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# Mapping Dye-sensitised Solar Cells Research in India : A Scientometric Study

Bharvi Dutt* and Suresh Kumar

*CSIR-National Institute of Science Technology and Development Studies, Delhi - 110 012, India*
**E-mail: bh_arvi@yahoo.com*

**ABSTRACT**

The paper examines 718 dye sensitised solar cell (DSSC) research articles published by Indian scientists during 2011-15, which were indexed in Web of Science. It looked into the entire gamut of research performance by performing sectors, institutions, multifarious collaborative aspects, co-authorship and citations etc. Private universities figure among top performing institutions and nano-related aspects dominated DSSC research. DSSC research by Indian researchers was found to be in tune with the mainstream science in the area as about 90 per cent of the research found place in international journals published from USA, the UK and other advanced countries of Europe with respectable impact factor.

**Key words:** Solar cells; Photovoltaics; Dye-sensitised solar cells; Scientometrics; India

## 1. INTRODUCTION

Indian government is making vigorous efforts to enhance the component of renewable energy in its total requirement of energy. Several policy initiatives have been taken by the government to harness the potential renewable energy sources. Some of the steps include creating institutional infrastructure like Solar Energy Corporation of India. Policy initiatives include reduction in solar power tariff from Rs. 16-18 / unit to Rs. 4.3 – 4.6 /unit. Other steps include making huge investments, overall 157 per cent increase in solar power capacity, solar pumps installations, installations of roof top solar panels, etc. At the international level India has taken the lead in the formation of International Solar Alliance of 121 tropical countries with the objective of utilisation and promotion of solar energy in member countries with abundant sun almost throughout the year.

The Government of India launched a Jawaharlal Nehru National Solar Mission (JNNSM), in 2010 which has set the target of 20,000 MW of grid connected electric power by 2022. Of the four broad strategies to achieve the ambitious target is to undertake aggressive R&D. Towards this end the Ministry of New and Renewable Energy (MNRE) of the Government of India has also funded several R&D projects on solar cell research. This indicates the recognition by the science policy planners about the crucial role of photovoltaics in the achievement of the proposed targets under JNNSM and otherwise to attain energy security in the country.

A study of solar cell research in India conducted during 1991 to 2010 suggests that among various types of solar cell research being carried out to develop a cost effective, efficient and environment friendly solar cells, the dye-sensitised solar cell (DSSC) is one of the candidates that is attracting lot of research efforts[1]. DSSC have received widespread attention in the recent past because of their low production cost, ease of fabrication and optical properties[2]. These types of photovoltaic cells have attracted much attention owing to their ease of production from relatively impure materials as low-cost alternatives to silicon solar cells[3]. China has considerably enhanced her position in DSSC around the world[4]. The present study, therefore, becomes important and aims to conduct a scientific measurement by looking into the entire gamut of research and development efforts in the area of DSSC research being carried out in India during 2011-2015. No study is available in literature which maps DSSC research in India.

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## 2. LITERATURE REVIEW

A few scientometrics studies are available that have dealt with DSSC research. Zhang[5], *et al.* have worked on innovation in China's DSSC industry and found that China was the most productive country in the field. A bibliometric study of solar power research conducted by Dong[6], *et al.* observed that globally DSSC research was increasing at an increasing rate. Sinha[7] in his study on trends in global solar photovoltaic research found that DSSC research was a hot topic of research and China was forging ahead in this field of research. A computer assisted road mapping study by Kajikawa[8], *et al.* found that DSSC was most active research topic among the major cell subjects. Kajikawa[9], *et al.* in their study on tracking emerging technologies in energy research have observed that dye-sensitised and organic solar cells have started emerging as important research materials. Vegetable-based DSSC as one of the promising research field was identified by Sasaki[10], *et al.*

in their research on emerging areas related to solar cell field using machine learning approach. However, there is no study reported in literature which exclusively focuses on DSSC research in India, hence the present study.

## 3. OBJECTIVES

The following are the objectives of the study:

- To examine the pattern of growth of the research output, its citation and co-authorship pattern;.
- To identify the performing sectors, prolific institutions involved in research in dye sensitised solar cell and to study the citation pattern;
- To examine international collaboration, the collaborating countries, institutions and their impact in terms of citation;
- To examine which aspects of dye sensitised solar research is being emphasised;
- To identify highly cited authors, most frequently used journals and impact factor distribution.

## 4. METHODOLOGY AND DATA COLLECTION

The data for DSSC for the period 2011 to 2015 was downloaded on 21 June, 2016 from Web of Science, Thomson Reuters using the query 'dye sensitised solar cell' or 'dssc'. The data was cleaned and standardised and was fed into foxpro database for analysis. The collaboration was categorised on institutional basis. Those papers which have emerged out of the collaboration among institutions within the city have been termed as local collaboration (LC) whereas the output originating out of institutions located in different cities within India has been termed as domestic collaboration (DC) and the ones which involved institution/s from any country other than India was defined as international collaboration (IC) whereas those involving one institution has been referred to as no collaboration (NC).

## 5. INDICATORS USED

### 5.1 Co-authorship Indicators

Different formulae are proposed by various authors are as follows:

One of the early measures of degree of collaboration is collaborative index (CI) suggested by Lawani[11] as:

$$\text{Collaborative Index (CI)} = \left(\sum_{i=1}^{k} jfj\right) / N$$

$fj$ = the number of papers having $j$ authors in collection K;

$N$ = the total number of papers in K. $N = Pj\, fj$; and

$A$ = the total number of authors in collection K.

It is simply the mean number of authors per paper. CI can be computed easily at several levels for the purpose of comparison i.e. subject-wise, institution and its department-wise, country-wise, etc. However, it is not easily interpretable on a scale of intensity, amount or quality because mean value (of CI) has no upper limit.

Degree of collaboration (DC) proposed by Subramanyam[12] is a measure which gives fraction of multiple-authored papers is given by:

$$\text{Degree of collaboration} = \frac{Nm}{Nm + Ns}$$

$Nm$ = number of multi authored papers in the discipline

$Ns$ = number of single papers in the discipline

DC can also be calculated and interpreted easily as a degree. Values of DC lies between zero and one and gives zero weight to single-authored papers. It ranks an entity higher which has a higher percentage of multiple-authored papers.

Collaboration coefficient (CC) was proposed by Ajiferuke and Tague[13] to remove the deficiencies pertaining to CI and DC. It is given by:

$$\text{Collaboration coefficient} = \left(\sum_{j=1}^{A} (1/j) fj\right) / N$$

It vanishes for a collection of single-authored papers, and distinguishes between single authored, two-authored, multi-authored papers. However, CC fails to yield 1 for maximal collaboration, except when number of authors is infinite. However, it should be taken equal to 1 for maximal collaboration.

$$\text{Relative citation impact} = \frac{C\%}{P\%}$$

where $C$ % is per cent of citations received by a unit (country (region), institution or an individual), $P$ % is per cent of publication by a unit (country (region), institution or an individual)

RCI = 1 indicates that country's citation rate is equal to world citation rate;

RCI > 1 indicates that country's citation rate is higher than world's citation rate; and

RCI < 1 indicates that country's citation rate is less than world's citation rate.

In this above statement word 'country' may be replaced with 'institution'. It can be used for country as well as institution comparison.

## 6. RESULTS AND ANALYSIS

### 6.1 Growth, Citations and Co-authorship

In all 718 publications were found to have originated during the period of study (2011-2015). The growth of publication output rose tremendously but seems to have declined in the last year. The reason may be some behind the schedule journals not yet indexed by WoS, However, the publications have been gradually increasing in absolute terms over the 5-year period, Fig. 1.

About 18 per cent publications did not receive any citations. The maximum number of (~50 %) publications received two citations. Subsequently, there was a sharp decline in quantum of publications receiving 3-5 and higher citation ranges, Fig. 2. There was one paper which received 365 citations, the only one that crossed the 3-digit mark. This paper was written in Japanese collaboration by a scientist from CSIR-IICT and dealt with the high efficiency aspect of DSSC.

Collaboration indices computed are: CI=4.70, DC=0.98, CC=0.73

CI is a measure of mean number of authors per paper. Although it is easily computable, it is not easily interpretable

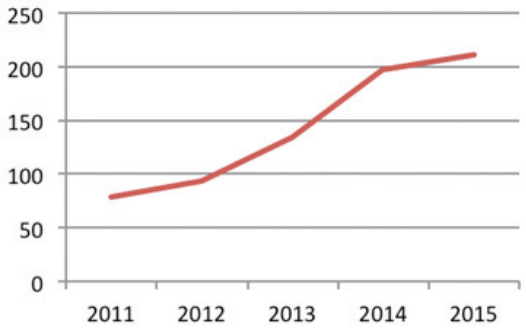



**Figure 1. DSSC publications during 2011-2015.**

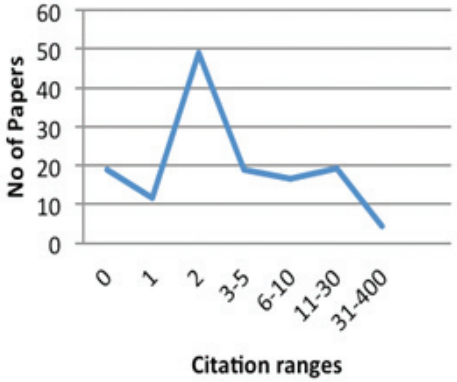



**Figure 2. Citation pattern.**

as a degree, for it has no upper limit. Moreover, it gives a non-zero weight to single-authored papers, which involve no collaboration.

DC is easy to calculate and easily interpretable as a degree (for it lies between zero and one), gives zero weight to single-authored papers, and always ranks higher a discipline (or period) with a higher percentage of multiple-authored papers. However, DC does not differentiate among levels of multiple authorships. DC essentially indicates fraction of multi-authored papers.

CC is indicated as zero for a data set containing all the single author papers and 'one' for infinite number of co-authored papers. It is considered as more compact indicator of authorship pattern than CI and DC, as it takes all single authored and multi-authored papers into consideration.

The value of CC for the entire gamut of solar cell research in India[14] and that for global solar cell research[15] is 0.64 and compares well with DSSC research in India at 0.73, though it is marginally higher. A study on collaboration pattern in natural sciences[16] observed that DC, CI, CC and modified collaborative coefficient (MCC), all the collaboration indices indicated an increasing trend during the period of study i.e. 1971-2007. CC was 0 in 1971 and 0.68 in 2007.

Single authored publications were minuscule (1.5 %) in proportion, Fig. 3. Around 55 per cent of publications originated out of multiple authorship comprising of 3-5 authors. However, the CPP shows only marginal variation among different co-authorship categories from single to five authored publications. The substantial rise in CPP was found in the case of mega-authored publications.

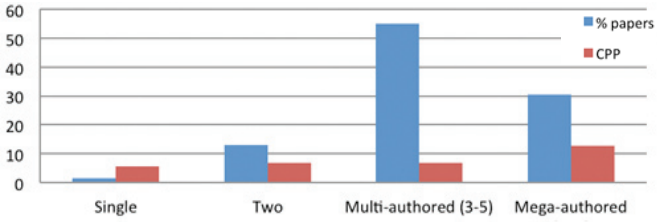
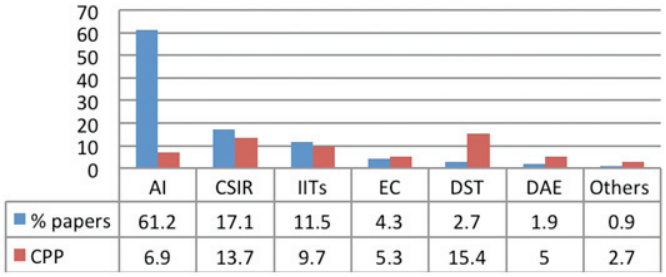



**Figure 3. Co-authorship pattern and CPP.**

### 6.2 Research Performing Sectors

The major contribution of output (90 %) emerges from three performing sectors, academic institutions (AI) (61 %), followed by that from Council of Scientific & Industrial Research (CSIR) (17 %) and Indian Institutes of Technology (IITs) (11.5 %) as shown in Fig. 4.

The highest citation per paper (CPP) was observed in respect of Department of Science and Technology (DST) followed by that of CSIR. Though AI outperformed all other performing sectors in terms of quantum of output, however, their citation average was relatively quite low.




| | AI | CSIR | IITs | EC | DST | DAE | Others |
|---|---|---|---|---|---|---|---|
| % papers | 61.2 | 17.1 | 11.5 | 4.3 | 2.7 | 1.9 | 0.9 |
| CPP | 6.9 | 13.7 | 9.7 | 5.3 | 15.4 | 5 | 2.7 |

**Figure 4. Research performing sectors and their citation per paper.**

### 6.3 Research Institutions

About 40 per cent of the output emerged out of 14 institutions which produced 1 per cent or more of the total output led by CSIR-Indian Institute of Chemical Technology (CSIR-IICT) followed by University of Madras, Amrita Vishwa Vidyapeeth, Indian Institute of Technology, Roorkee (IITR), and Indian Institute of Technology, Bombay (IITB) as shown in Table 1. These five accounted for more than half of the output of these prominent institutions and one fifth of the total output.

RCI is a measure of both the influence and visibility of a nation's research in global perspective. It is defined as the ratio of a country's share of world citations to the country's share of world publications.

The highest CPP was received by CSIR-National Chemical Laboratory (CSIR-NCL) followed by that of IIT-R, Indian Association for the Cultivation of Science (IACS), Amrita Vishwa Vidyapeeth and CSIR-IICT. All other institutions had their CPP in single digit with the lowest being in respect of Alagappa University (AU). An earlier 20 years study on the entire gamut of solar cell research in India demonstrated that IACS has been very active in photovoltaic research and has outperformed all other institutions in India in terms of quantum of research output[1]. Other prominent research performing institutions in that study included IITs, AU, CSIR-IICT, etc.

**Table 1. Distribution of output according to research institutions and their citations**

| Institute | Papers (%) | C (%) | CPP | RCI |
|---|---|---|---|---|
| CSIR-Indian Institute of Chemical Technology, Hyderabad | 53 (7.4) | 616(10.1) | 11.6 | 1.4 |
| University of Madras, Madras | 26 (3.6) | 143(2.4) | 5.5 | 0.7 |
| Amrita Vishwa Vidyapeetham University, Kochi | 26 (3.6) | 314(5.2) | 12.1 | 1.4 |
| Indian Institute of Technology, Roorkee | 26 (3.6) | 378(6.2) | 14.5 | 1.7 |
| Indian Institute of Technology, Bombay | 23 (3.2) | 228(3.7) | 9.9 | 1.2 |
| CSIR-National Chemical Laboratory, Pune | 20 (2.8) | 350(5.7) | 17.5 | 2.0 |
| Madurai Kamraj University, Madurai | 20 (2.8) | 99(1.6) | 4.9 | 0.6 |
| Indian Association for the Cultivation of Science, Kolkata | 13 (1.8) | 165(2.7) | 12.7 | 1.5 |
| Pondicherry University, Pondicherry | 13 (1.8) | 100(1.6) | 7.7 | 0.9 |
| Banaras Hindu University, Varanasi | 13 (1.8) | 51(0.8) | 3.9 | 0.4 |
| Sharda Univ, Noida, | 13 (1.8) | 67(1.1) | 7.4 | 0.6 |
| Indian Institute of Delhi, Delhi | 11 (1.5) | 66(1.1) | 6.0 | 0.7 |
| Bhabha Atomic Research Centre, Bombay | 10 (1.5) | 48(0.8) | 4.8 | 0.5 |
| Alagappa University, Karaikudi | 10 (1.5) | 16(0.3) | 1.6 | 0.2 |
| Sub total | 277 (38.6) | 2641(43.3) | 9.5 | 1.1 |
| Others | 441 (61.4) | 3453(56.7) | 7.8 | 0.9 |
| Total | 718 | 6094 | 8.5 | |

### 6.4 Institutional and Country Collaboration

A rigorous articulation of aspects and reasons for fostering collaboration in research has been done in their seminal work by Katz and Martin[17]. The purpose for which people engage in research collaboration has also been elucidated by Beaver[18]. Multi-authored or multi-addressed papers could be used as a proxy to measure collaboration was initially suggested by Smith[19].

These include domestic as well as international collaboration work. Publications in collaboration receive more citation than those without any collaboration. The papers written in international collaboration receive more citations than those written in domestic collaboration. This suggests that internationally collaborative work embodies more important segment of the world science[20].

Number of institutions involved in a research effort is also one of the dimensions of collaborative aspect. Table 2 suggests that about 60 per cent of the output involved two or more institutions. It is also observed that the larger the number of institutions more is the likelihood of higher citations, however, the trend does not sustain beyond a point. Fig. 5 depicts the distribution of total output in terms of different nature of collaborative aspects i.e. NC, LC, DC, and IC.

**Table 2. R&D output in terms of number of institutions involved**

| Number of institutions | Papers (%) | Citations | CPP |
|---|---|---|---|
| One | 283 (39.4) | 1850 | 6.5 |
| Two | 231 (32.2) | 1928 | 8.3 |
| Three | 127 (17.7) | 1598 | 12.6 |
| Four & above | 77 (10.7) | 718 | 9.3 |
| Total | 718 | 6094 | 8.5 |

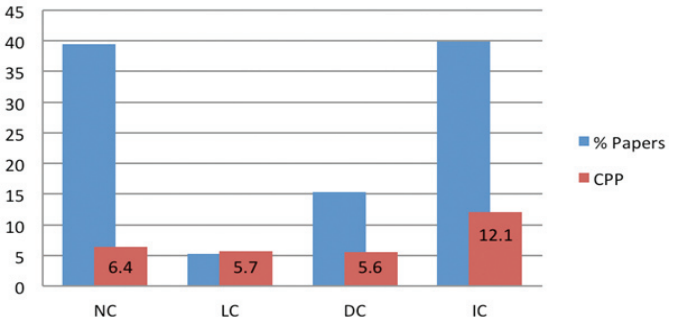



**Figure 5. Nature of collaboration and CPP.**

We see that about 40 per cent of the research output has emerged without any institutional collaboration designated as NC. About 5 per cent of publications have resulted out of LC and about 15 per cent originated out of DC. In all these three categories of collaborative aspects the CPP exhibited only marginal variation, which implied that the indigenous collaboration did not substantially result in changes in CPP. However, the research output originated out of IC efforts exhibited CPP more than twice that of DC.

Solar cell research is a frontier area of research endeavor where most of the countries which intend to go green in their energy requirements are involved in grappling the R&D problems. Finding new materials, improve efficiency and develop cost-effective solar cells are the core problems, and hence, there may be synergistic outcome in collaboration among different countries, institutions and researchers.

Of the entire gamut of collaboration 40 per cent of the output emerged as a result of IC where 34 countries were involved. The prominent lead international linkages have been with twenty countries which included South Korea, Taiwan, Japan, Greece and Saudi Arabia. However, twenty countries led the research with South Korea being the dominant international collaborative partner, followed by Taiwan, Greece, Switzerland and Italy as shown in Fig. 6.

In all there were 7526 keywords which were highly scattered and a large number of them appeared disjointed. However, an effort was made to standardise the same and draw some inference as to the direction and emphasis of research

in DSSC. Figure 7 depicts the top 20 keywords. Aspects related to 'nano', 'efficiency', 'electrodes and electrolytes', 'performance', 'conversion', 'films', 'dyes and pigments' etc. are some of the dimensions of research worked upon by the R&D scientists engaged in DSSC research in India.

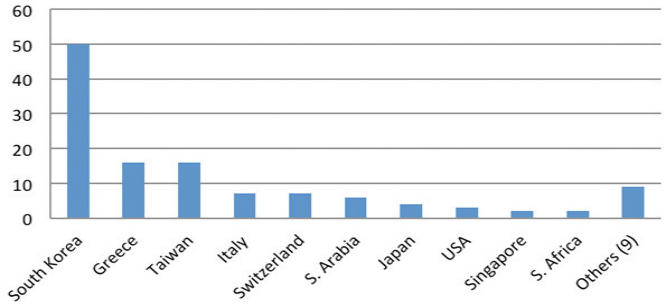



**Figure 6. Lead collaborative countries in DSSC research.**

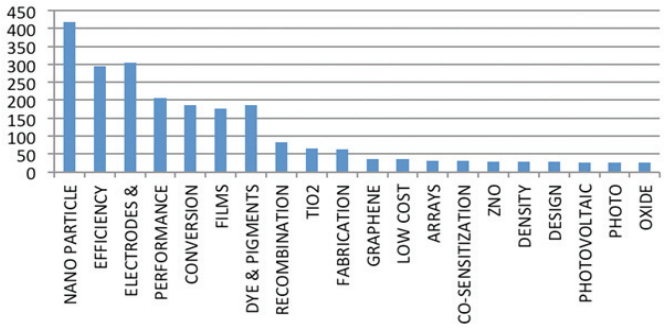



**Figure 7. Direction and emphasis of research in DSSC.**

## 6.5 Highly Cited Papers

Table 3 presents the top ten publication receiving 50 or more citations. From Table 4 we observe that out of 7 highly cited papers 3 have emerged out of CSIR-Indian Institute of Chemical Technology (IICT), Hyderabad. In the earlier study[1] as well encompassing all kinds of solar cell G.D. Sharma ranked as the most prolific scientist.

**Table 3. Top 10 papers getting 50 or more citation**

| Highly cited papers | Citations |
|---|---|
| Liyuan, Han. *et al. Energy & Environmental Science*, 2012, 5(3), 6057 – 6060. | 365 |
| Thomas, Sara. *et al. J. Materials Chemistry* A, 2014, 2(13) 4474 – 4490. | 92 |
| Bajpai, Reeti. *et al.* ACS *Applied Materials & Interfaces*, 2011, 3(10) 3884 – 3889. | 82 |
| Singh, Kamaljit & Arora, Sucharita, *Critical Reviews in Environmental Science and Technology*, 2011, 41(9), 807 – 878. | 81 |
| Mohammad, Shahid. *et al. J. Cleaner Production*, 2013, 53, 310 – 331. | 66 |
| Baheti, Abhishek. *et al. J. Organic Chemistry*, 2011, 76 (12), 4910 – 4920. | 59 |
| Numata, Youhei. *et al. Advanced Functional Materials*, 2013, 23(14), 1817 – 1823. | 55 |
| Muduli, Subas. *et al. Solar Energy,* 2012, 86 (5), 1428 – 1434. | 55 |
| Mandal, G. & Ganguly, T. *Indian J. Physics*, c2011, 85(8), 1229 – 1245. | 55 |
| Marszalek, Magdalena. *et al. J. Materials Chemistry*, 2012, 22(3), 889 – 894. | 51 |

**Table 4. Highly productive authors**

| Authors with affiliation | Publications |
|---|---|
| Ganesh D. Sharma (Jaipur Engineering College, Jaipur) | 36 |
| Surya Prakash Singh (CSIR- IICT, Hyderabad) | 34 |
| K.R. Justin Thomas (Indian Institute of Technology, Roorkee) | 30 |
| Shantikumar V. Nair (Amirita Vishva Vidhiyapeethan, Kochi) | 23 |
| Llingamallu Giribabu (CSIR- IICT, Hyderabad) | 23 |
| Malapaka Chandrasekharam (CSIR-IICT, Hyderabad) | 23 |
| A. Sreekumaran Nair (Amrita Vishwa Vidyapeetham University, Kochi) | 20 |

## 6.6 Journals and their Country of Origin

From Table 5, we observe that the entire output was published in journals originating from the western world and only about 3 per cent publications have emerged out of journals published from India.

**Table 5. Countries of origin of journals**

| Country | Journals | Papers | % of Papers | Cumulative % |
|---|---|---|---|---|
| England | 42 | 267 | 37.2 | 37.2 |
| USA | 71 | 209 | 29.2 | 66.4 |
| Netherlands | 27 | 102 | 14.2 | 80.6 |
| Switzerland | 15 | 42 | 5.8 | 86.4 |
| Germany | 15 | 41 | 5.7 | 92.1 |
| India | 9 | 24 | 3.3 | 95.4 |
| Serbia | 1 | 7 | 1.0 | 96.4 |
| China | 3 | 5 | 0.7 | 97.1 |
| South Korea | 2 | 5 | 0.7 | 97.8 |
| Romania | 2 | 4 | 0.6 | 98.3 |
| Poland | 2 | 3 | 0.4 | 98.8 |
| Japan | 2 | 2 | 0.3 | 99.0 |
| Others (Australia, UAE, France, Singapore, Slovenia, Taiwan, Turkey) | 7 | 7 | 0.9 | 100.0 |
| Total | 198 | 718 | 100.0 | 100.0 |

## 6.7 Most Frequently used Journals

Table 6 depicts most frequently used journals that accounted for 40 per cent of the output. The remaining output was scattered in 182 journals. The entire output is published in journals originating from the western world and have considerably respectable impact factor. It is notable that no Indian journal figures in the list.

**Table 6. Most frequently used journals**

| Journal | Country | I.F. | Papers |
|---|---|---|---|
| *RSC Advances* | UK | 3.2 | 53 |
| *Electrochimica Acta* | UK | 4.8 | 28 |
| *Journal of Materials Science-Materials in Electronics* | Netherlands | 1.8 | 20 |
| *Spectrochimica Acta Part A* | UK | 2.5 | 18 |
| *J. Materials Chemistry A* | UK | 8.2 | 18 |
| *J. Physical Chemistry C* | USA | 4.5 | 18 |
| *Dyes and Pigments* | UK | 4.1 | 15 |
| *J. Nanoscience and Nanotechnology* | USA | 1.3 | 15 |
| *Solar Energy* | UK | 3.6 | 15 |
| *Dalton Transactions* | UK | 4.1 | 14 |
| *Physical Chemistry Chemical Physics* | UK | 4.4 | 14 |
| *Organic Electronics* | Netherlands | 3.4 | 13 |
| *ACS Applied Materials & Interfaces* | USA | 7.1 | 13 |
| *Journal of Power Sources* | Netherlands | 6.3 | 13 |
| *Journal of Renewable and Sustainable Energy* | USA | 0.9 | 12 |
| *Journal of Solid State Electrochemistry* | USA | 2.3 | 10 |
| Sub-total | | | 289 |
| Others (182) | | | 429 |
| Total | | | 718 |

## 7. CONCLUSIONS

Dye-sensitised solar cell (DSSC) research in India as reflected in Web of Science during 2011-15 showed a gradual rising trend. About 18 per cent publication did not receive any citations. Academic institutions outperformed all other performing sectors, however, their Citations per paper (CPP) was relatively lower. The Department of Science and Technology received highest CPP. A few private institutions like Sharda University and Amritha Vishwa Vidyapeeth University figured among top performing institutions and had respectable CPP. These are relatively new institutions and have demonstrated research capability in the area of DSSC. However, Council of Scientific and Industrial Research-Indian Institute of Chemical Technology (CSIR-IICT) outperformed all other institutions with double digit CPP. Two fifths of the output emerged out of international collaboration (IC) with 34 countries and the CPP of IC output was twice that of indigenous output. The DSSC research by Indian researchers is a part of the international mainstream research in the areas as about 80 per cent publications have appeared in journals originating from USA, UK, Netherlands, Switzerland and Germany with impressive impact factor. The direction and emphasis of research appeared to be on aspects of 'nano', 'efficiency', 'electrodes & electrolytes', 'performance' and 'conversion', etc. This study shall also facilitate the library professionals and academicians to identify right journal in field of DSSC.

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## CONTRIBUTORS

**Dr Bharvi Dutt** received his BSc from Delhi University, Masters in Computer Applications form BITS, Pilani and PhD from University of Mysore. He has superannuated from CSIR-National Institute of Science Technology and Development Studies, Delhi. He has published around 30 papers in research performance evaluation and science communication in national and international journals and three books.

Contribution in the current study, he conceptualised the study and its framework. Carried out the analysis and interpretation of data, written the first draft of the manuscript and finalised the article after feedback from the co-author.

**Dr Suresh Kumar** received his MLibSc From Annamalai University and PhD from Indira Gandhi National Open University, working in CSIR-National Institute of Science Technology and Development Studies, New Delhi for last 30 years. His major area of interest is bibliometric/scientometrics. He has about 90 publications to his credit.

Contribution in the current study, he did data downloading, cleaning and tabulation. Carried out literature review, indicators interpretation and feedback on the draft manuscript.