collaboration coefficient observed the a maximum of is 0.71 in the year 2011, a minimum of 0.67 in the year 2013, and an average MCC is 0.69. The maximum RGR of 0.96 has been recorded in the year 2011 and the minimum RGR of 0.19 has been counted in the year 2019, while the maximum doubling time of 3.57 has been counted in the year 2019 and the minimum doubling time of 0.72 has been counted in the year 2011. Indian Institute of Technology, Bombay 407(4.33%) research publications. AIP Conference Proceedings research having 397 (7.15%) research journals. A maximum of 1140 of highly cited publications is identified for Babu, S.S., Praveen, V.K., Ajayaghosh, (2014) A. Functional π-gelators and their applications: Chemical Reviews, 144(4):1973-2129.

Keywords: Scientometric, Solar cell, solar energy, Relative citation index, Degree of Collaboration, Co-author index.

History of the Solar Cell

The photovoltaic effect was first reported by Edmund Becquerel in 1839 when he observed that the action of light on a silver-coated platinum electrode immersed in electrolyte produced an

electric current. Forty years later, the first solid-state photovoltaic devices were constructed by workers investigating the recently discovered photoconductivity of selenium. In 1876, William Adams and Richard Day found that a photocurrent could be produced in a sample of selenium when contacted by two platinum contacts. In 1894, Charles Fritts prepared what was probably the first large-area solar cell by pressing a layer of selenium between gold and another metal. In the following years, photovoltaic effects were observed in copper-copper oxide thins well as in lead sulfide and thallium sulfide.

These early cells were thin-film Schottky barrier devices, where a semitransparent layer of metal deposited on the semiconductor provided both the asymmetric electronic junction, which is necessary for photovoltaic action and access to the junction for the incident light. In the 1950s, the development of silicon electronics followed the discovery of a way to manufacture p-n junctions in silicon. Naturally, n-type silicon wafers developed a p-type skin when exposed to the gas boron dichloride. Part of the skin could be etched away to give access to the n-type layer beneath. These p-n junction structures produced much better-rectifying action than Schottky barriers and better photovoltaic behavior. The first silicon solar cell was reported by Chapin, Fuller, and Pearson in 1954 and converted sunlight with an efficiency of six percent. [1]

Bibliometric study

Nelson, J. (2003)[2], DOE (1980)[3], Barnett, A. A. (1978)[4]. Solar power is a renewable resource that is available everywhere in the world. Solar energy is widely available throughout the world and can contribute to reduced dependence on energy imports. Solar cells, popularly known as Photovoltaic (PV) cells, are electrical devices that help us to convert solar energy into direct current

Verma, S. S. (2016)[5]. Solar cells are devices in which sunlight releases electric charges. Hu. C, Richard M. White, R.M, (1983)[6]. Solar cells are a promising and potentially important technology and are the future of sustainable energy for human civilization. Solar cells need to absorb a range of energy (Ranabhat, Kiran. et al., 2016)[7]. The temperature of solar cells was derived based on the calculation of heat generation and a given global heat transfer coefficient. Bach, U. et al. (1998)[8]. Power generated from sustainable and environmentally benign solar cell technologies is one of the key aspects in the development of clean renewable energy.

Rokas Kondrotas Chao Chen Jiang Tang, (2018)[9]. Solar energy photovoltaic technology has developed rapidly for the past years and researchers over the world have been working hard on improving the efficiency and reducing the cost of photovoltaic devices. Wang, Ao Xuan, Yimin (2018)[10], Krebs et al., (2009)[11]. The International Energy Agency hopes to make solar cells the largest source of electricity in the world by 2050. Several scientometric studies have reported analysis of solar energy literature, but fewer only available on solar cell research. Therefore, the present study aims to find the status of solar cells' research performance.

Review of Literature

Kavitha R et.al (2018)[12] this analysis the research output on Solar cells using the Scopus database from 1978 to 2017. The Out of 1, 50,201 solar cell research publications, 4430 (2.95%) were from open access sources, and 1, 45,771 (97.5%) were from other sources. On average,

there were 111 open access papers per year and 3,755 papers in a year. There exists study growth of publications. 55% of articles appeared during the last six years of 2012 and 2017. More than 10000 articles can be seen only from 2012 (10854, 7.23%). In the year 2017, it raises to one and half times i.e. 15113 (10.06%). Nearly 14 countries contributed more than 2750 publications. 96,377 (64.17%) papers were published as Journal articles.

Bharvi and KhaiserNikam (2014)[13] The paper looks into collaboration in solar cell research in India as reflected by the publications indexed in Web of Science for a period of 20 years from 1991-2010. Almost half of the total output emerged out of domestic and international collaboration. Academic institutions had an almost equal proportion of output emerging from domestic as well international collaboration. Among the prolific institutions, the National Physical Laboratory-Delhi of the Council of Scientific and Industrial Research had the highest publications emerging out of collaborative research.

Bharvi Dutta and Khaiser Nikam(2015)[14] He examines global solar cell research as reflected in Science Citation Index-Expanded (SCI-E) for the years 1991, 1995, 2000, 2005, and 2010 have been studied. Using various bibliometric indicators, the study examined the pattern of co-authorship and nature of collaboration concerning different types of institutions, countries, and prolific institutions. It also looked into the impact of collaboration in terms of citations. The study observed a peculiar behavior were in a publication from certain prolific countries and institutions emerging from domestic collaboration resulted in a higher impact than those from international collaboration.

Bensi Dong et.al (2012)[15] in this study on solar power research, some significant points have been obtained on the research performance throughout the period from 1991 to 2010. There are 45,559 articles in 2924 journals listed in 122 SCI subject categories. The research on solar power focused on physics, materials Sciences, chemistry, energy & fuels, and engineering fields. Meanwhile, more attention was paid to polymer science and optics fields. 137 countries were producing SCI papers about solar power. The USA showed the greatest count of world articles and the international collaborative articles. Mainland China and South Korea showed the highest growth pace during 1996–2010.

Sivasami K (2019)[16] He examines the discussion on Scientometric analysis of solar cells research performance from 2009 to 2018, a total of 46676 records were retrieved and downloaded during the study period. solar cells research publications show an increasing trend, 55925 authors were contributed to this research during the study period, amongst Kim J H has first position 505 contributions, remaining 55924 authors were contributed below 500 contributions. Institutions wise contributed “Chinese AcadSci” has the first position with 3153 contributions,

Ravichandran.S & Vivekanandhan. S (2021)[17] examines the Scientometric analysis of wastewater management research publications from 2010 to 2019 from the Scopus online database. This study identified that a maximum of 2842(14.31%) research publications with 19857 citations are contributed in the year 2019. Ngo, H.H, contributed a maximum of 101 (0.51%) research publications, maximum of 19355 articles were contributed by joint authors and the average degree of collaboration was 0.97. The range of the Collaborative Co-efficient was

(0.76-0.69), and the range of the Collaborative index was (4.85-4.09). A maximum of 2102(10.58%) research publications are contributed in Bio resource technology, the ministry of education, china with 863(22.32%) research publication, and China has contributed a maximum of 5919(29.80%) research publications. A maximum of 18037 (90.82%) research publications are contributed by article.

Gangland Prathap (2014)[18] the analysis of this paper of science of polymer solar cells and the technology based on it is now pursued as a very exciting and promising during the period 1986 to 2013 the area of research at leading universities, we conduct a comprehensive and in-depth bibliometric analysis of this area that breaks down scholarly performance into three components—quantity, quality, and consistency. We have taken the h-index and the z-index together to create two-dimensional maps that allow better visualization of the information production process. We see from the analyses that the z-index is more versatile than the h-index in assigning a single number to evaluate performance from the point of view of its ability to reconcile quantity, quality, and consistency

Alex Fabianne de Paulo and Geciane Silveira Porto (2017)[19] this paper aims to identify the development of solar energy technologies through open innovation. Manuscripts about solar energy and open innovation published between the years 2000 and 2014 in journals indexed by Web of Science Core Collection were used to create a database and terms related to solar energy and open innovation were sought in papers title, International cooperation is prevalent in countries like the Netherlands, United Kingdom, Spain, and Germany. A national partnership occurs in Japan, the United States, France, Italy, and South Korea. China has a predominant local cooperation profile, but it will be a major international collaborative actor in solar energy research next year.

Ravichandran. S and Vivekanandhan S. (2020)[20] analysis of solid waste management research publications (2010-2019) using Scopus database with a total number of 5198 research publications. The study identified that a maximum of 694 (13.35%) research publications are contributed in the year 2019, and the compound annual growth rate was 3.67. A maximum of 3907(75.16%) research publications are contributed by article, maximum of 43 (0.83%) research publications are contributed by Huang G.H, India. Out of 5198 research publications, 579 (11.14%) research publications are contributed by single authors, and the remaining 4619 (88.86%) research publications are contributed by multi-author's and the average degree of collaboration was 0.88. From this study, the relative growth rate is 0.63 in the year 2011 and 0.14 in the year 2019 at the same time doubling time was 1.10 in the year 2011 and 4.84 in the year 2019.

Methodology

The data have been collected from the Scopus database, the study period was during (2010-2019). The search string was used, "Solar Cells" in the Title search box, the field was used, and the period field was select from 2010 to 2019. A total of 8017 records were retrieved from the Scopus database. (TITLE-ABS-KEY ("Solar Cell") AND PUBYEAR > 2009 AND PUBYEAR < 2020 AND (LIMIT-TO (AFFILCOUNTRY,"India"))). The data was collected on 31.12.2020.

Objectives

The following objectives are framed for the present study;

- To find out year-wise publications in Solar Cells research
- To find author-wise contribution in Solar Cells research
- To find out authorship pattern, co-authorship index in Solar Cells research
- To find out the Degree of collaborations in solar Cell research
- To find CI, CC, MCC Indexing in solar cell research
- To find out RGR and doubling time in solar cell research
- To identify document types contributed to Solar Cells research
- To examine top ten institutions, countries that contributed to Solar Cells
- To examine top ten journals contributed, funding agency in Solar Cells
- To subject wise in solar cell research
- To find out Highly cited paper in solar cell research

Finding and Data collections

Year wise distributions in solar cell research publications

Table 1 Year wise distributions in solar cell research publications

S.No	Years	Publications	%	Cumulative	%
1	2010	203	2.53	203	2.53
2	2011	327	4.08	530	6.61
3	2012	353	4.40	883	11.01
4	2013	523	6.52	1406	17.54
5	2014	772	9.63	2178	27.17
6	2015	831	10.37	3009	37.53
7	2016	1033	12.89	4042	50.42
8	2017	1147	14.31	5189	64.72
9	2018	1412	17.61	6601	82.34
10	2019	1416	17.66	8017	100.00
	Total	8017	100.00		
	CAGR	21.44			

Table1 shows that year-wise distributions research publications for solar cell research during the study period of 2010-2019. From this study, it is identified that a maximum of 1416(17.66%) research publications are contributed the year 2019, followed by publications of 1412(17.61%) research publications, third place is 1147(14.31%) research publications. And compound annual growth rate [CAGR] value is 21.44.

Compound Annual Growth Rate [CAGR]

The Compound Annual Growth Rate [CAGR] is one of the useful measures to identify the growth, over the multiple time periods. It can be measure from the initial number of publications to ending number of publications. The mathematical formula of CAGR is used Ashok Kumar and Gopala Krishnan (2013)[21]

The compound annual growth rate was calculated by the following formula,

$$\mathbf{CAGR} = \left[\frac{\mathbf{Ending\ Value}}{\mathbf{Begining\ Value}}\right]^{\left[\frac{1}{\mathbf{\#\ of\ Years}}\right]} -1$$

During the ten year study period compound annual growth rate is calculated by the publications of beginning year and ending year. From the study it is identified that the CAGR is 21.44

Citations per Publication (CPP)

Bharvi and Khaiser (2016)[22.] From this study, CPP has been used to assess the impact of Solar cell research publications for the years, countries, institutes, and authors for the below-mentioned formula,

$$\text{CPP} = \frac{\text{Total Citations of a Country or Institution}}{\text{Total of Publications}}$$

CPP has been broadly used in the scientometric assessment to stabilize the variation in volumes of literature published by the different institutions / countries and etc.

World Vs Indian contributions in solar cell research performance

Table 2 world Vs Indian contributions in solar cell research performance

S.No	Publications Years	Global output	% of	Indian output	112058 of %
1	2010	6353	5.67	203	0.18
2	2011	8322	7.43	327	0.29
3	2012	9458	8.44	353	0.32
4	2013	10593	9.45	524	0.47
5	2014	12022	10.73	772	0.69
6	2015	12167	10.86	832	0.74
7	2016	12358	11.03	1032	0.92
8	2017	12984	11.59	1147	1.02
9	2018	13936	12.44	1411	1.26
10	2019	13865	12.37	1416	1.26
	Total	112058	100.00	8017	7.15

Table 2 shows that world Vs Indian contributions in solar cell research performance, a total of 112058(100%) records were contributed in solar Cells research during the study period 8017 (7.15%) papers were contributed by Indian scientist during the study period. Global publications are increasing from 5.67 percent to 12.37 percentage, and Indian output also increasing from 0.18 to 1.26 percent.

Author-wise Contributions solar cell research publications

Table 3 Author wise Contributions solar cell research publications

S. No	Name of the Author	Affiliation	No. of Papers	%	Citations	%
1	Sharma, G.D.	Indian Institute of Technology, Bombay.	181	21.65	3152	18.69
2	Patil, P.S.	Council of Scientific and Industrial Research India, Chennai.	98	11.72	3174	18.82
3	Singh, S.P.	National Physical Laboratory India, Delhi.	88	10.53	1837	10.89
4	Kim, J.H.	Indian Institute of Technology Delhi.	86	10.29	2939	17.43
5	Ramasamy, P.	Indian Institute of Science, Bengaluru.	74	8.85	302	1.79
6	Dutta, V.	Indian Institute of Chemical Technology, Mumbai.	66	7.89	1026	6.08
7	Muthukumarasamy, N	Academy of Scientific and Innovative Research AcSIR, Chennai	65	7.78	951	5.64
8	Giribabu, L.	Shivaji University, Maharashtra	62	7.42	1387	8.23
9	Mali, S.S.	Savitribai Phule Pune University, Pune.	62	7.42	1721	10.21
10	Pathan, H.M.	Indian Association for the Cultivation of Science, west Bengal.	54	6.46	373	2.21
Total			836	100	16862	100

Table 3 depicts the top 10 ranking of authors in the field of solar cell research publications in India for the selected ten year study period. During the study period it is identified that maximum number of 181 (21.65%) research publications are contributed by Sharma, G.D. with 3152(18.69%) citations. Followed by Patil, P.S 98(11.72%) publications with 3174(18.82%) citations and Singh, S.P. with 88 (10.53%) and received 1837(10.89%) citations during the study period.

Authorship pattern of solar cell research publications in India

Table 4 Authorship pattern of solar cell research

S.No	Authorship pattern	No. of Publications	%
1	Single author	197	2.46
2	Two authors	1578	19.68
3	Three authors	1724	21.50
4	Four authors	1592	19.86
5	Five authors	1143	14.26
6	Six and above authors	1783	22.24
	Total	8017	100.00

Table 4 shows that authorship pattern in solar cell research performance, contributed by 8017 Publications. Amongst six and above authors contributions are 1783(22.24%), five authors collaborative are 1143(14.26) papers, four authors collaborative are 1592(19.86%) papers, three authors collaborative are 1724(21.50%) papers, double authors collaborative are 1578(19.68%) papers, Single author collaborative are 197(2.46%) papers. It reveals that single author contributions are less compare with multi-authored papers.

Co-authorship Index (CAI)

To study how the pattern of co-authorship and the use of co-authorship index suggested by Garg and Padhi (2001)[23] has been explained the under mentioned formula. To evaluate the co-authorship index (CAI) is the whole data set was divided into 5 block years.

$$CAI = \left[\frac{(Nij/Nio)}{(Noj/Noo)}\right] \times 100$$

Where as
Nij: Number of publications having j authors in i block
Nio: Total publications of i block
Noj: Number of publications having j authors for all blocks
Noo: Total number of publications for all authors and the all blocks
Here CAI=100 implies that a country's co-authorship effort for a particular authorship correspond to the world average
CAI > 100 reflects higher than average co-authorship effort
CAI < 100 reflects lower than average co-authorship effort by that country for a given type of authorship pattern.

Co authorship index of solar cell research Publications

Table 5 Co authorship index of solar cell research Publications

5 years Block	Single Author	CAI	Two Author	CAI	Three Author	CAI	More than three Author	CAI	Total
2010-2014	75	140.1	408	95.17	1198	98.89	497	102.60	2178
2015-2019	122	85.03	1170	101.8	3261	100.4	1286	99.03	5839
Total	197		1578		4459		1783		8017

Table 5 shows that Co-Authorship Index values are calculated by block year period for solar cell research publications for the selected ten-year study period. From the study, it is identified that CAI for two, and three authorship contributions are increasing trend from 1st block year to 2nd block year. At the same time, CAI is decreasing trend for single and more than three authors from 1st block year (102.60) to 2nd block year (99.03).

Degree of Collaboration (DC) of solar cell research Publications

Degree of collaboration is relationship between single author and multi author contributions. The degree of collaboration is calculated by the Subramanian (1983)[24] formula, used by Vivekanandhan (2016), [25] Sivasamy (2020).[26] Ravichandran (2021)[27]

$$DC = \frac{Nm}{(Nm + Ns)}$$

Where DC = Degree of Collaboration

N_m = Number of Multi authored publications

N_s = Number of single authored publications

In the present study, Nm = 7820, Ns= 197

So that the degree of collaboration is =7820/ (197+7820) = 0.98

Degree of Collaboration (DC) of solar cell research Publications

Table 6 Degree of collaboration (DC) of solar cell research Publications

year	Single Author Publications	Multi Author Publications	Total Author Publications	Degree of Collaboration DC= Nm/(Nm+Ns)
2010	6	196	202	0.97
2011	12	315	327	0.96
2012	16	337	353	0.95
2013	24	500	524	0.95
2014	17	755	772	0.98
2015	20	812	832	0.98

2016	23	1009	1032	0.98
2017	17	1130	1147	0.99
2018	33	1378	1411	0.98
2019	29	1388	1417	0.98
Total	**197**	**7820**	**8017**	**0.98**

Table 6 shows the degree of collaboration in solar cell research publications for the ten-year studies period. From this study, it is identified that the degree of collaboration is between 0.97in the year 2010 and 0.98 in the year 2019. The average degree of collaboration is 0.98. From this study, it is identified that the majority of solar cell research publications are contributed by collaborative authors.

Collaborative Coefficient (CC)

The pattern of co-authorship collaboration among the authors can be measured with the following formula suggested by Ajiferuke, et al. (1988)[28]

$$CC = 1 - \left[\sum_{j=0}^{k} \left(\frac{1}{j}\right) \times Fj/N\right]$$

Whereas,
Fj = Number of publications with j author papers
N = Total number of the research publications and
k = the greatest number of authors/ paper in the given field.

Collaboration Index (CI)

The simple indicator are presently employed in the publications to the collaboration index, which is to be understand nearly as the mean number of authors per paper are suggested by Ajiferuke, et al.(1988)[28]

$$CI = \frac{\sum_{j=1}^{k} jfj}{N}$$

Here

J - The number of co-authored papers appearing in a discipline
N - The total number of publications in the field over the same time period of interval and
k - The highest number of authors per paper in a same time field.

Modified Collaboration Coefficient

The modified collaboration coefficient (MCC) counted by the formula which is suggested by (Savanur and Srikanth, 2010)[29]

Which is given below:

Where,

$$MCC = \frac{N}{N-1}\left[1 - \frac{\sum_{j=1}^{k} jfj}{N}\right]$$

j = the number authors in an article i.e. 1, 2, 3.....

Fj = the number of j authored articles

N = the total number of articles published in a year, and

A = the total number of authors per articles

Collaborative Measures in Solar cell Research Publications

Table 7 Collaborative Measures in Solar cell Research Publications

year	1	2	3	4	5	6	7	8	9	>9	CC	CI	MCC	Total
2010	6	30	47	40	36	21	8	7	5	2	0.70	4.21	4.23	202
2011	12	66	59	57	60	32	21	8	8	4	0.69	4.17	4.18	327
2012	16	69	70	70	44	42	22	11	6	3	0.68	4.08	4.10	353
2013	24	109	117	107	56	46	25	17	12	11	0.67	4.02	4.03	524
2014	17	134	186	144	105	67	42	28	27	22	0.70	4.31	4.32	772
2015	20	159	179	175	129	69	46	17	16	22	0.70	4.15	4.16	832
2016	23	205	212	211	139	86	53	38	34	31	0.70	4.28	4.28	1032
2017	17	241	242	220	164	94	62	42	33	32	0.70	4.25	4.25	1147
2018	33	262	325	287	199	127	73	52	26	27	0.70	4.16	4.16	1411
2019	29	303	287	281	211	127	80	45	22	32	0.69	4.15	4.15	1417
Total	197	1578	1724	1592	1143	711	432	265	189	186	6.94	41.78	41.86	8017

It is observed from Table 6, the collaborative coefficient is calculated and presented during the ten year study period from 2010 to 2019. For solar cell research publications, it is observed from the table 7 highest collaboration coefficient is 0.70 in the most of year and lowest CC is 0.67 in the year 2013, average CC is 0.69. The collaboration index observed from the table 7 maximum of collaboration Index is 4.31 in the year 2014, minimum of 4.02 in the year 2011, and average CI is 4.17. The Modified collaboration coefficient observed from the table 7 maximum of modified collaboration coefficient is 0.71 in the year 2010, minimum of 0.67 in the year 2013, and the average MCC is 0.69.

RGR and doubling time

The doubling time is the time taken for the doubling of the number of records actually published within a stipulated period. The doubling time is calculated from the relative growth rate (difference between the logarithms of beginning and end of the year from the study) and the natural logarithm number is used, the difference has a value of 0.693. Thus the corresponding

doubling time for each specific period of interval and for both publications and pages can be calculated by the following formula,

$$Dt = \frac{0.693}{R(a)}$$

RGR and doubling time of solar cell research

Table 7 RGR and doubling time of solar cell research

S.No	Publications year	No. of record	Cumulative	W1	W2	W2-W1 (Ra)	Mean (Ra) W2-W1	Doubling time	Mean Dt (a)
1	2010	203	203		5.31				
2	2011	327	530	5.31	6.27	0.96		0.72	
3	2012	353	883	6.27	6.78	0.51	0.47	1.36	1.03
4	2013	524	1407	6.78	7.25	0.47		1.49	
5	2014	772	2179	7.25	7.69	0.44		1.58	
6	2015	832	3011	7.69	8.01	0.32		2.14	
7	2016	1032	4043	8.01	8.30	0.29	0.26	2.35	2.74
8	2017	1147	5190	8.30	8.55	0.25		2.77	
9	2018	1411	6601	8.55	8.79	0.24		2.88	
10	2019	1416	8017	8.79	8.99	0.19		3.57	
	Total	8017	32064						

Table 7 explains the relative growth rate and doubling time of Solar cell publications during 2010- 2019. On the observation of current table, it found that the maximum RGR 0.96 has been recorded in the year 2011 and minimum RGR 0.19 has been counted in the year 2019, while the maximum doubling time 3.57 has been counted in the year 2019 and the minimum doubling time 0.72 has been counted in the year 2011. It can be seen in table 7 that the value of average relative growth rate of publications [R (a)] increased and decreased gradually from 0.96 to 0.19 during 2010 to 2019. The corresponding mean doubling time [Dt (a)] for the period increased from 0.72 to 3.57.

Document Types of solar cell research

Table 8 Document Types of solar cell research

S.No	Document Types	No.of Publications	%
1	Article	5500	68.60
2	Conference Paper	2003	24.98
3	Review	285	3.55
4	Book Chapter	173	2.16
5	Erratum	23	0.29

6	Book	17	0.21
7	Editorial	4	0.05
8	Letter	4	0.05
9	Retracted	3	0.04
10	Data Paper	1	0.01
11	Undefined	4	0.05
	Total	8017	100.00

Table 8 shows that document types in solar cell research contributions, a total of eleven document types were contributed in this research. Amongst articles were occupies the first position with 5500, Conference Paper has second place with 2003 records, Review has the third place with 285 records, and followed by Book Chapter has 173 records, Erratum 23, Book 17, Editorial, Letter, Retracted, Data Paper, Undefined has contributed below 5 percent contributions.

Relative Citation Index (RCI)

The relativ citation index (RCI) was developed by the Institute of Scientific Information (now Thomson Reuters, USA) and examine the impact of different countries and institutions in the field of Pollution Control research publications. The scientific impact of leading countries was examined by using two relative indicators, namely citations per paper (CPP) and relative citations index (RCI). Citations per paper (CPP) is a relative indicator computed as the average number of citations per paper. It has been broadly used into the bibliometric studies as it normalizes a large difference in the volumes of publications among the most productive countries, institutions, and authors.

To measure the both influence and visibility of a country research in global wise, the following formula has been used by Bharvi Dutt and Khaiser Nikam (2016)[30]

$$\text{RCI} = \frac{\text{A Country share of the World Citations}}{\text{A Country share of the World Publications}}$$

RCI = 1 indicate that a country's citation rate is equal to the world citation rate
RCI > 1 indicate that a country's citation rate is greater than the world citation rate
RCI < 1 indicate that a country's citation rate is lower than the world citation rate

Institutions of solar cell research Publications

Table 9 Institutions of solar cell research Publications

S.No	Institutions	No.of paper	%	Citations	%	RCI	CPP
1	Indian Institute of Technology, Bombay	407	16.64	4649	10.44	11.42	1.15
2	Council of Scientific and Industrial Research India, Chennai	333	13.61	7783	17.47	23.37	1.12
3	National Physical Laboratory India, Delhi	285	11.65	6659	14.95	23.36	1.15

4	Indian Institute of Technology Delhi, New Delhi.	281	11.49	4666	10.48	16.60	1.14
5	Indian Institute of Science, Bengaluru	222	9.08	3545	7.96	15.97	1.06
6	Indian Institute of Chemical Technology, Mumbai.	209	8.54	5085	11.42	24.33	1.35
7	Academy of Scientific and Innovative Research AcSIR, Chennai	193	7.89	2191	4.92	11.35	1.17
8	Shivaji University, Maharashtra	186	7.60	4911	11.03	26.40	1.37
9	Savitribai Phule Pune University, Pune	183	7.48	1332	2.99	7.28	1.17
10	Indian Association for the Cultivation of Science, West Bengal	147	6.01	3720	8.35	25.31	1.09
	Total	2446	100.00	44541	100.00	185.40	11.78

Relative citation indexes are Institutions identified during the ten-year study period on solar cell research publications are shown in table 9. From the study, it is identified that a maximum of 407(16.64%) research publications are contributed by the Indian Institute of Technology, Bombay, followed by 333(13.61%) research publications by are Council of Scientific and Industrial Research India, Chennai, and third-placed in National Physical Laboratory India, Delhi with 285(11.653.04%) research publications. This study confirmed that more than 17% of research publications are contributed by the Indian Institute of Technology, Bombay. The remaining nearby 83% of research publications are identified in the other form documents. The Maximum citations of 7783(17.47%) Council of Scientific and Industrial Research India, Chennai and the Relative citation index (RCI) the maximum 26.40 of the Sivaji University, Maharashtra.

Collaborative Country wise in solar cell research Publications

Table 10 country wise solar cell research Publications

S.No	Country	No. of paper	%	Citations	%	h-index	CPP	RCI
1	South Korea	506	17.51	11486	25.28	50	22.70	1.44
2	United States	339	11.73	9712	21.37	46	28.65	1.82
3	Japan	180	6.23	4315	9.50	32	23.97	1.52
4	United Kingdom	168	5.82	3279	7.22	29	19.52	1.24
5	Saudi Arabia	153	5.30	3076	6.77	27	20.10	1.28
6	Taiwan	126	4.36	3682	8.10	30	29.22	1.86
7	Greece	110	3.81	2640	5.81	30	24.00	1.53
8	Australia	92	3.18	2448	5.39	27	26.61	1.69
9	Singapore	92	3.18	3101	6.82	27	33.71	2.14
10	Germany	88	3.05	1705	3.75	24	19.38	1.23
	Others- 67 Countries	1035	35.83	45444	100.00			
	Total	2889	100.00					

Table 10 shows the top 10 collaborative countries' research publications for solar cell research during the study period from 2010-2019. From this study, it is identified that a Maximum of 506(17.51%) research publications by South Korea, followed by the United States with 399(11.73%) research publications, third place in Japan with 180(6.23%) research publications.

The maximum citations of 11486(25.28) in South Korea and the Relative citation index is a maximum of 2.14 in the country of Singapore. CPP is a maximum of 33.71and the H-index is 50.

Journal of solar cell research activities in India.

Table 11 the journal of solar cell research activities in India.

S.No	Journal	No. of papers	%	citations	%	RCI
1	Aip Conference Proceedings	397	22.29	502	2.33	1.26
2	Solar Energy	267	14.99	4445	20.61	16.65
3	Journal Of Materials Science Materials In Electronics	232	13.03	1882	8.73	8.11
4	Rsc Advances	175	9.83	2946	13.66	16.83
5	Materials Today Proceedings	154	8.65	392	1.82	2.55
6	Solar Energy Materials And Solar Cells	139	7.80	4134	19.17	29.74
7	Journal Of Physical Chemistry C	128	7.19	2926	13.57	22.86
8	Materials Research Express	107	6.01	328	1.52	3.07
9	Journal Of Alloys And Compounds	91	5.11	2190	10.15	24.07
10	Physical Chemistry Chemical Physics	91	5.11	1825	8.46	20.05
	total	1781	100.00	21570	100.00	145.19

Table 11 shows the top 10 Journals' research publications for solar cell research during the study period from 2010-2019. AIP conference proceeding 397(22.29%) first place, Second place going to the Solar Energy has 267(14.99%), and the third place. Journal of Materials Science Materials in Electronics, has 232(13.03%) document values and has third place. The maximum value of Citations of 4445 (20.61%) for Solar Energy, and the RCI maximum of 29.74 for solar energy materials and solar cells.

Funding agency in solar cell research publications

Table 12 Funding agency in solar cell research publications

S.No	Funding agency	Publications	%
1	Department of Science and Technology, Government of Kerala	514	21.74
2	Department of Science and Technology, Ministry of Science and Technology, India	332	14.04
3	University Grants Commission	267	11.29
4	Science and Engineering Research Board	237	10.03
5	Council of Scientific and Industrial Research, India	231	9.77
6	University Grants Committee	230	9.73
7	Ministry of New and Renewable Energy India	165	6.98
8	Bangladesh Council of Scientific and Industrial Research	163	6.90
9	National Research Foundation of Korea	116	4.91
10	Department of Science and Technology, Government of West Bengal	109	4.61
	Total	2364	100.00

Table- 12 deals with the funding sponsor for solar cell research activities. During the study period, a total number of 2364 research publications are sponsored by the top ten funding agencies in the field of solar cell research activities. This study identified that the maximum number of 514 21.74%) publications are sponsored by the Department of Science and Technology, Government of Kerala. Followed by the Department of Science and Technology, Ministry of Science and Technology, India has sponsored 332(14.04%) publications. The third-ranking sponsored agency is University Grants Commission with 267(11.29%) publications.

Subject-wise solar cell of research publications

Table 13 Subject-wise solar cell of research publications

S.No	Subject	Publications	% TP	Citations	%	h-Index	CPP
1	Agricultural and Biological Sciences	34	0.76	142	0.38	6	4.18
2	Arts and Humanities	1	0.02	2	0.01	1	2.00
3	Biochemistry, Genetics, and Molecular Biology	253	5.67	4884	13.00	33	19.30
4	Business, Management and Accounting	35	0.78	556	1.48	6	15.89
5	Chemical Engineering	971	21.77	17173	45.72	52	17.69
6	Chemistry	2208	49.51	11319	30.13	77	5.13
7	Computer Science	866	19.42	3235	8.61	22	3.74
8	Decision Sciences	52	1.17	71	0.19	4	1.37
9	Earth and Planetary Sciences	36	0.81	171	0.46	5	4.75
10	Economics, Econometrics and Finance	4	0.09	8	0.02	2	2.00
	Total	**4460**	**100.00**	**37561**	**100.00**		

Table 13 shows the subject research publications for solar cell research during the study period from 2010-2019. Chemistry 2208(49.51%) first place, Second place going to Chemical Engineering has 971 (21.77%), and third place Computer Science has 866(19.42%) documents. The maximum value of Citations 17173(45.72%) of Chemical Engineering and CPP is maximum 19.30, H-index is 77.

Highly cited paper solar cell of research publications

Table 14 highly cited paper solar cell of research publications

S.No	Paper	Country	Document	Authors
1	Babu, S.S., Praveen, V.K., Ajayaghosh, A. Functional π-gelators and their applications, Chemical Reviews, 144(4),2014, 1973-2129. Citations = 1140.	India,	Review	3
2	Dutta, S., Bhaumik, A., Wu, K.C.-W. Hierarchically porous carbon derived from polymers and biomass: Effect of interconnected pores on energy applications, Energy and	India, Taiwan	Review	3

	Environmental Science, 7(11), 2014, 3574-3592. Citations = 819.			
3	Gupta, V., Chaudhary, N., Srivastava, R., Sharma, G.D., Bhardwaj, R., Chand, S. Luminescent graphene quantum dots for organic photovoltaic devices, Journal of the American Chemical Society,133(26), 2014, 9960-9963. Citations = 733	United Arab Emirates, India	Article	6
4	Han, L., Islam, A., Chen, H., Malapaka, C., Chiranjeevi, B., Zhang, S., Yang, X., Yanagida, M. High-efficiency dye-sensitized solar cell with a novel co-adsorbent, Energy and Environmental Science, 5(3), 2012, 6057-6060. Citations = 591.	China, Japan	Article	8
5	Das, S., Jayaraman, V. SnO2: A comprehensive review on structures and gas sensors, Progress in Materials Science, 66, 2014, 112-255. Citations = 519.	India	Review	2
6	Kyaw, A.K.K., Wang, D.H., Gupta, V., Leong, W.L., Ke, L., Bazan, G.C., Heeger, A.J. Intensity dependence of current-voltage characteristics and recombination in high-efficiency solution-processed small-molecule solar cells, ACS Nano, 7(5), 2013, 4569-4577. Citations = 483	China, South Korea, United Arab Emirates, United States	Article	7
7	Kamal, C., Ezawa, and M. Arsenene: Two-dimensional buckled and puckered honeycomb arsenic systems, Physical Review B - Condensed Matter and Materials Physics, 91(8), 2015, Article. No 85423. Citations = 468	India, Japan	Article	3
8	Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A., Kim, K.-H. Solar energy: Potential and future prospects, Renewable and Sustainable Energy Reviews, 82, 2018, 894-900. Citations = 448.	Bangladesh, India, Viet Nam, South Korea	Review	5
9	Kyaw, A.K.K., Wang, D.H., Gupta, V., Zhang, J., Chand, S., Bazan, G.C., Heeger, A.J. Efficient solution-processed small-molecule solar cells with inverted structure, Advanced Materials, 25(17), 2013, 2397-2402. Citations = 422.	China, South Korea, United Arab Emirates, United States	Article	7
10	Babu, S.S., Prasanthkumar, S., Ajayaghosh, A. Self-assembled gelators for organic electronics, Angewandte Chemie - International Edition, 51(8), 2012, 1766-1776. Citations = 421	India	Review	3

During the highly cited paper Maximum 1140, Babu, S.S., Praveen, V.K., Ajayaghosh, A.(2014) Functional π-gelators, and their applications, Chemical Reviews, 144(4): 1973-2129. Second of highly cited paper 819, Dutta, S., Bhaumik, A., Wu, K.C.-W. (2014) hierarchically porous carbon derived from polymers and biomass: Effect of interconnected pores on energy applications, Energy and Environmental Science, 7(11): 3574-3592. Third of highly cited paper 733, Gupta, V., Chaudhary, N., Srivastava, R., Sharma, G.D., Bhardwaj, R., Chand, S.(2014) Luminescent graphene quantum dots for organic photovoltaic devices, Journal of the American Chemical Society,133(26): 9960-9963.

Finding and Conclusion

❖ From this study, it is identified that a maximum of 1416(17.66%) research publications are contributed to the year 2019, followed by journals of 1412(17.61%) research publications, third place is 1147(14.31%) research publications.

❖ World Vs. Indian contributions to solar cell research performance, Global publications are increasing from 5.67 percent to 12.44 percentage, and Indian output also growing from 0.18 to 1.26 percent

❖ It is found that the author of Sharma, G.D. S. 181 (21.65%) articles are the leading author contributing the highest articles. Authorship pattern amongst six and above authors contributions are 1783(22.24%)

❖ The study it is identified that CAI for single, two, and three authorship contributions are increasing trend from 1st block year to 2nd block year. At the same time, CAI is decreasing trend for more than three authors from 1st block year (102.60) to 2nd block year (99.03).

❖ From this study, it is identified that the degree of collaboration is between 0.97 in 2010 and 0.98 in 2019. The average degree of collaboration is 0.98. From this study, it is identified that collaborative authors contribute to the majority of solar cell research publications.

❖ The highest collaboration coefficient is 0.70 in most of the years, and lowest CC was 0.67 in 2013, and the average CC is 0.69. The collaboration index observed the maximum collaboration Index is 4.31 in the year 2014, a minimum of 4.02 in the year 2011, and an average CI is 4.17. The Modified collaboration coefficient observed a maximum of is 0.71 in the year 2011, a minimum of 0.67 in the year 2013, and an average MCC is 0.69.

❖ To study the maximum RGR of 0.96 has been recorded in the year 2011, and a minimum of RGR of 0.19 has been counted in the year 2019, while the full doubling time of 3.57 has been measured in the year 2019, and the minimum doubling time of 0.72 has been calculated in the year 2011.

❖ Documents types were contributed to this research. Amongst journal articles were occupies the first position with 5500, the source-wise distribution of research output of solar cell research activities in India. AIP Conference Proceedings research has 397, a high number of its Journals.

❖ Maximum of the collaborated country of 506(17.51%) research publications by South Korea, followed by the United States with 399(11.73%) research publications, third place in Japan with 180(6.23%) research publications. And Relative citation index (RCI) is the maximum 2.14 in the country of Singapore.

❖ From this study of AIP conference proceeding 397(22.29%) first place, Second place going to the Solar Energy has 267(14.99%), and the third place. Journal of Materials Science Materials in Electronics has 232(13.03%) document values and third place. The maximum value of Citations of 4445 (20.61%) for Solar Energy, and the RCI maximum of 29.74 for solar energy materials and solar cells.

❖ During the subject of Chemistry 2208(49.51%) first place, Second place going to the Chemical Engineering has 971 (21.77%), and third place. Computer Science has 866(19.42%) document values and has third place. Citations 17173(45.72%) of Chemical Engineering

❖ During the highly cited paper Maximum with 1140, Babu, S.S., Praveen, V.K., Ajayaghosh, A. (2014) Functional π-gelators, and their applications, Chemical Reviews, 144(4): 1973-2129.

Conclusion:

The overall ten-year study period identified the Solar cell research publications from the SCOPUS database are increasing gradually. Now a day's many institutions and research centers are doing many more research activities in the field of the Solar cell. This study concludes that a maximum of Indian authors' research publications are collaborated by South Korea, followed by the United States of America. So developed countries are doing many more research activities in the field. At the same time, developing countries also want to do many more research activities in the area of Solar cell research and provide better service to the public**.**

Reference

1. https://www.sciencedirect.com/topics/chemistry/photovoltaic-effect

2. **Nelson, J. (2003).** The Physics of Solar Cells. *Imperial College Press*, London.

3. **DOE (1980),** Photovoltaics Program, Subprograms, and Applications, U.S. *Department of Energy Report* 5210-5.

4. Barnett, A. A. (1978), *Physics Today*, Vol. 31, No. 3, 11.

5. **Verma, S. S. (2016),** Next Generation Solar Cells: The Future of Renewable Energy, *Renewable Energy*, Vol.2 (10). Pp.1-52

6. **Hu.C, Richard M. White, R.M, (1983).**Solar Cells: From Basics to Advanced Systems, *T. Michael Slaughter (ed.) McGraw-Hill*, United States of America

7. Ranabhat, Kiran. et al., (2016), an Introduction to Solar Cell Technology. "*Journal of Applied Engineering Science*", Vol.14:4 (405), Pp. 481-491

8. **Bach, U. et al., (1998),** "Solid-state dye-sensitized mesoporous TiO2 solar cells with high photon-to-electron conversion efficiency" *Nature* 395, pp. 583–585

9. Rokas Kondrotas, Chao Chen, Jiang Tang, (2018), Sb_2S_3 Solar Cells, "*Joule*", Vol. 2 (5), Pp. 857-878

10. **Wang, Ao Xuan, Yimin (2018),** "A detailed study on loss processes in solar cells", *Energy*, Vol. 144, Pp. 490-500

11. **Krebs. et al., (2009),** Solar Energy Materials and Solar Cells 2009, 10.1016/*journals of solmat.*10.004

12**. Kavitha R et.al (2018)** solar cell research output: a bibliometric study, "Knowledge Librarian" *An International Peer Reviewed Bilingual E-Journal of Library and Information Science*,5 (2):244-259.

13**. Bharvi and Khaiser Nikam (2014)** Scientometrics of collaboration pattern in solar cell research in India, *Annals of Library and Information Studies* 61, March 2014: 65-73.

14. **Bharvi Dutta and KhaiserNikam (2015)** a scientometric overview of collaboration pattern in global solar cell research, *Annals of Library and Information Studies*, 62, September 2015:157-167.

15. **Bensi Dong et.al (2012)** A bibliometric analysis of solar power research from 1991 to 2010 A bibliometric analysis, *Scientometrics*, 93:1101–1117.

16**. Sivasami K (2019**) Scientometric analysis of solar cells research performance, International *Journal of Civil Engineering and Technology*, 10(03): 3336-3343.

17. Ravichandran.S & Vivekanandhan. S (2021). Scientometric analysis of waste water management research publications from SCOPUS database during 2010-2019, *Library Philosophy and Practice (e-journal)*, 5139, 1-18.

18**. Gangan Prathap (2014)** A three-dimensional bibliometric evaluation of research in polymer solar cells, *Scientometrics*, 101:889–898.

19. **Alex Fabianne de Paulo and Geciane Silveira Porto (2017)** solar energy technologies and open innovation: A study based on bibliometric and social network analysis, *Energy Policy*, 108: 228-238.

20.**Ravichandran.S and Vivekanandhan S.(2020)** Bibliometric Analysis of Solid Waste Management Research Publications (2010-2019) using SCOPUS Database, *International Journal of Library and Information Studies*, Vol.10 (4) ISSN: 2231-4911.

21. Ashokkumar, L. and Gopalakrishnan, S. (2013). Indian literature output on Textile Research: A Scientometric Study. *Journal of Advances in Library and Information Science*, 2(4), 251-258.

22. Bharvi, D. and Khaiser, N. (2016). Scientometric analysis of global solar cell research. *Annals of Library and Information Studies*, 63, 31-41.

23. **Garg, K.C. and Padhi, P. (2001).** A study of collaboration in laser science and technology. *Scientometrics*, 51(2), 415-427.

24. **Subramanyam K (1983).** Bibliometric Studies of research collaboration: *A review. Journal of Information Science*. 6(1), 33-38.

25**. Vivekanandhan. S et.al (2016)** Growth of literature in pollution control Research output: A Scientomentric Study. *Journal of Advanced in Library and information science*, 5 (2):170-178.

26. **Sivasamy.K et.al (2020)** Scientometrics Analysis of Leprosy Research Publications. *International Journal of Library and information Studies*, 10 (3): ISSN: 2231-4911.

27. **Ravichandran S and Vivekandhan S (2021).** Wireless sensor network research output in India research publications from SCOPUS database during 2010-2019. *Library Philosophy and Practice (e-journal),* 5509, 1-12

28 **Ajiferuke, I., Burrel, Q. and Tauge, J. (1988**). Collaborative Co-efficient: A single measure of the degree of collaboration in research. *Scientometrics*, 14, 421-433.

29**. Kiran Savanur and Srikanth. (2010)** Modified Collaborative Coefficient: a new measure for quantifying degree of research collaboration. *Scientometrics*, 1-11.

30. **Bharvi, D. and Khaiser, N. (2016).** Scientometric analysis of global solar cell research. *Annals of Library and Information Studies*, 63, 31-41.